

# Cosmic Background Rejection of the ICARUS experiment at Fermilab

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## #1 Cosmic Background at the ICARUS detector at Fermilab

The ICARUS-T600 is a LArTPC with a total mass of 760 tons of liquid argon, located at Fermilab along the Booster Neutrino Beam (BNB) at 600 m from the neutrino source, and 6° off-axis the Neutrino from the Main Injector (NuMI) beamline. ICARUS will search for evidence of sterile neutrinos within the Short-Baseline Neutrino program. In addition it will perform measurement of neutrino cross-sections with the NuMI beam and Beyond Standard Model searches.

Being installed at shallow depth, ICARUS is exposed to a large flux of cosmic rays, which, if in time with the neutrino beam, could determine an event trigger, and, eventually, they could mimic a neutrino interaction.

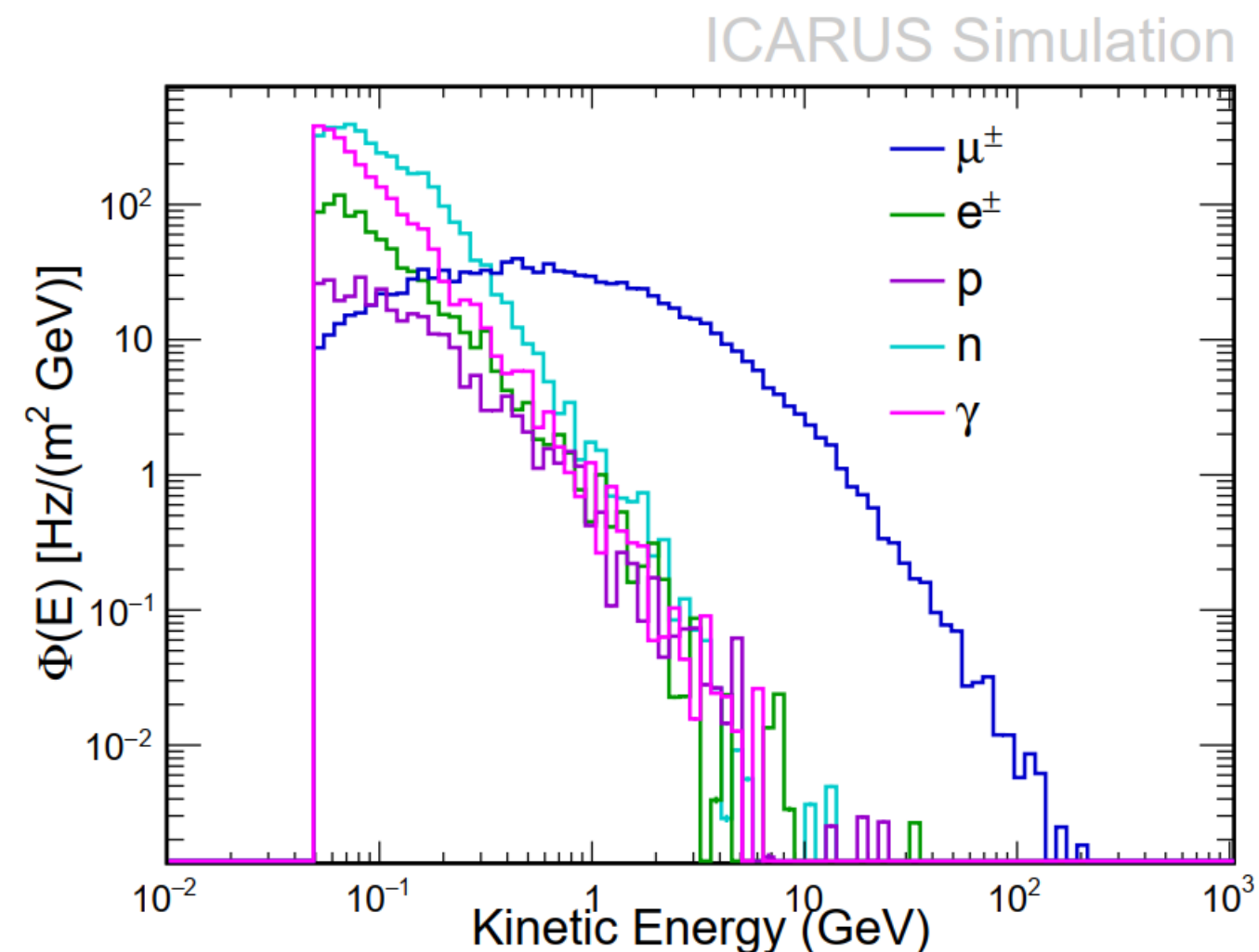
The expected rates of cosmic ray induced events and neutrino interactions are:

- 1  $\nu$  every 180 / 53 spills for BNB (1.6  $\mu$ s) / NuMI (9.6  $\mu$ s);
- 1 cosmic  $\mu$  every 55 / 6 spills for BNB (1.6  $\mu$ s) / NuMI (9.6  $\mu$ s).

The cosmic induced background can be distinguished in two main categories:

- **In-Time interactions:** cosmic particles entering the detector during the beam spill;
- **Out-of-Time interactions:** cosmic particles crossing the detector read-out window.

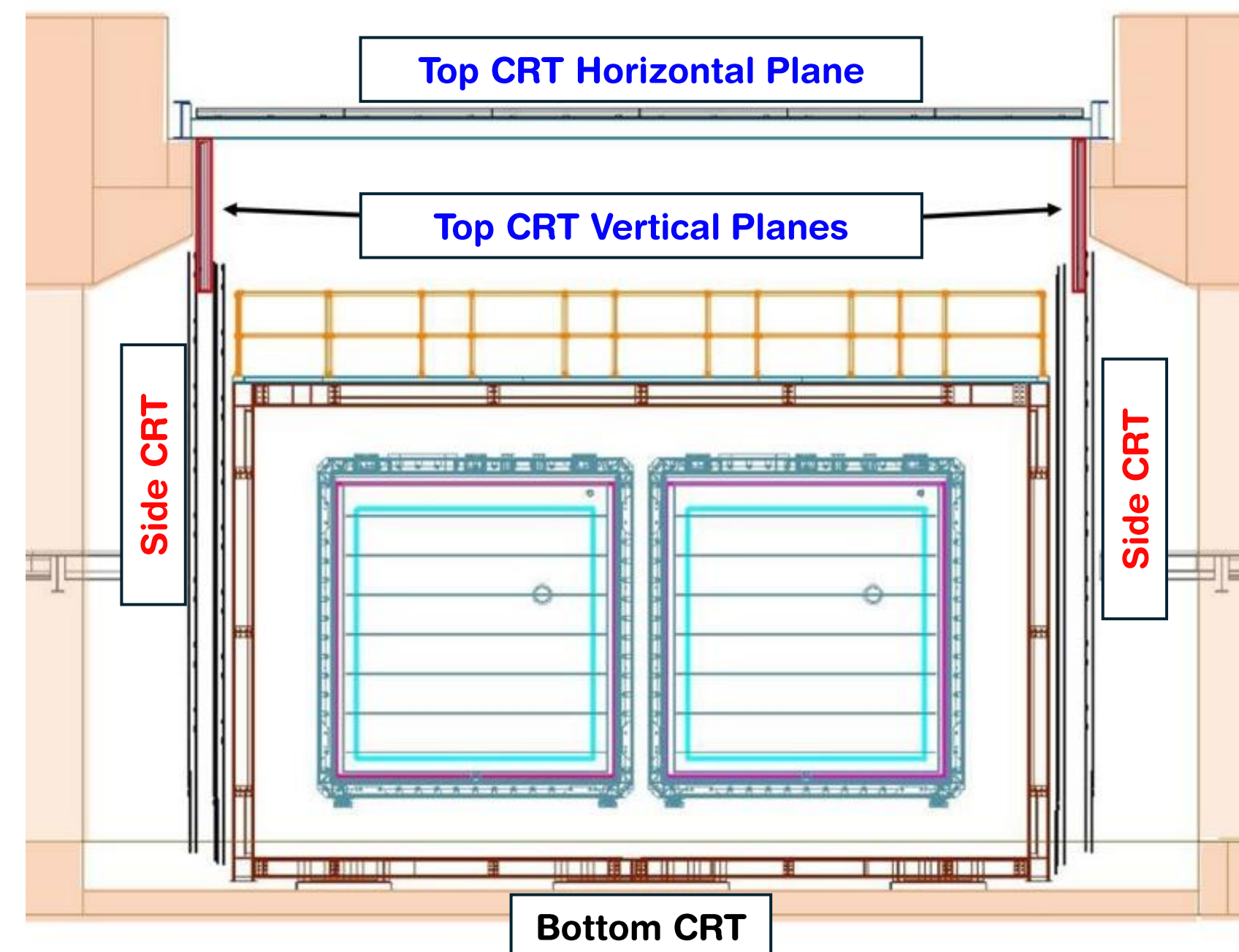
### Flux of cosmic particles at ICARUS



### ICARUS Simulation

Particle	No OB [Hz]	With OB [Hz]
$\mu^\pm$	~17100	~12800
p	~50	0.1
$\gamma$	~100	<<0.1
n	~1400	6.8

To mitigate the cosmic ray flux, a 3 m **concrete overburden** is installed above the ICARUS apparatus. A Cosmic Ray Tagger (**CRT**) system surrounding the detector allows to detect muons reaching the TPC.

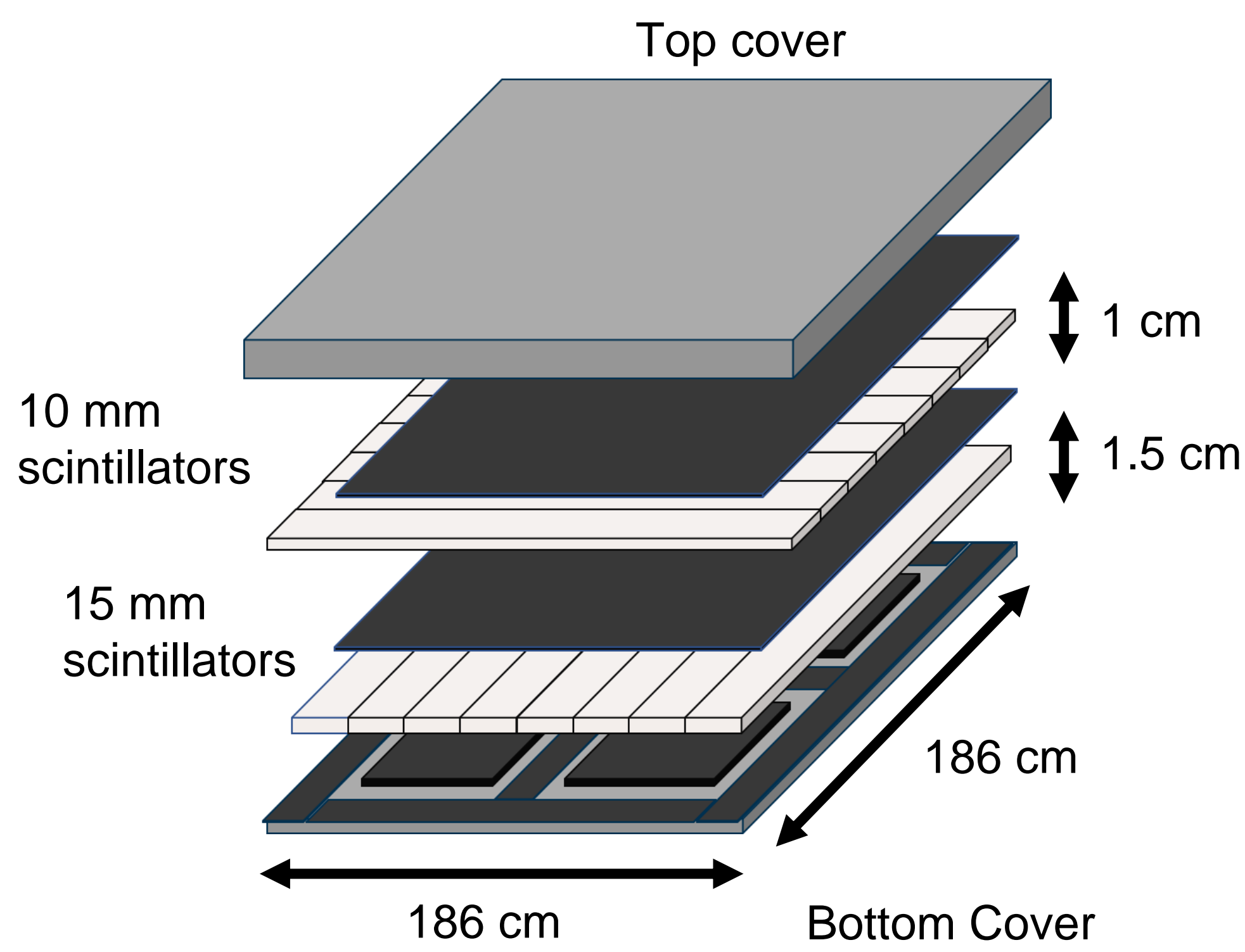


The CRT system is designed to provide a  $\sim 4\pi$  coverage of the TPC. It is divided in: **Bottom CRT**, **Side CRT** and **Top CRT**.

The CRT provides spatial ( $\sim$ cm resolution) and timing ( $\sim$ ns resolution) coordinates of the particle crossing points.

## #2 The Top CRT

- It is composed of 39 vertical modules and 84 horizontal modules, intercepting **80% of the incoming CR  $\mu$  flux**.
- Hodoscope module consisting of 2 orthogonal layers of scintillator bars. Each layer consists of eight 23 cm wide bar. The scintillator layers are encased in Al boxes.

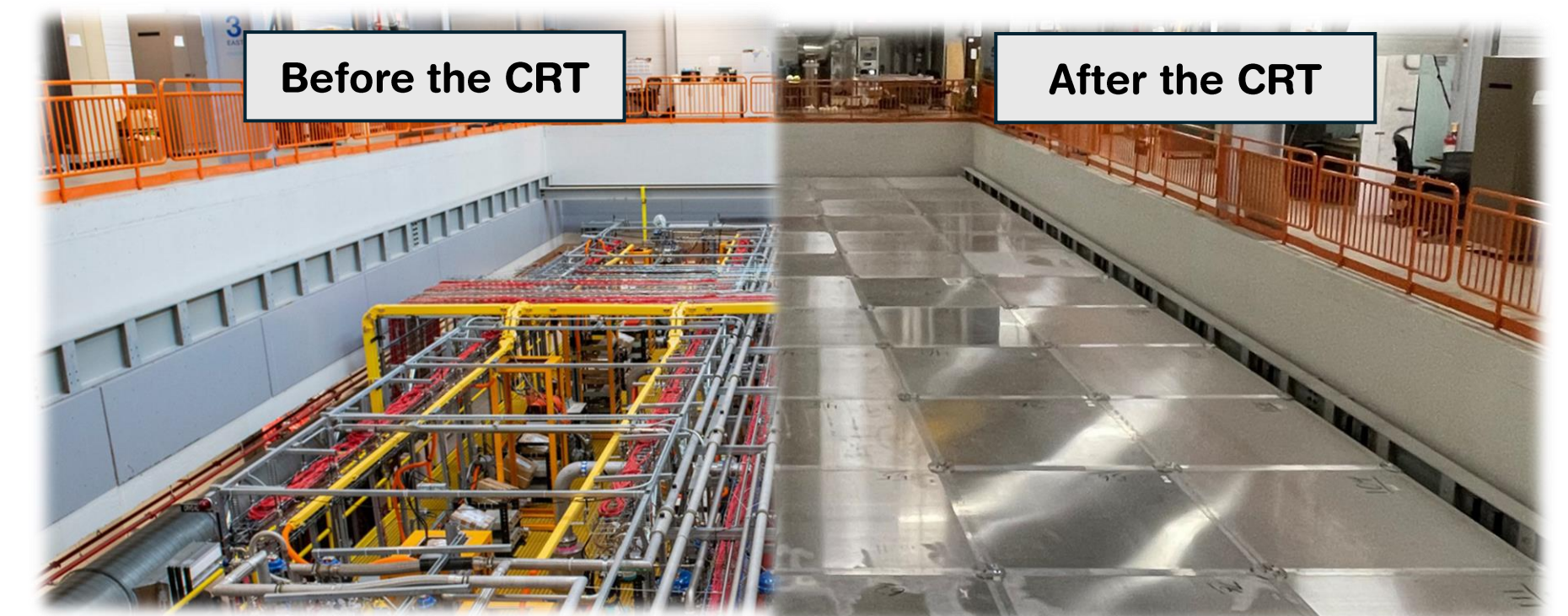


- Scintillation light is collected by two WLS fibres per bar each read-out at one end by one SiPM.
- The CRT trigger is provided by coincidence signals on both (AND) scintillation layers.

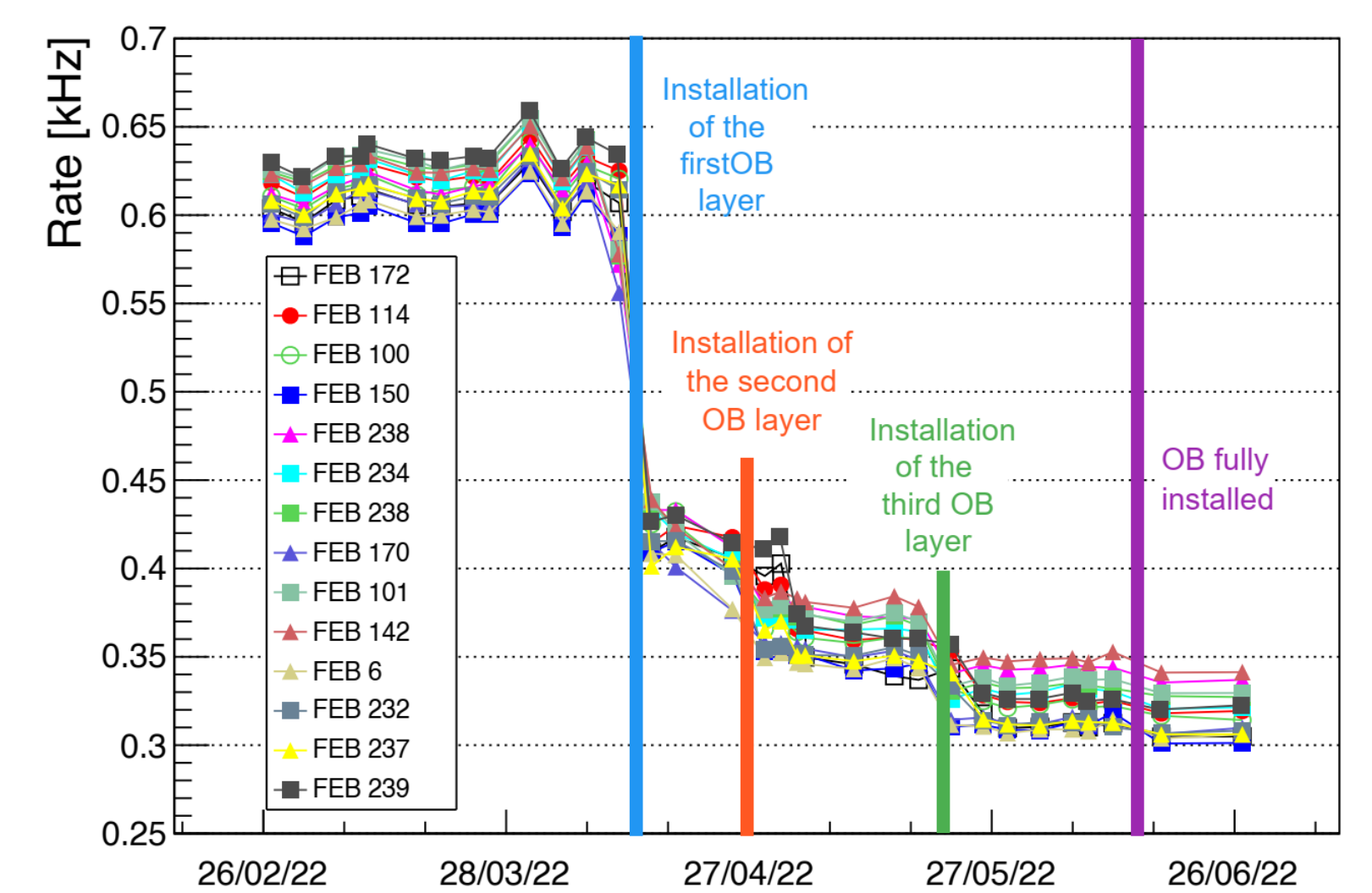


## #3 CRT Commissioning

- The commissioning of the CRT was completed in spring 2022.

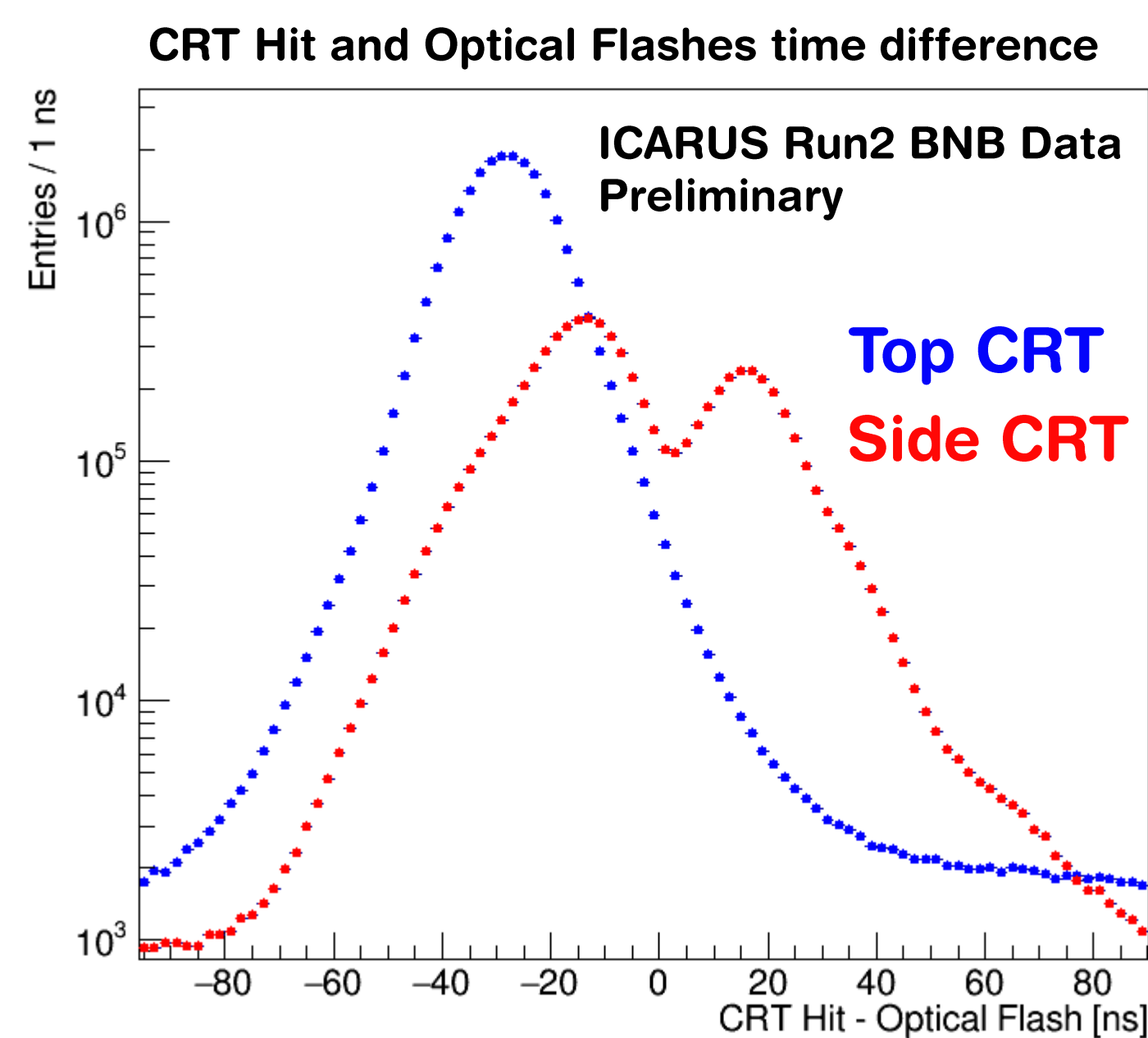


- The CRT system was in data-taking during the installation of the concrete overburden.
- The rate measured by Top CRT horizontal modules decreased from  $\sim 600$  Hz/module to  $\sim 330$  Hz/module, in agreement with the expected cosmic muon rate ( $\sim 100$  Hz/m<sup>2</sup>).



## #4 CRT-PMT Matching

- The timing resolution of the CRT system ( $\sim$ ns) and of the Photo-Detection System ( $<$ ns) and their synchronization by means of the global event trigger, determines the possibility to associate each reconstructed **Optical Flash with one or more CRT hits** using only **timing** information.



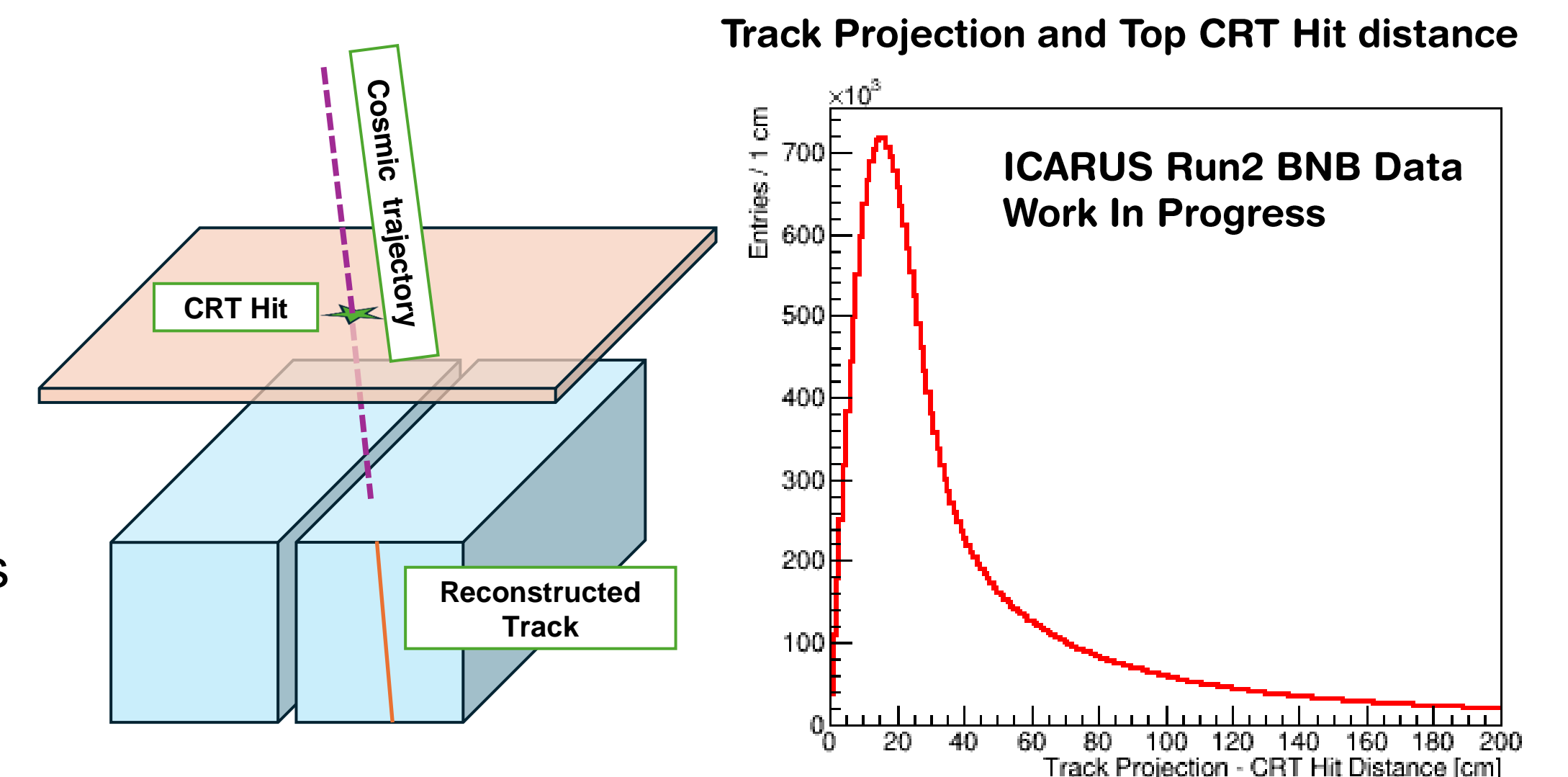
- By selecting events with optical flashes in time with the beam spill and not matched with any CRT hit we can determine an enhanced sample of fully contained neutrino interactions, effectively **suppressing the In-Time cosmic induced background**.

Classification	NuMI [%]		BNB [%]	
	OnBeam	OffBeam	OnBeam	OffBeam
No CRT match	39.0	12.7	32.4	12.3
1 Entering from Top	34.4	62.8	46.5	63.4
1 Entering from Side	10.7	10.5	8.5	10.5
1 Entering from Top 1 Exiting from Side	2.5	4.7	3.6	4.8
1 Exiting from Top	2.0	0.5	1.3	0.5
1 Exiting from Side	5.6	1.9	2.5	1.8
Others	5.8	6.9	5.3	6.7

## #5 CRT-TPC Matching

- The **rejection of the Out-Of-Time cosmics** can be achieved by associating the TPC reconstructed tracks with the CRT hits.

- The **CRT-TPC matching** is performed using spatial information: the reconstructed tracks are projected onto the CRT planes and the spatial distance between the projection and the CRT hit is used for the classification.



- A large dataset of  $> 10$  million TPC reconstructed tracks from ICARUS Run 2 was used to perform a **«cosmic tomography»** of the Top CRT.

