Sterile Neutrino Searches with the ICARUS Detector

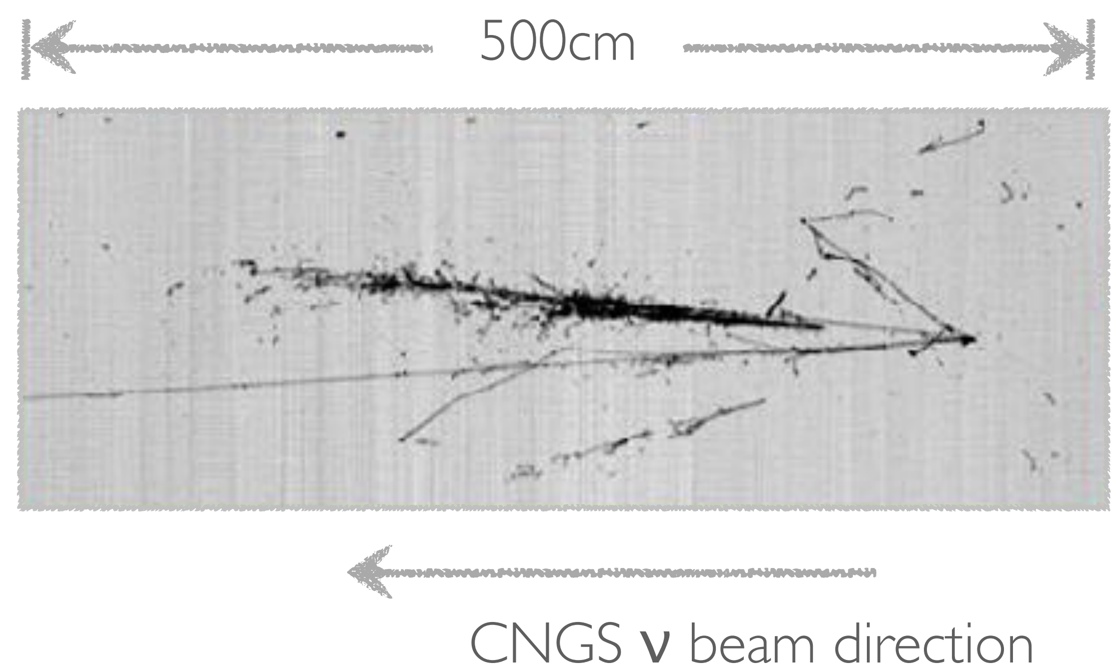
Yun-Tse Tsai (SLAC)
On behalf of ICARUS Collaboration

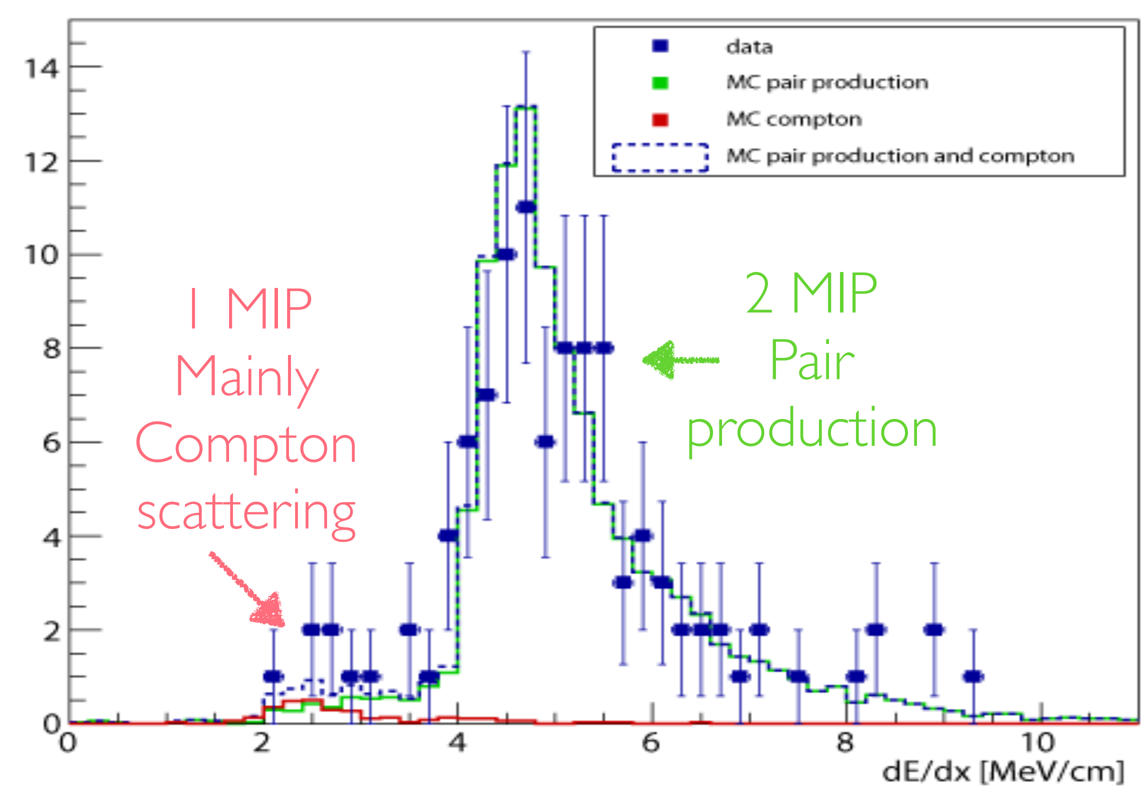
NuFact Workshop
August 17th, 2018

SLAC NATIONAL ACCELERATOR LABORATORY

LArTPC Detector

- Liquid-Argon Time-Projection Chamber
- LAr: large interaction rate
- Modular and scalable
- Millimeter resolution
- Calorimetric measurement
  - e/γ separation
- Low threshold
  - Supernova ν_e





ICARUS Detector

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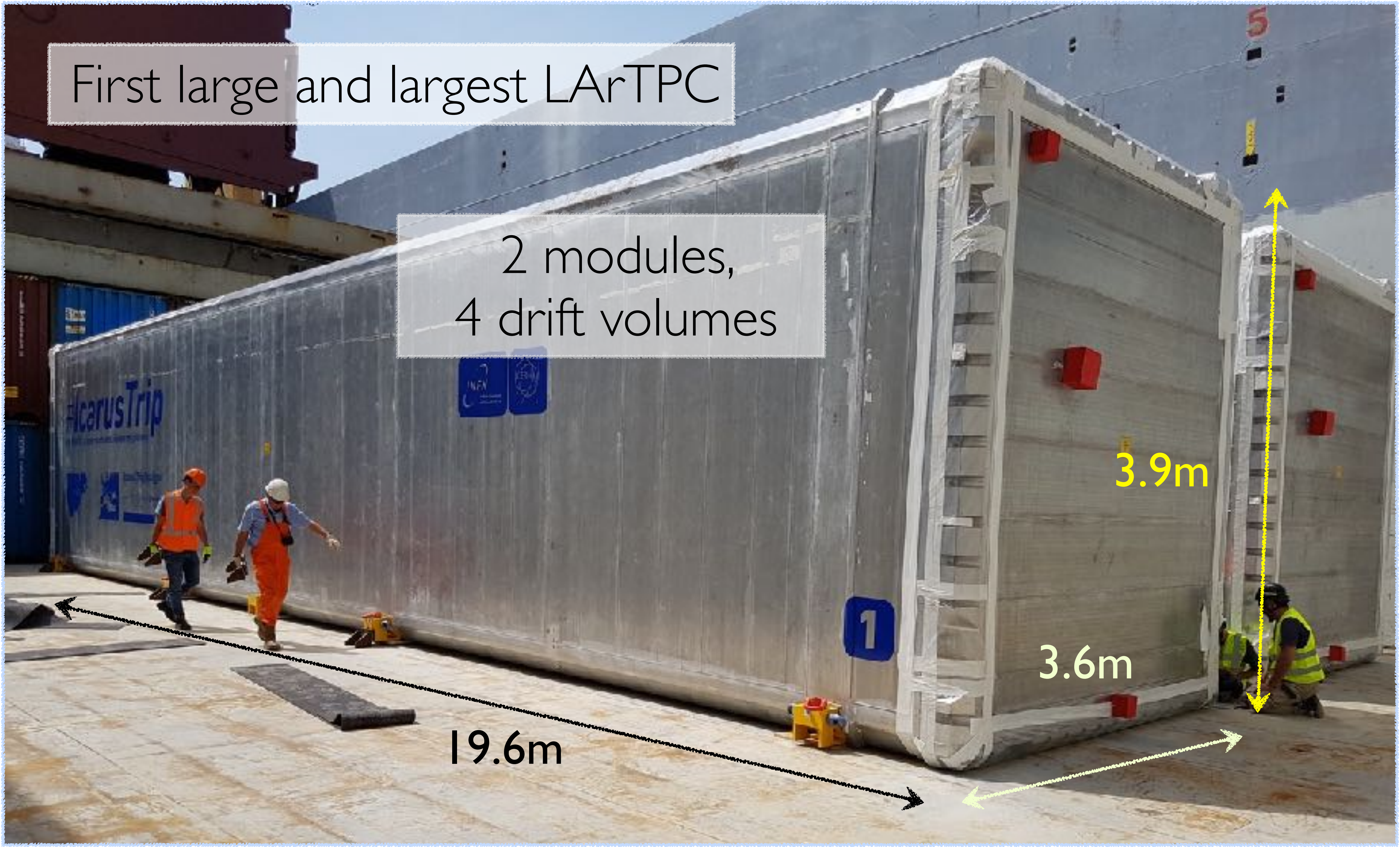

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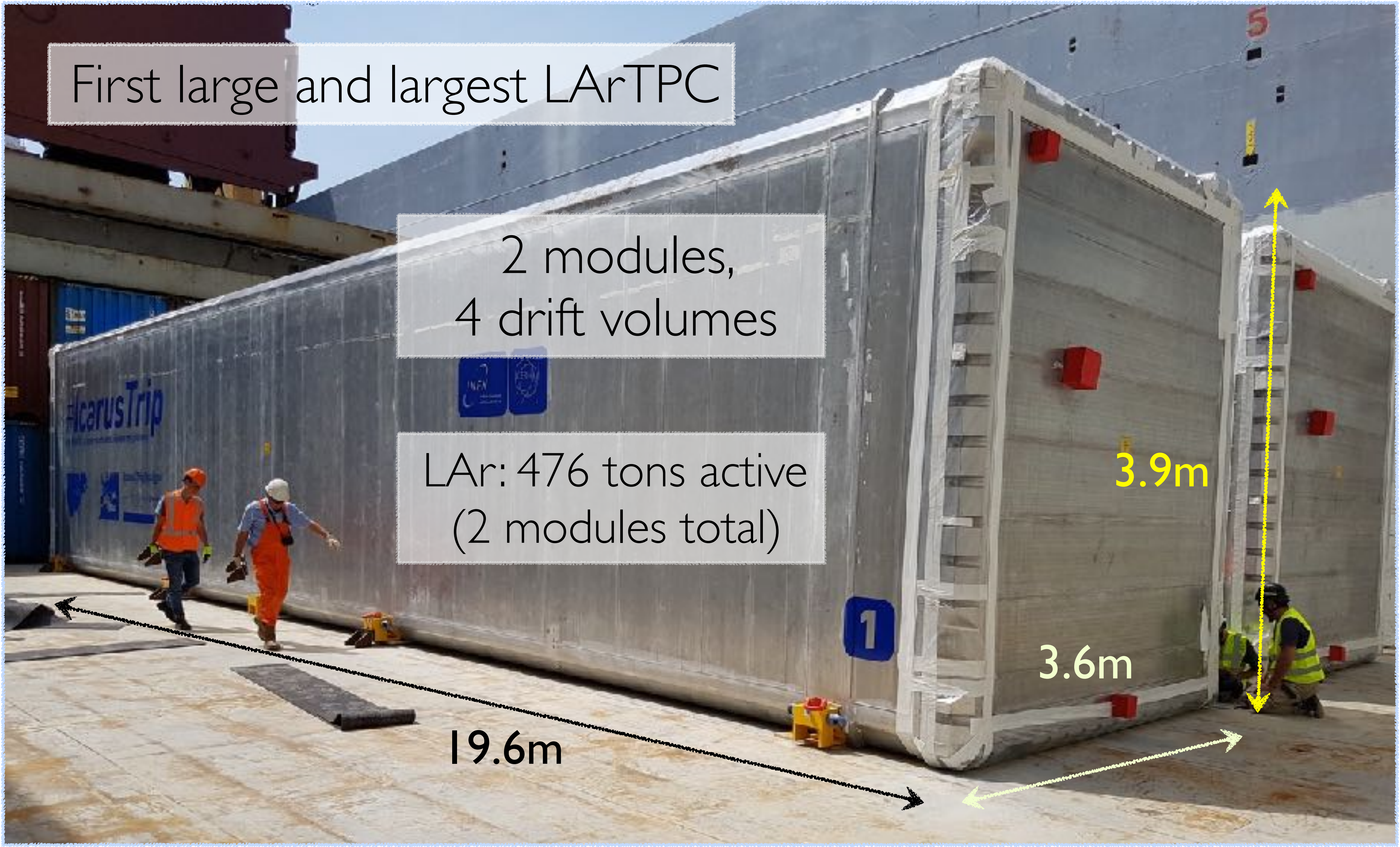

ICARUS Detector Module

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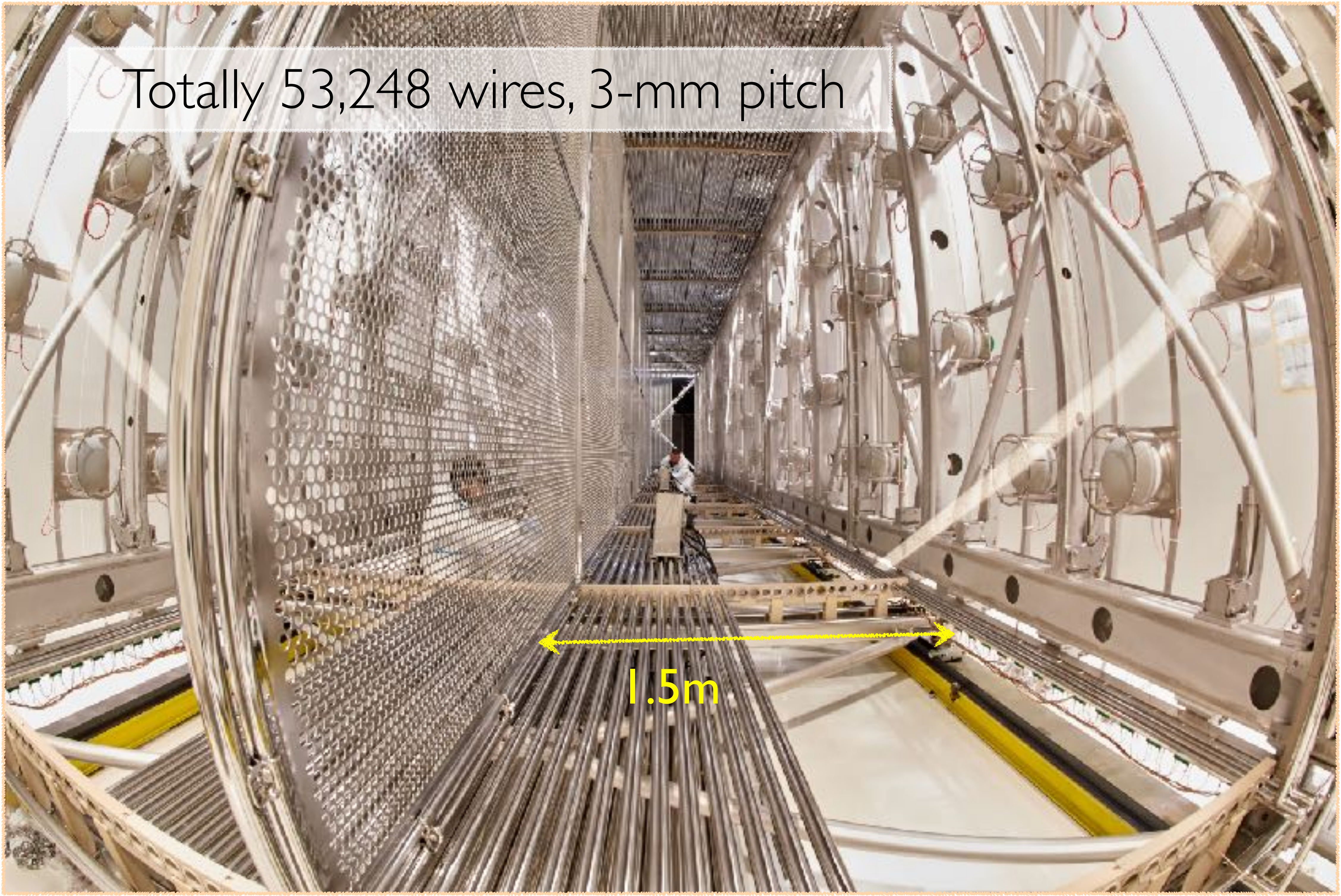

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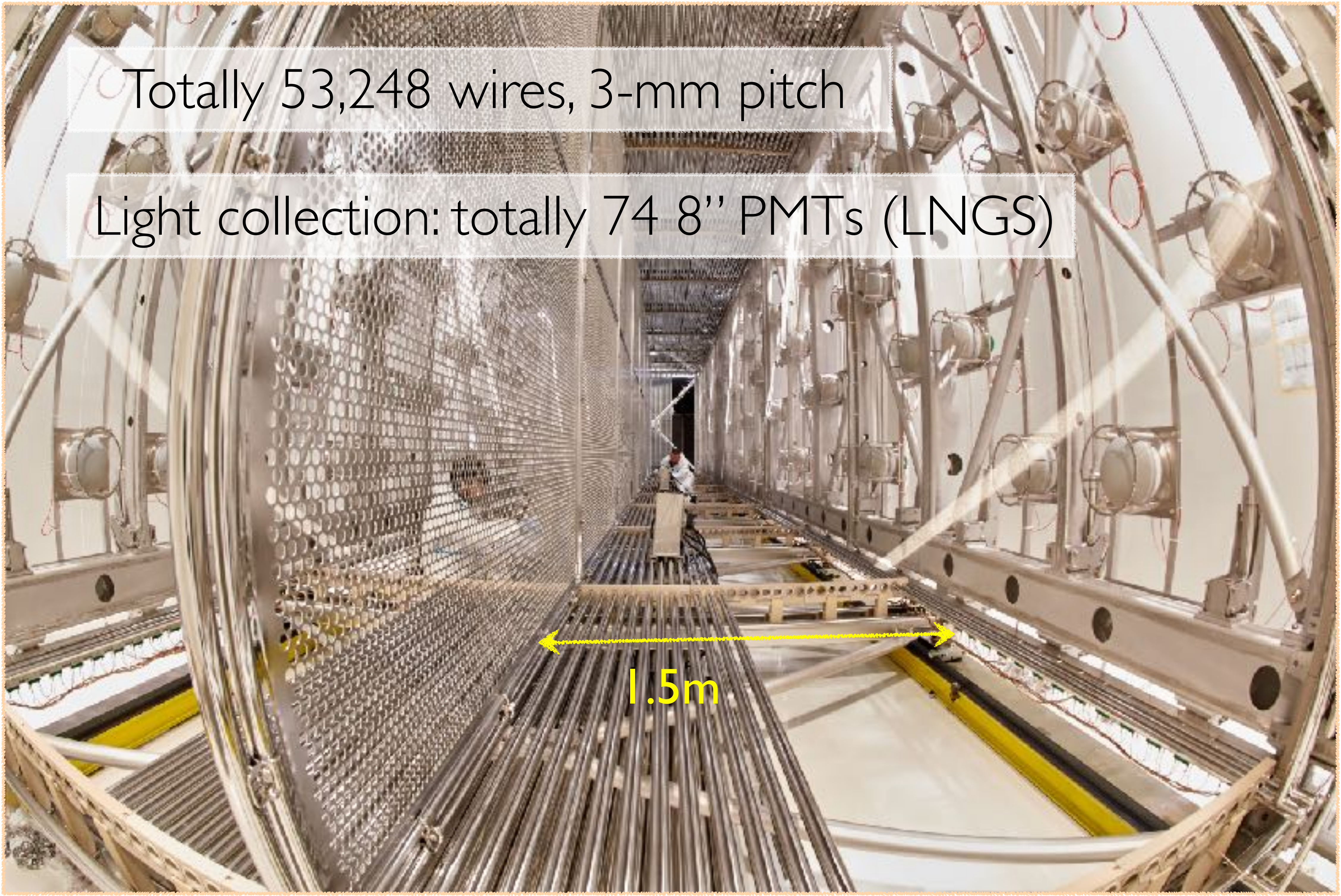

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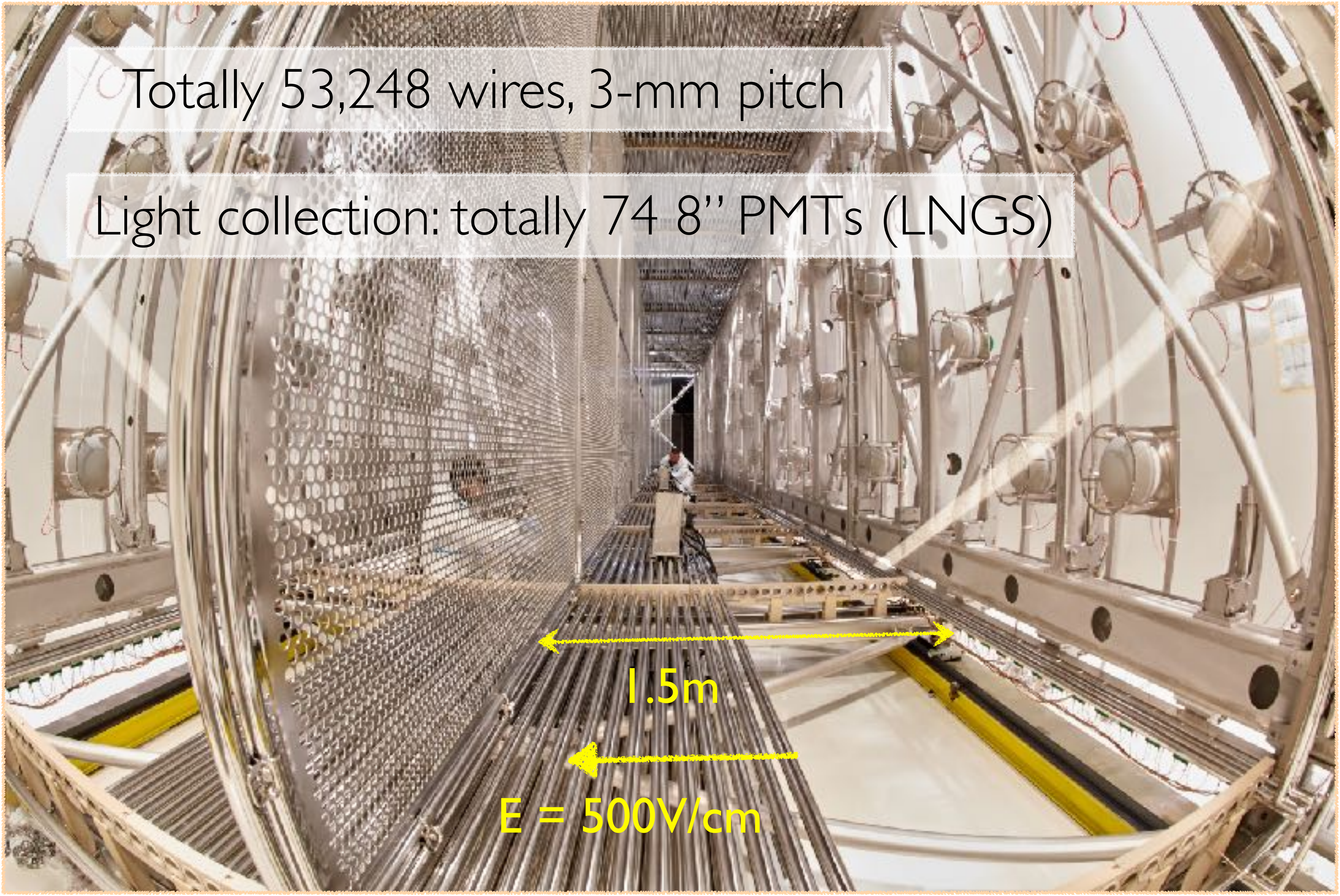
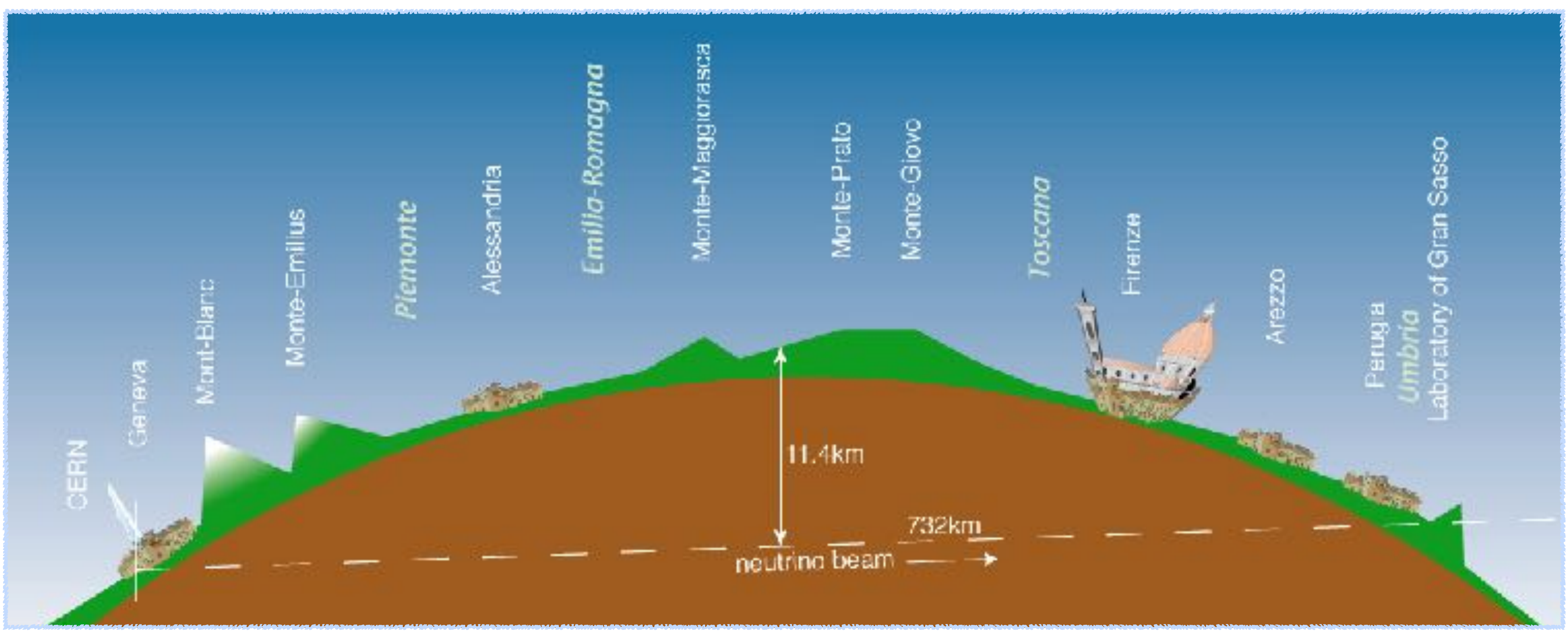


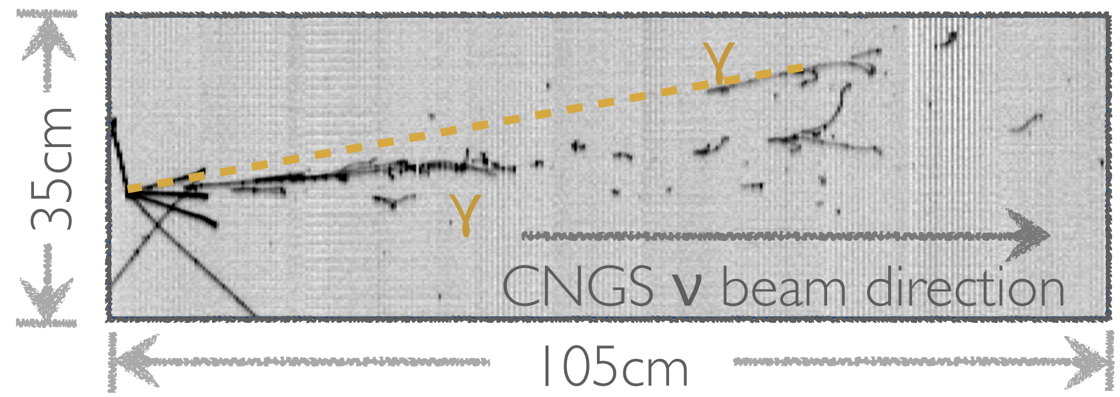
ICARUS at Gran Sasso

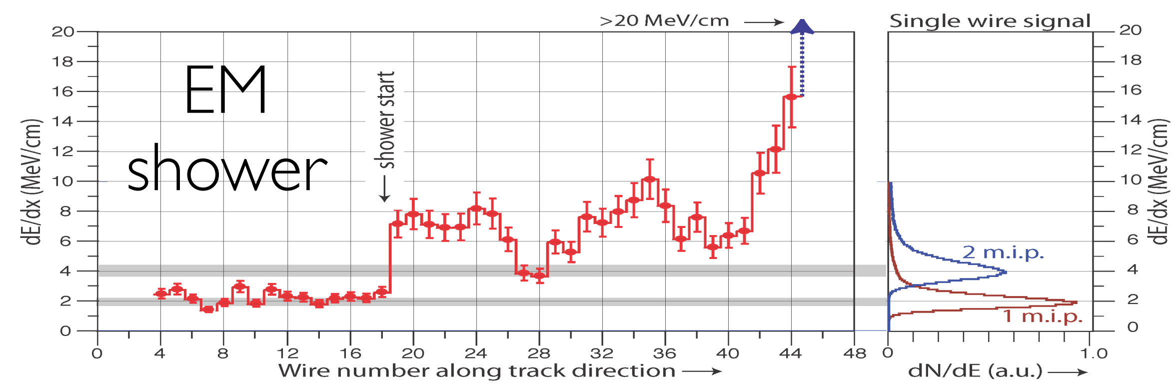
- ν_μ from CERN to Gran Sasso (CNGS): 730 km
- Average ν_μ energy: 20 GeV. $L/E_\nu \sim 36.5$ m/MeV
- Underground detector (1400 m deep)
- Operated 2010-2013, collected 8.6×10^{19} POT

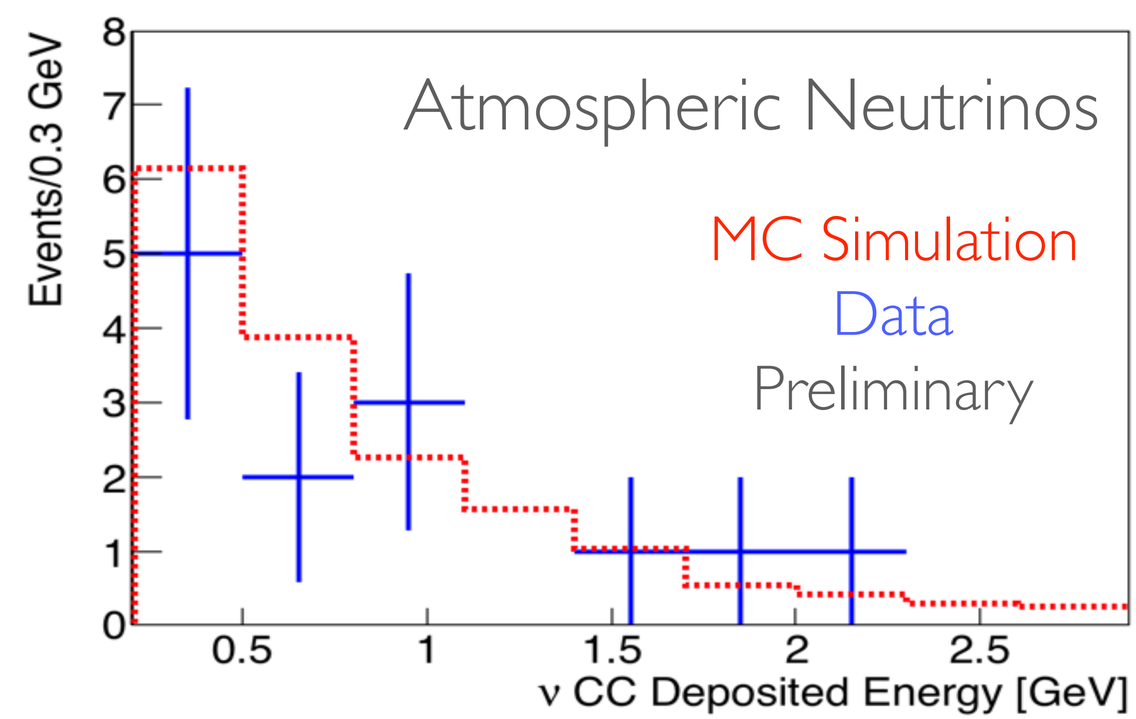


Neutrino Identification

- Demonstrated detector performance, tracking and calorimetry
- Identified ν_e-Ar charged-current (CC) interactions from CNGS beams
  - Reconstructed π^0 mass
  - Separated e and γ
- Validated automatic selection of atmospheric ν_μ and ν_e events (0.48kton-y exposure)
  - Deposited E_ν > 200MeV
  - Similar E_ν to BNB ν!

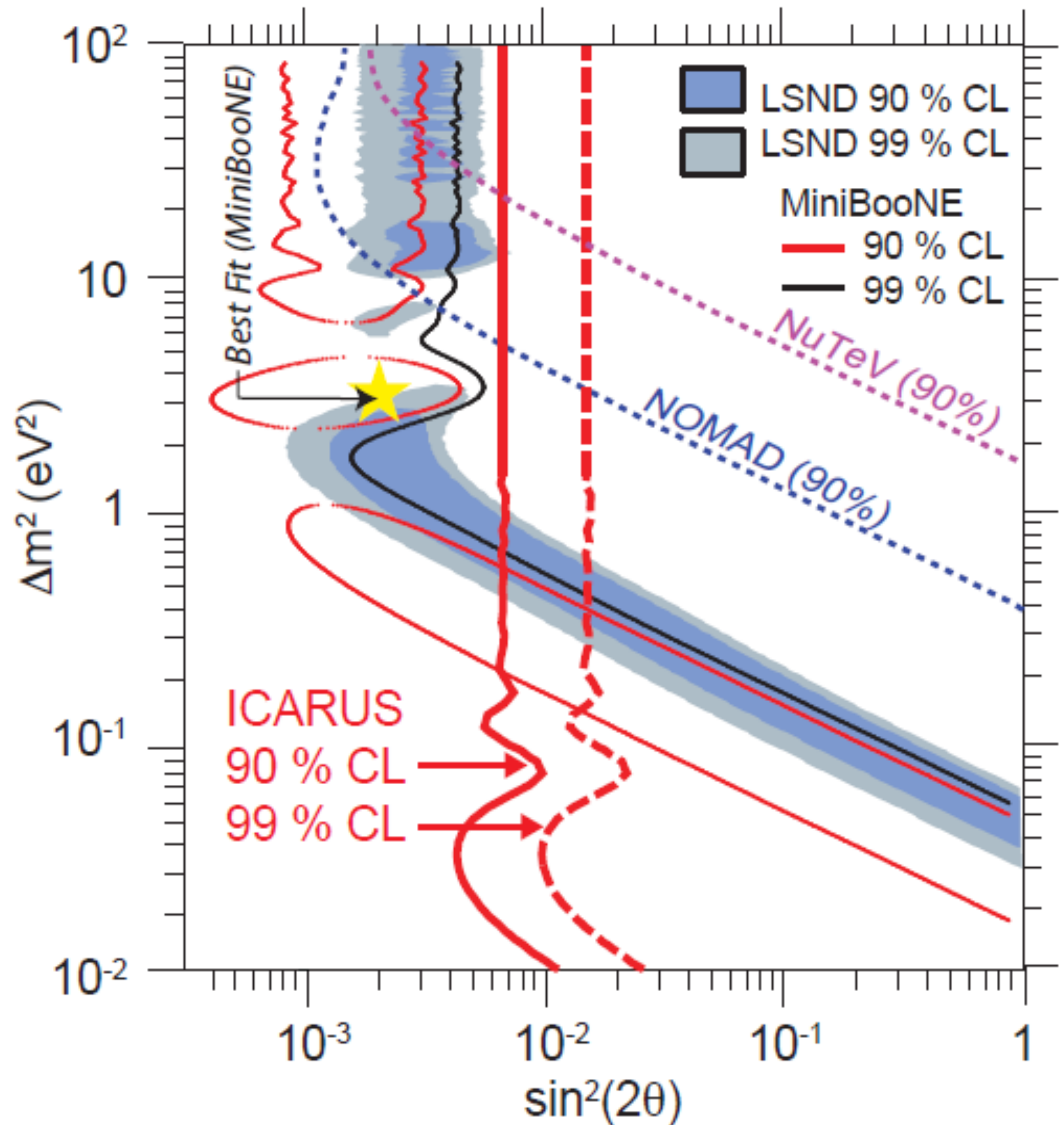






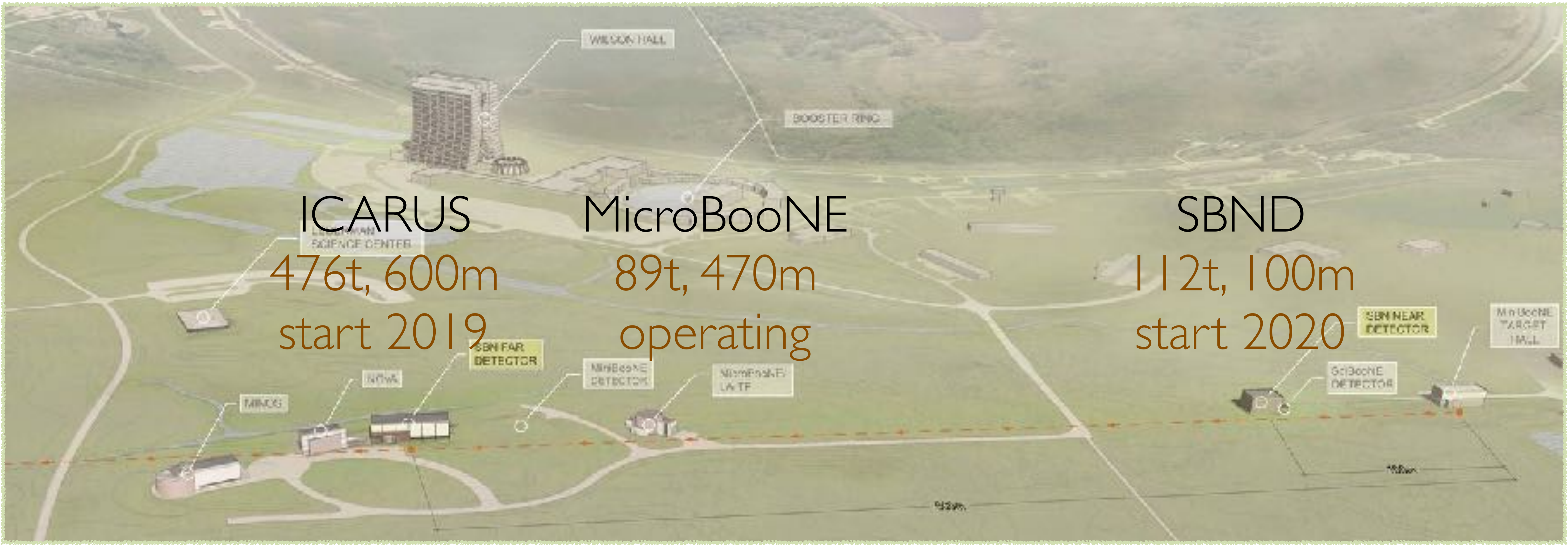
Sterile Neutrino Search

- $\nu_\mu \rightarrow \nu_e$ appearance measurement
- ν_e-Ar CC interactions
- Event energy < 30GeV
- Utilize dE/dx for electron selection
- Expected 8.5±1.1 events out of 7.93×10^{19} POT
- 7 ν_e visually identified
- Results compatible with no additional anomalous contributions



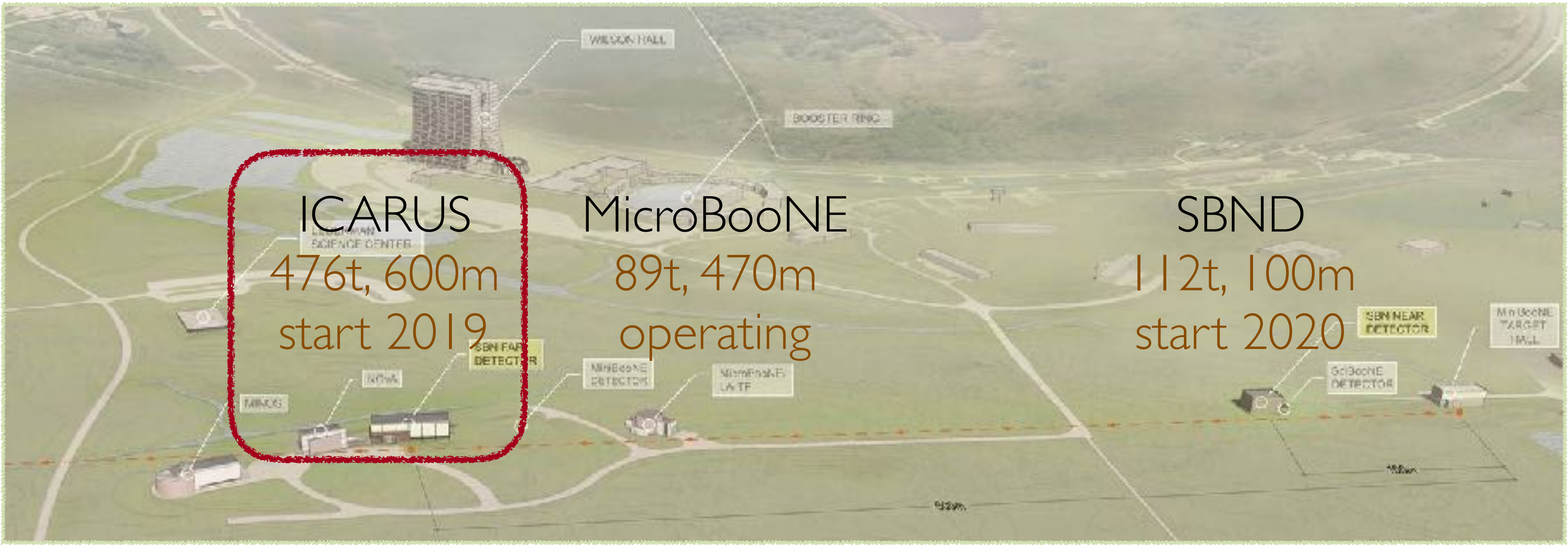
ICARUS publication list
http://icarus.lngs.infn.it/publications.php

ICARUS at SBN



- SBN: Address anomalies from LSND, MiniBooNE: sterile ν?
- BNB ν_μ from Fermilab accelerator and 3 LArTPC detectors
- ICARUS: far detector measuring $\nu_\mu \rightarrow \nu_e$ oscillation
  - ν-Ar cross sections from off-axis NuMI
  - Potential in astroparticle and exotic physics?

ICARUS at SBN



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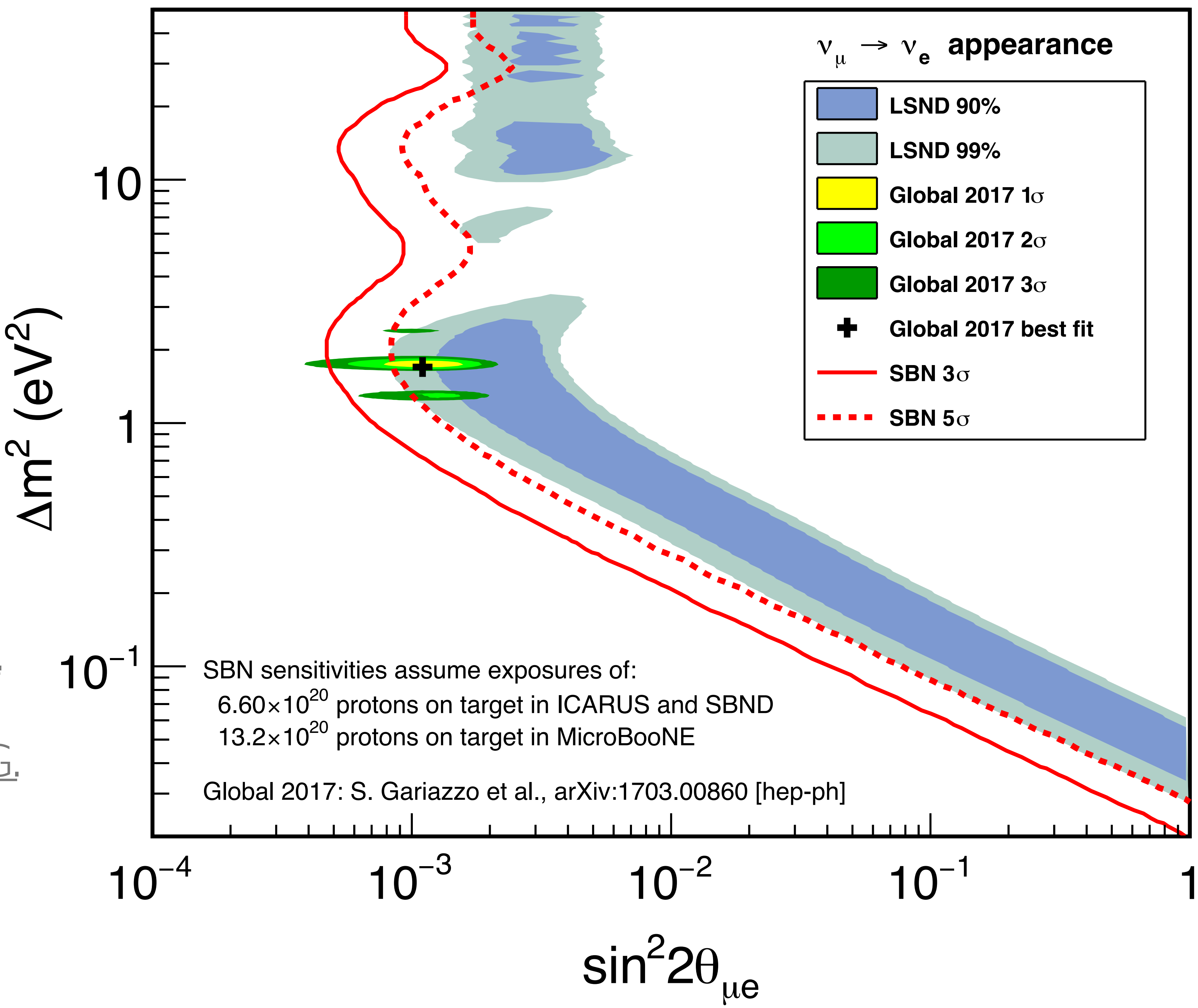
ICARUS Collaboration

Brookhaven National Laboratory, United States
Colorado State University, United States
Fermilab, United States
University of Houston, United States
INFN Sezione di Catania and University, Catania, Italy
INFN GSSI, L'Aquila, Italy
INFN LNGS, Assergi, L'Aquila, Italy
INFN Sezione di Milano Bicocca, Milano, Italy
INFN Sezione di Napoli, Napoli, Italy
INFN Sezione di Padova and University, Padova, Italy
INFN Sezione di Pavia and University, Pavia, Italy
Los Alamos National Laboratory, United States
University of Pittsburgh, United States
SLAC National Accelerator Laboratory, United States
University of Rochester, United States
University of Texas at Arlington, United States

>80 scientists from 16 institutions

SBN Sensitivity

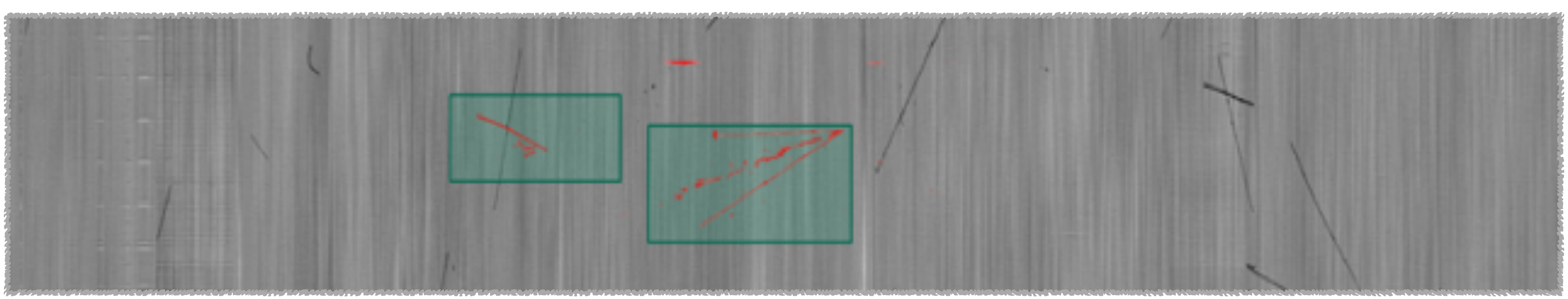


See SBN (A. Fava) and Global Fits (G. Karagiorgi)

Challenges on Surface

- Detectors of SBN program located at surface
  - Expect 11kHz of cosmic rays in ICARUS
- Detector upgrade to cope with cosmic rays
  - Improved light collection system
  - Cosmic ray taggers (CRT)
  - A 3-meter concrete overburden

Cosmic ray data taken in Pavia overlaid with CNGS ν-Ar interactions



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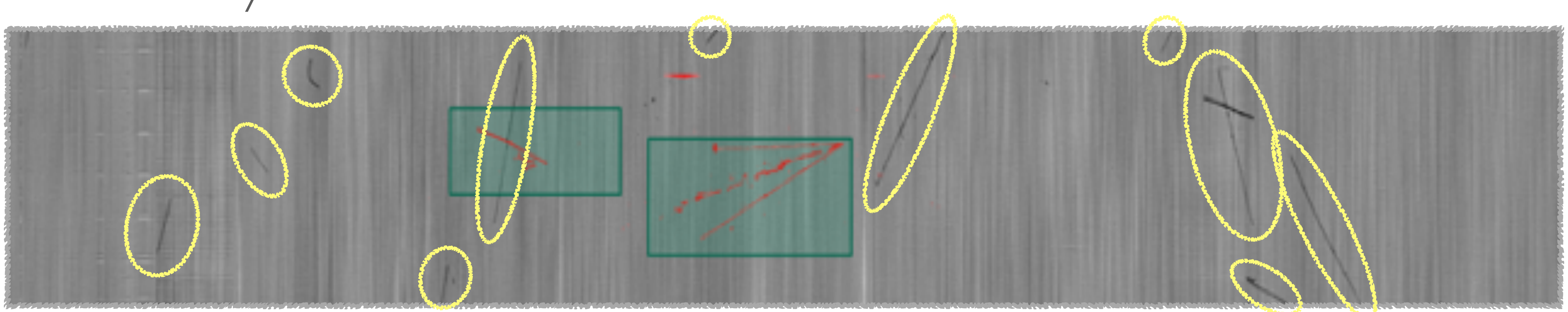
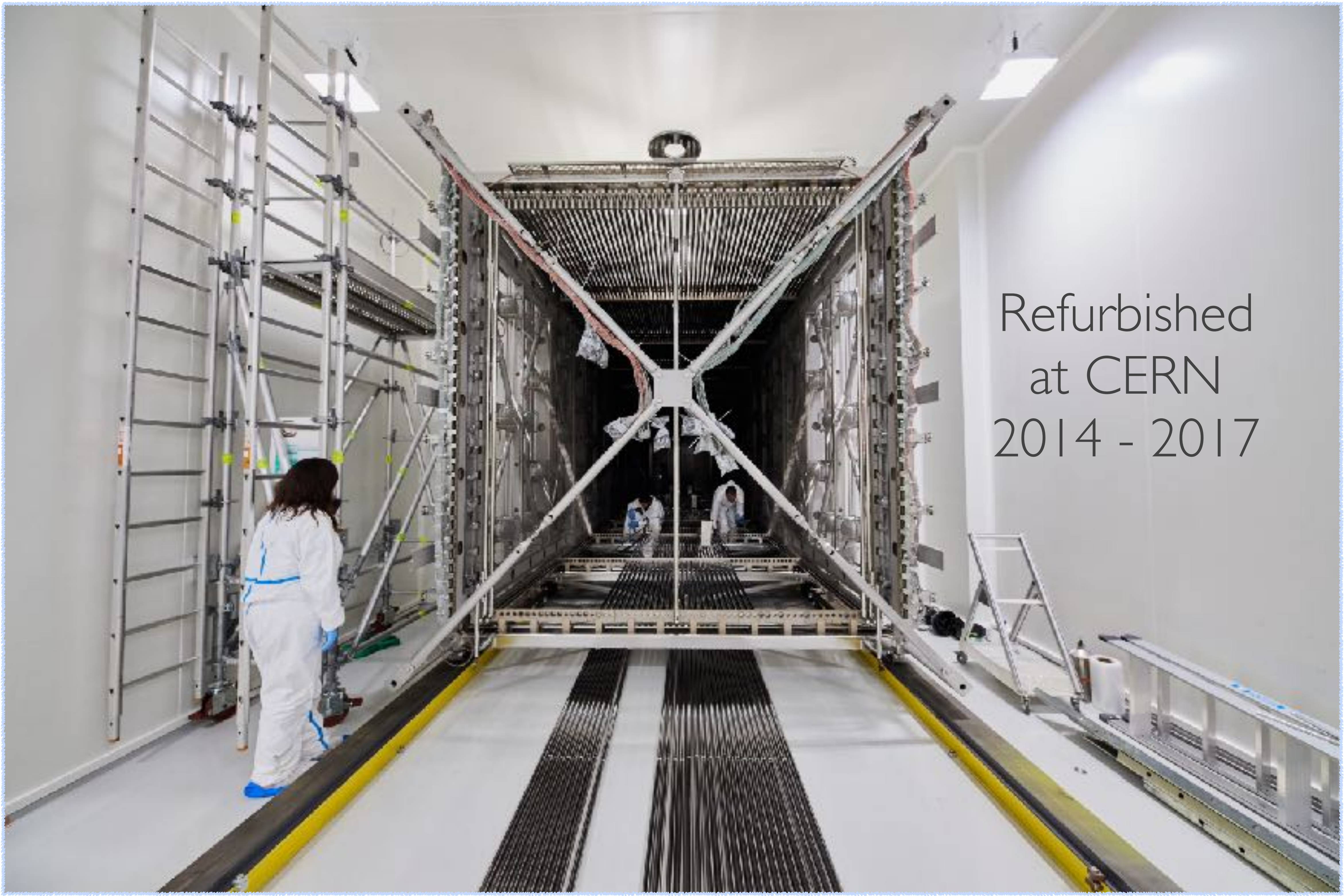


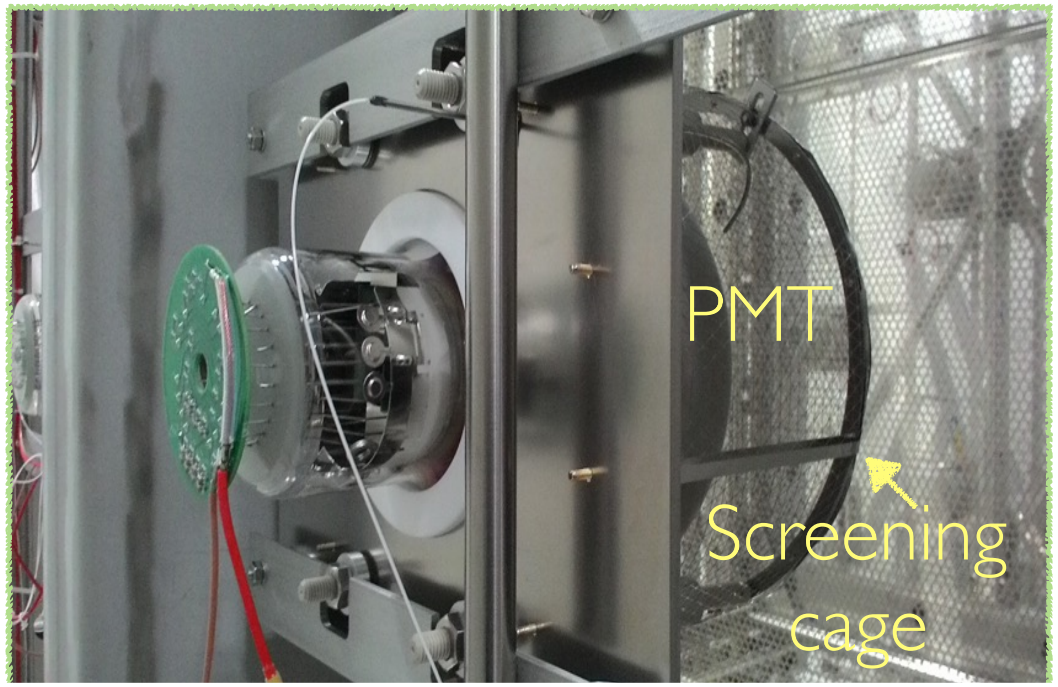

Refurbished
at CERN
2014 - 2017

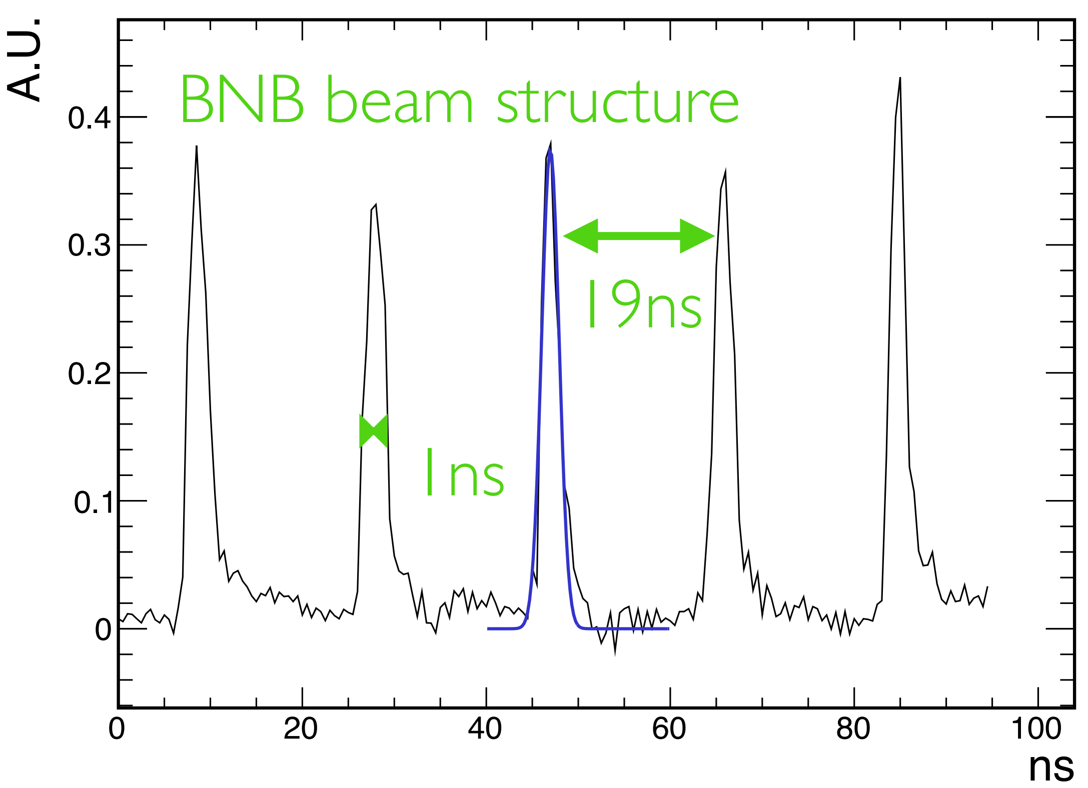
Overhaul and Upgrade

- Upgraded light collection system
- Modified TPCs
  - New cathode with improved planarity
- Upgraded TPC readout electronics
- New DAQ and trigger system
- New cold vessels and thermal insulation
- Renovated cryogenic and LAr purification system
- Cosmic ray taggers
- Overburden

Upgrade on PMT

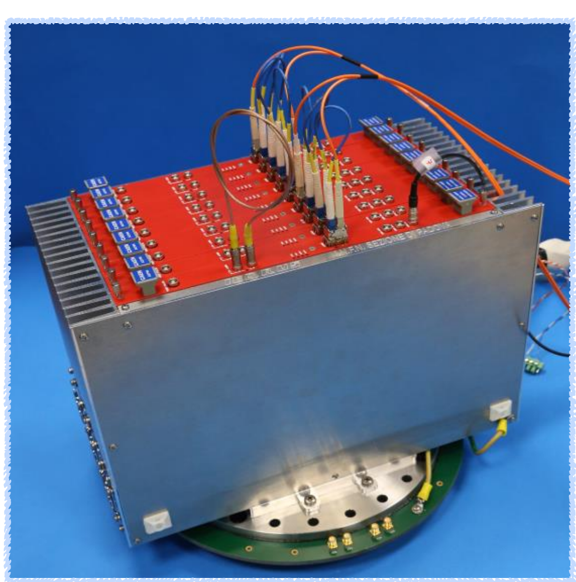
- Improve
  - Event time t_0 determination
  - Cosmic ray rejection/event selection
  - Triggering
- 360 8" Hamamatsu PMTs
  - High coverage: 5% cathode
  - Better granularity
  - Better time resolution (500MHz)
  - Screening cage for each PMT
  - Sensitive to deposited energy down to 100MeV

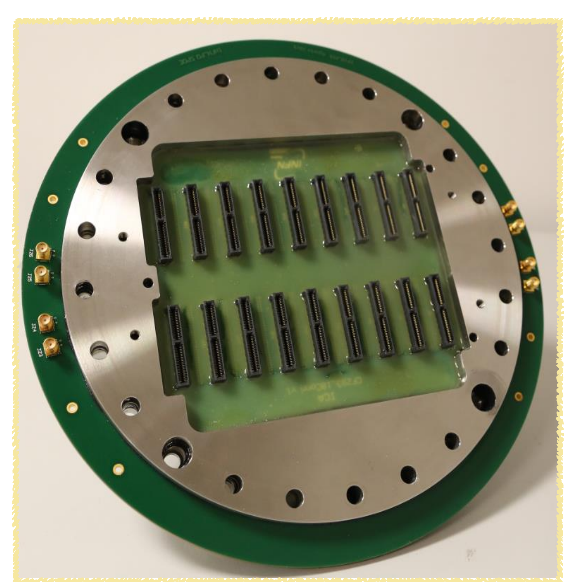


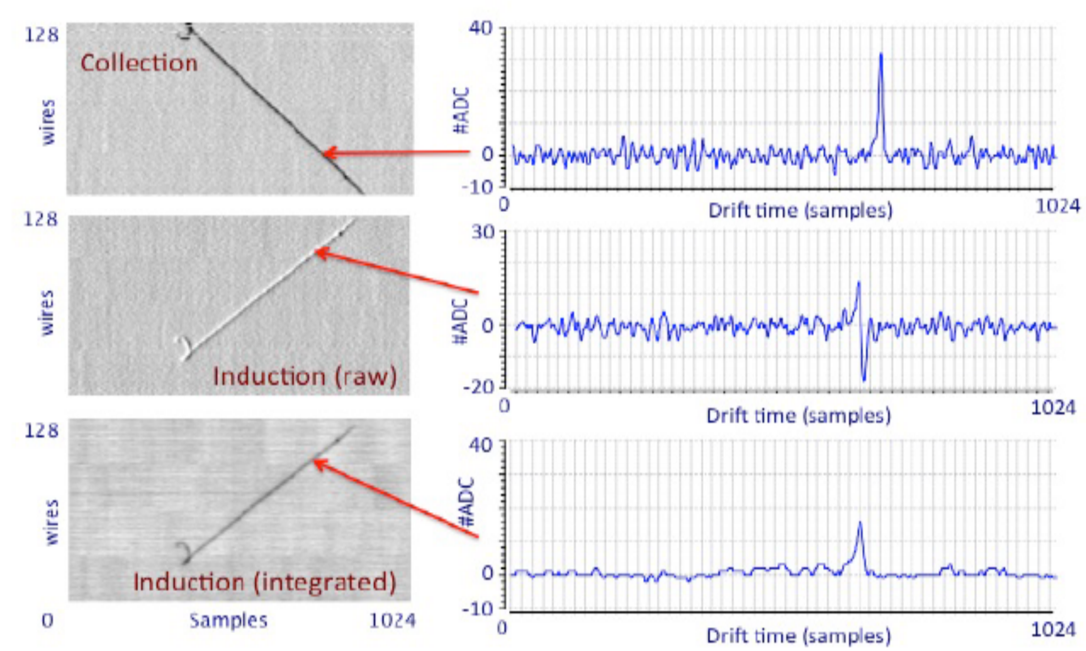


Upgrade on TPC Readout

- Multiplexing (16) 10-bit ADC → Serial 12-bit ADC
  - Synchronous sampling time for all the channels
- Digitization remains at 2.5MHz (400ns)
- Improved module throughput: 64Mb/s → Gb/s
- Faster shaping time (~0.6μs), improved electronic response shape; expect to have S/N~10

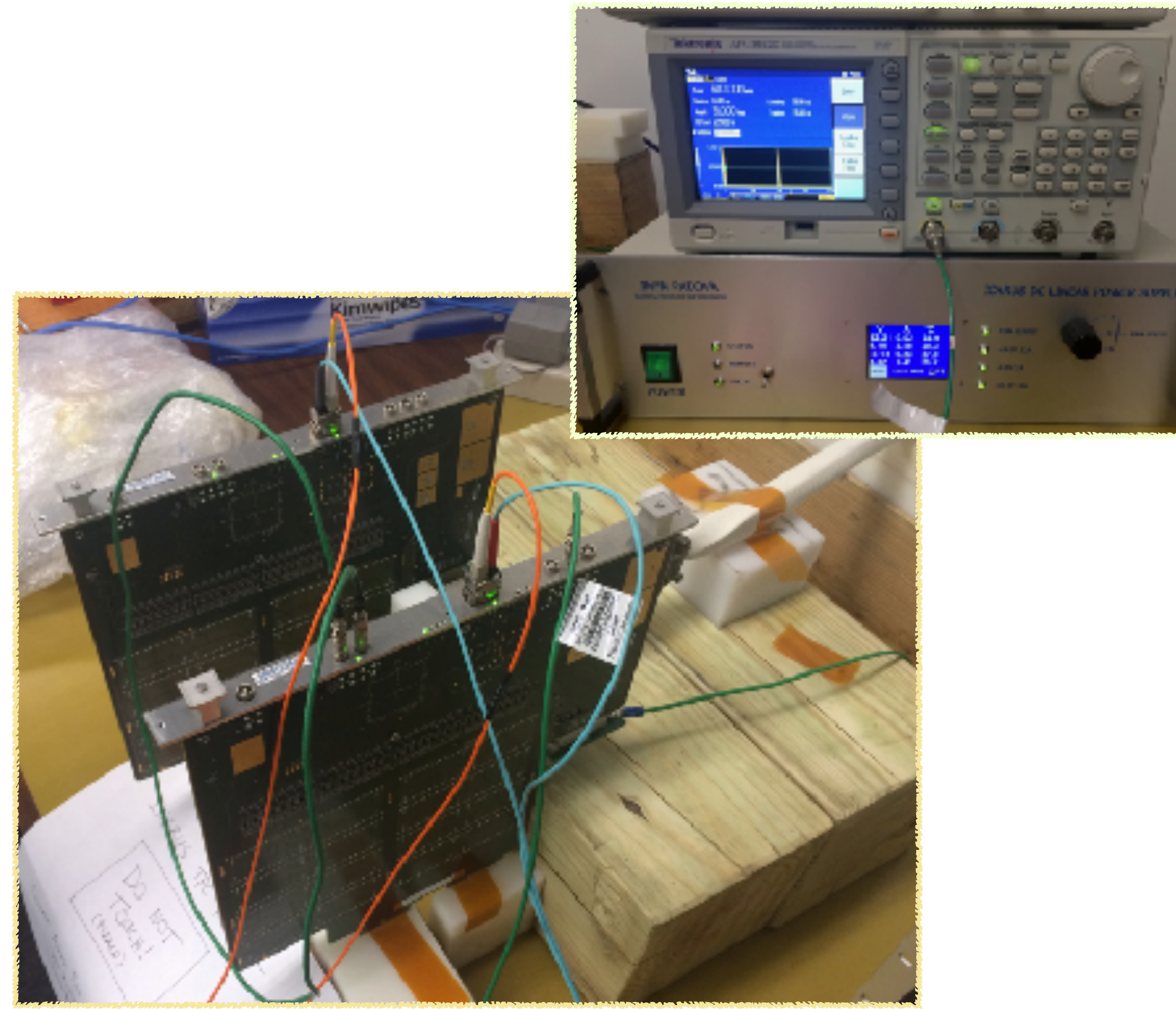


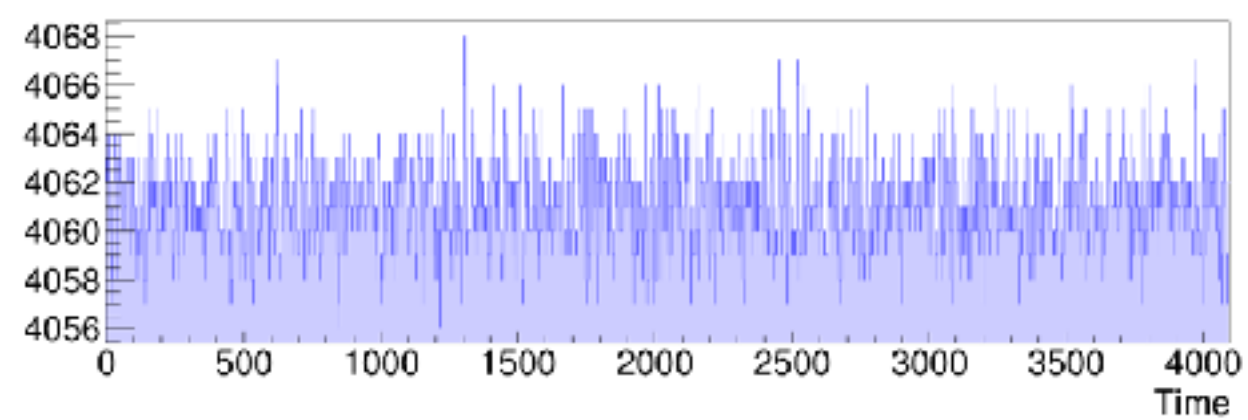




Upgrade on DAQ & Trigger

- Develop DAQ software
- Event assembling rate 1Hz→15Hz (expected)
- Design the self-trigger based on the PMT data
- Trigger logics combined with input from CRT
- Plan to design high-level, software-based triggers
- Establish interfaces with slow control system





June - July 2017
from CERN to Fermilab
Buon viaggio!

#IcarusTrip
IcarusTrip.fnal.gov


BARNHART
#IcarusTrip
United Kingdom
Ireland
Denmark
Austria
France
North Atlantic Ocean
MN
WI
MI
IA
IL
IN
OH
NY
PA
MD
DE
WV
KY
VA
NC
SC
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MA

Installation

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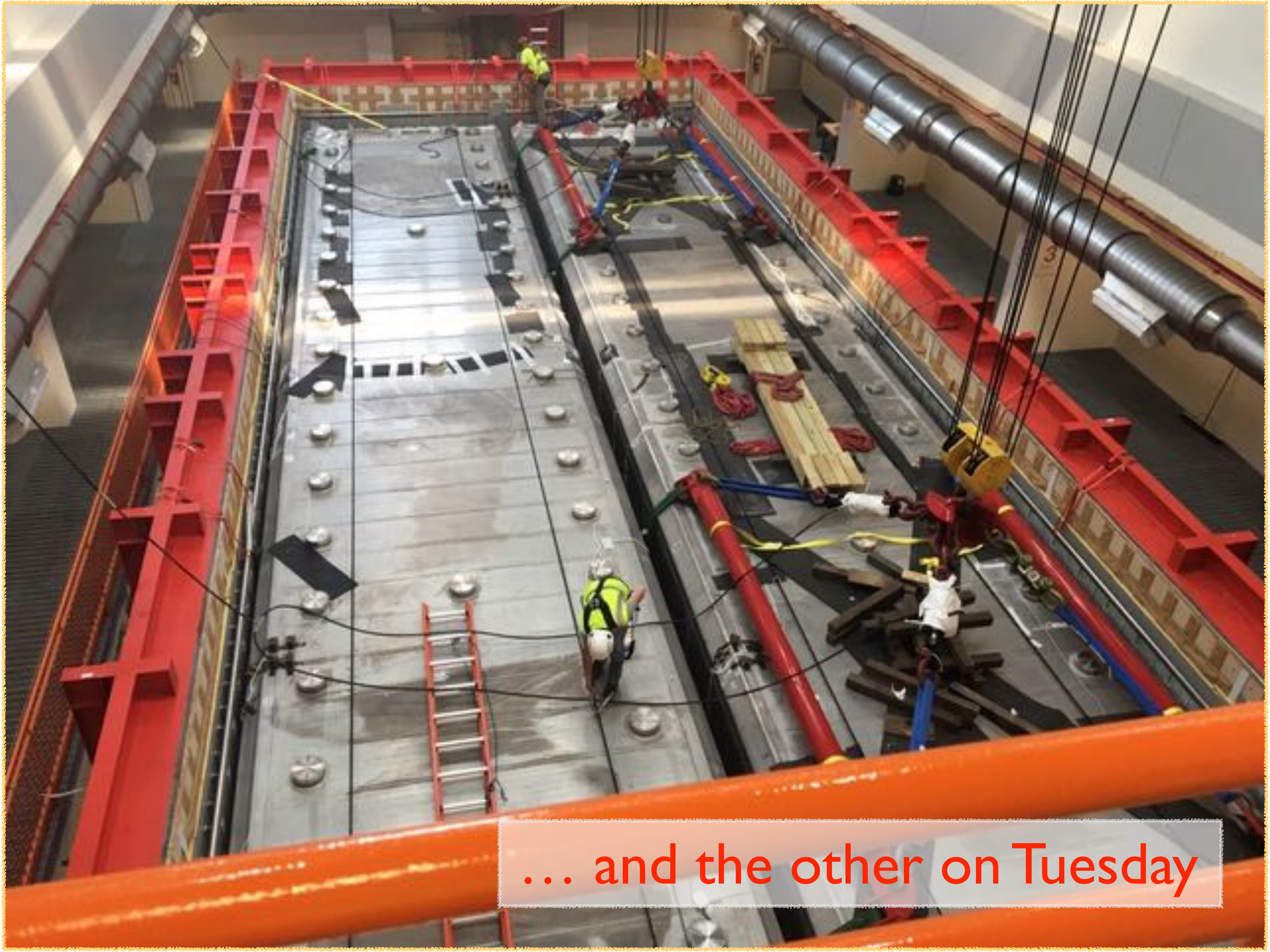

Installation

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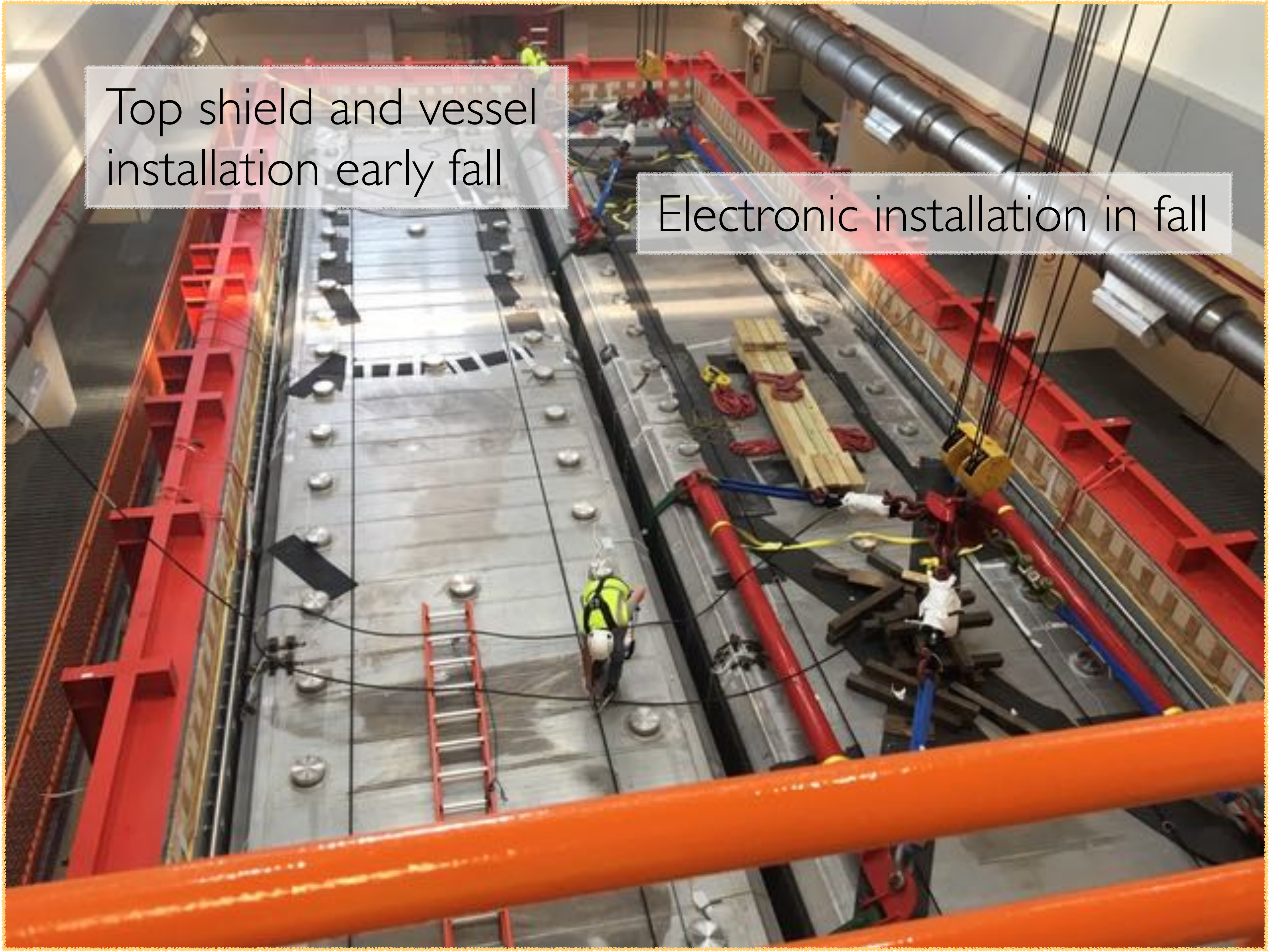

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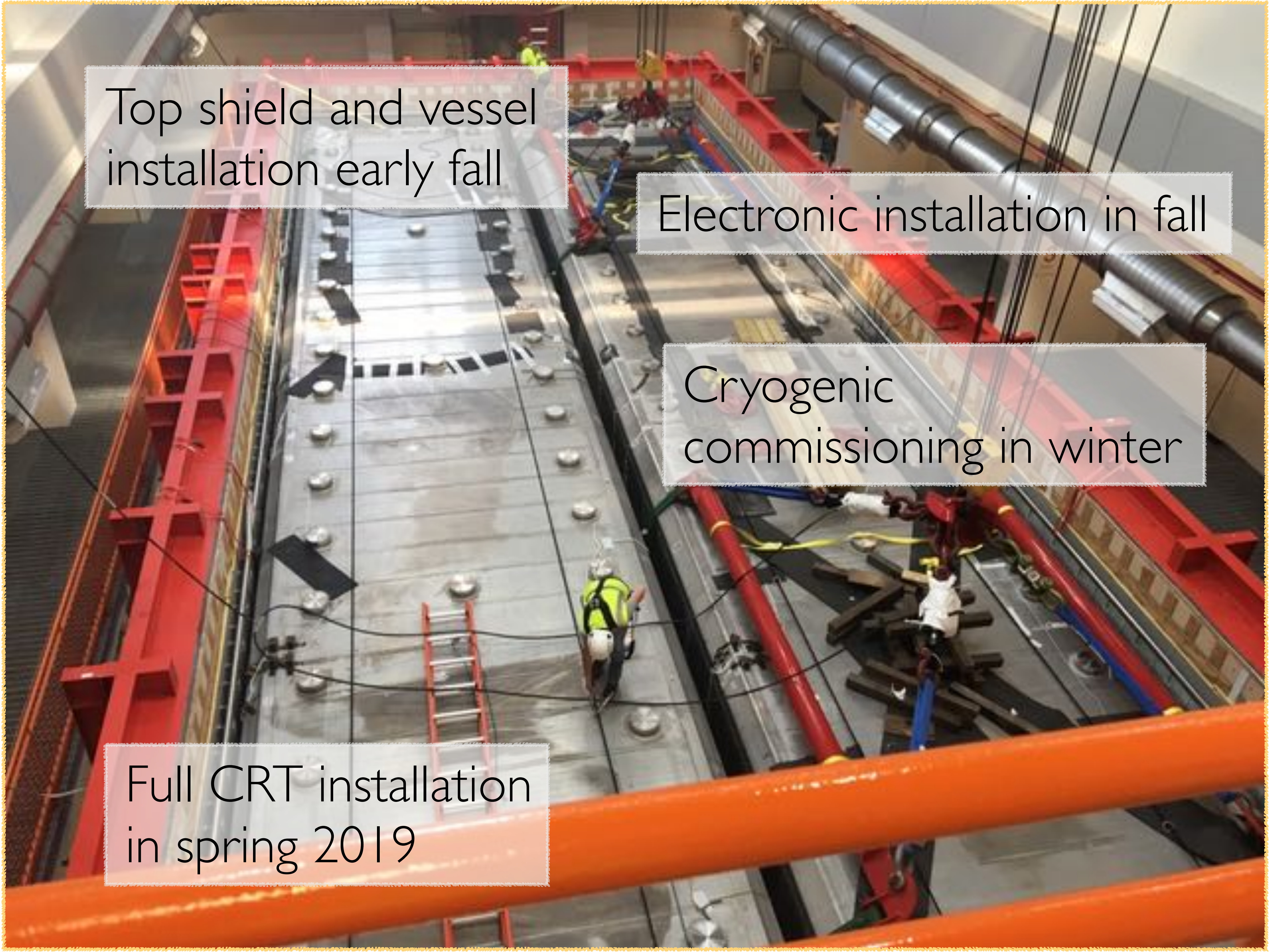
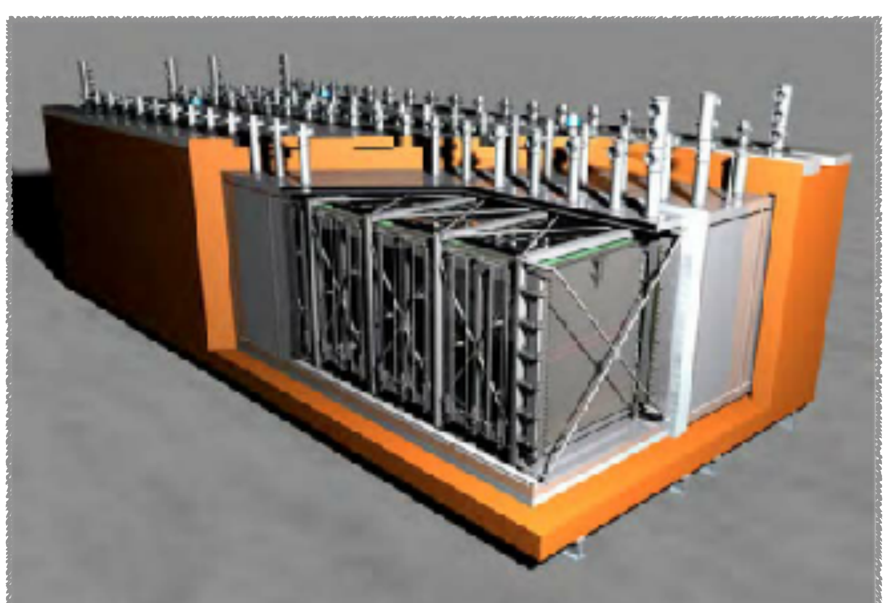


Commissioning Plan

Aug. 2018 Jan. 2019 May 2019 Sep. 2019

- Tests on wire connectivity, noise and grounding, wire biasing.
- Installation of readout electronics, DAQ, internal slow control system

- Cryogenics: Assembly, vacuum, cooling, filling with LAr, purification, stabilization

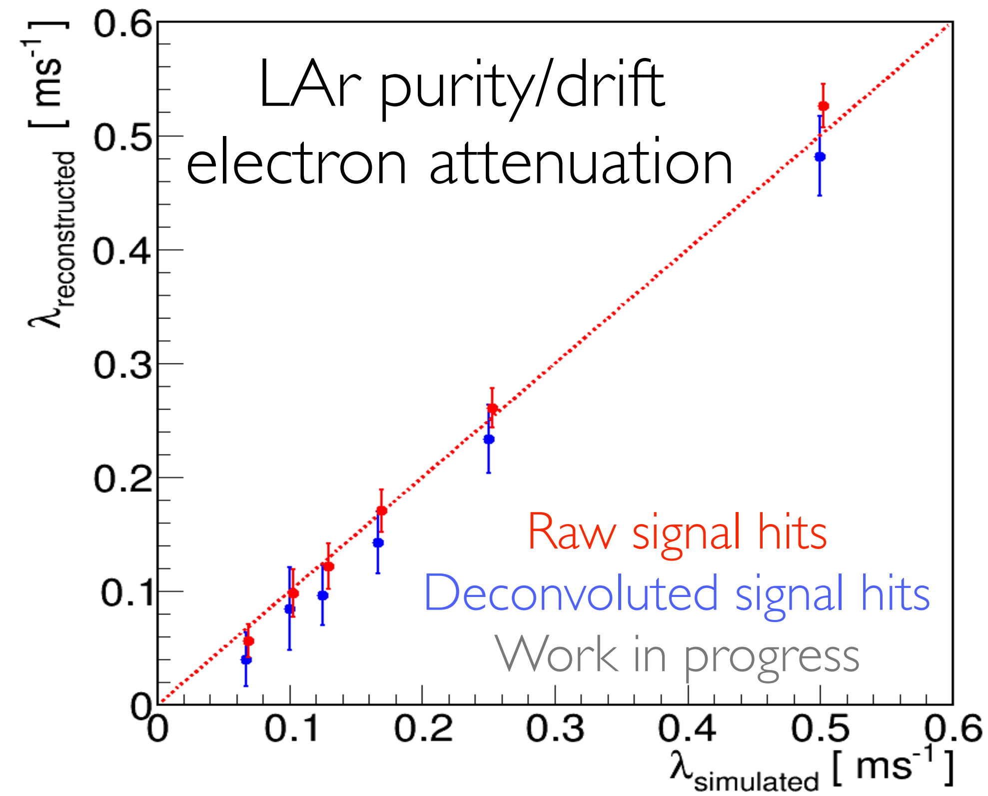


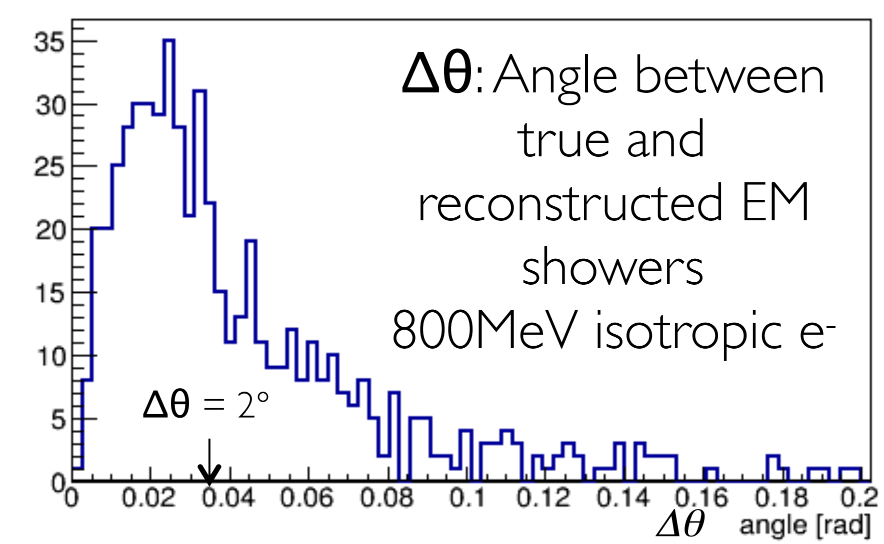
- DAQ, data transferring, trigger
- Verification on LAr purity and data
- CRT commissioning

- Data taking!

Event Reconstruction

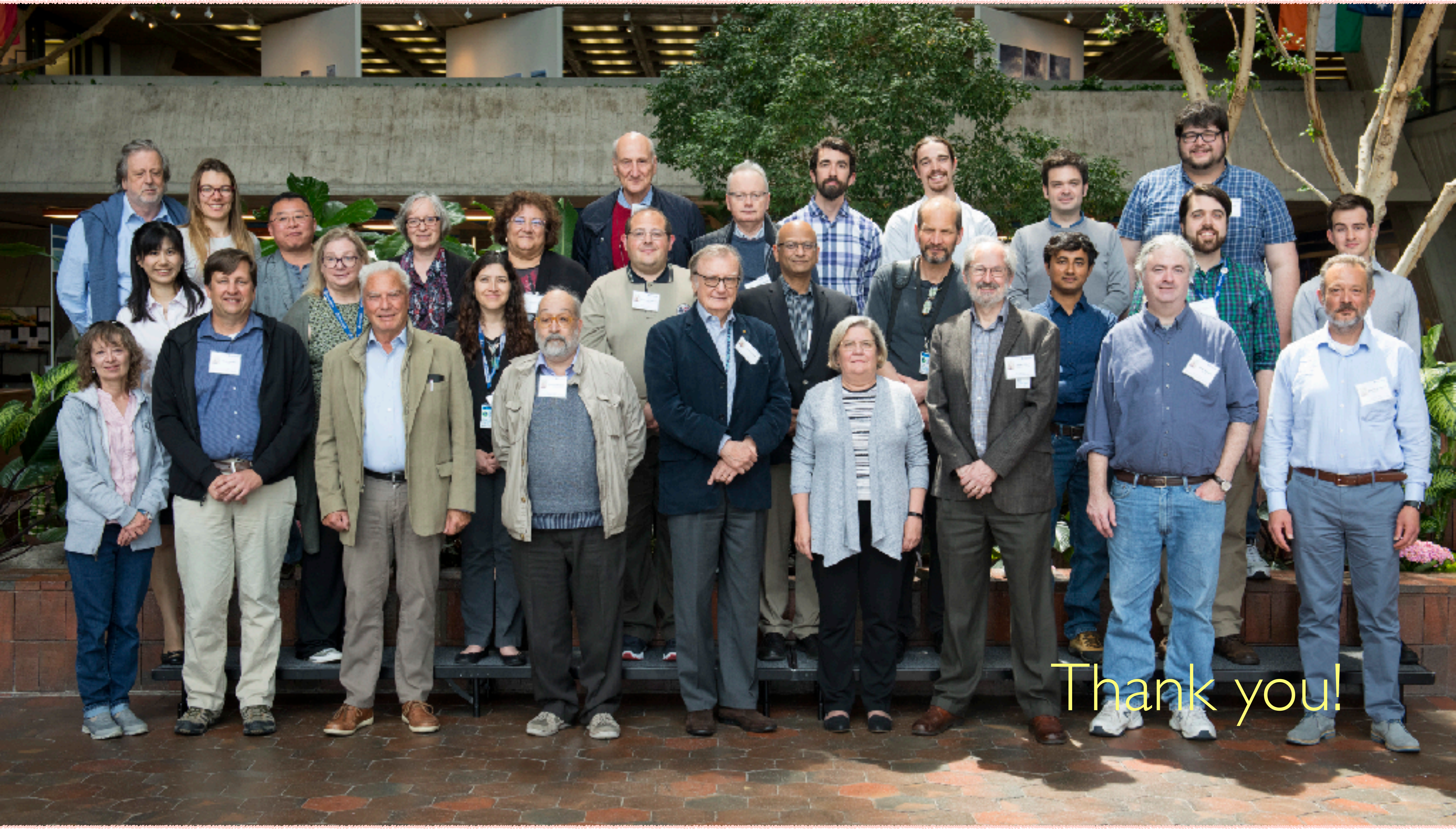
- Common SBN framework for simulation and reconstruction being developed
- Learned a lot from previous ICARUS and MicroBooNE
- Simulated upgraded TPC electronic responses, realistic noise, and upgraded PMT signals
- Improve track and shower reconstruction
- Identify particles by dE/dx vs range





Summary

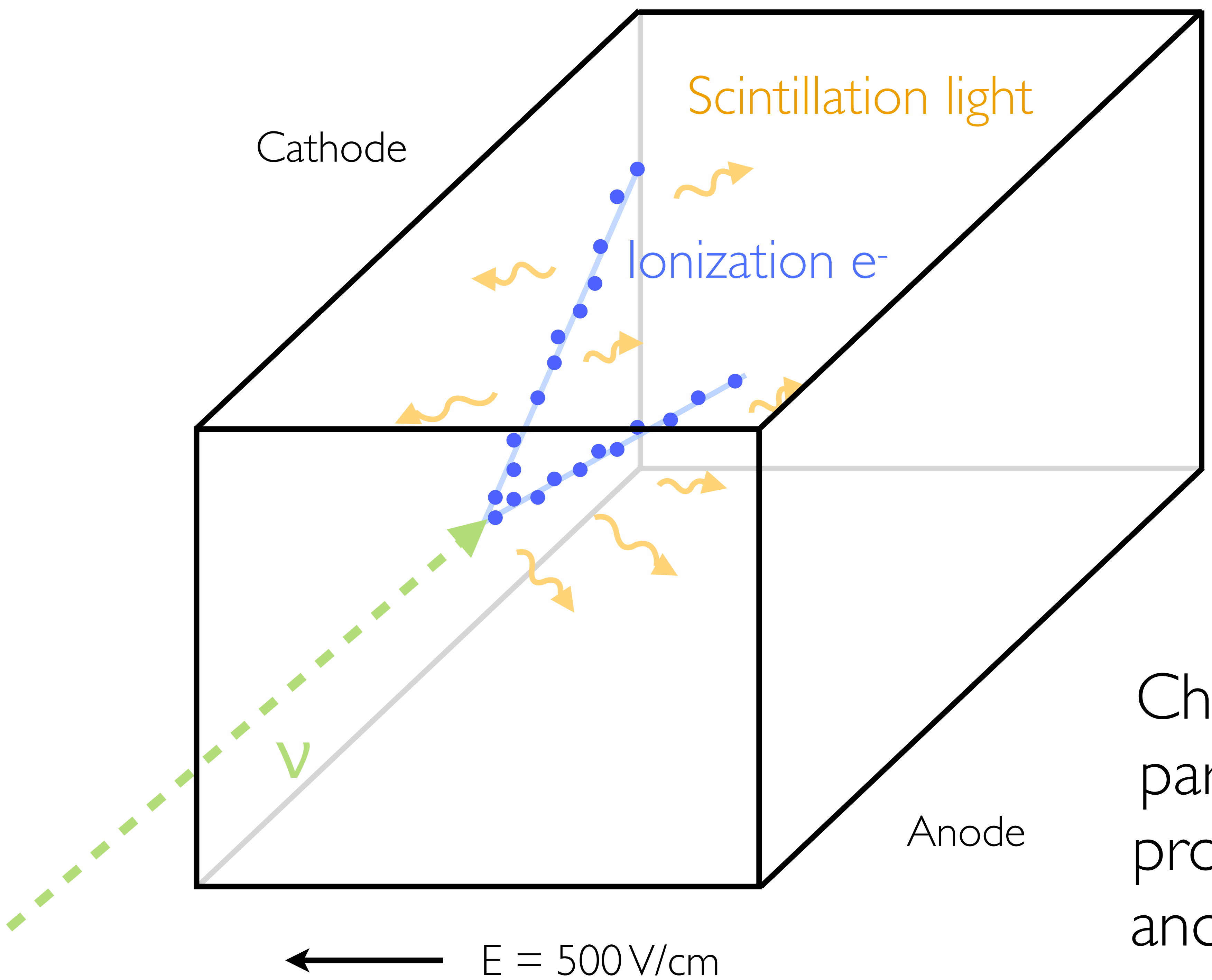
- LArTPC: a promising technology of neutrino detectors
- ICARUS operation at Gran Sasso demonstrated its physics capabilities
  - Long baseline $\nu_\mu \rightarrow \nu_e$ measurement compatible with no sterile neutrino
- The upgraded ICARUS now serves as the far detector in the SBN program
  - Aim to address LSND/MiniBooNE anomaly
- Detector being installed, plan to start operation next year. Stay tuned!



ICARUS installation video: https://youtu.be/1Qmr7WEKy-Q

Backup

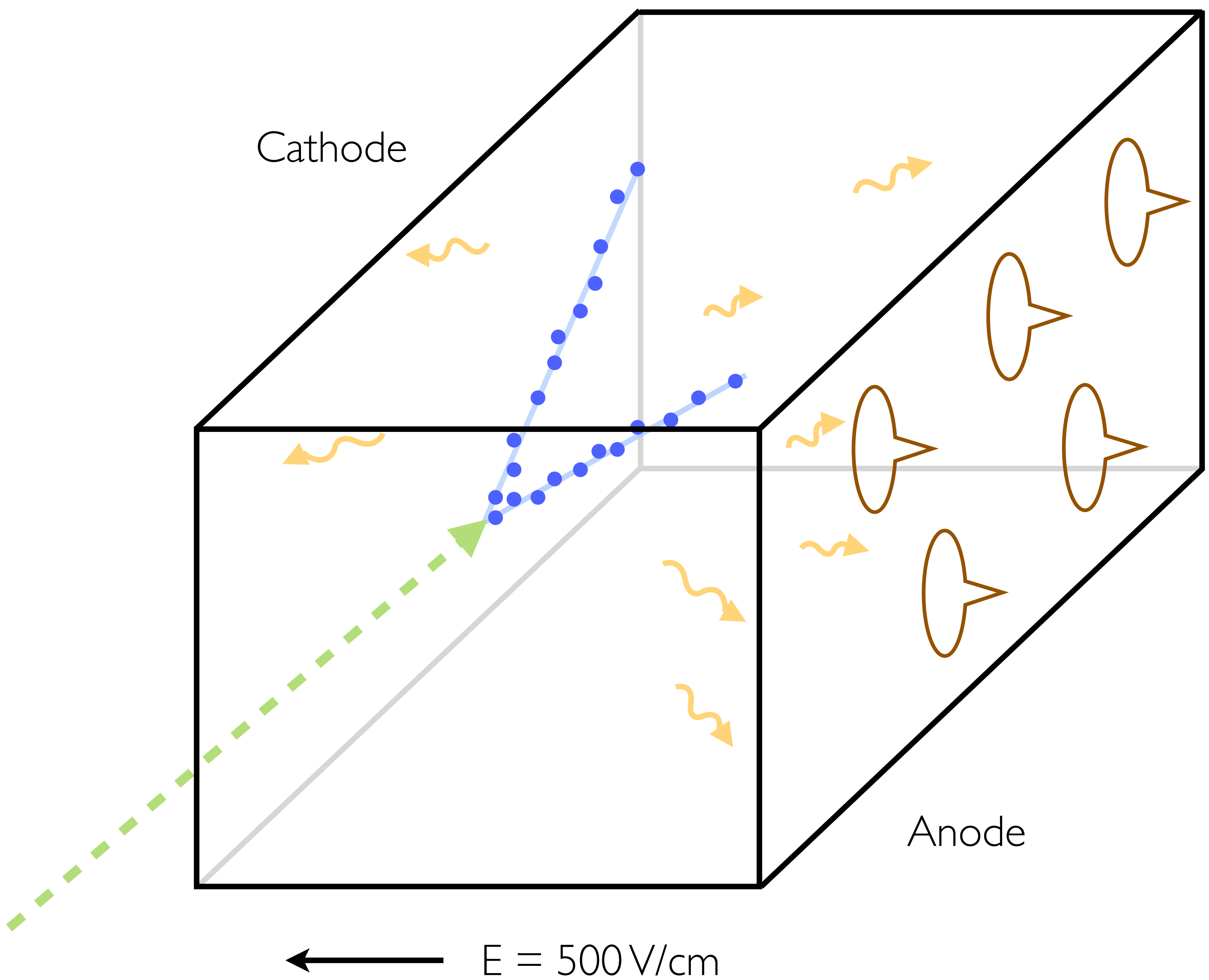
How A LArTPC Works



Incoming neutrino interacting with LAr

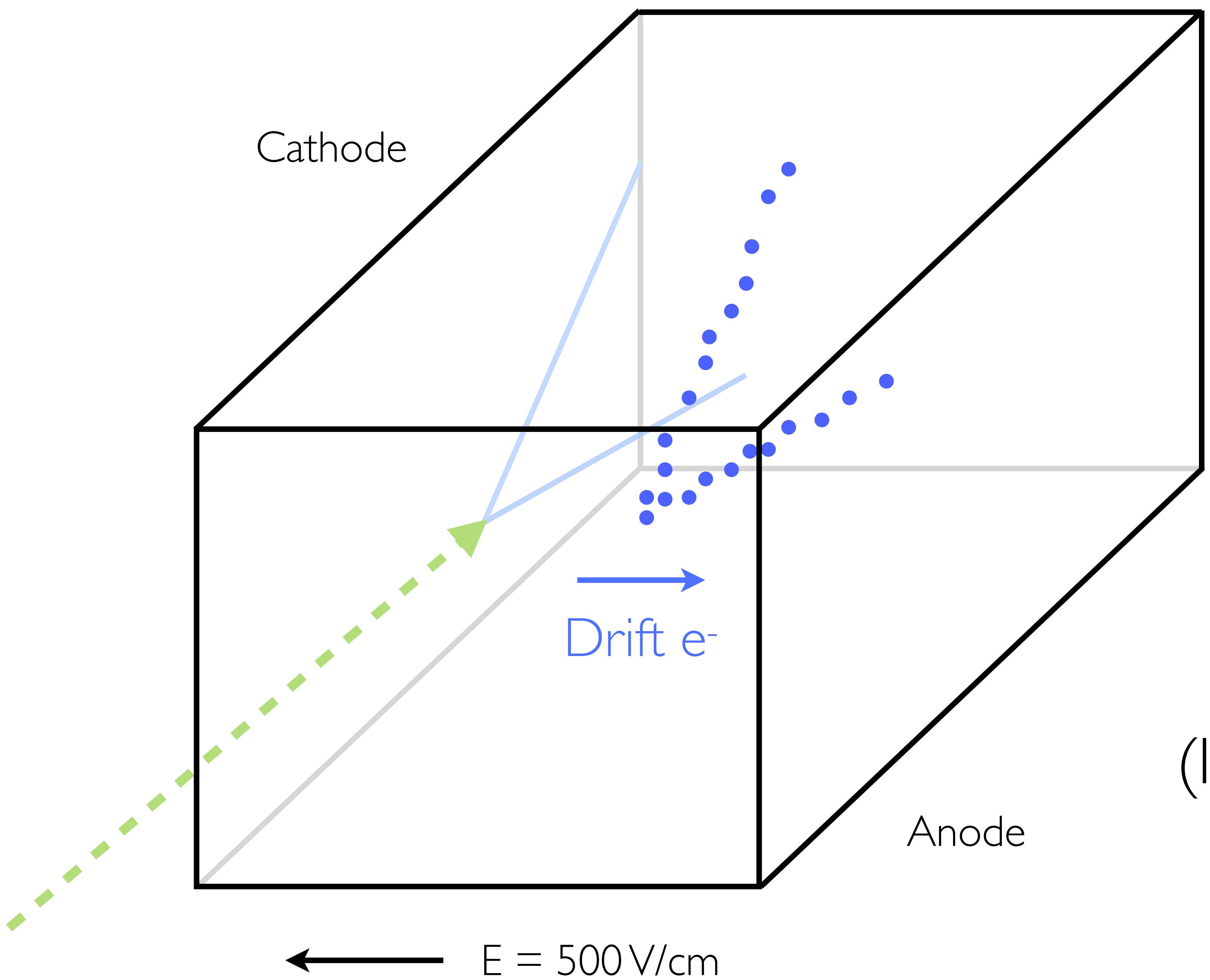
Charged secondary particles ionize LAr, producing electrons and scintillation light

How A LArTPC Works



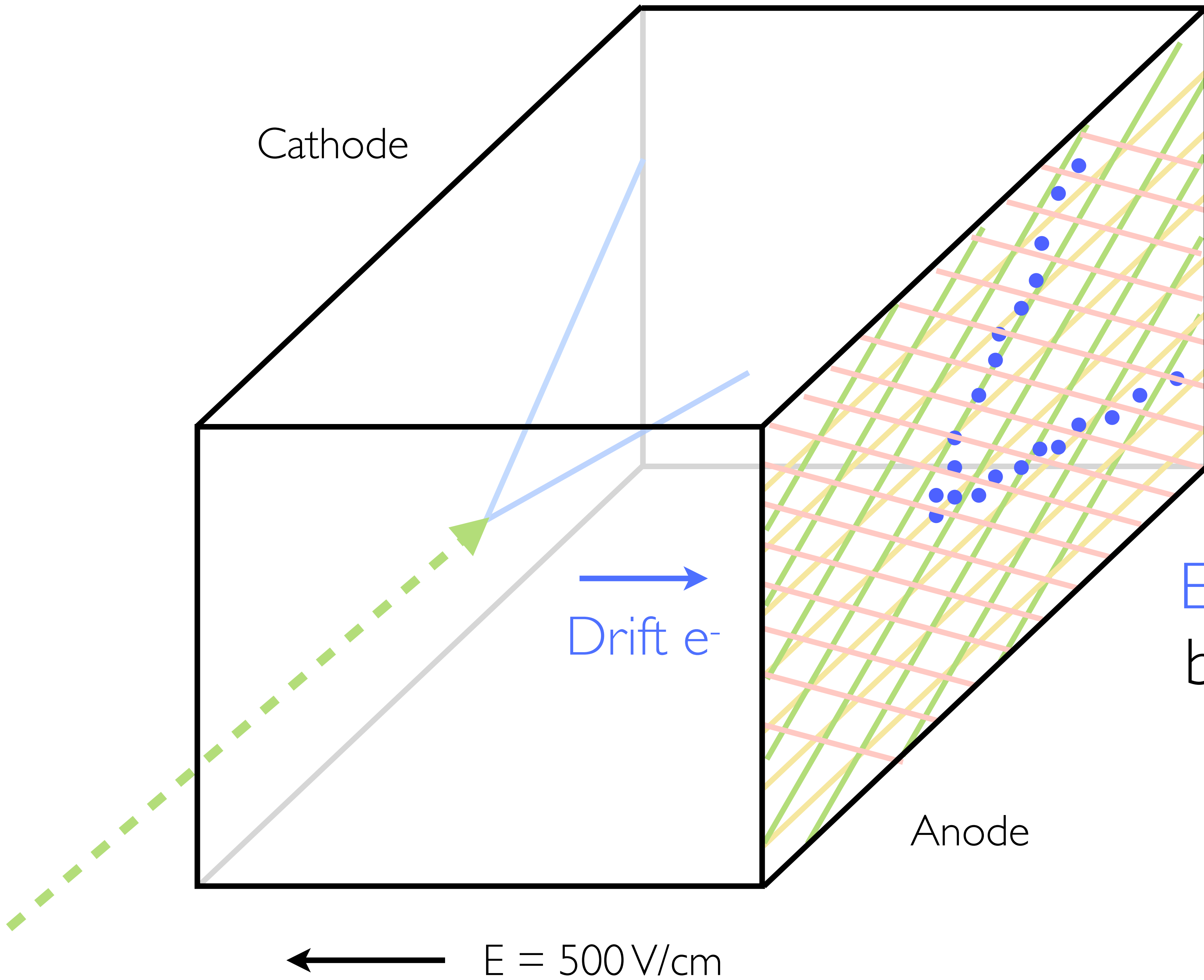
Light collected by PMT, determining event time t_0

How A LArTPC Works



Electrons drift towards anode (longest drift time at ICARUS: 0.9ms)

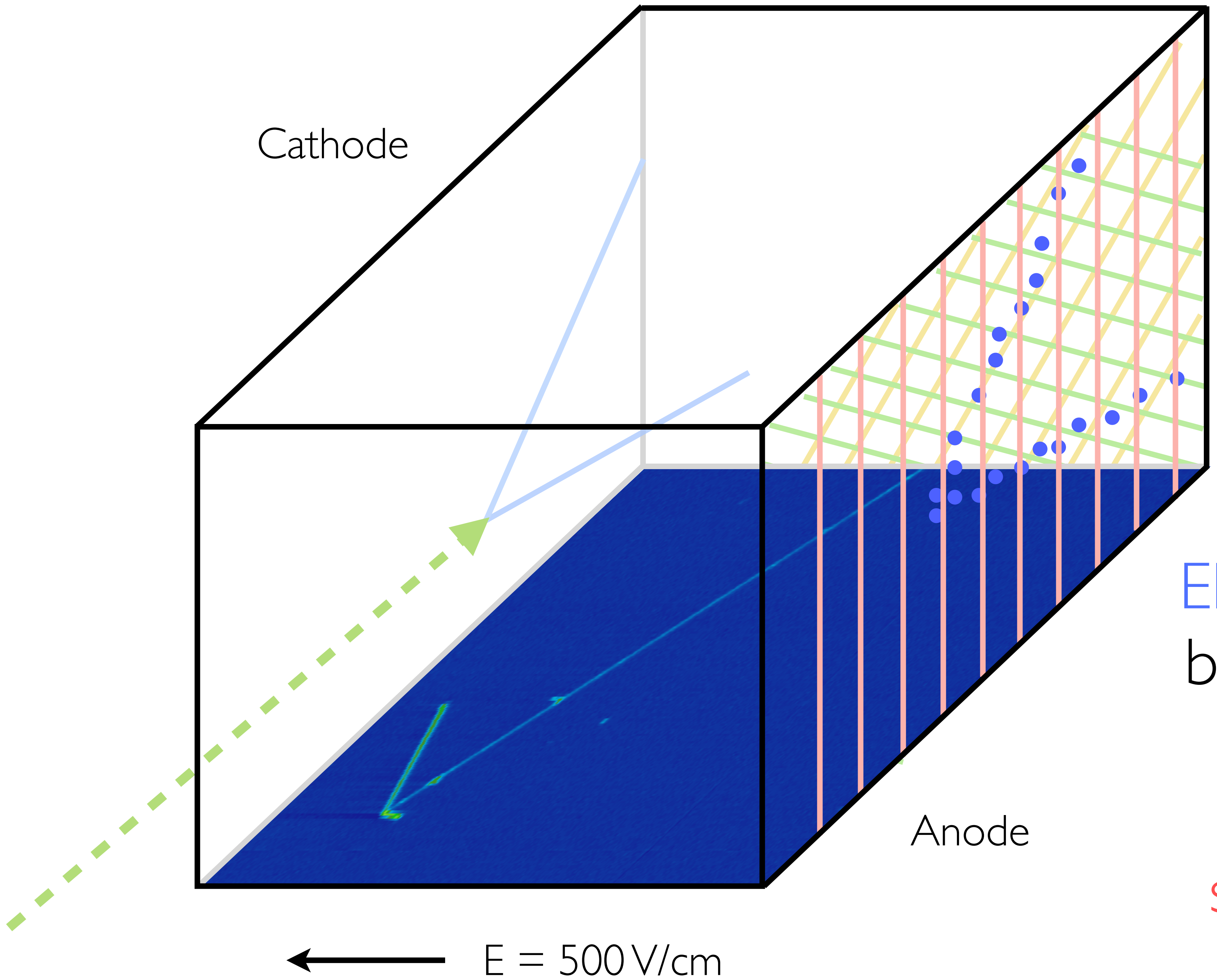
How A LArTPC Works



2 induction planes
1 collection plane

Electrons detected by the wire planes at anode, providing the spatial, kinematic information.

How A LArTPC Works



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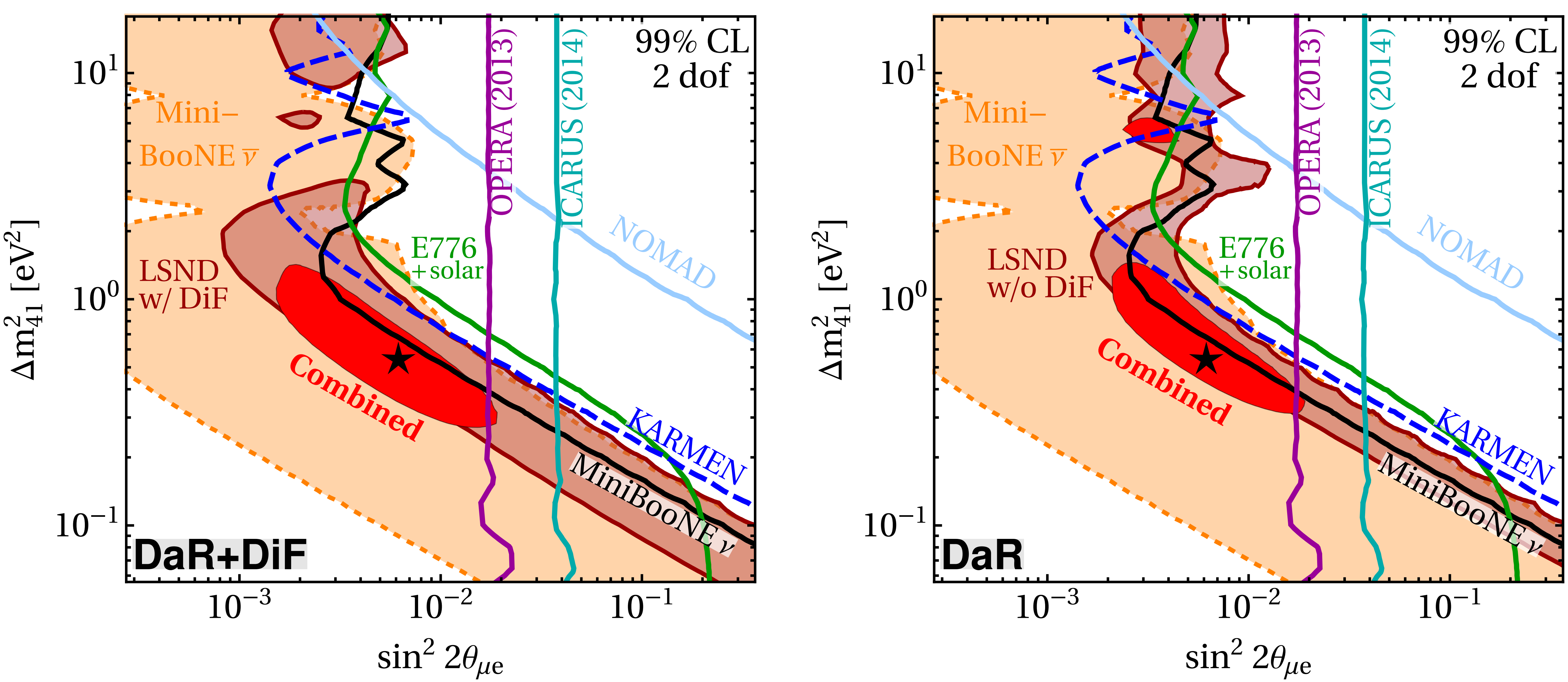
Anomaly



99% CL
2 dof
Mini–
BooNE $\overline{\nu}$
LSND
w/ DiF
OPERA (2013)
ICARUS (2014)
NOMAD
E776
+solar
KARMEN
MiniBooNE ν
Combined
DaR+DiF
Δm^2_{41} [eV^2]
$\sin^2 2\theta_{\mu e}$
99% CL
2 dof
Mini–
BooNE $\overline{\nu}$
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w/o DiF
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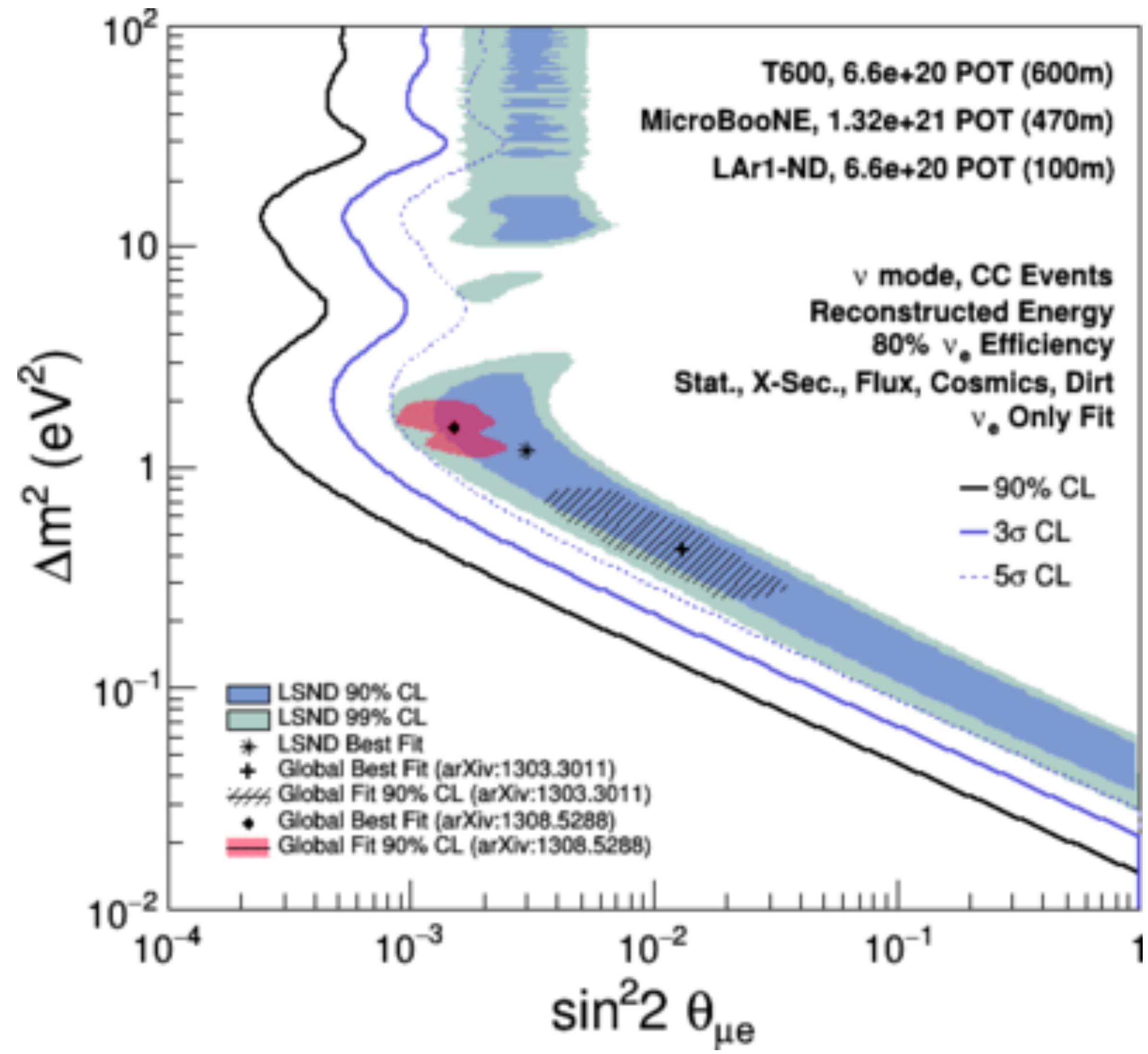
LSND Anomaly

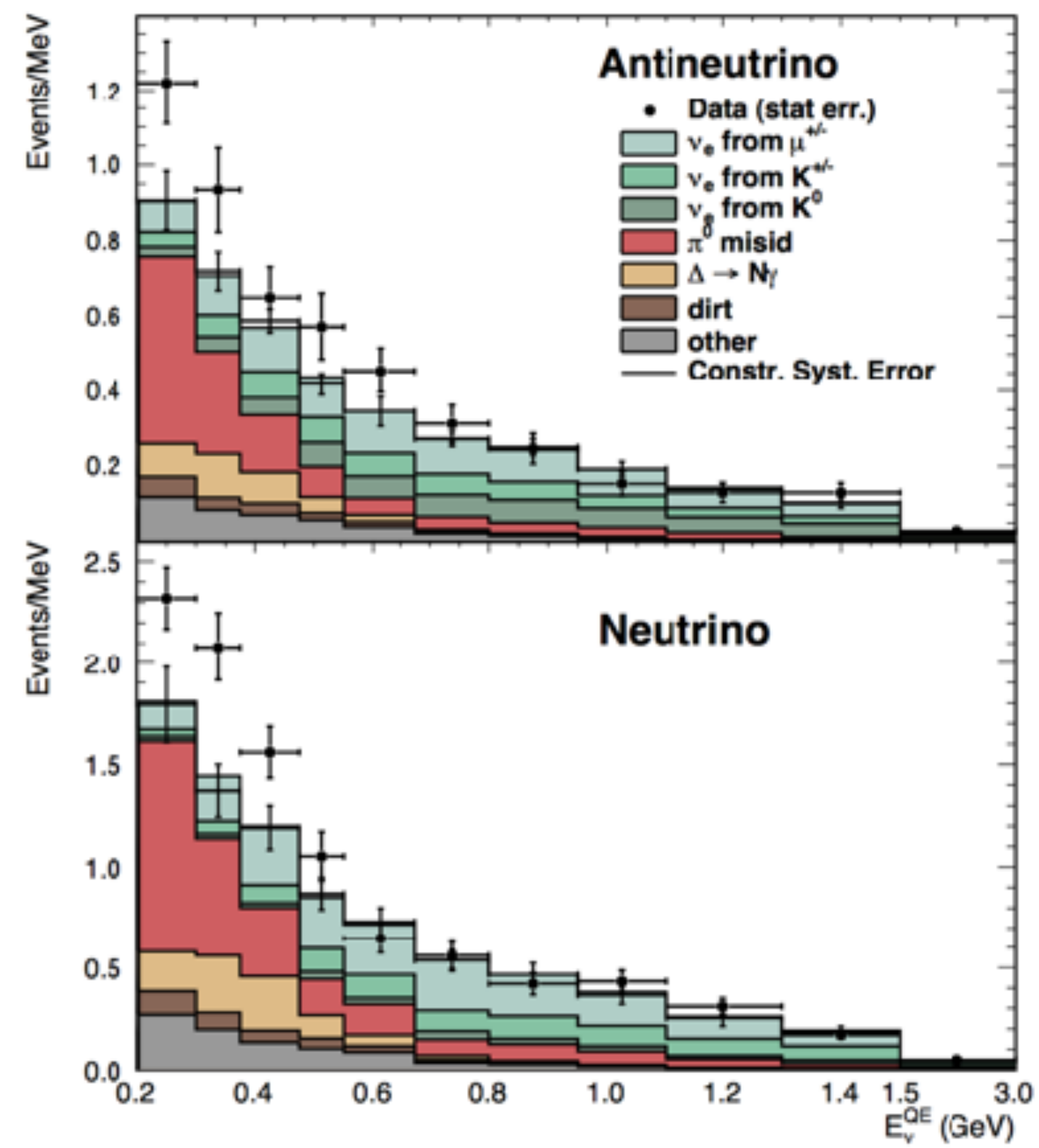
- MicroBooNE: Measure $\nu_\mu \to \nu_e$ oscillation to address LSND anomaly
- LSND: $\bar{\nu}_\mu \to \bar{\nu}_e$
  - L/E ~ 1m/MeV
  - Liquid Scintillator Neutrino Detector
  - best fit ($\sin^2 2\theta$, Δm^2): (0.003, 1.2eV^2)
    - high Δm^2!
  - existence of sterile ν?



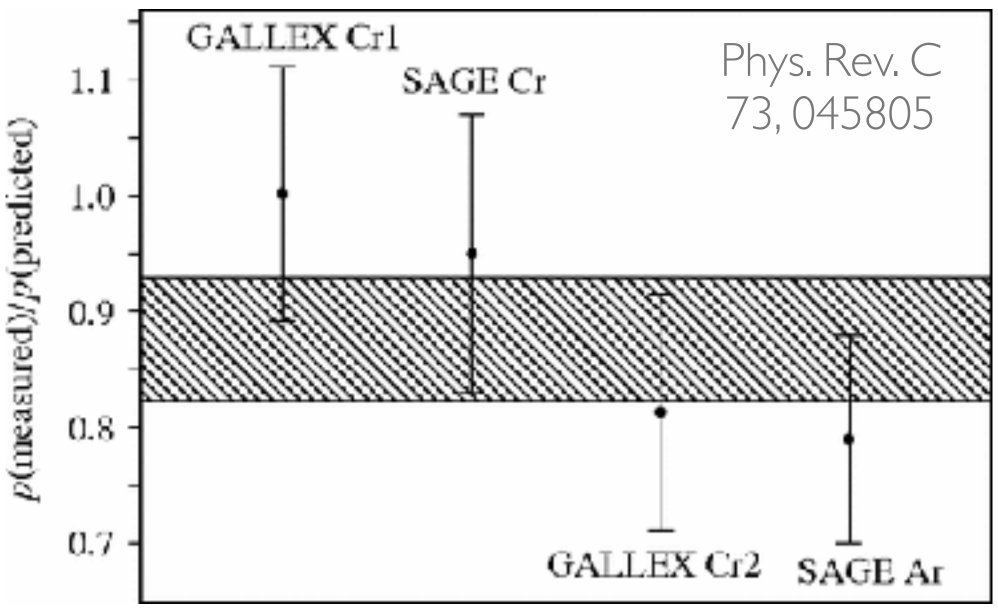
MiniBooNE Anomaly

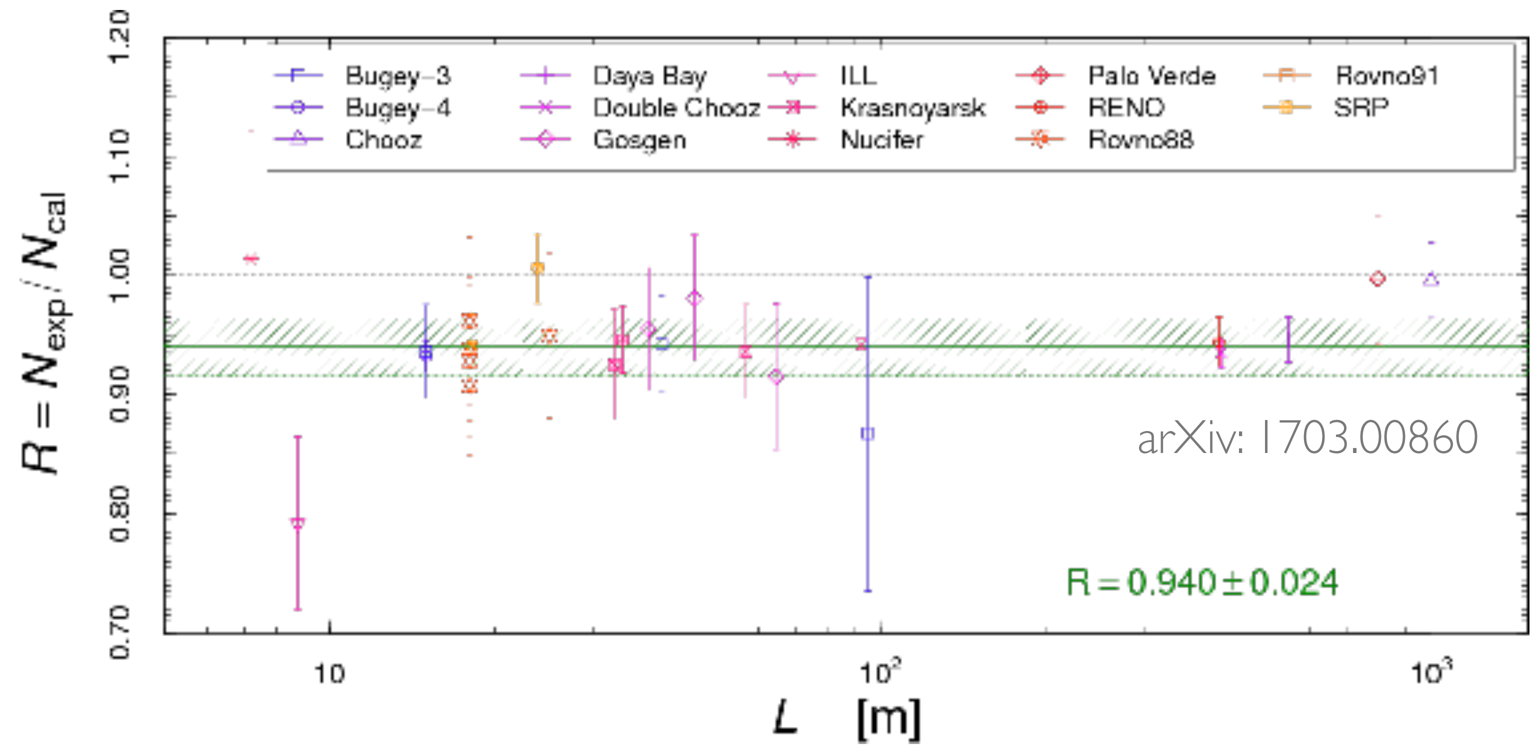
- MicroBooNE: Measure $\nu_\mu \rightarrow \nu_e$ oscillation to address MiniBooNE low energy excess
- MiniBooNE: $\nu_\mu \rightarrow \nu_e$ & $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
  - L/E ~ 1m/MeV
  - Cherenkov detector with mineral oil
    - cannot distinguish between e^- and γ
  - e^-: existence of sterile ν?
  - γ: exotic physics?

Phys. Rev. Lett. 110, 161801



Gallium & Reactor Anomalies

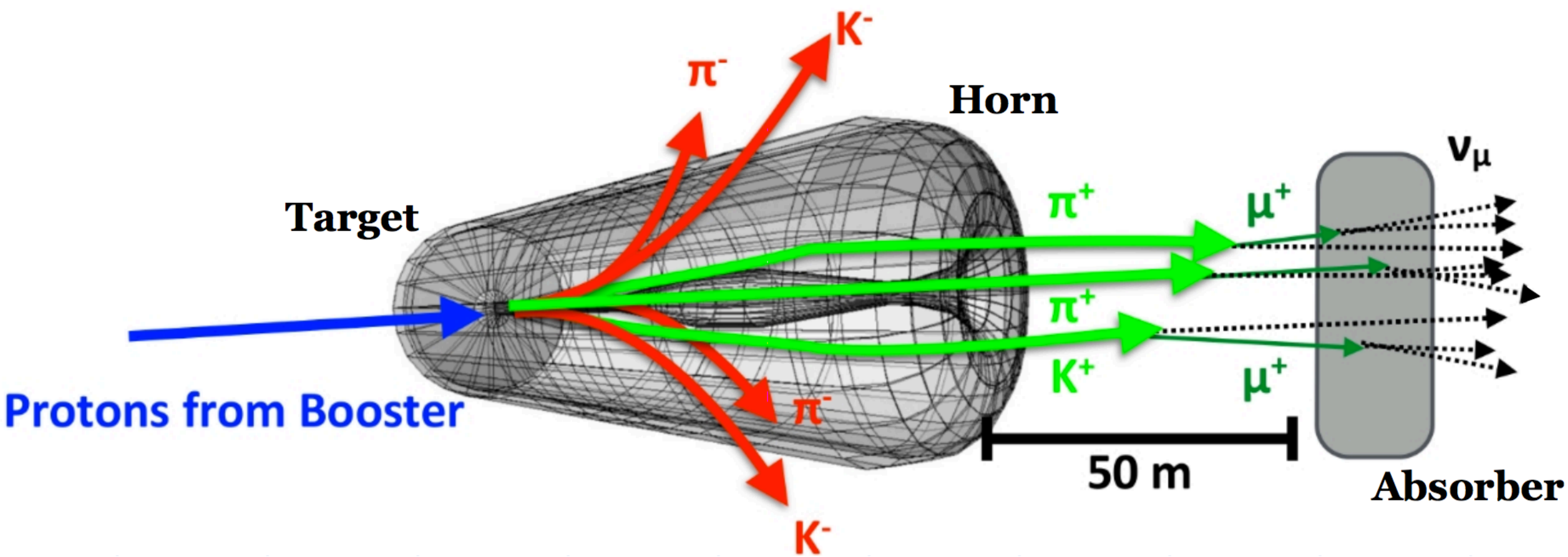




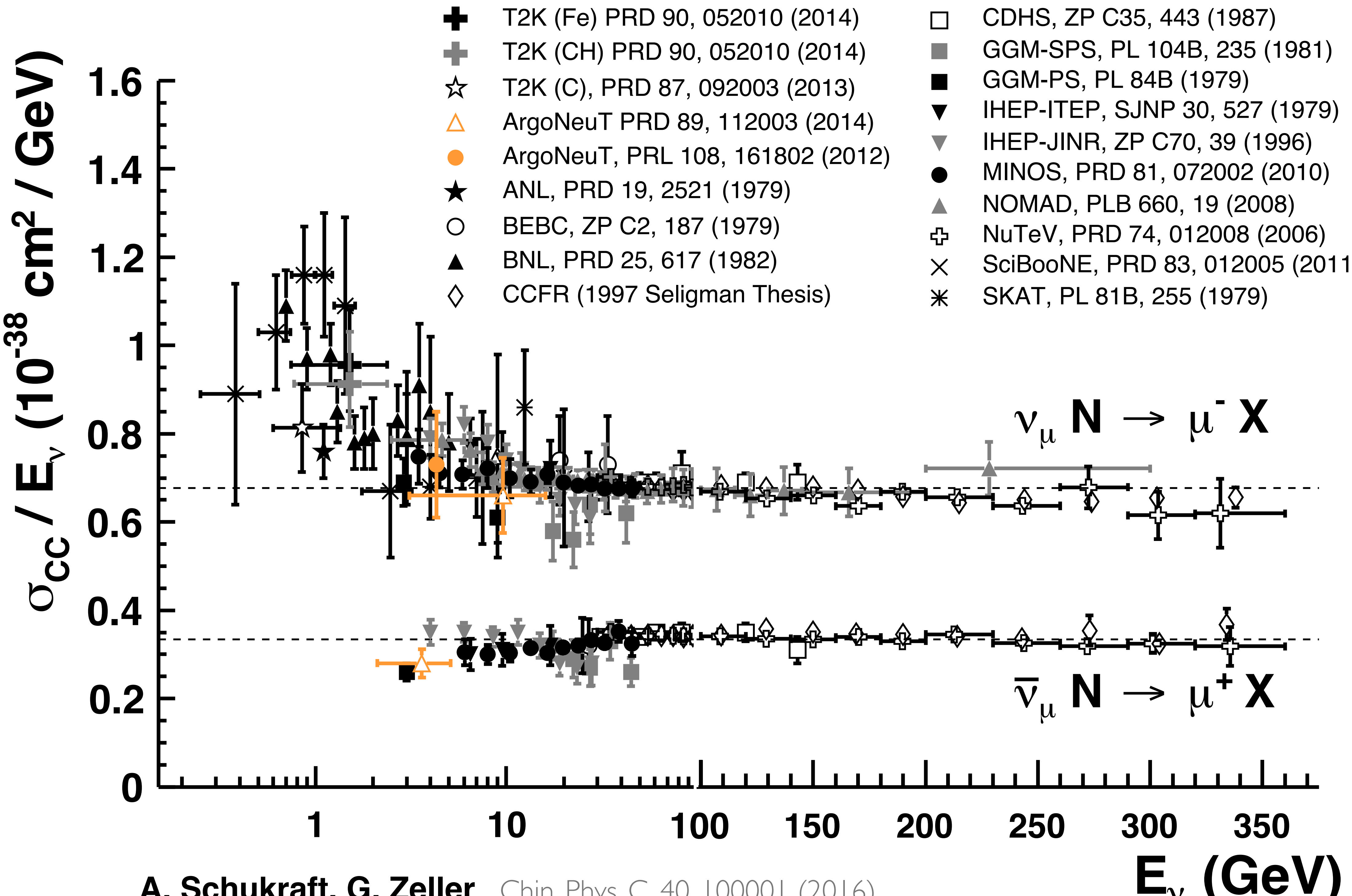
- Measurements of absolute event rates
- Event deficit in Gallium experiments with ν_e sources from radioactive Ar and Cr
- Measured absolute reactor $\overline{\nu}_e$ flux lower than expected

Neutrino Source

- 8 GeV protons from Booster collide with a Be target
- Secondary particles focused by the magnetic horn
- Charged pions, kaons decays into muons and ν_μ
- All decay products absorbed by earth except ν_μ



ν_μ Inclusive Cross Section



A. Schukraft, G. Zeller Chin. Phys. C, 40, 100001 (2016)