The Cosmic Ray Tagger of the SBN Far Detector at Fermilab

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SBN Program

Persisting neutrino anomalies

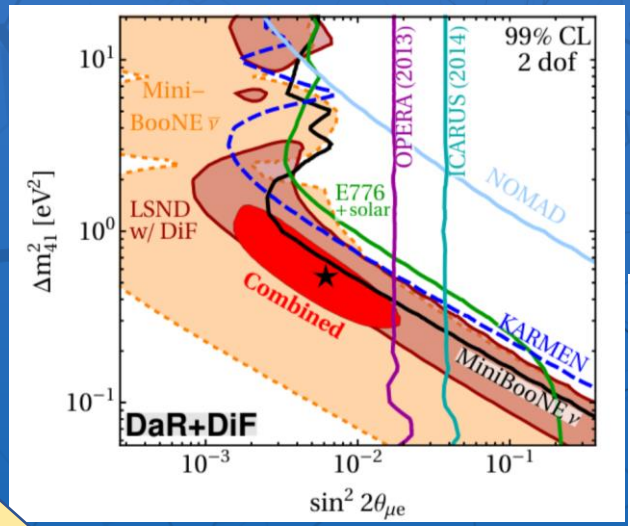
$\bar{\nu}_e$ appearance from $\bar{\nu}_\mu$ beam in LSND experiment, 3.8 σ CL.

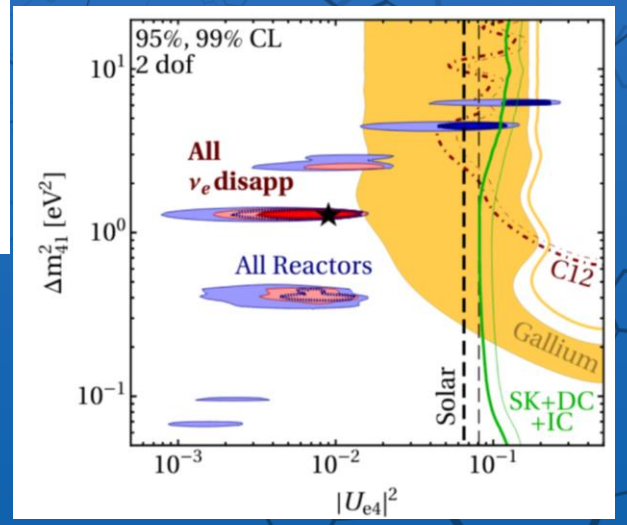
ν_e disappearance by SAGE, GALLEX experiments during their calibration with Mega-Curie sources, with observed/predicted ratio of $R = 0.84 \pm 0.05$.

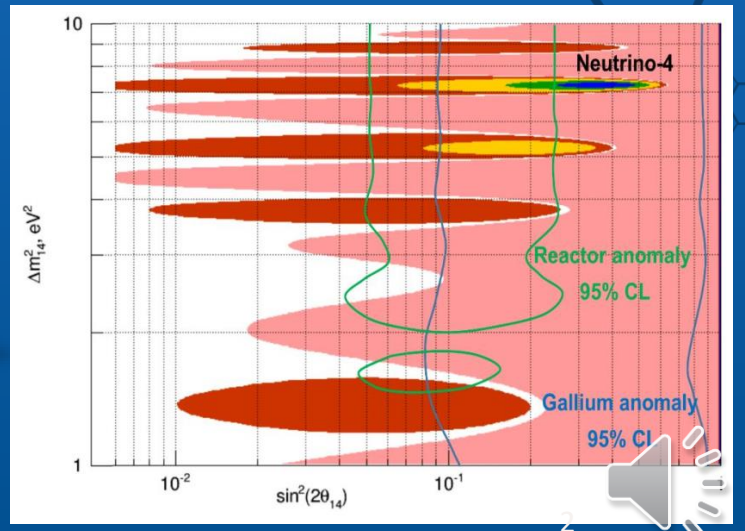
$\bar{\nu}_e$ disappearance of near-by nuclear reactor experiments with $R = 0.934 \pm 0.024$.

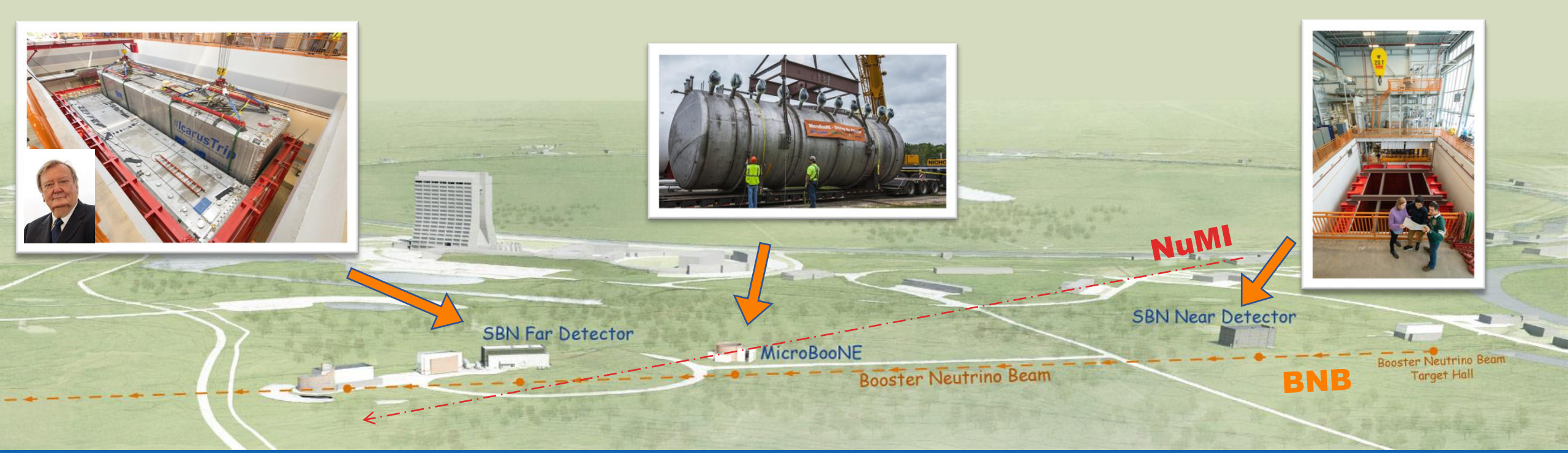
Neutrino-4 experiment observed an oscillating pattern at 3.5 σ CL with a possible interpretation as sterile neutrino - $\bar{\nu}_e$ oscillation with ~ev² Δm^2.

New result –> https://arxiv.org/abs/2003.03199









Short-Baseline Neutrino Program at Fermilab

https://arxiv.org/abs/1503.01520

Three liquid argon TPCs along the BNB studying both appearance ($\nu_\mu \rightarrow \nu_e$) and disappearance ($\nu_\mu \rightarrow \nu_\mu$) channels. 3 years of data taking ($6.6\ 10^{20}$ POT) will allow to confirm or definetly rule out the light sterile neutrino hypothesis.

Detector	Distance from BNB target	Active LAr Mass
SBND	110 m	112 t
MicroBooNE	470 m	87 t
ICARUS	600 m	476 t

On axis BNB $\nu_\mu / \bar{\nu}_\mu$ $< E_\nu > \sim 700$ MeV

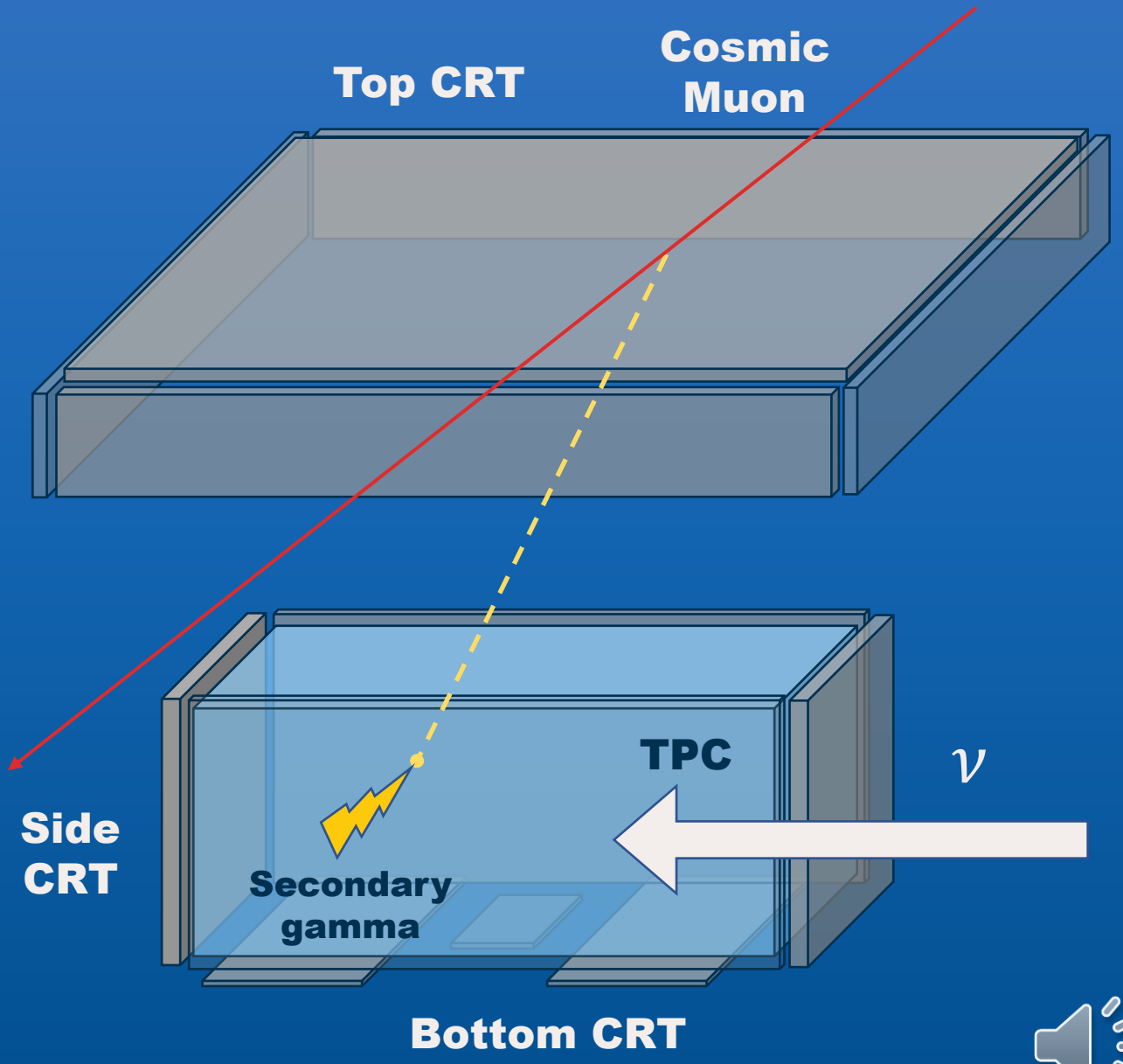
Off axis NuMI $\nu_\mu / \bar{\nu}_\mu$ $< E_\nu > \sim 2$ GeV

Cosmic Ray induced Background

- ~11 kHz trigger rate due to cosmic ray.
- ~11 cosmic ray μ in the detector volume in a 1 ms long time window of the TPC readout.
- Background to $\nu_e CC$ events from γ induced by cosmic ray muons through/near the TPC.

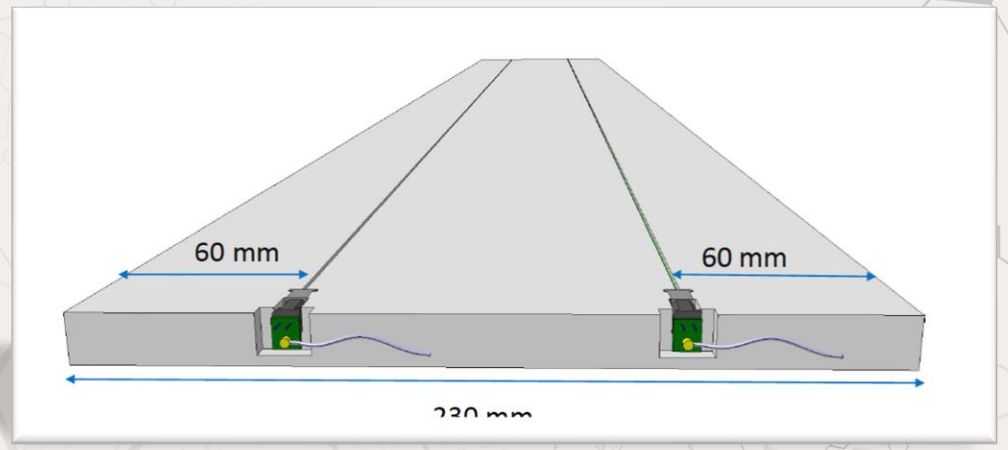
Cosmic Ray Tagger (CRT):
4π coverage of the LAr-TPC.

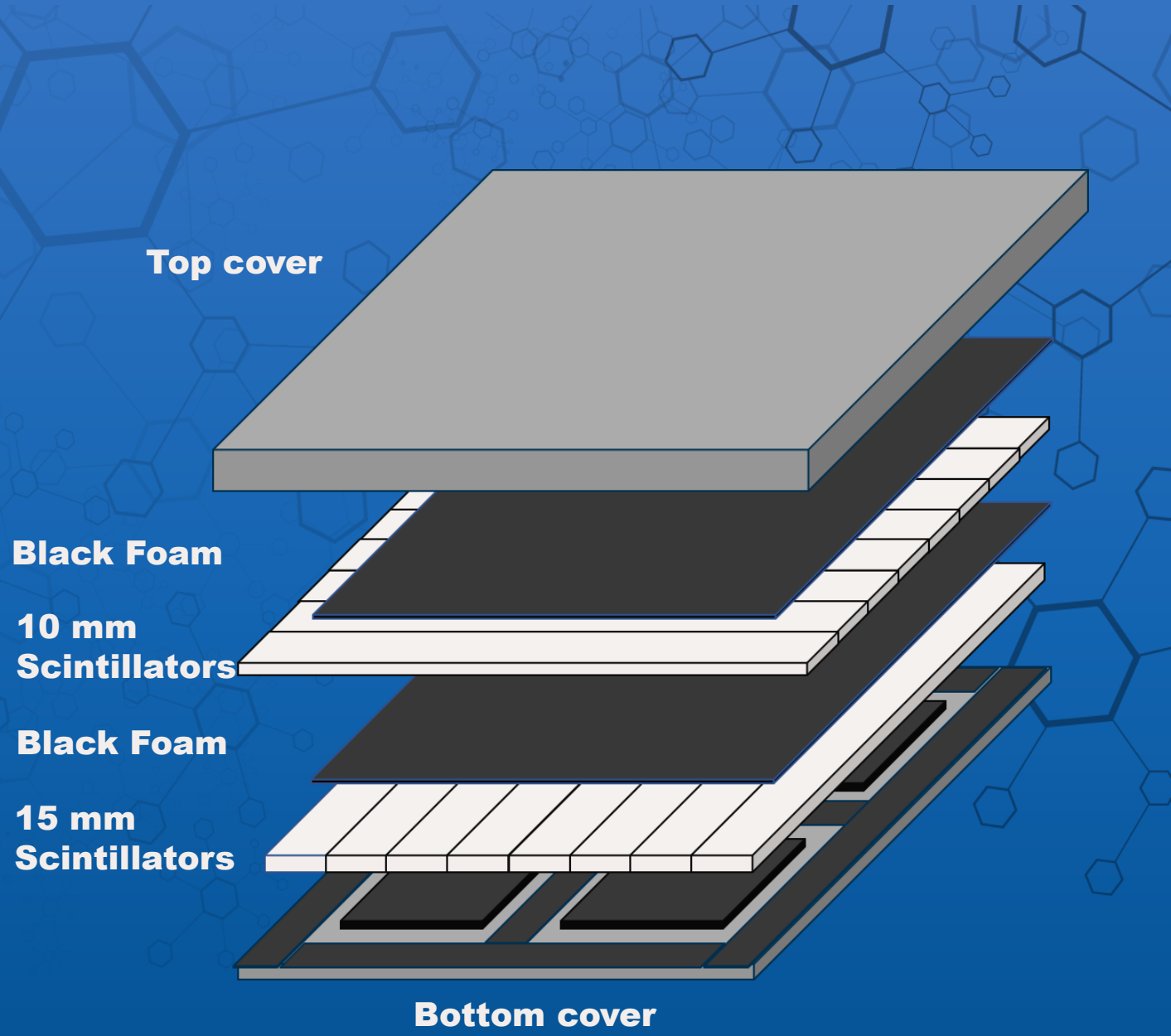
Top CRT:
123 modules, 80% cosmic μ tagging.



Top Cosmic Ray Tagging module

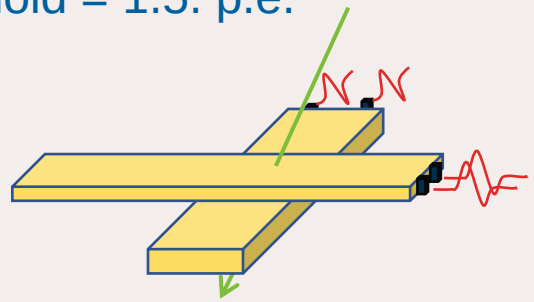
- Hodoscope module consisting of 2 orthogonal layers of eight 23 cm wide scintillator bars each, encased in 1.86 x 1.86 m² Al boxes.
- Scintillation light is collected by two WLS fibres per bar each readout at one end by one SiPM.





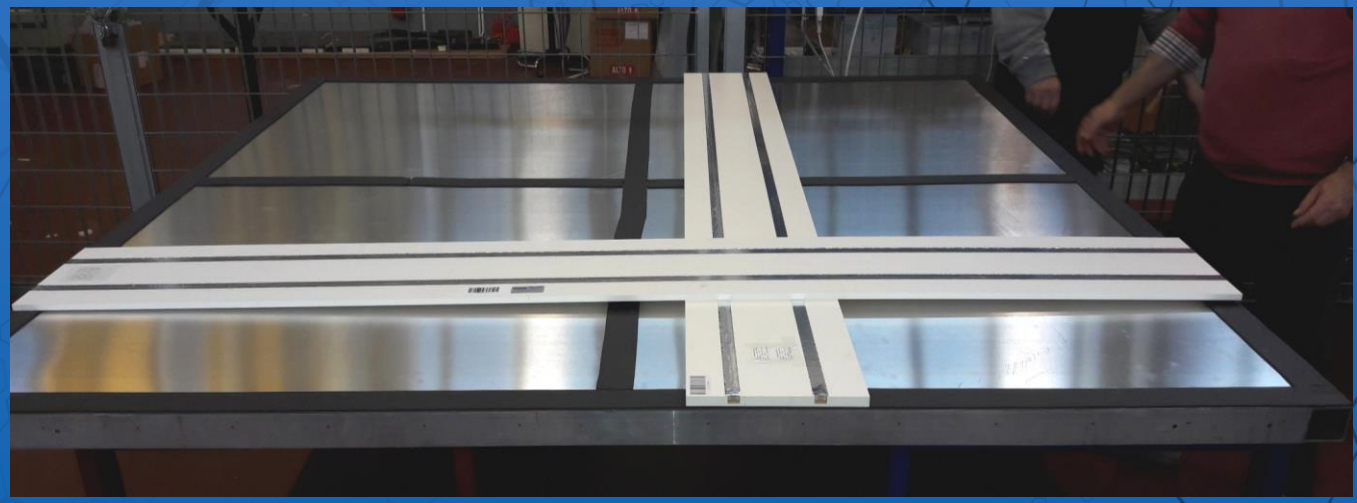
Trigger

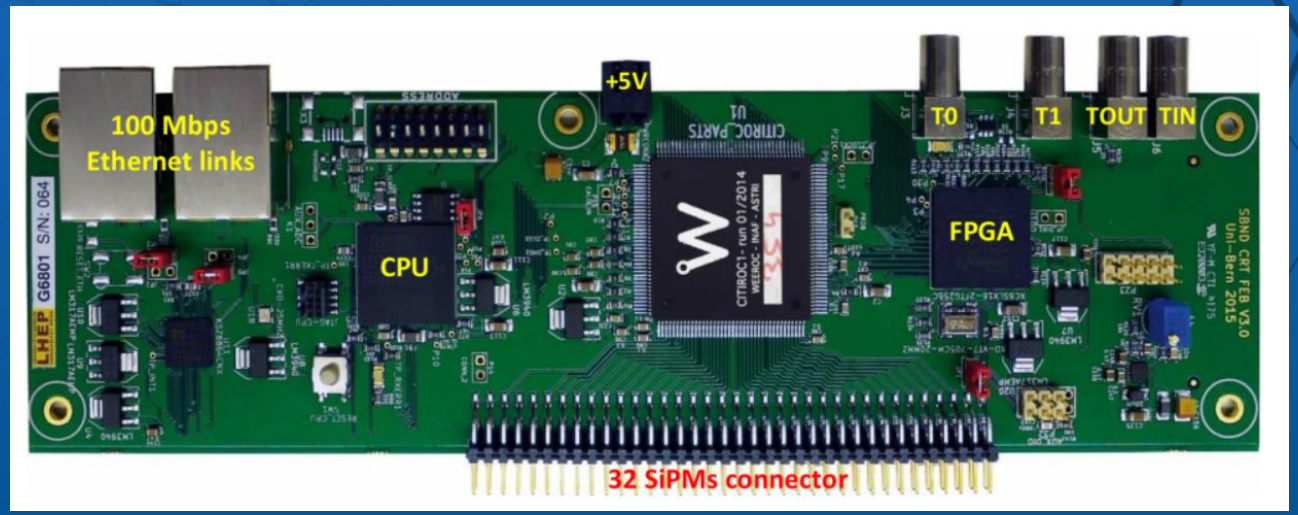
- SiPM threshold = 1.5. p.e.



- Trigger defined as the coincidence of signal in both (AND) scintillator layer.

- **Position information** (on the 23 x 23 cm² hodoscope grid) and **timing information** (with a ~2 ns resolution) for cosmic rays tagging purpose.





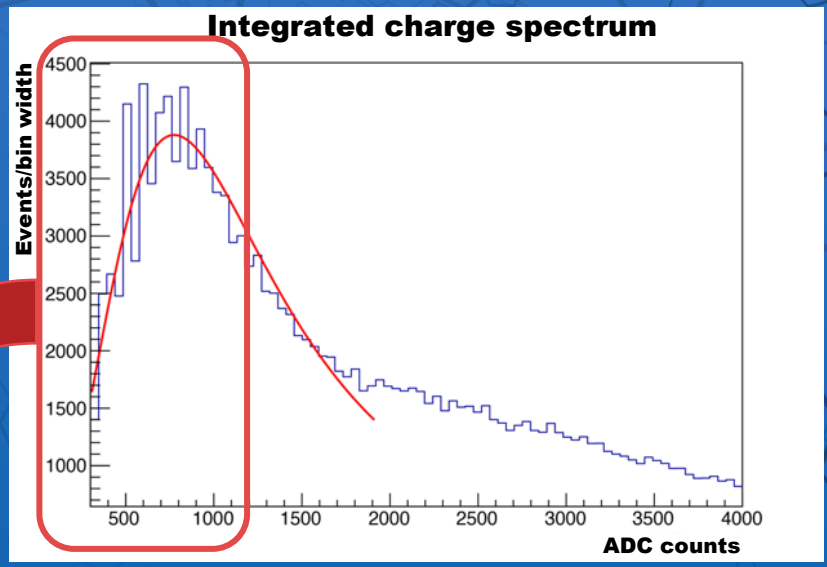
Scintillators Light Yield

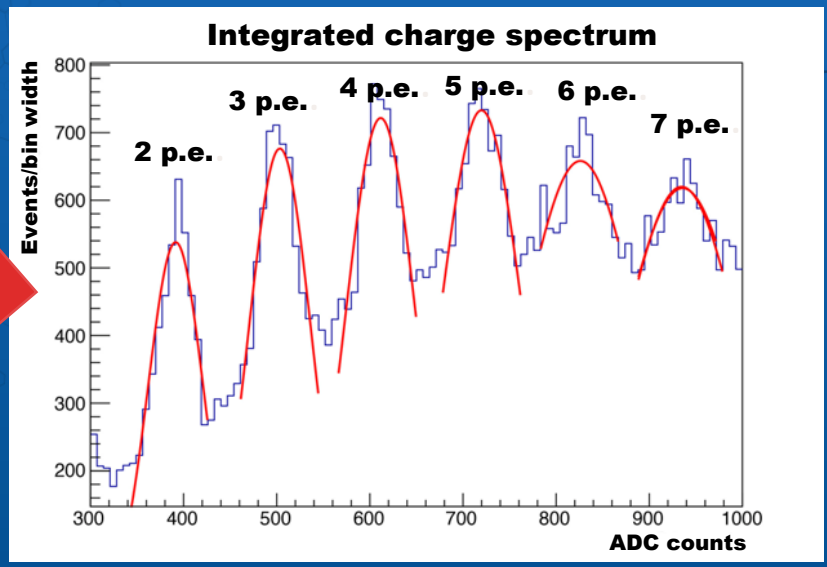
- Modules were tested in terms of light yield in dedicated cosmic ray runs.

- Light yield for m.i.p. are obtained from the integrated charge spectrum of each channel.

$$LY = \frac{MPV - Ped}{1\ p.e.}$$

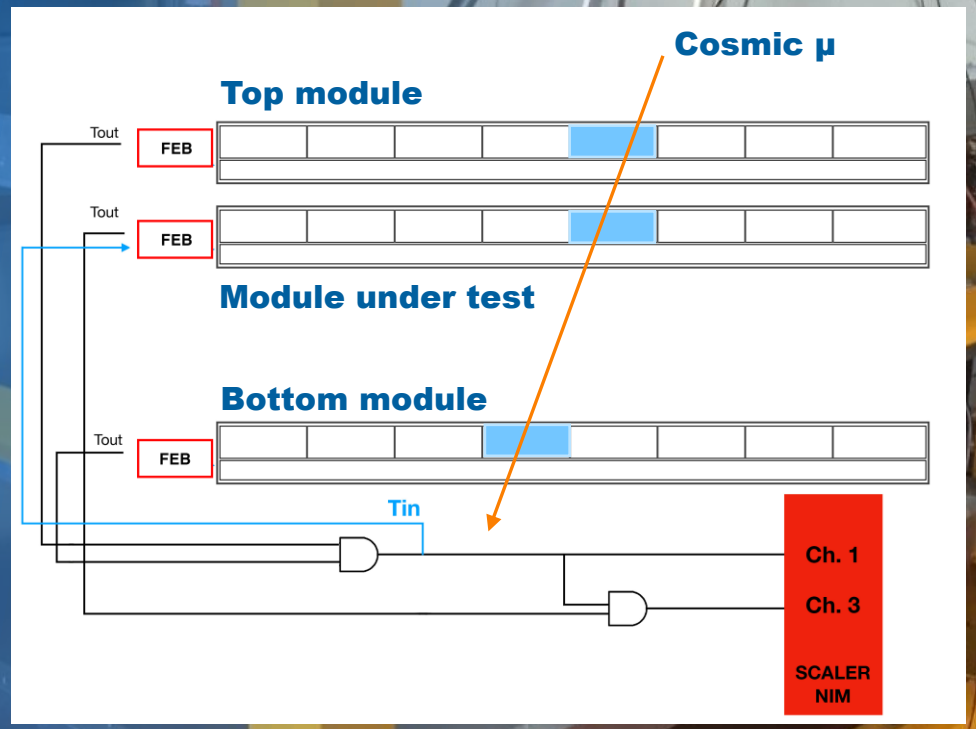
- Preliminary results are:
  - **6 p.e. for 10 mm bars**;
  - **20 p.e. for 15 mm bars**.





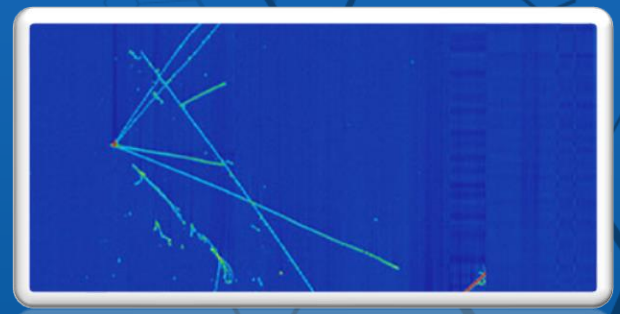
Hodoscope Efficiency

- Test Stand setup.
- External trigger: coincidence of top and bottom modules.
- Efficiency evaluated as the fraction of the external trigger in coincidence with a trigger from the module under test.
- Average CRT module efficiency is **96.0%**, in **compliance** with the experiment requirements.



Conclusions

- 125 Top CRT modules were built and tested at the Frascati National Laboratories (LNF) with a joint effort of INFN and CERN.
- Timing resolution of the CRT modules: $\sigma = 2$ ns.
- Light yield measurements for m.i.p. : 6 (20) photoelectrons for the 10 (15) mm thick scintillator bars.
- The average module efficiency is 96%, in **compliance** with the experiment requirements.
- Currently the modules are at CERN, on their way to FNAL.
- Installation on the top of ICARUS detector was expected this fall, but postponed due to COVID-19 pandemic.
- The SBN program will begin taking data by the end of 2020.



SBN Proposal	ICARUS @FNAL		CRT LNF -> @CERN -> FNAL		SBN Program
2015	2017	2018	2019	2020	2021