# Identification of Cosmic Rays in the ICARUS Experiment Using Precision Timing

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The ICARUS-T600 Detector

- Operated underground for 3 years at LNGS in Italy as the first large scale Liquid Argon Time Projection Chamber (LArTPC)
  - 760 tons Liquid Argon; 3.6 x 19.6 x 3.9 m^3, 1 mm^3 spatial resolution
- Shipped to CERN for upgrades
  - ✓ New TPC electronics
  - ✓ Upgrades to light collection system including 360 8" Photomultiplier Tubes (PMT)s
- Now operating on the surface at Fermilab as the SBN Far Detector
  - Exposed to BNB and NuMI ν beams
  - **~10 cosmic muon tracks in detector per ~1 ms drift time in each readout**
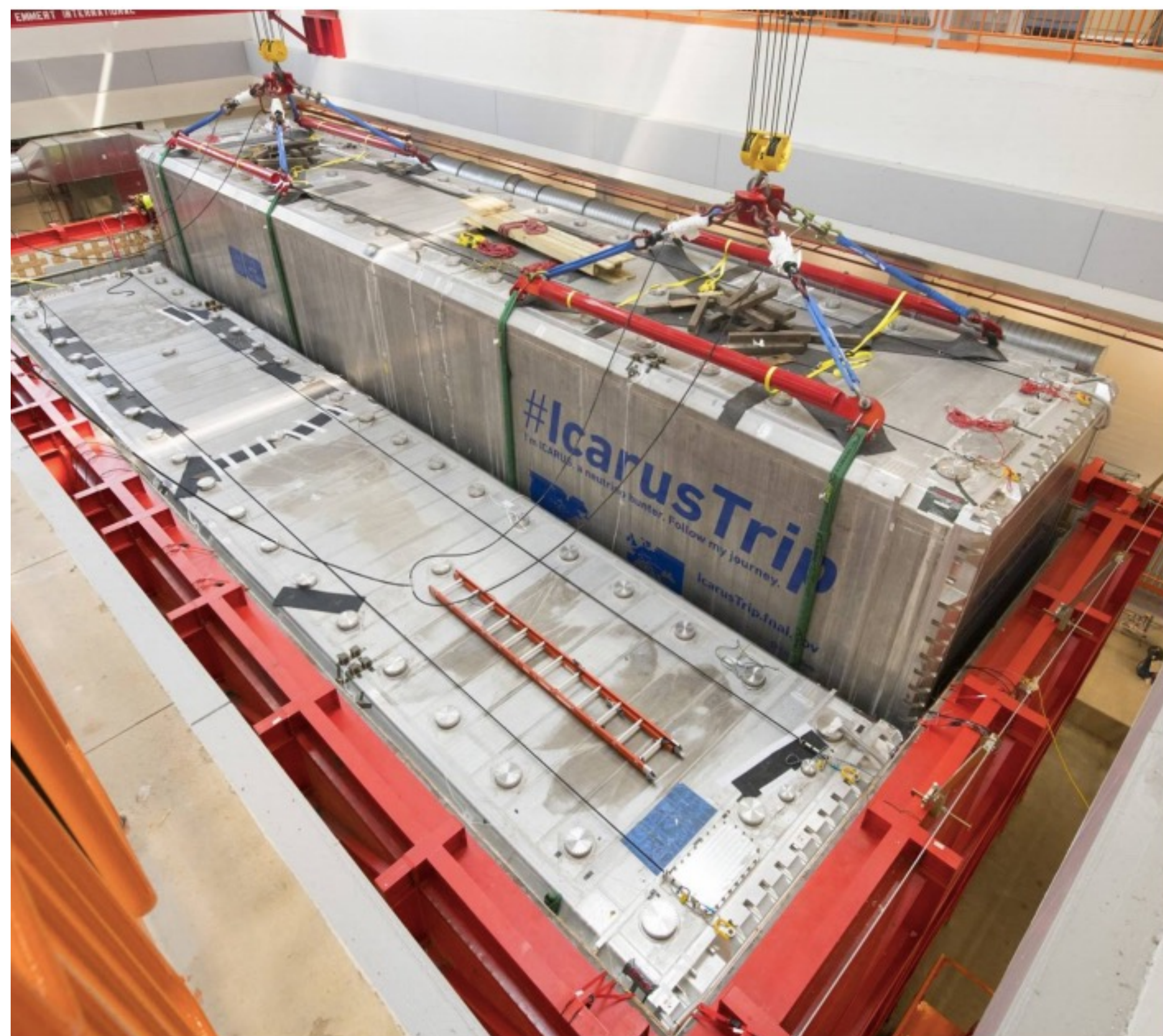
One of the ICARUS TPCs being lowered into the cryostat at Fermilab

Photomultiplier Tubes (PMTs)

- 360 8" Hamamatsu R5912-MOD PMTs for new optical detection system mounted behind the TPC wire plane
- Detects scintillation light from charged particles interacting in the Liquid Argon with a few nanosecond response time
  - Trigger signal is generated by discriminated pairs of PMT signals above a threshold (Majority logic) in coincidence with BNB/NuMI beam spills (1.6/9.6 µs)
  - Used for the trigger of the full detector to provide the global timing of events
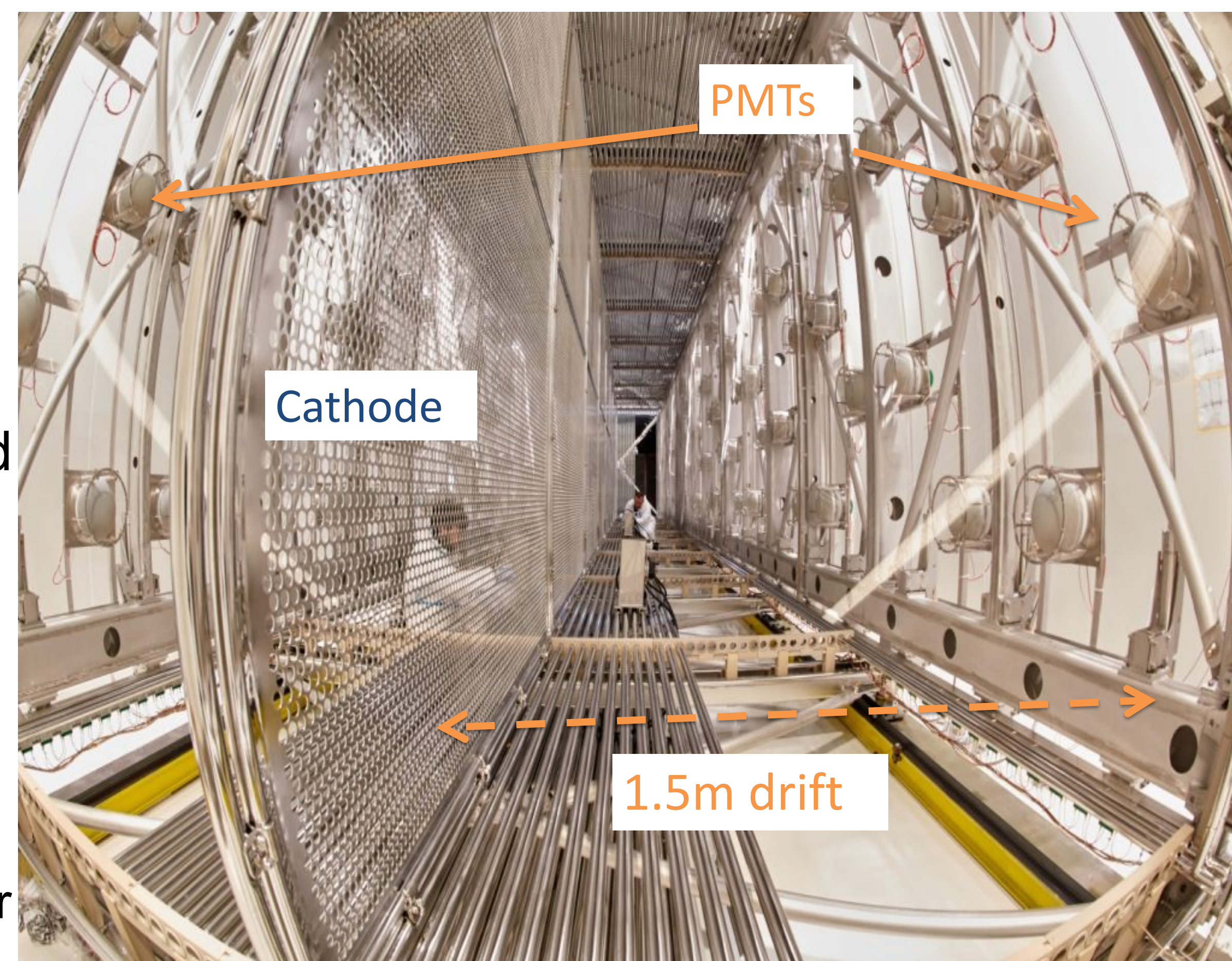
View inside one of the TPCs during upgrades at CERN

PMT Flash Timing

Distribution of PMT scintillation signal timing with respect to the opening of the neutrino beam gates shows excess PMT light over the standard cosmic background rate, demonstrating the trigger performance
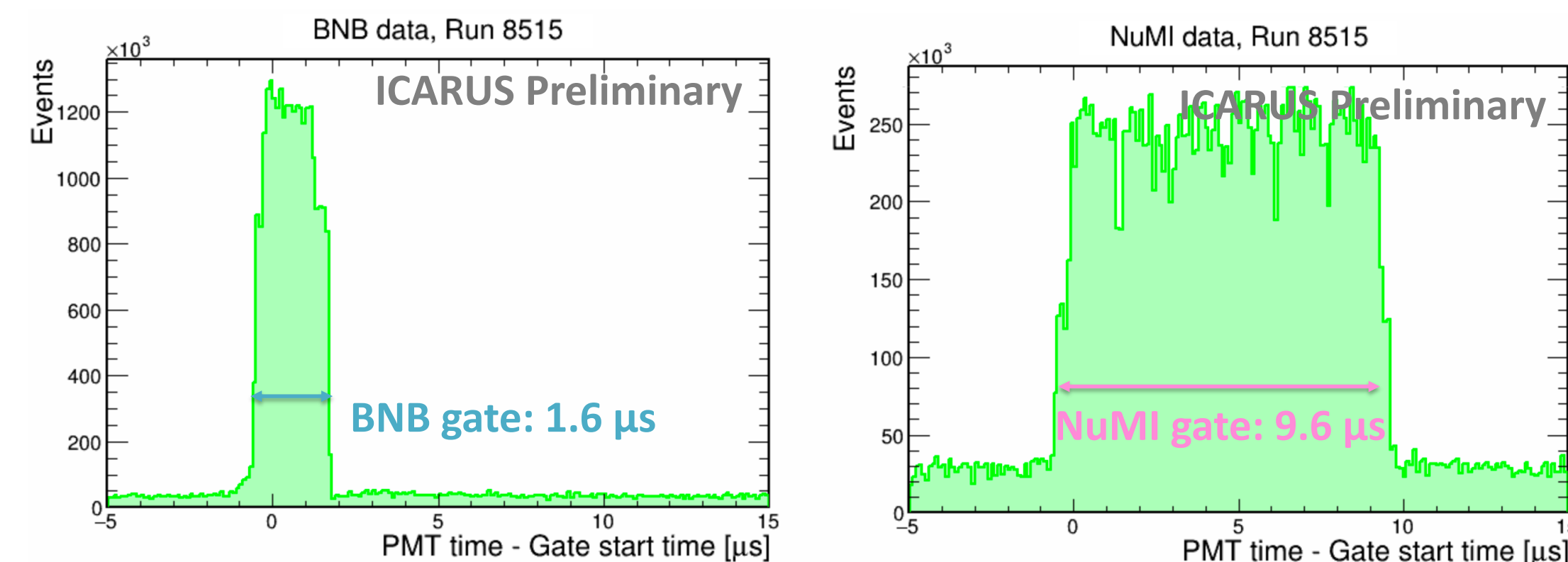
Cosmic Ray Tagging (CRT) System

Surround ICARUS cryostat (~1,000 m^2 coverage) with 2 layers of fiber embedded plastic scintillator to mitigate cosmogenic background source experienced at shallow depth
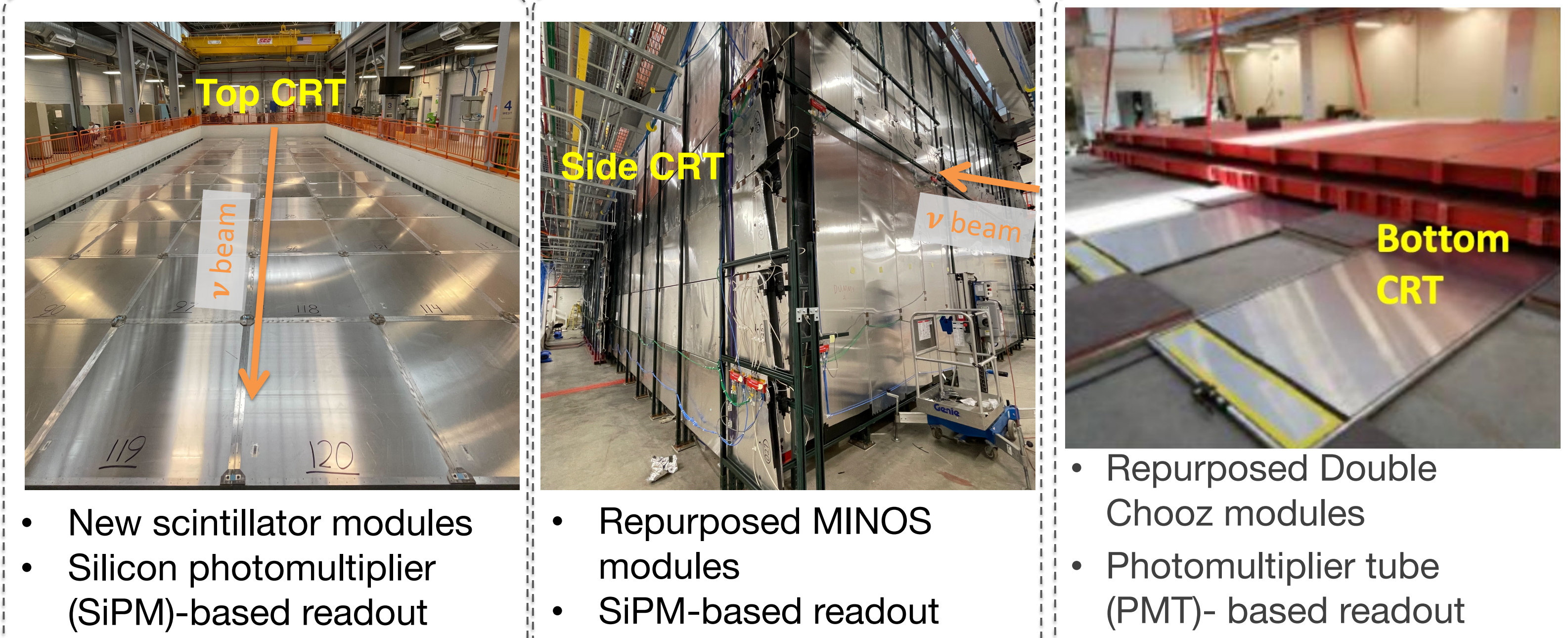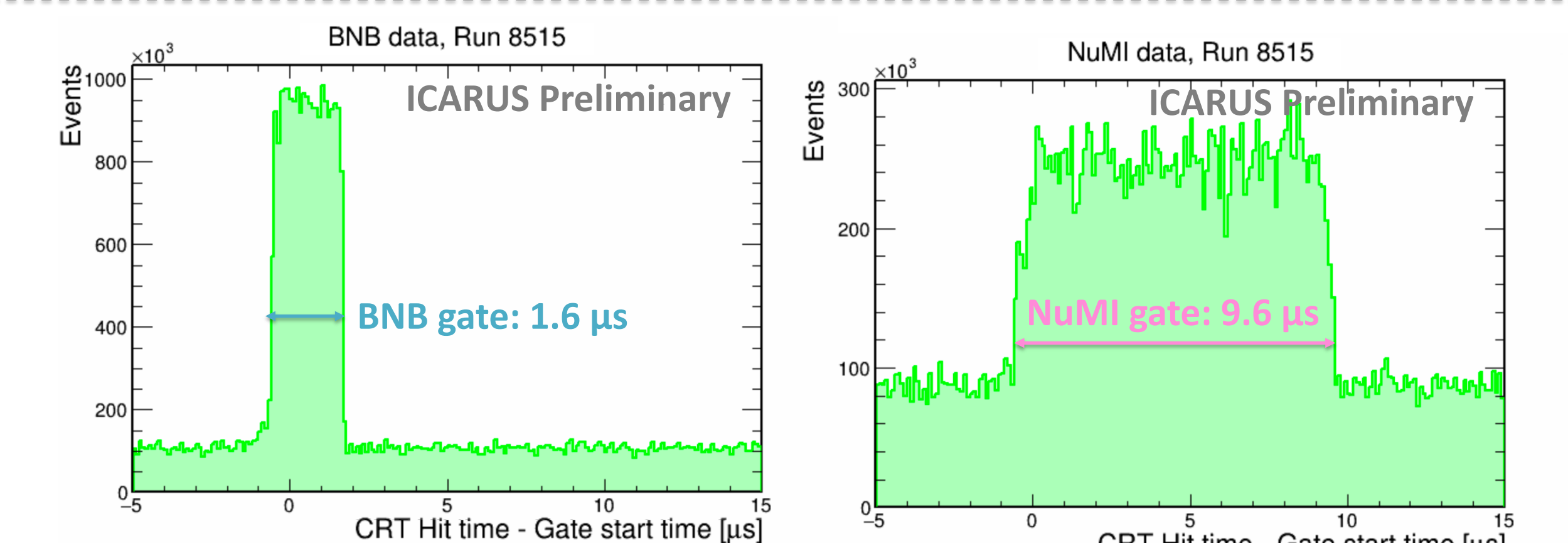

- New scintillator modules
- Silicon photomultiplier (SiPM)-based readout
- Repurposed MINOS modules
- SiPM-based readout
- Repurposed Double Chooz modules
- Photomultiplier tube (PMT)- based readout

CRT Hit Timing

Looking at the CRT timestamp with respect to the opening of the neutrino beam gates, we see clear signals associated with the BNB and NuMI beams

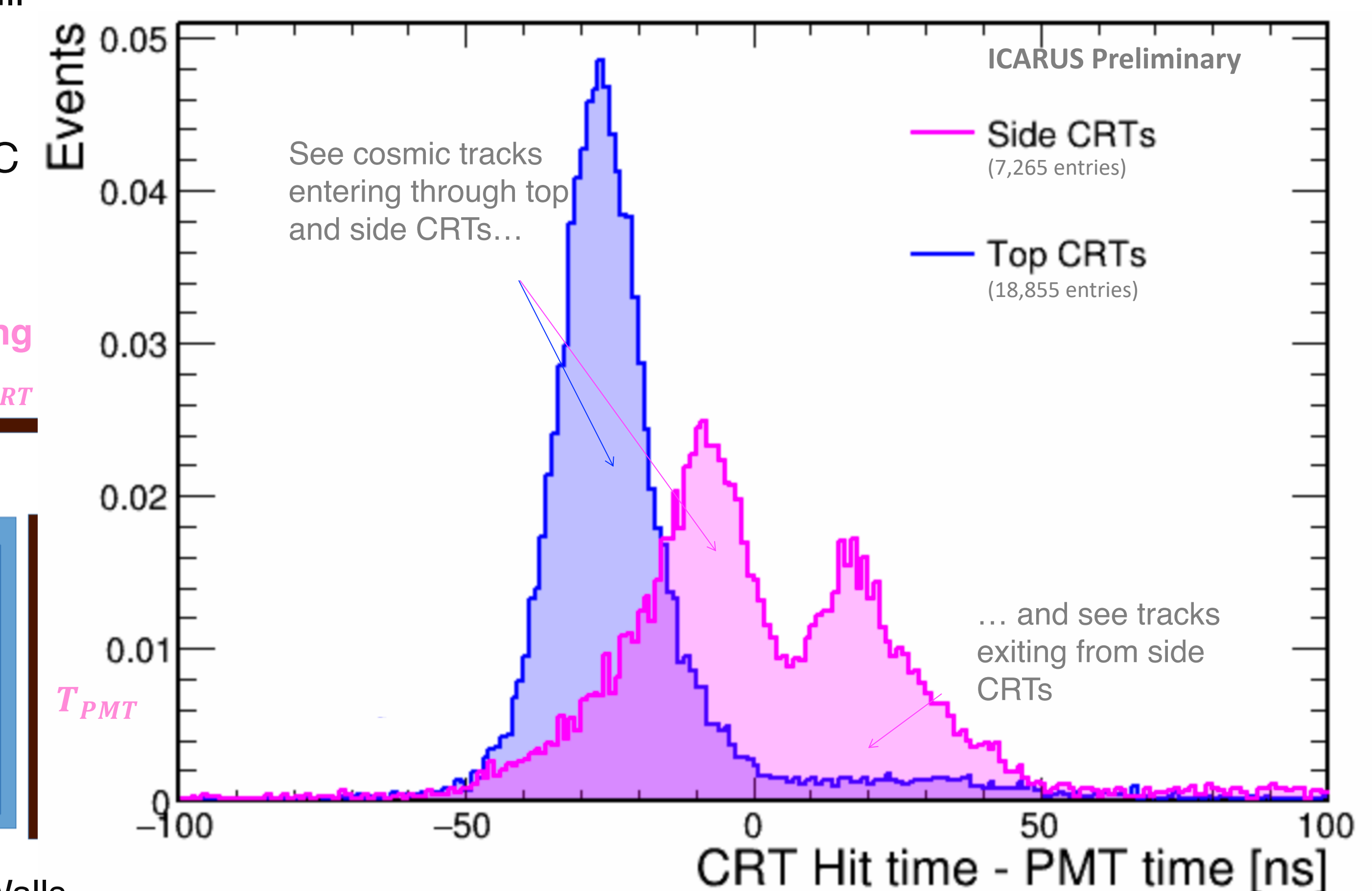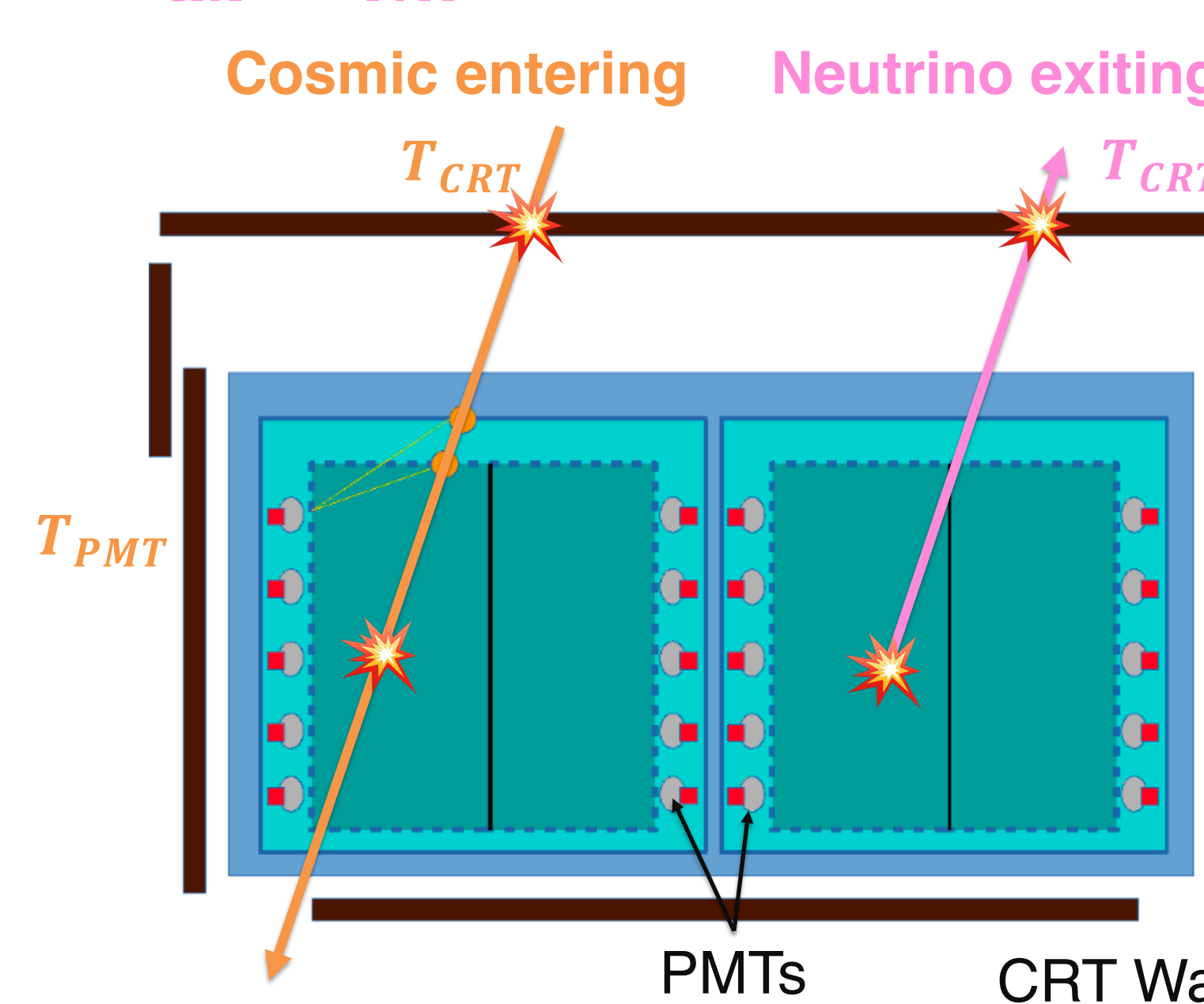

CRT – PMT Matching with beam data

- Uses ns-level timing information from CRT Hits and PMT signals to distinguish between tracks entering and exiting the ICARUS cryostat
  - Cosmic tracks entering the TPCs will hit CRTs first
    $$T_{CRT} - T_{PMT} < 0$$
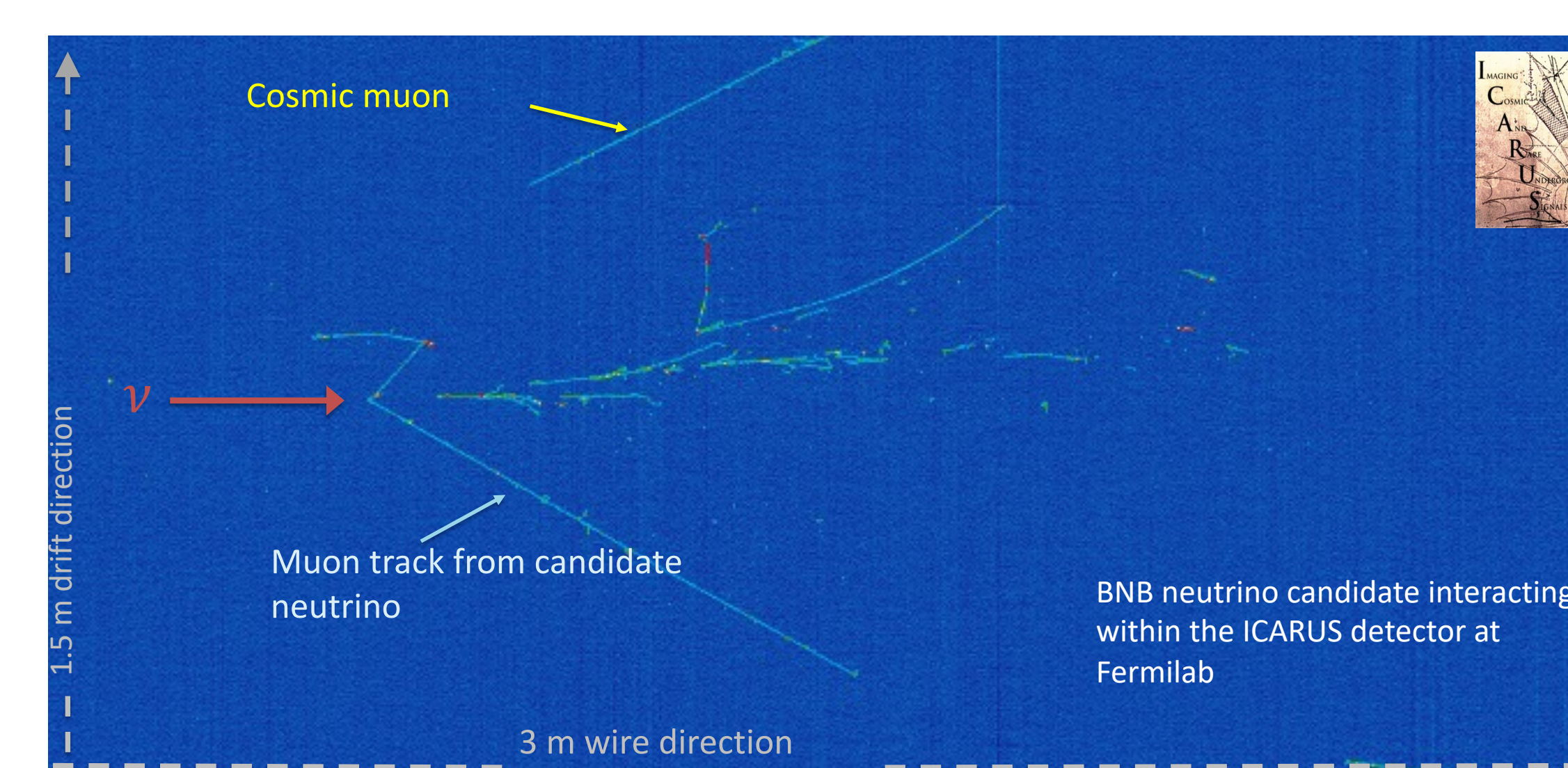 - Particles with tracks leaving the TPC will hit the PMTs first
    $$T_{CRT} - T_{PMT} > 0$$

Cosmic entering Neutrino exiting

T_{CRT} T_{CRT} T_{PMT} T_{PMT}

PMTs CRT Walls

See cosmic tracks entering through top and side CRTs… … and see tracks exiting from side CRTs

ICARUS Preliminary
Side CRTs (7,265 entries)
Top CRTs (18,855 entries)

Summary

- The timing in ICARUS is synchronized across CRT and PMT sub-systems with a few ns precision, allowing us to perform additional neutrino event selection/cosmic rejection
- ICARUS is taking ν beam data
- Stay tuned for exciting physics!

Cosmic muon
ν
Muon track from candidate neutrino
BNB neutrino candidate interacting within the ICARUS detector at Fermilab
3 m wire direction

COLORADO STATE UNIVERSITY

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SBN Program

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