THE PHOTON DETECTION SYSTEM OF SBND

LIDINE 22

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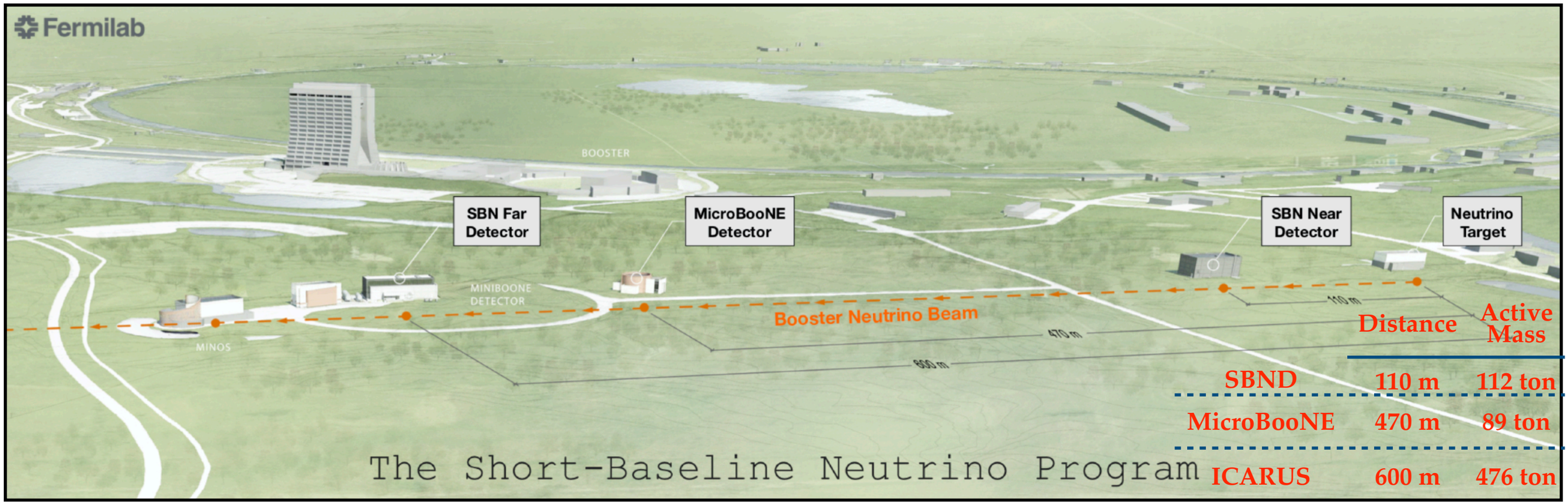
SBN PROGRAM



	Distance	Active Mass
SBND	110 m	112 ton
MicroBooNE	470 m	89 ton
ICARUS	600 m	476 ton

- The Short-Baseline Near Detector (SBND) is one of the three detectors integrating the Short-Baseline Neutrino (SBN) Program at Fermilab
  - Three Liquid Argon Time Projection Chambers (LArTPC) will detect neutrinos produced at the Booster Neutrino Beam (BNB)
- SBN physics goal: search for light ($\Delta m^2 \sim 1\ \mathrm{eV}^2$) sterile neutrino oscillations

SHORT-BASELINE NEAR DETECTOR (SBND)

- SBND physics goals:
  - Located 110 m from the BNB target, it will **measure the unoscillated neutrino flux**, enabling precise sterile neutrino oscillation searches in combination with the SBN Program far detectors (μBooNE and ICARUS)
  - SBND will record ~2M neutrino interactions per year, allowing the **study of ν – Ar interactions** with unprecedented precision at ~1 GeV energies
- Beyond Standard Model searches
- R&D for future LArTPC experiments:
  - High performance Photon Detection System (PDS)
  - New **applications of scintillation light** in LArTPC detectors

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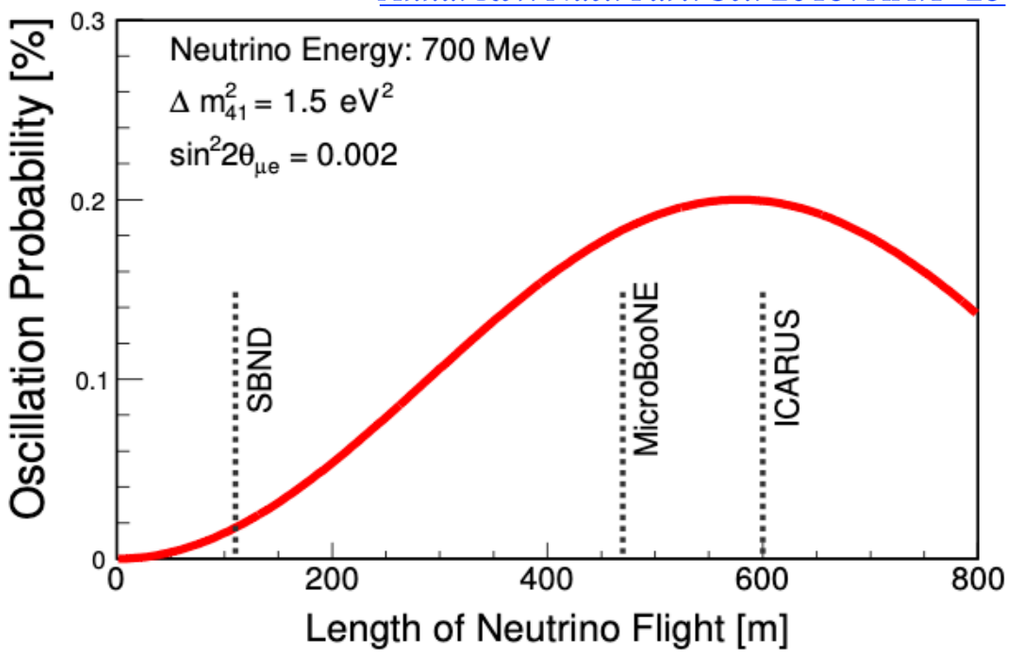
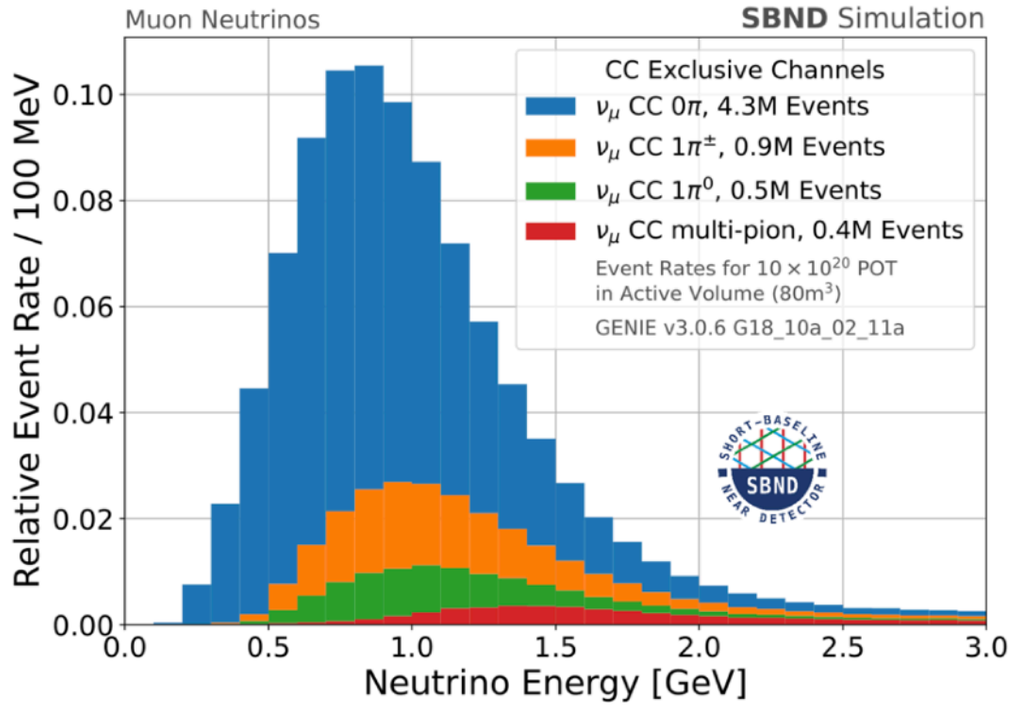
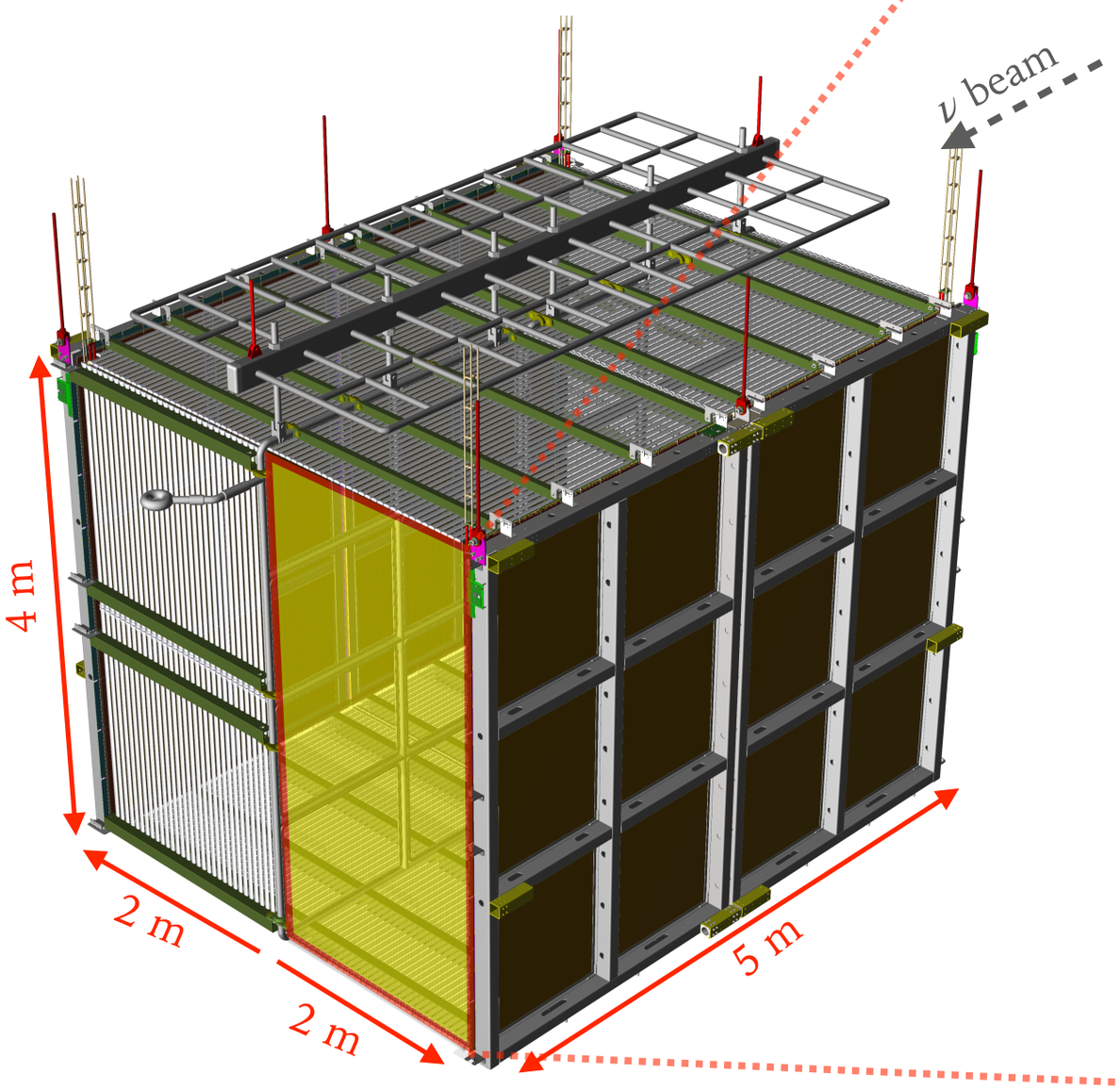
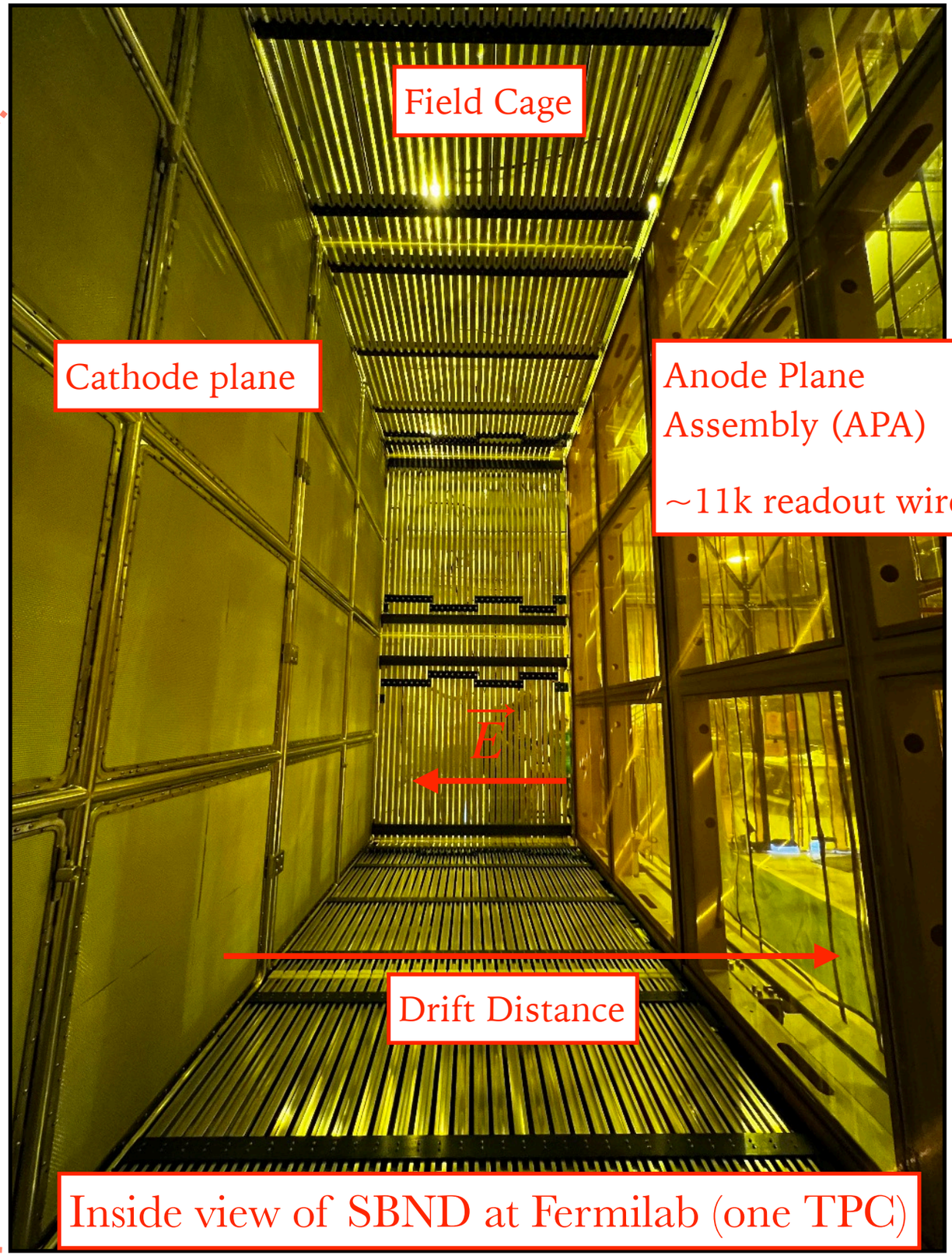




SBND DETECTOR

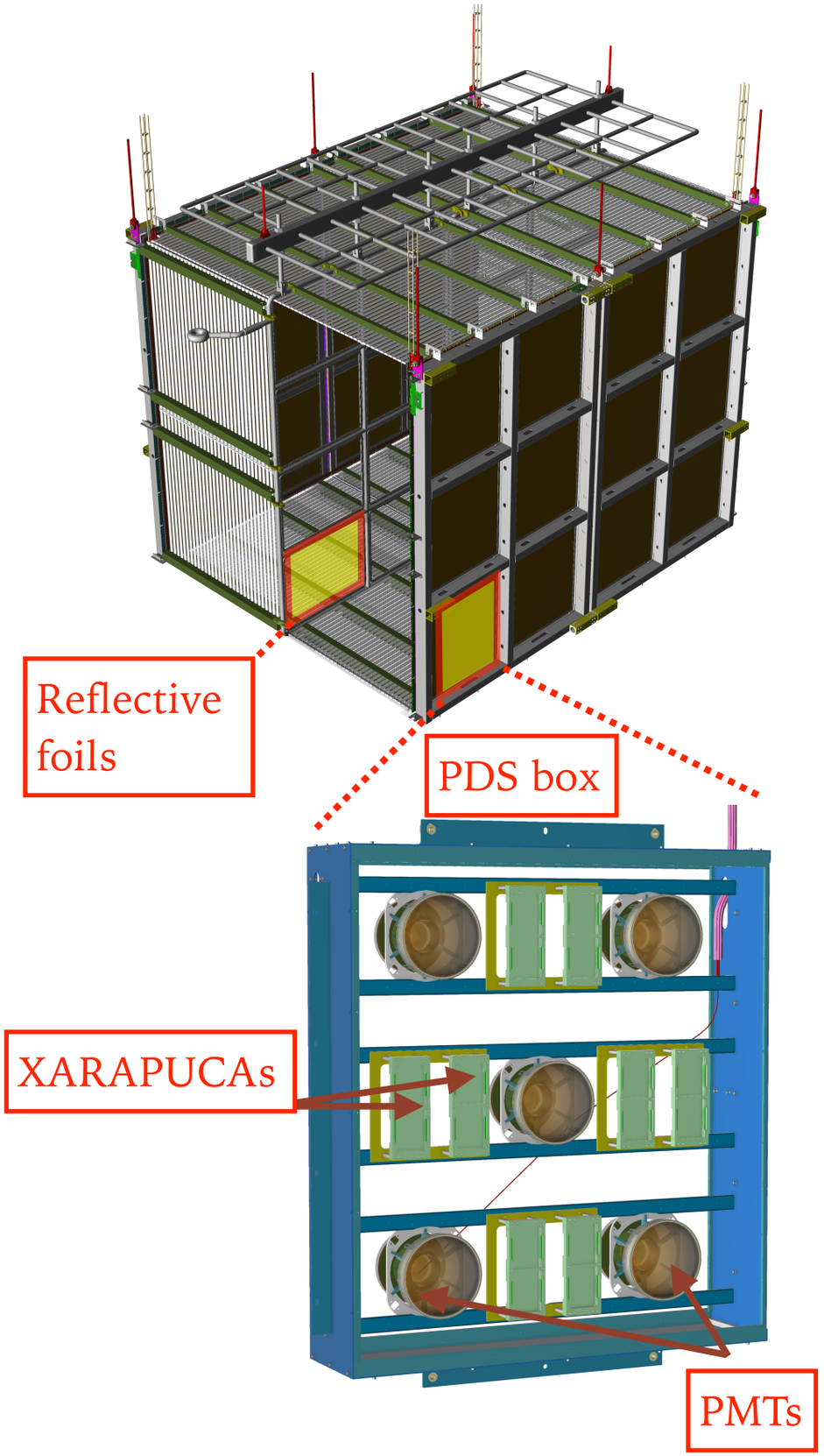
- 112 ton active volume
- 2 drift regions (2 m each)
- TPC construction finished in June 2022
- Detector installation inside the cryostat expected next spring





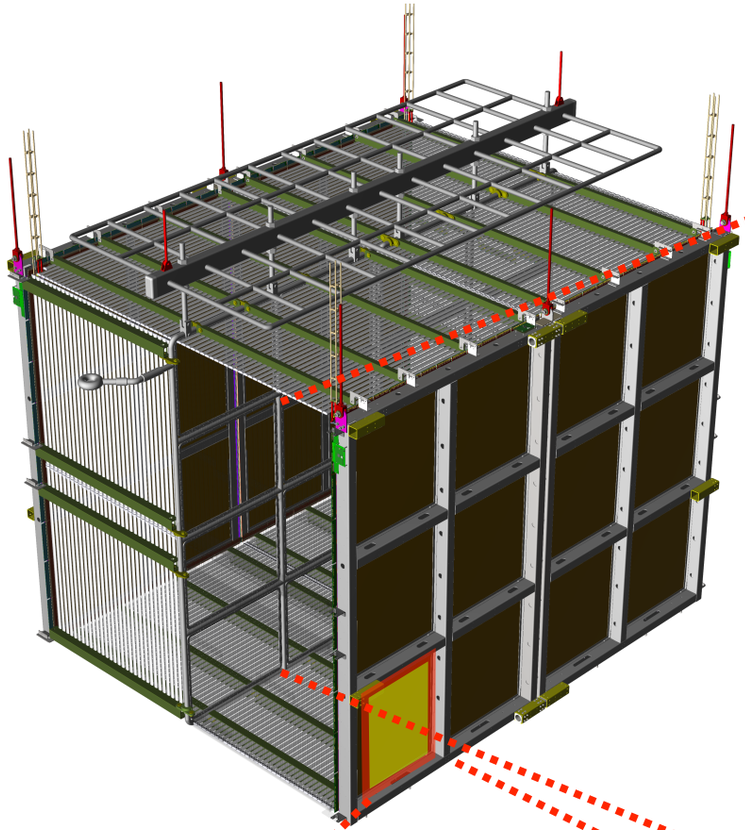
Inside view of SBND at Fermilab (one TPC)

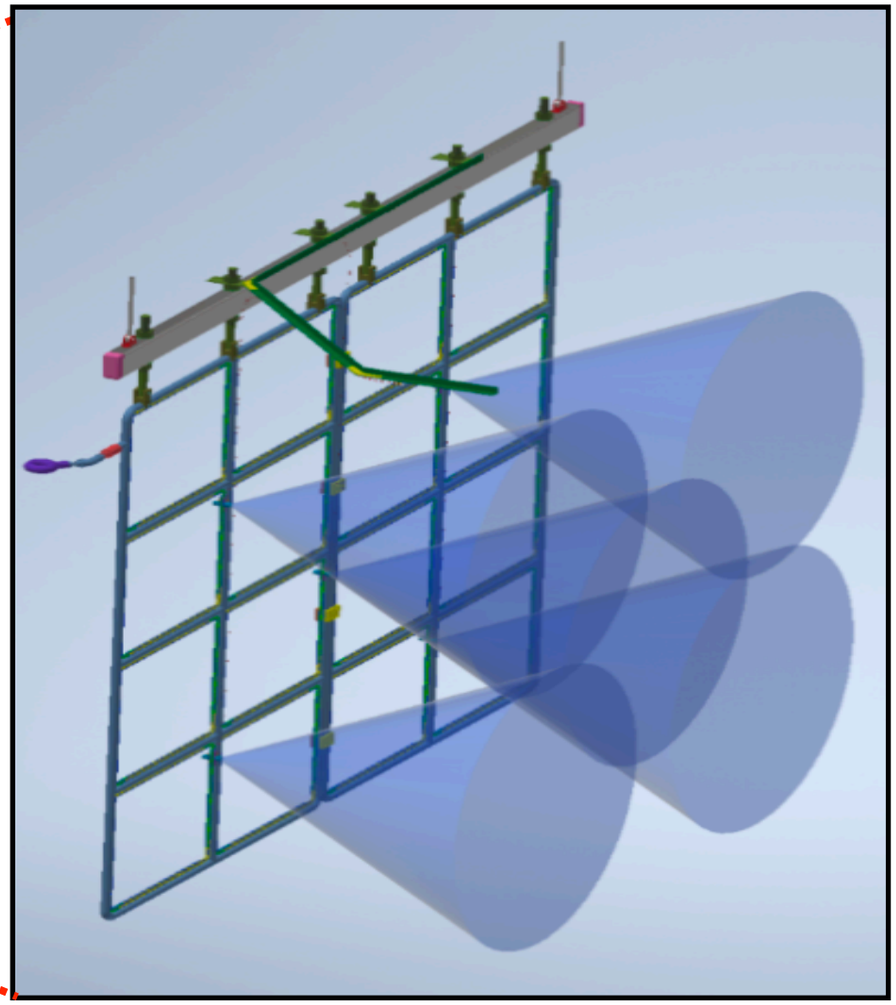
SBND PDS DESIGN



- SBND PDS: R&D opportunity for LArTPC technology
- Hybrid concept combining two photon detection technologies:
  - Primary system: 120 **PMTs**
  - R&D: 192 **XARAPUCAs**
- Optical detectors arranged in **24 PDS boxes** mounted behind the wire planes
- Passive elements: **reflective foils** installed in the cathode to enhance light collection
- Calibration system:
  - 5 **diffusers** located at each side of the cathode
  - Optic fibers connect the diffuser to a laser system

SBND PDS DESIGN

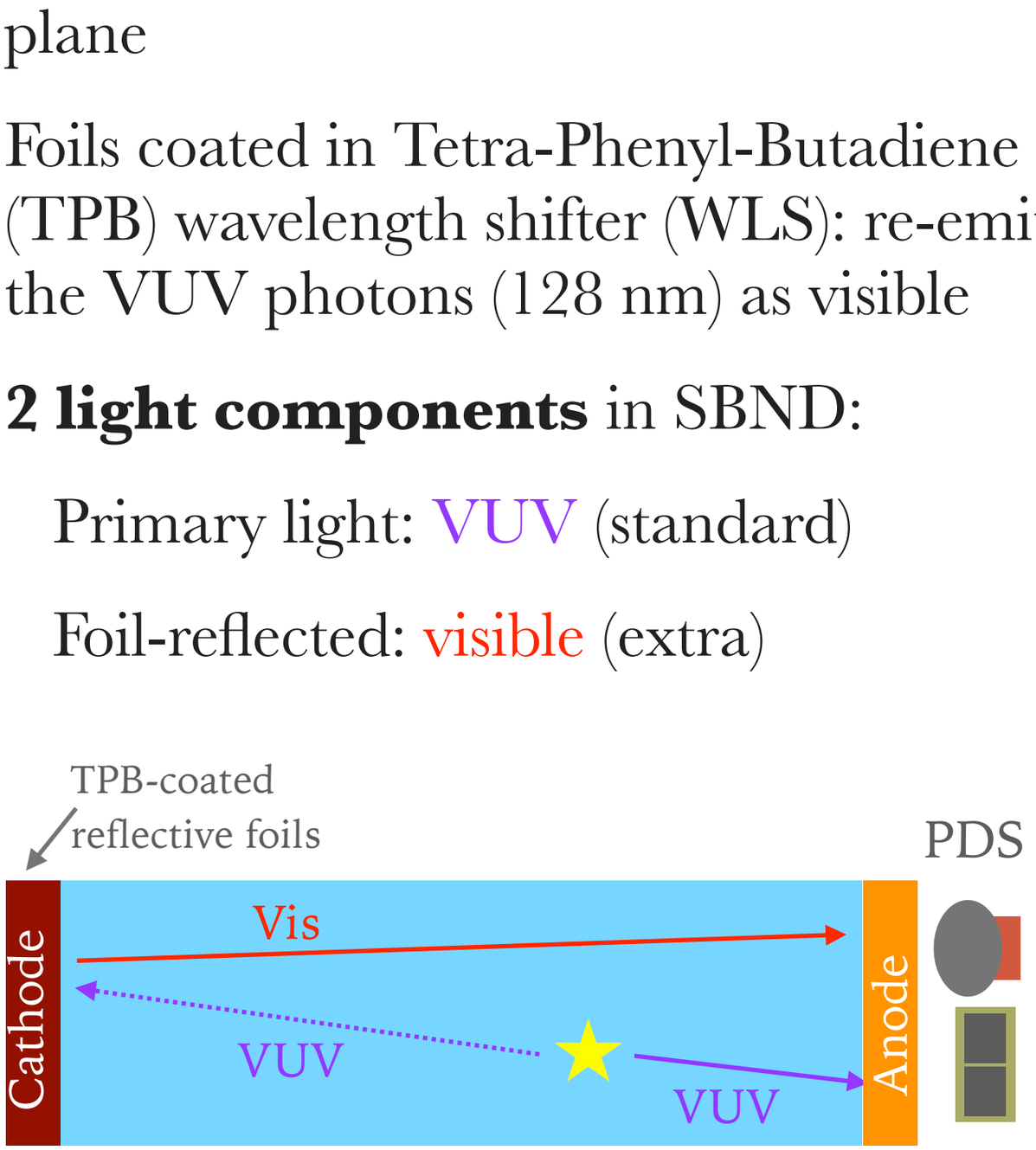


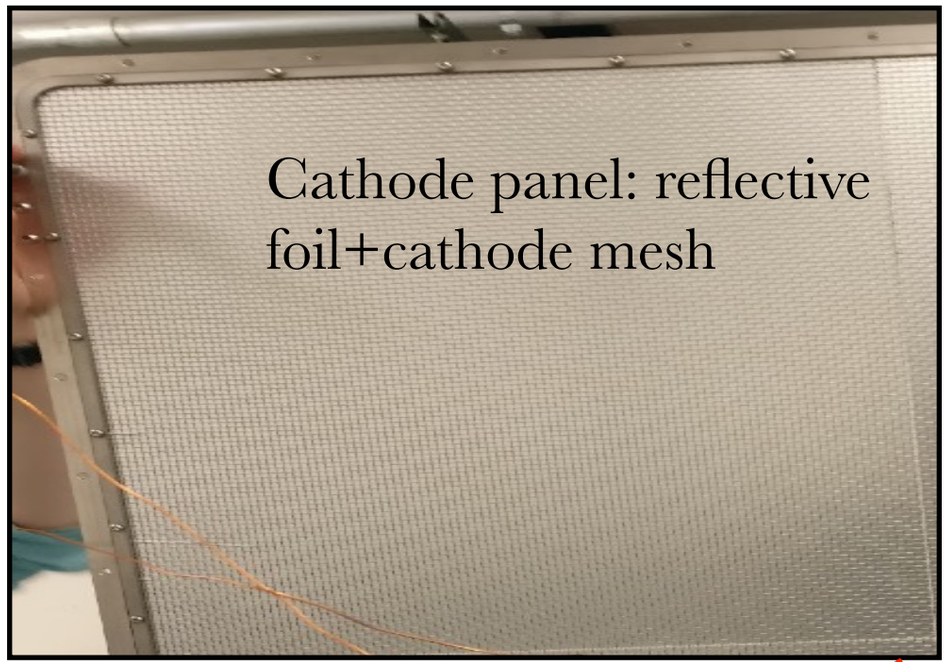


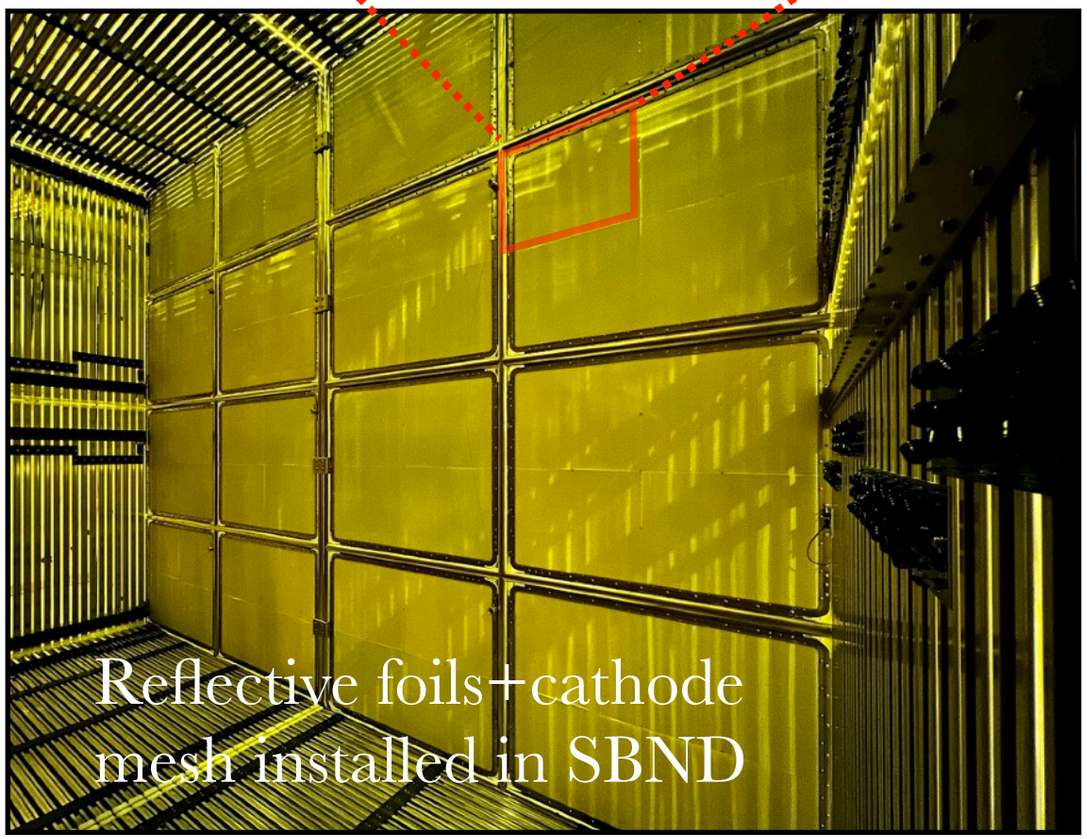
- Calibration system:
  - 5 **diffusers** located at each side of the cathode
  - Optic fibers connect the diffuser to a laser system

CATHODE REFLECTIVE FOILS

- Highly **reflective foils** installed in the cathode: enable recovering part of the photons emitted towards the cathode plane
- Foils coated in Tetra-Phenyl-Butadiene (TPB) wavelength shifter (WLS): re-emits the VUV photons (128 nm) as visible
- **2 light components** in SBND:
  - Primary light: VUV (standard)
  - Foil-reflected: visible (extra)



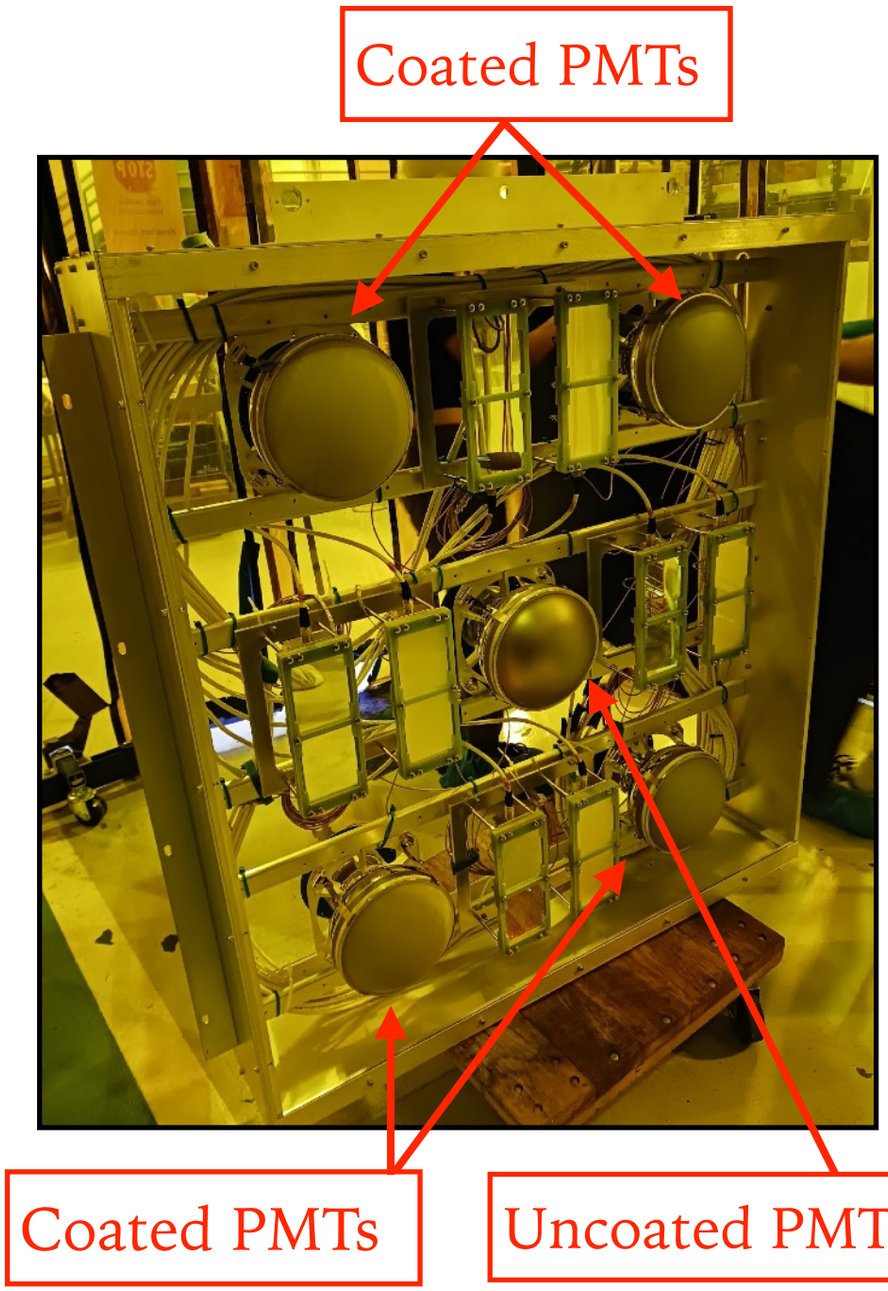




PMT SYSTEM

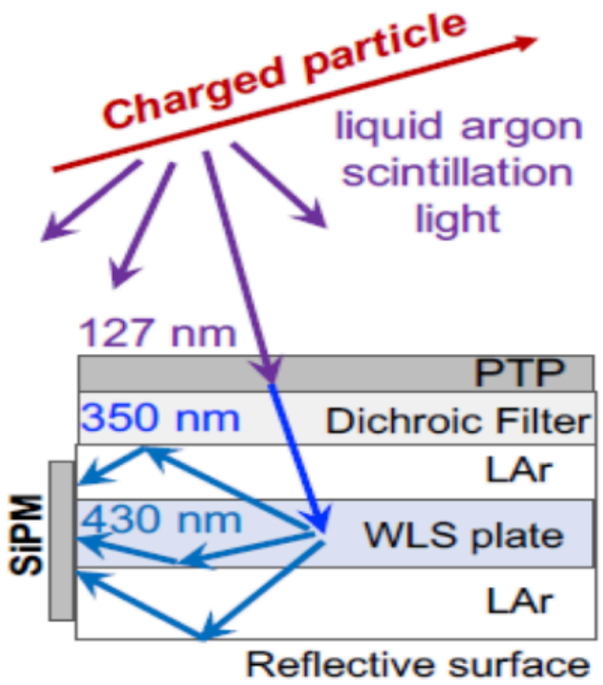
- Primary system: 120 8” Hamamatsu R5912 **PMTs**
  - Used for trigger building
- Sensitive to the two light components:
  - 96 coated (corners) in TPB: sensitive to VUV+Vis
  - 24 uncoated (central): sensitive only to Vis photons
- Fast readout electronics by CAEN (2 ns sampling time)
- PMT system developed and first tested by Coherent Captain Mills (CCM) experiment
  - Physics run in fall 2019
  - PMTs installed in the PDS boxes shipped to Fermilab last year

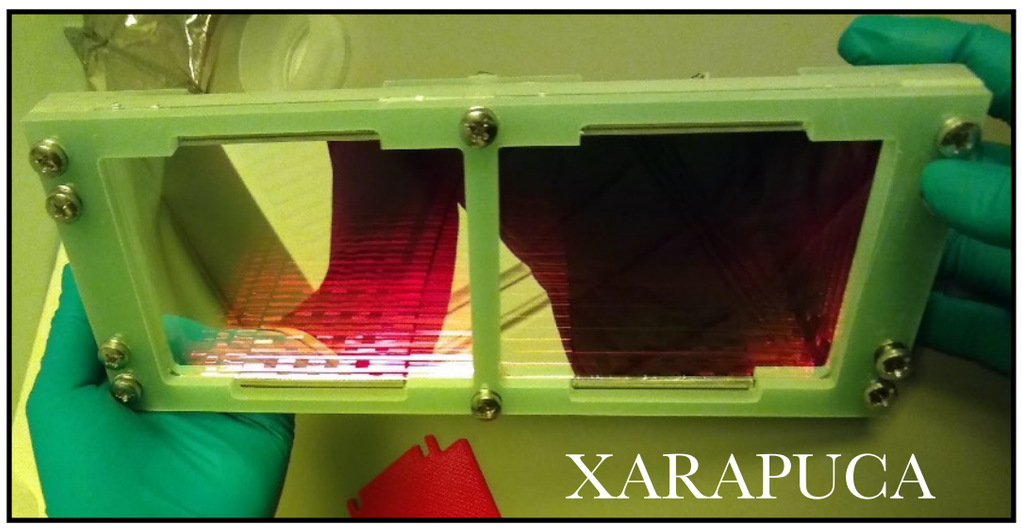
Fully assembled PDS box at Fermilab

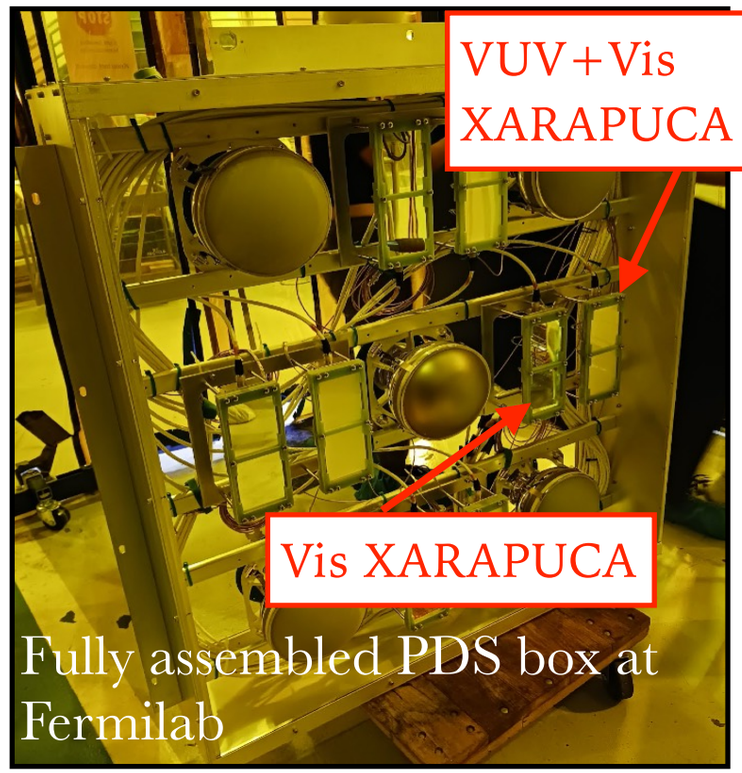


XARAPUCA SYSTEM

- R&D system: 192 **X-ARAPUCAs**
- Light trap: combination of WLSs and dichroic filters
  - 1/2 Vis sensitive (450 nm filter cutoff)
  - 1/2 VUV+Vis sensitive (pTP WLS+400 nm filter cutoff)
- Photon collection by SiPMs:
  - 4 boards with 8 SiPM by SensL (x176)
  - 4 boards with 4 SiPM by Hamamatsu (x16)
- Readout electronics:
  - x176 by DAPHNE (12.5 ns sampling time)
  - x16 by APSAIA (2 ns sampling time)
- Same detection technology will be used by DUNE experiment
- XARAPUCA mounting on the PDS boxes finished last month







SBND PDS: CURRENT STATUS

- Exciting time at SBND: **PDS boxes installation in the detector completed this week**!

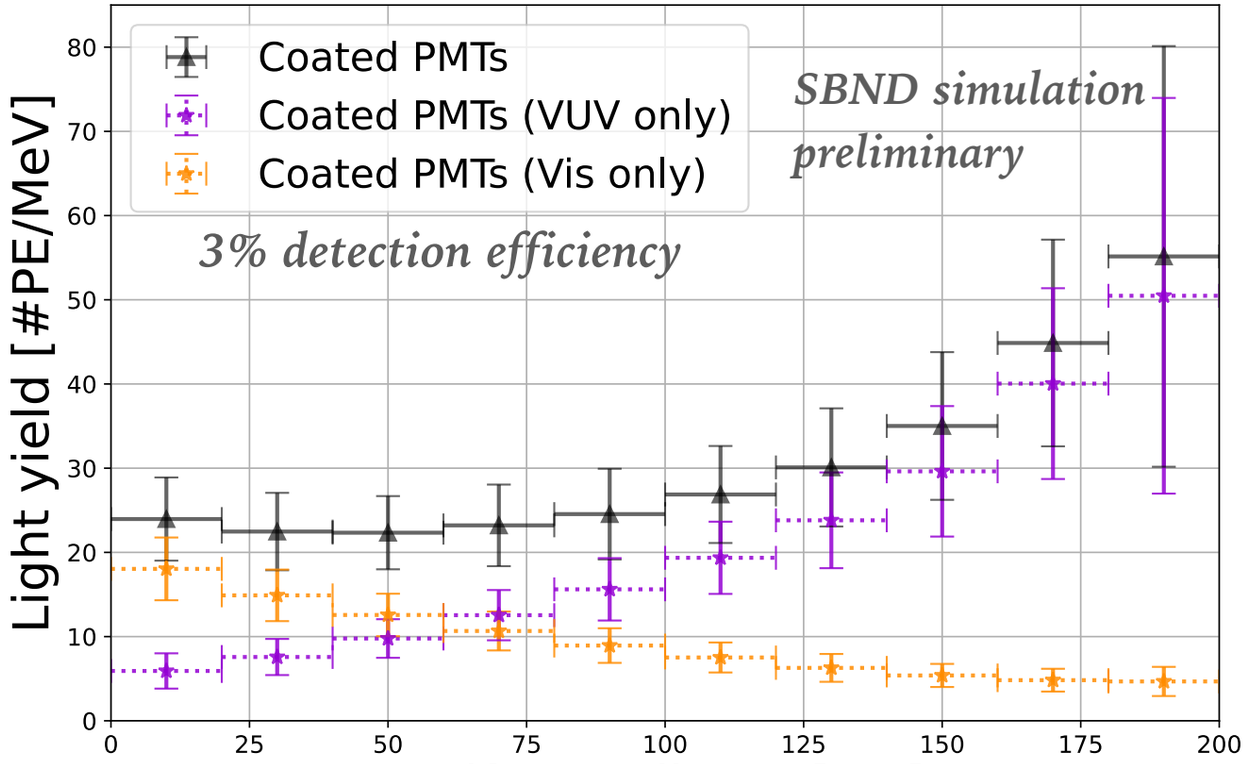
Inside view of SBND: PDS installed in the west APA

LIGHT YIELD (LY)

- SBND PDS design focuses on maximizing the physics output and detector performance by enhancing the **light collection and its uniformity** thanks to

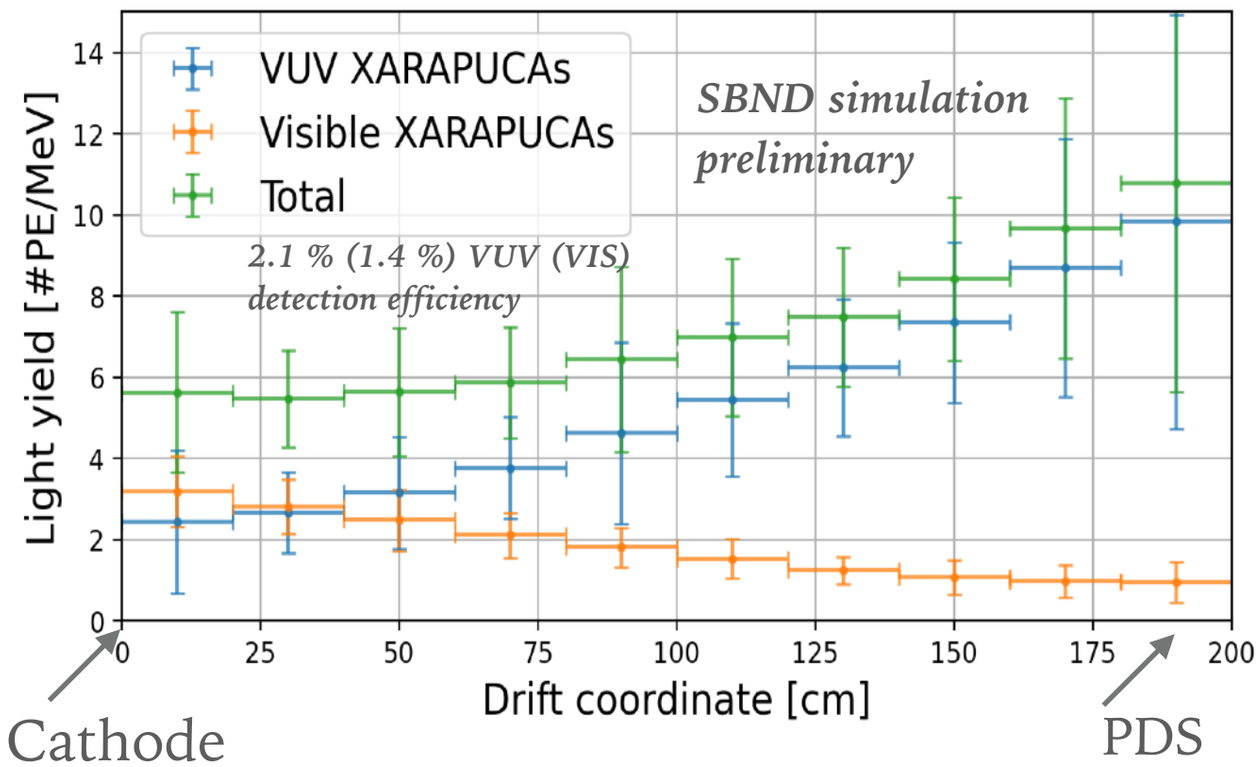
  (i) the hight density of optical channels

  (ii) the TPB-coated reflective foils installed in the cathode



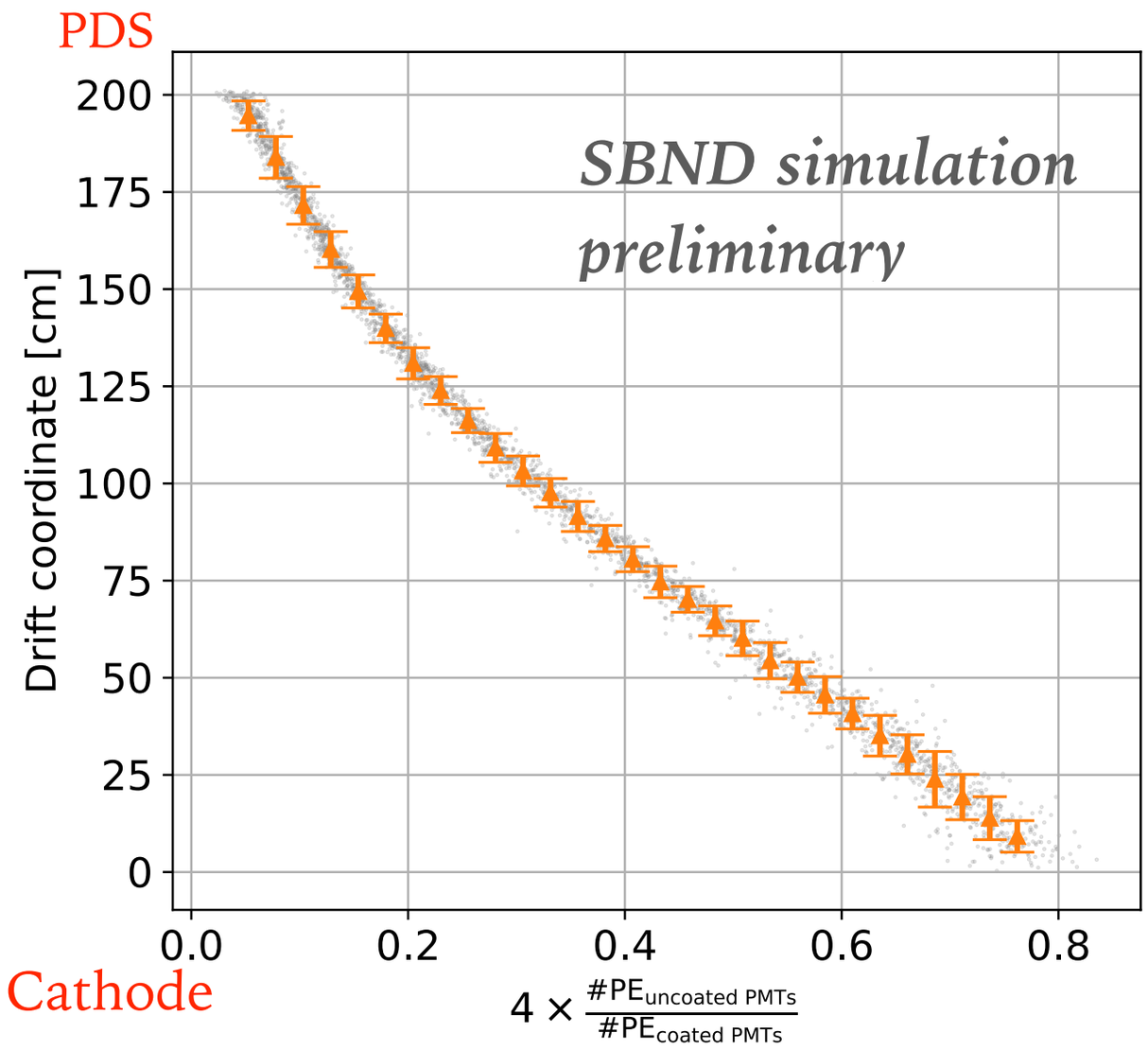
SBND high LY

- Lower detection thresholds
- Calorimetric/PID reconstruction using light
- Improves resolution (more photons, less fluctuations)



POSITION RECONSTRUCTION

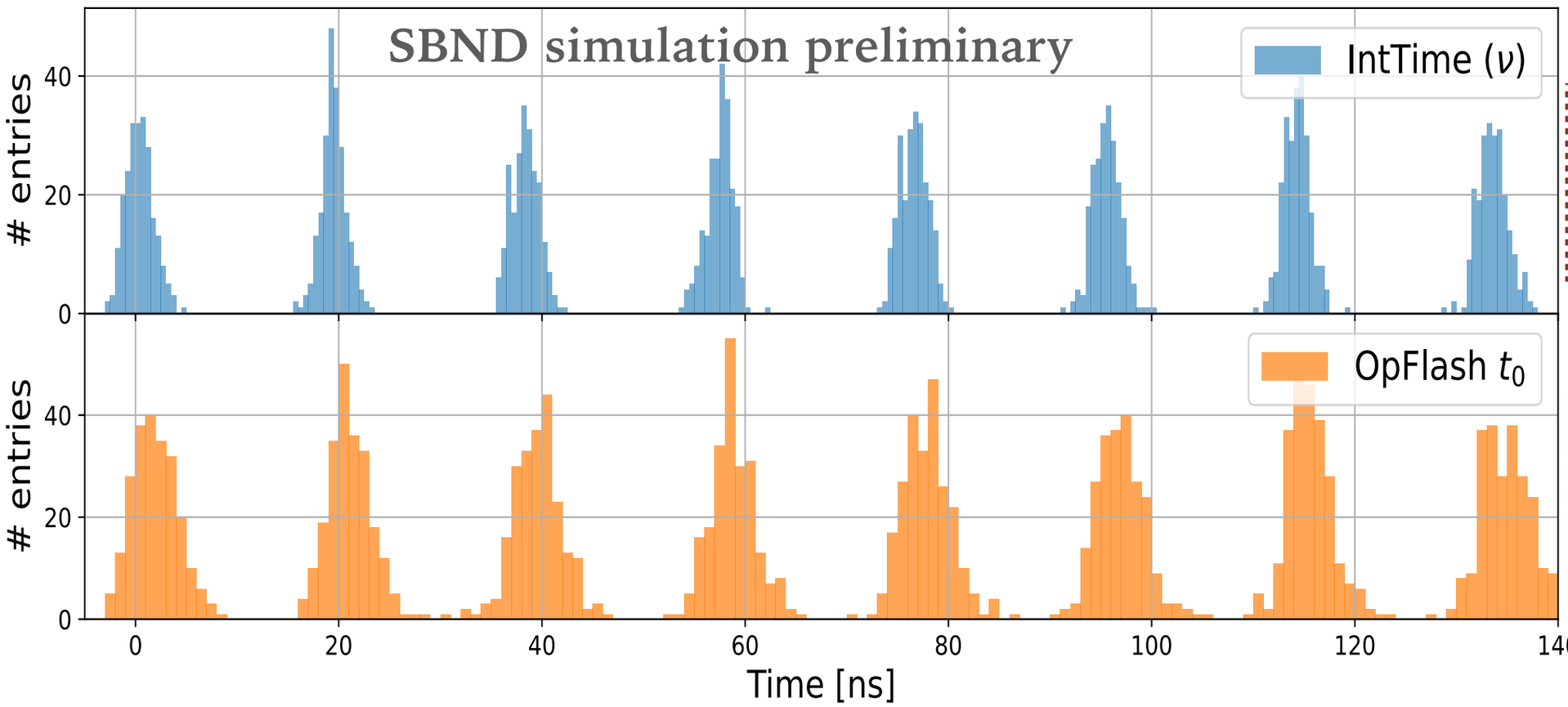
- SBND PDS will provide an independent 3D reconstruction using only scintillation light signals
  - Crucial for PDS-TPC matching → See Iker's poster about flash matching!
- Optical detectors able to **distinguish between the two light components**: Allows drift (X) coordinate estimation



- Correlation between
  - Ratio of photons detected by the uncoated/coated PMTs
  - Mean drift distance of the interaction
- Similar correlation available too from XARAPUCAs

TIME RESOLUTION

- Beam ν's produced in a 1.6 μs time window (beam spill)
  - Light signal during the beam spill: likely a ν interaction
- Closer look to the beam spill: ν's produced in "packets"



Top: simulated neutrino arrival time distribution at SBND

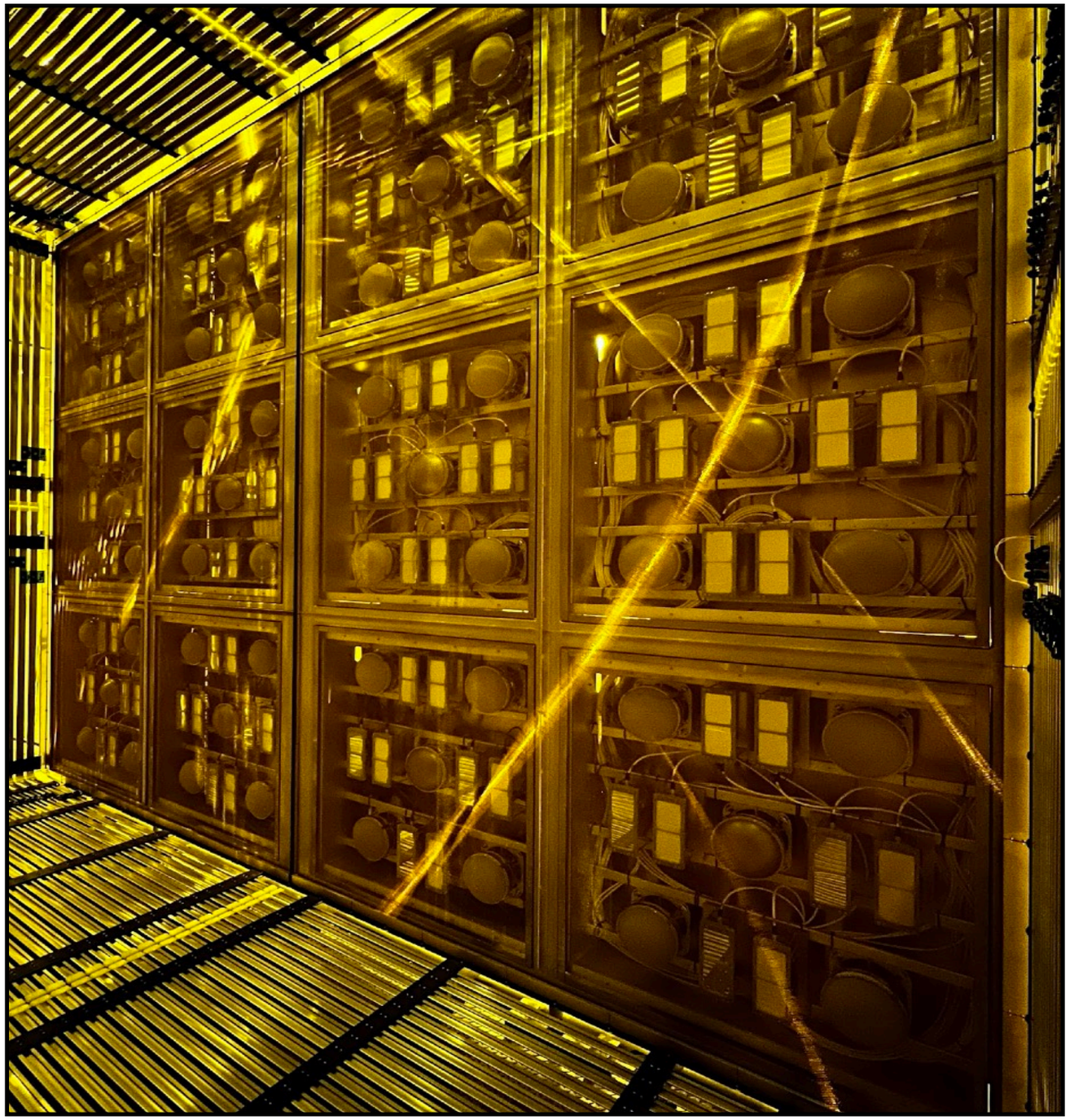
Bottom: neutrino times from light signals (PDS-only reconstruction)

- With a PDS time resolution ~2 ns: SBND is potentially able to resolve the beam inner structure

→ Already proved by μBooNE (public note 115)

  - Reduce in-time cosmic contamination
  - BSM searches (beam-produced particles "between buckets")

SUMMARY



- LAr is a very prolific scintillator
  - SBND is the LArTPC detector using the most advanced Photon Detection System so far
- An accurate detection and reconstruction of the light signals can lead to an overall improvement of the LArTPC technology
- Great opportunity to explore and develop new applications of the scintillation light!
- PDS installation completed
  - First data expected next year!

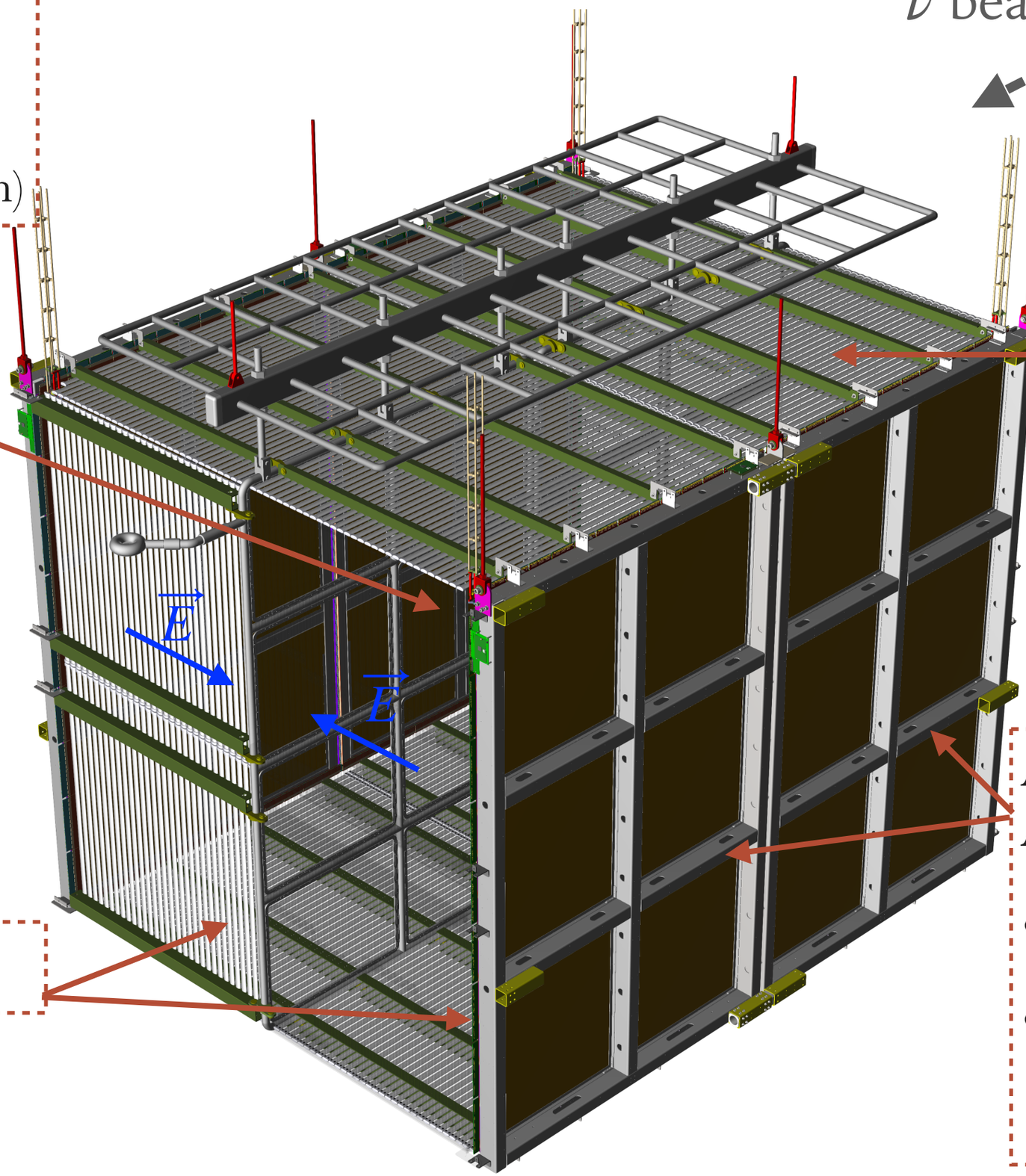
Thank you!

Backup

SBND DETECTOR: TPC

Active volume:

- 112 ton of LAr
- 2x2 m (drift) x 4 m (height) x 5 m (length)



Field Cage

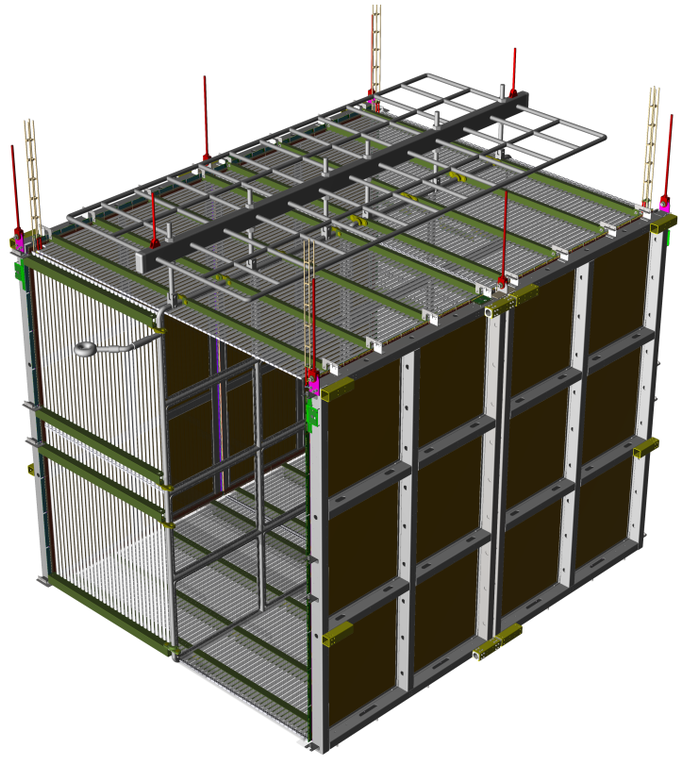
Cathode Plane Assembly (CPA)

2 drift regions

Anode Plane Assemblies (APAs)

- 3 wire planes
- ~11k readout wires

SBND PDS DESIGN



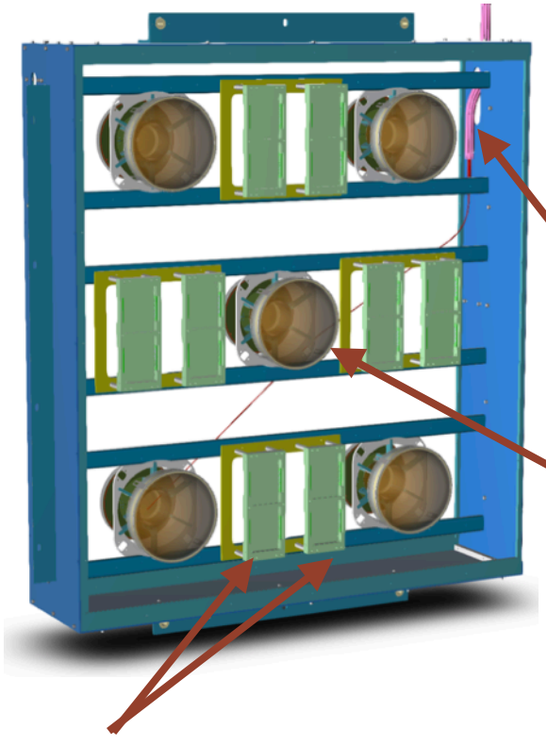
Passive Components

- Reflective foils installed in the cathode
- Foils coated in Tetra-Phenyl-Butadiene WLS (TPB): VUV photons re-emitted as visible
- SBND PDS sensitive to 2 light components:
  - Primary light: VUV (standard)
  - Foil-reflected: visible (extra)

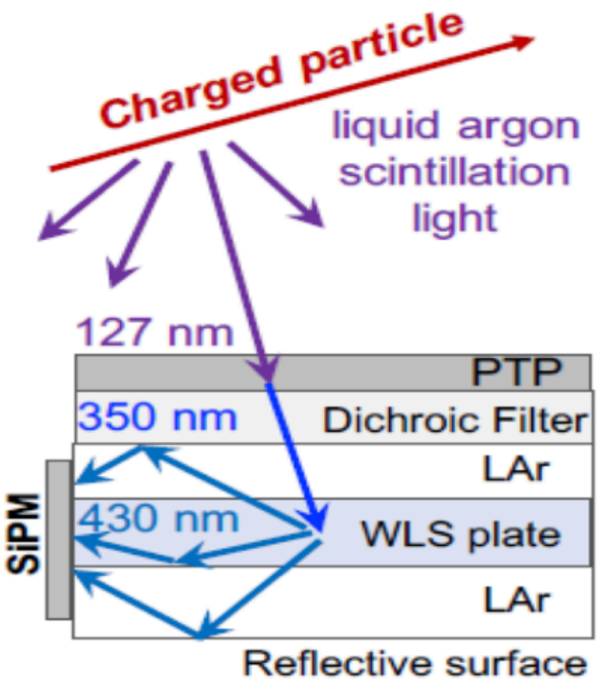
- Detection of LAr scintillation photons (VUV) challenging: wavelength shifters (WLS) are typically used

Active Components

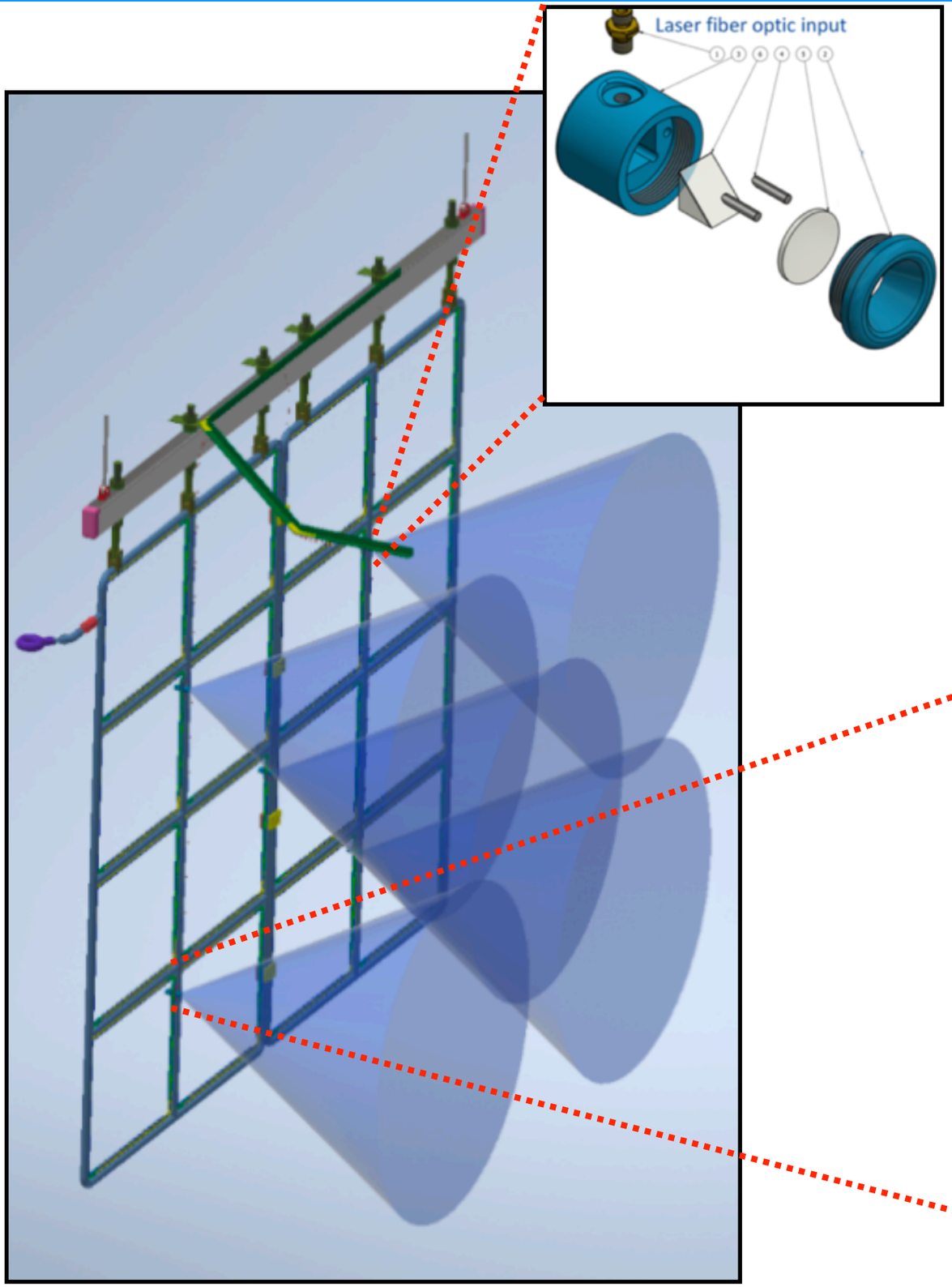
- Hybrid concept with two different detection technologies



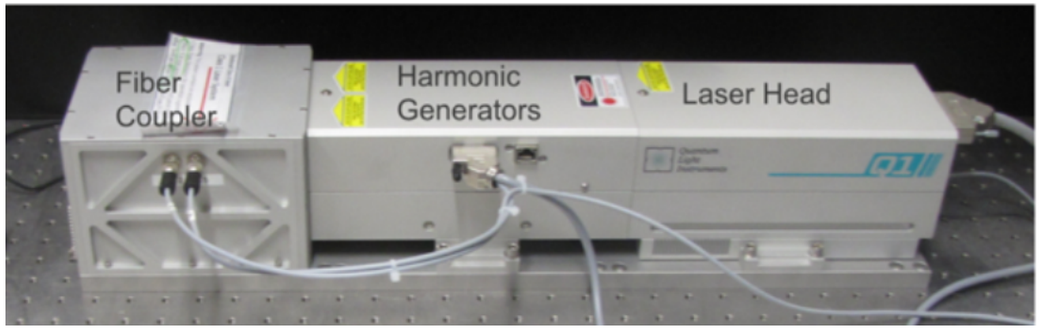
- Primary system (well known technology): 120 8" Hamamatsu R5912 **Photomultipliers Tubes (PMT):**
  - 96 coated (corners) in TPB
  - 24 uncoated (central)
- Secondary system (R&D): 192 **X-ARAPUCAs:**
  - Light trap (WLS + dichroic filters
  - Readout by SiPMs
- 1/2 VUV sensitive, 1/2 visible sensitive



SBND PDS CALIBRATION SYSTEM



- Laser system
- 2 wavelengths (213 nm and 532 nm)

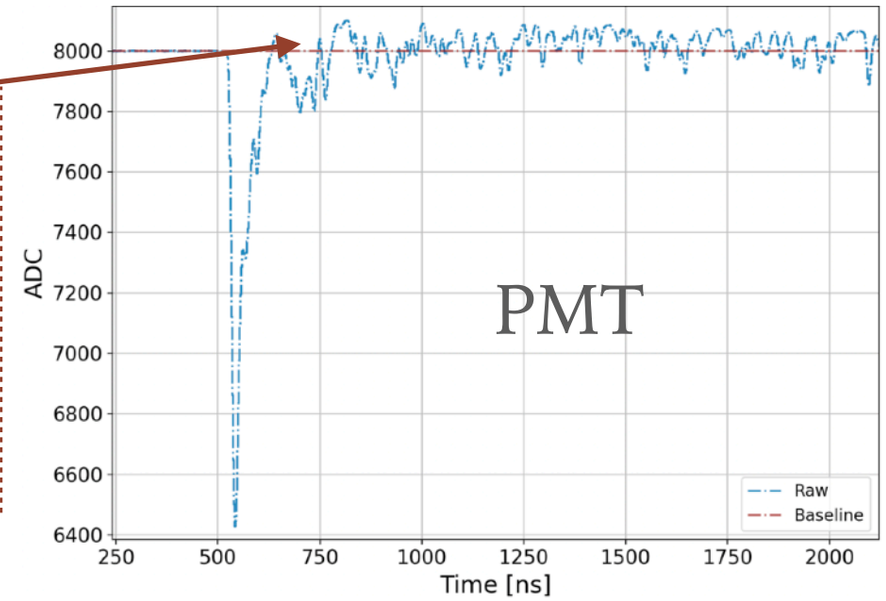


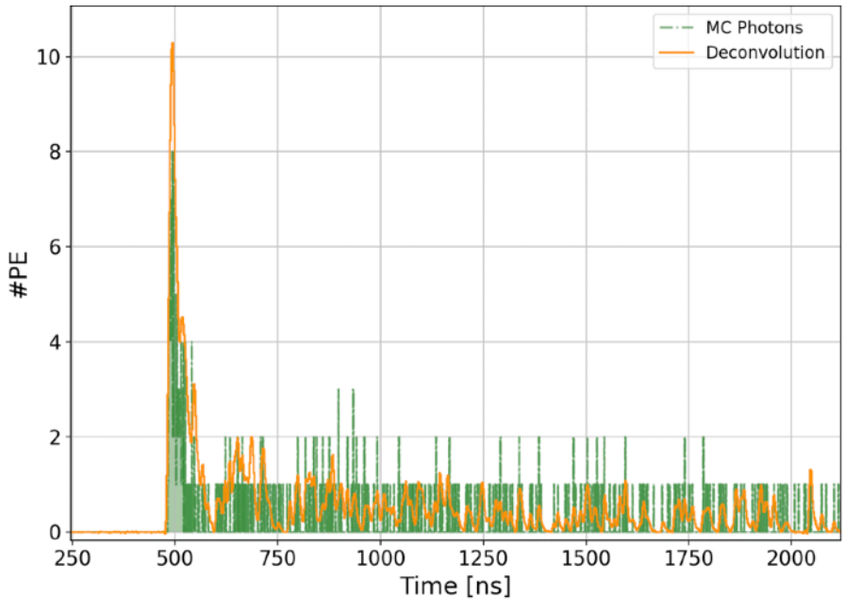
- Diffuser + optic fiber installed in SBND

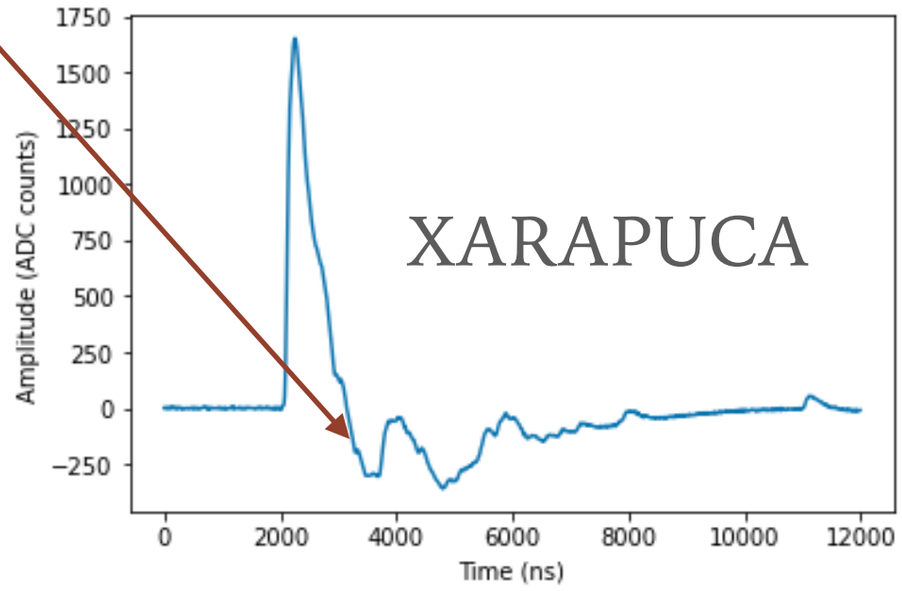
PDS SIGNAL RECONSTRUCTION

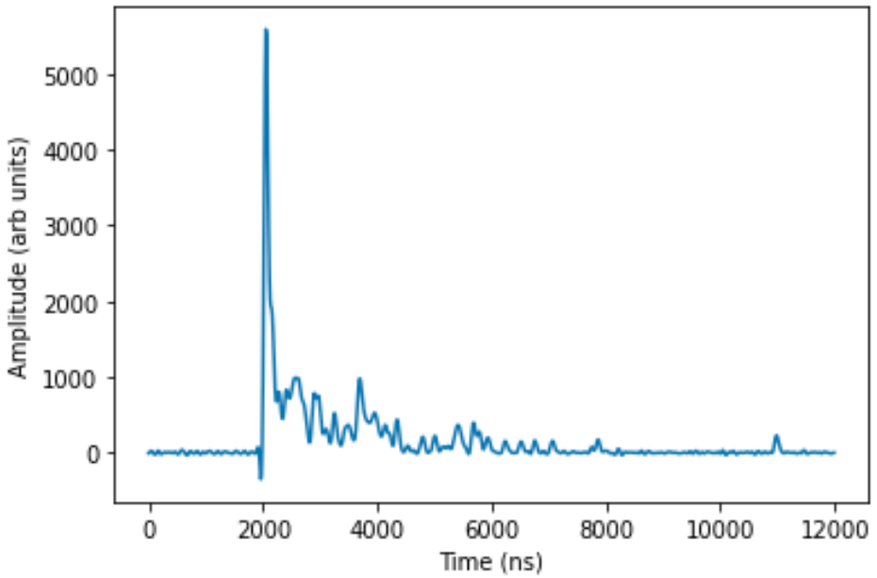
- An accurate reconstruction of the light signals is needed for the new applications
  - SBND will be using **AC coupled readouts**→bipolar waveforms (overshoot)
  - Standard reconstruction tools shared by the LAr community not optimized for bipolar waveforms
  - SBND is working on a deconvolution-based light signal treatment to allow realistic digitization and accurate reconstruction (both PMT & XARAPUCAs)

Overshoot makes total output charge recovering challenging



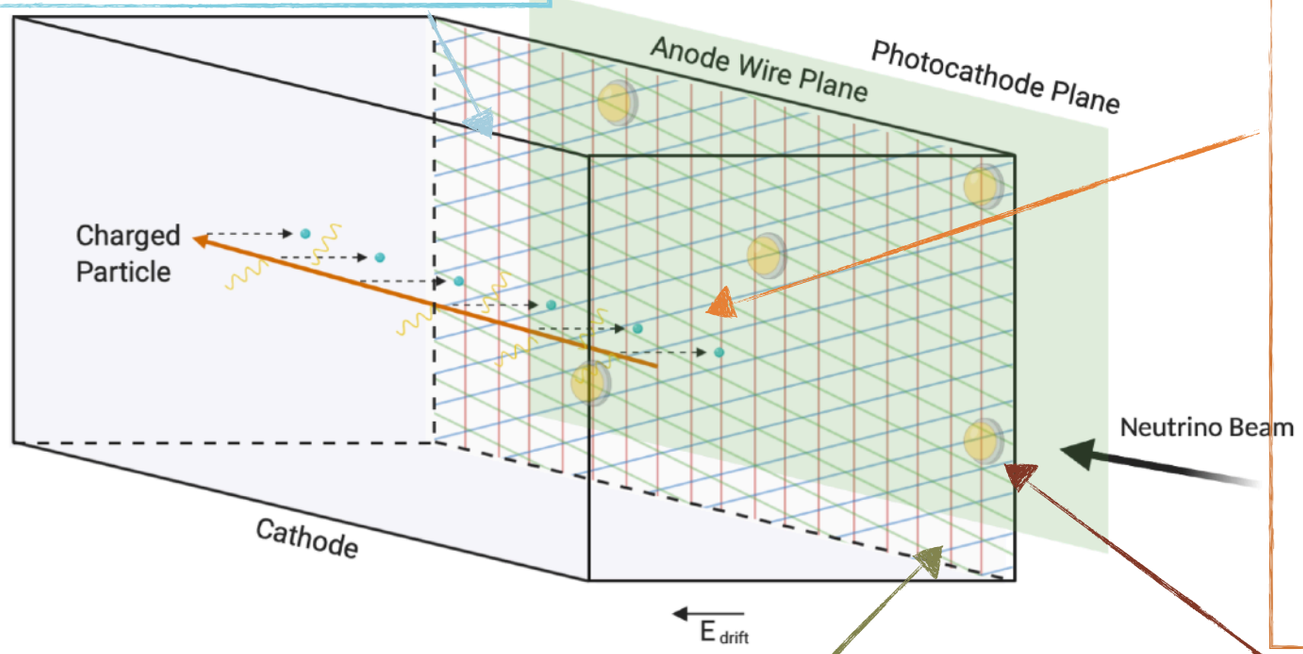




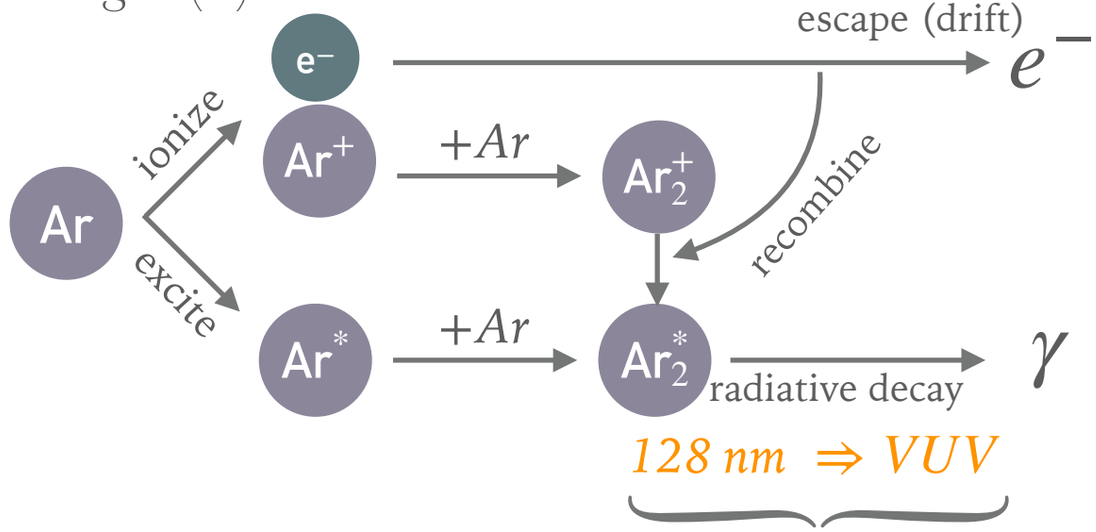


LARTPC AT WORK

LAr as medium target

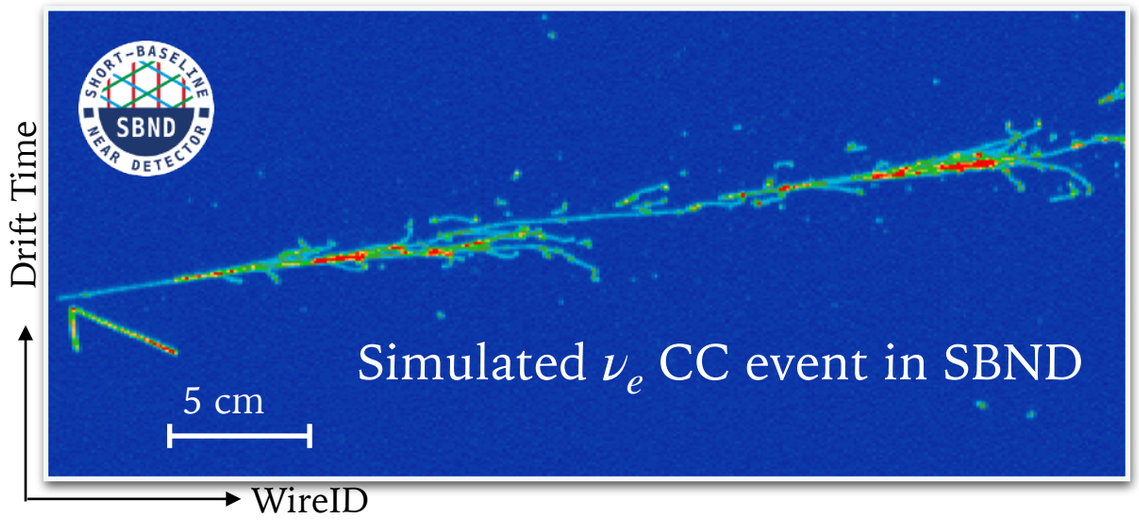


- Two complementary signals: Charge (Q) and Light (L)



Absorbed by most materials!

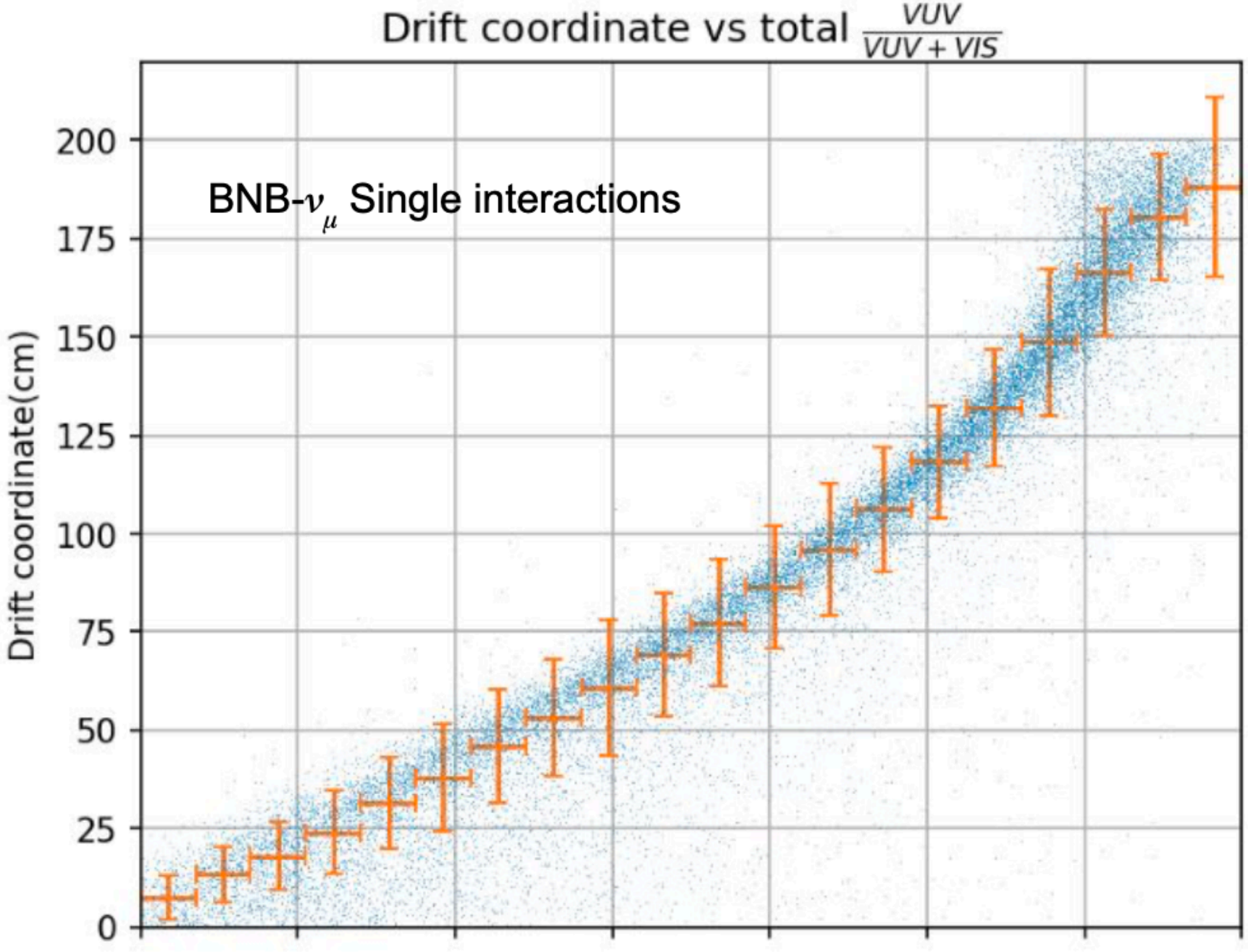
- Charge readout (wires)
- The released electrons drift under the influence of an electric field
- Primary reconstruction based on the charge



- Photon readout
- Light mainly used for trigger purposes thus far
  - However Q and L produced in a similar amount at the operational electric fields (500 V/cm)
- Full potential of light singlas has not been explored yet
  - Requires a **sophisticated PDS (as SBND!)**

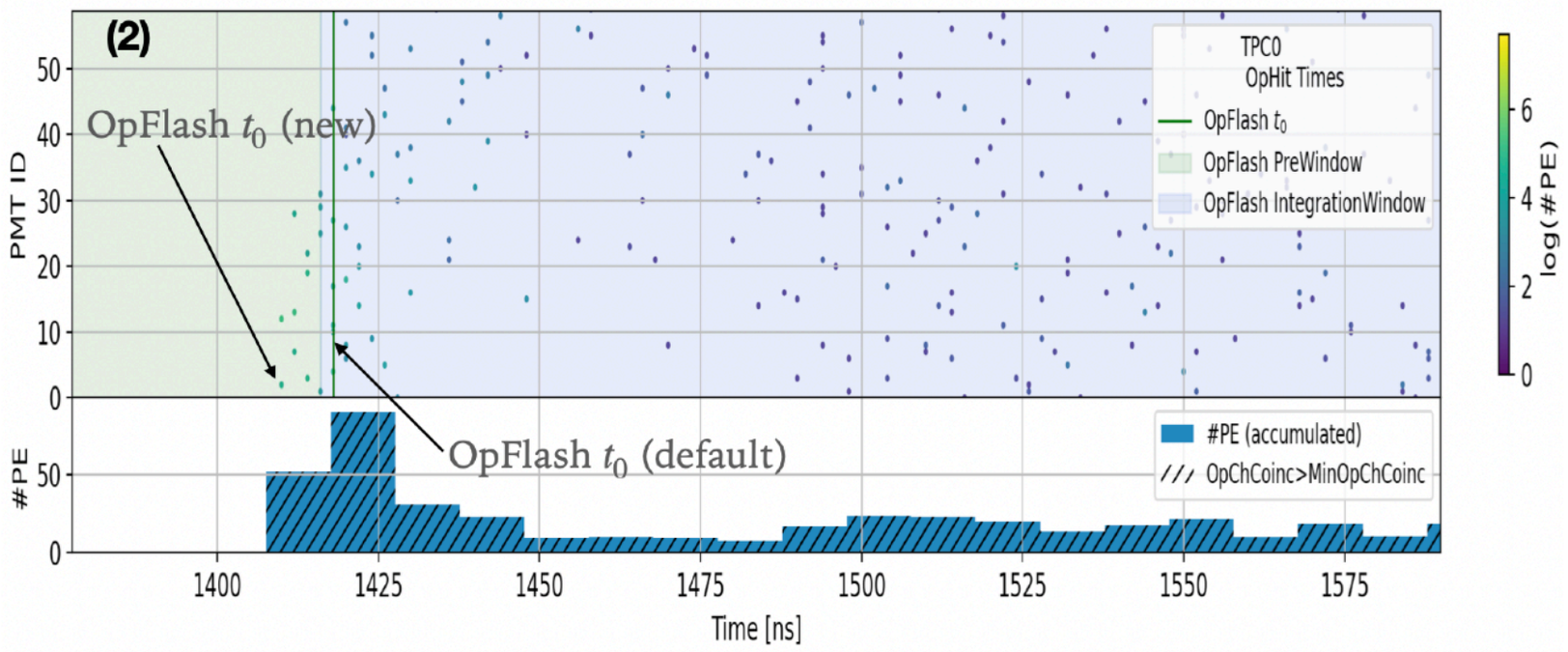
DRIFT RECONSTRUCTION (XARAPUCAS)

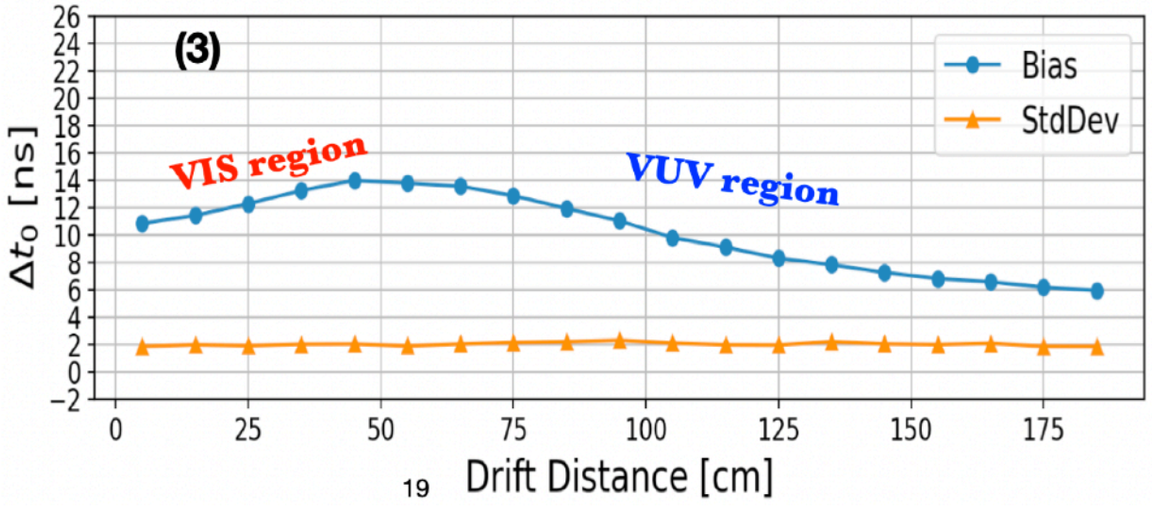
- Drift reconstruction for XARAPUCAs:

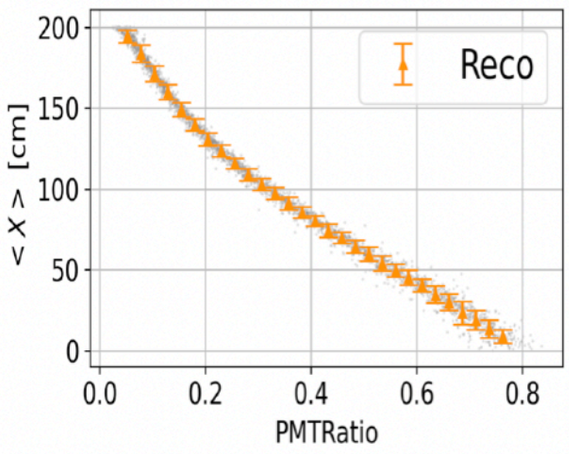


RECONSTRUCTION

- Three main factors limiting the t_0 resolution were identified:
  1. RiseTime
  2. OpFlash clustering
  3. Propagation







XARAPUCA SYSTEM

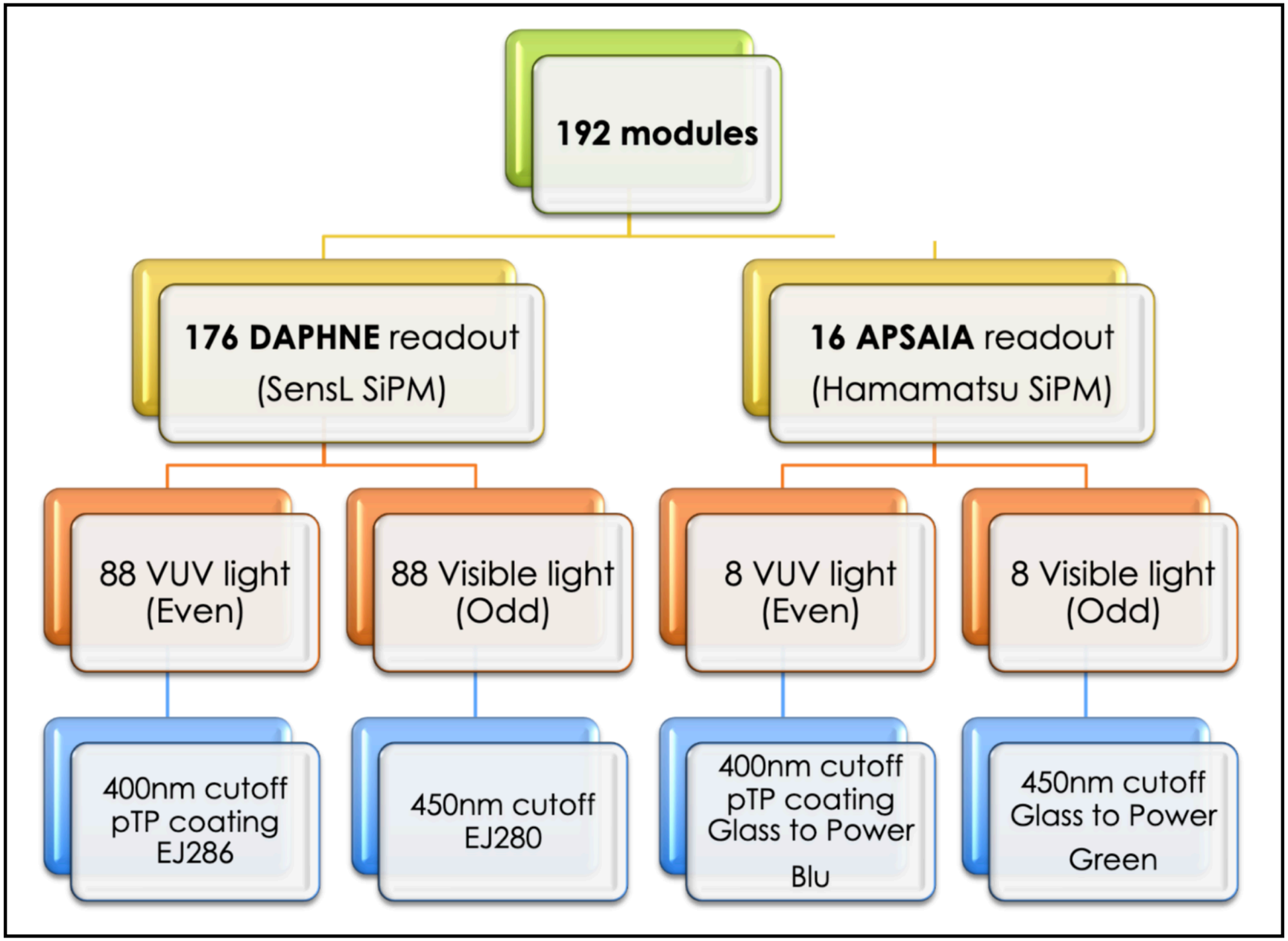


Diagram credit: Ana Machado

PDS INSTALLATION