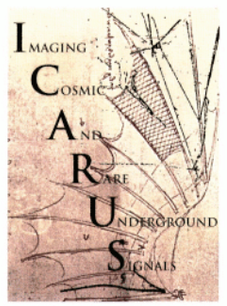
Commissioning, operation, and early result from the light collection system of the ICARUS T600 detector at the Short Baseline Neutrino project

Andrea Scarpelli, *on behalf of ICARUS collaboration*

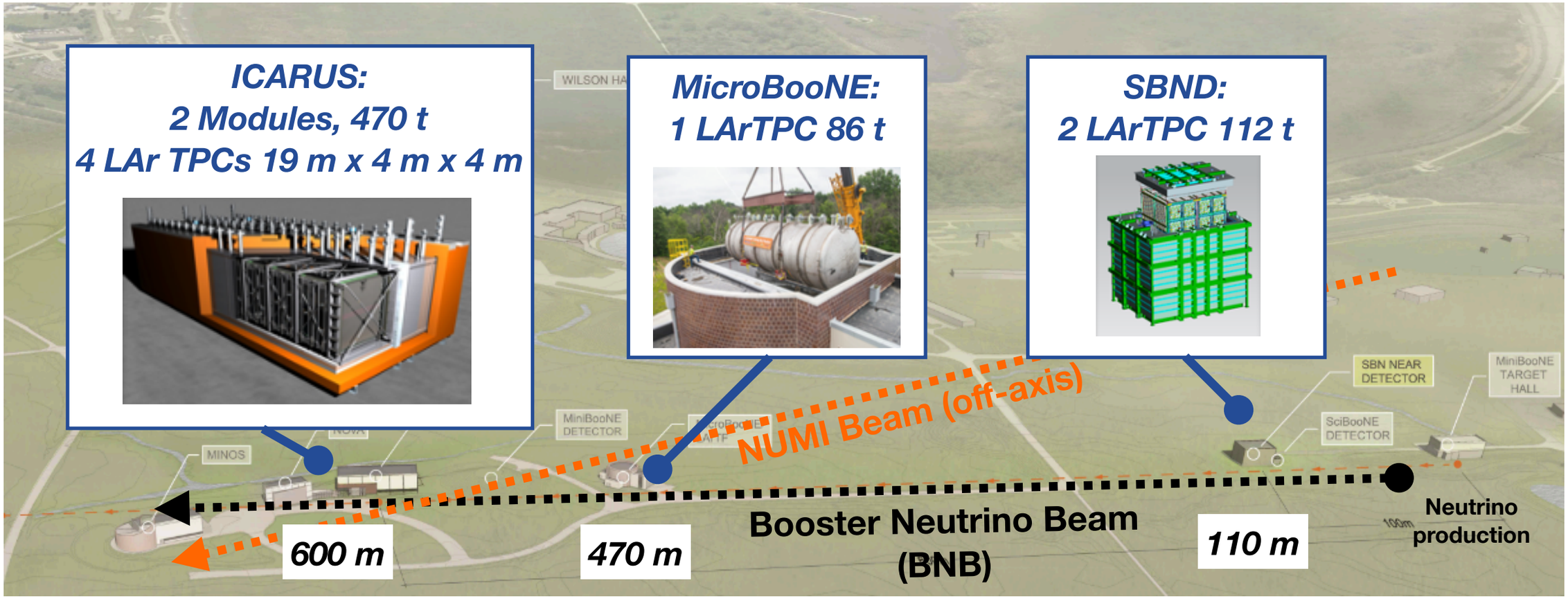
Brookhaven National Laboratory

TIPP2021 26 May 2021



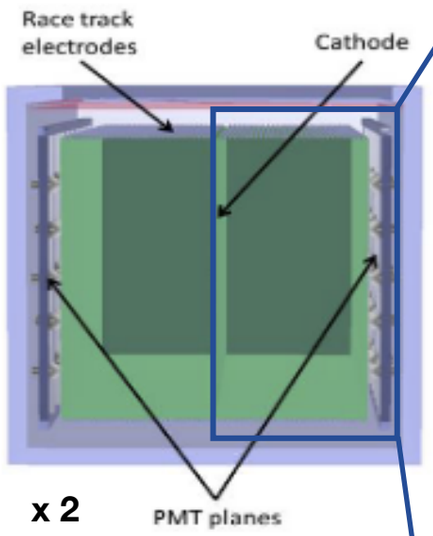
ascarpell@bnl.gov

THE SBN PROJECT @FNAL

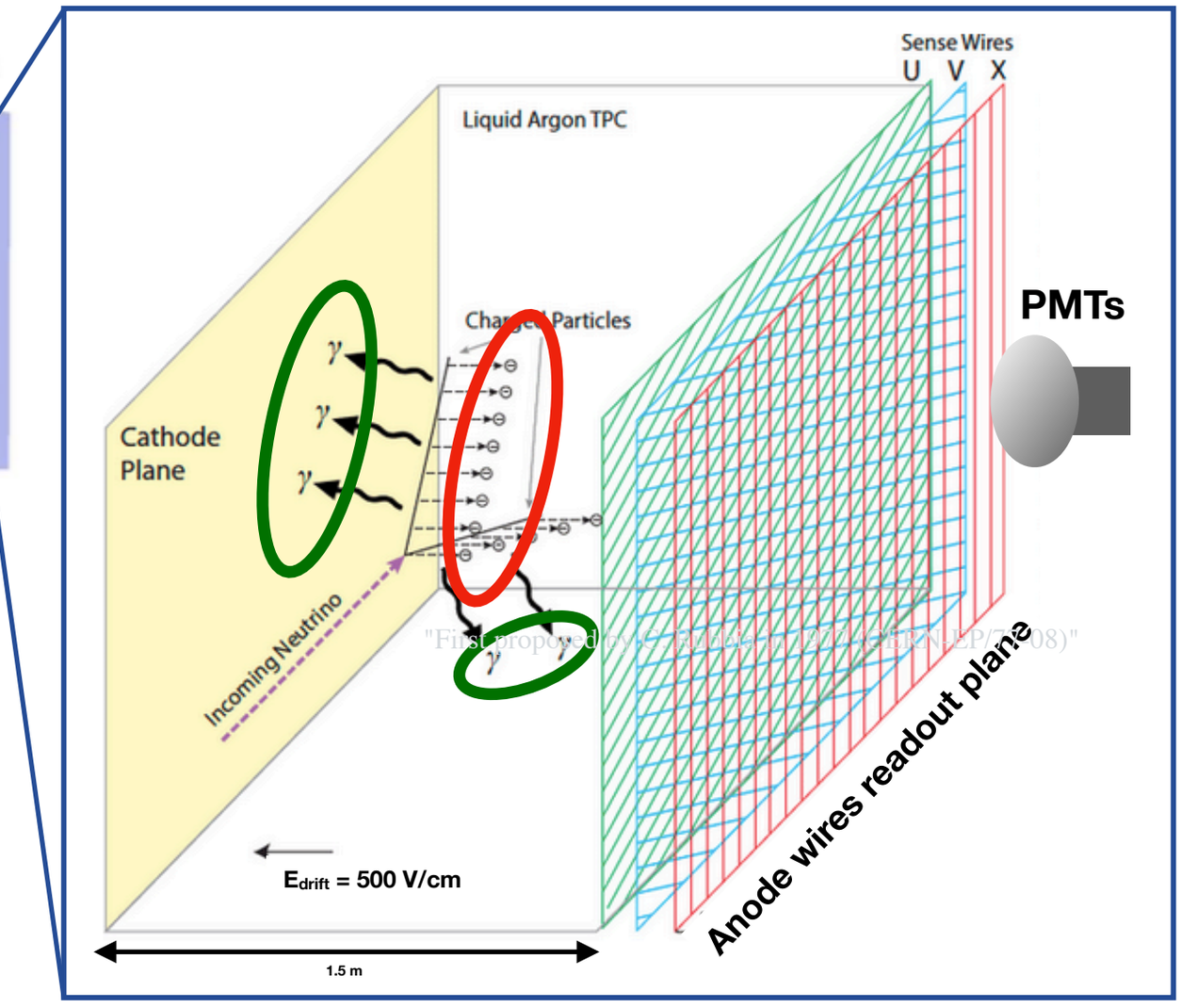


- ***Physics goals***
  - Search for anomalies in the Booster Neutrino Beam (BNB) ν_μ disappearance and ν_e appearance
  - v-Ar cross-section measurements with NUMI off-axis beam, dark matter searches, Neutrino-4 anomaly, …
- ***Detectors: ICARUS + MicroBooNE + SBND along the Booster Neutrino Beamline***
  - All three detectors uses the ***Liquid Argon Time Projection Chamber technology (LArTPC)***

THE LArTPC TECHNOLOGY

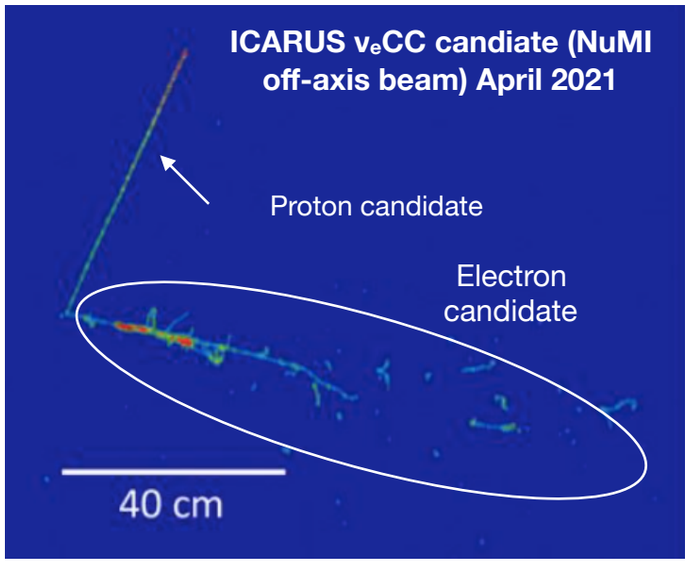


ICARUS LArTPC:
- 2 cryostat modules
- 2 LAr TPC per module
- 90 PMT per TPC = 360 PMTs in total
- 53248 wires ~ 3 mm spacial resolution



"First proposed by C. Rubbia in 1977 (CERN-EP/77-08)"

Electrons from Ar ionization drift **(time ~1m/mm)** to the anode wire readout. Image of the event interaction is created



Scintillation light from de-excitations of Argon ecximers
- Singlet state : **fast light** component (~ **6 ns**)
- Triplet state: **slow light** component (**~1.6 µs**)
- Light yield ~**20k photons /MeV** (@500 V/cm drift)
- Wavelength: 125 nm

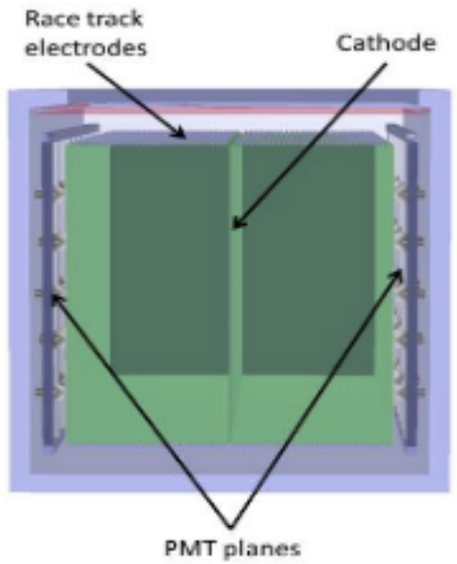
- **SBN Program uses the LArTPC technology for its imaging capability:**
  - Easy topological selection of the different flavor of neutrinos and identification of the sub-products of the interactions with particular attention to the separation between electrons and photons
  - **Early light signal used for timing the charge deposits, online event selection**

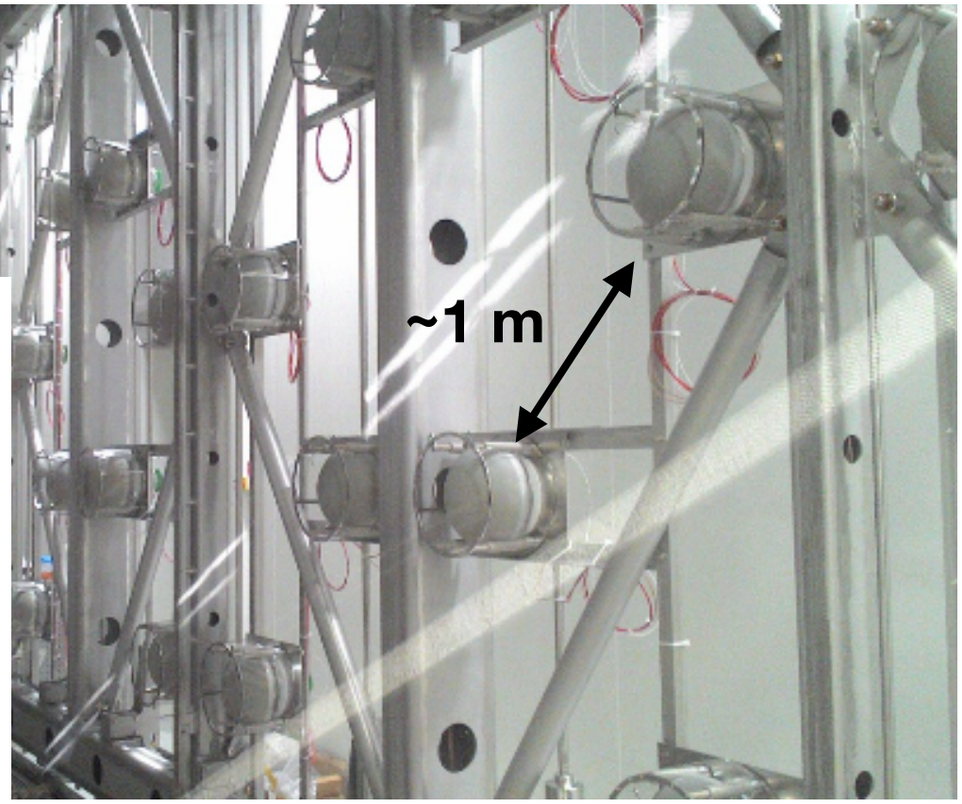
THE PHOTODETECTION SYSTEM

- **Main requirements for the experiment goals**
  - Expected neutrino interaction event threshold ~15 Photoelectrons / MeV - Event localization better than 50 cm
  - Excellent timing resolution (~ns) to proper identify the neutrino events within the beam arrival window

- **360 PMTs 8” HAMAMATSU R5912-MOD Fully characterized at CERN test-stand**
  - Coated by evaporation of 250 µg/cm^2 of Tera-Phenyl-Butadiene (wavelength shifter) *M. Bonesini, et al. JINST 12 P12020 (2018)*
  - Transit Time resolution ~1 ns , Dark rate < 5kHz , 12% uniform Quantum Efficiency *B. Ali-Mohammadzadeh et al 2020 JINST 15 T10007*
  - Stable Gain of 10^7 at 87 *K* to detect down to Single Photoelectrons (SP) light *M. Babicz et al, 2018 JINST 13 P10030*

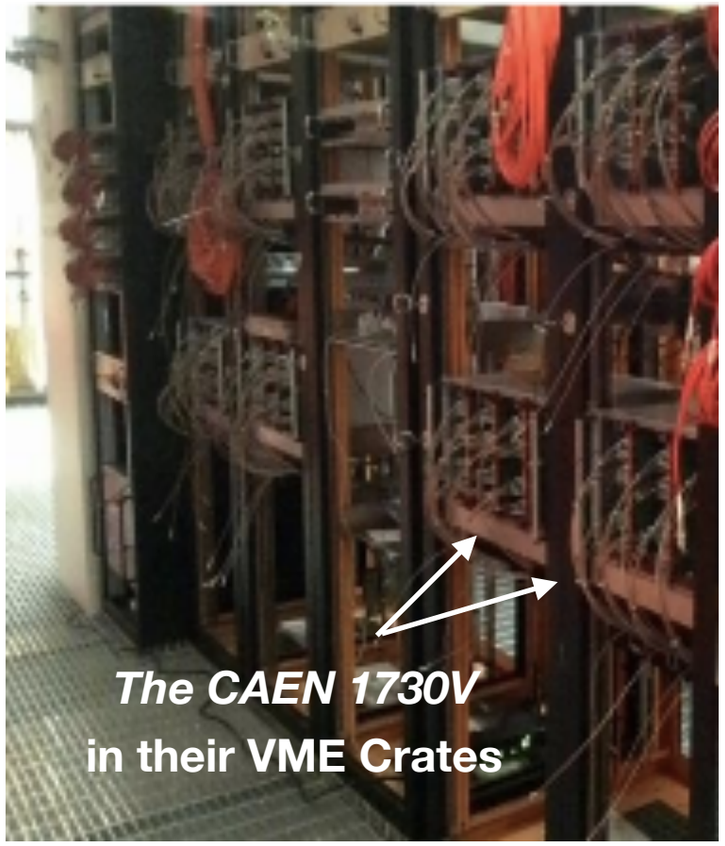
Front facing PMT Planes. 90 per side and 360 in total



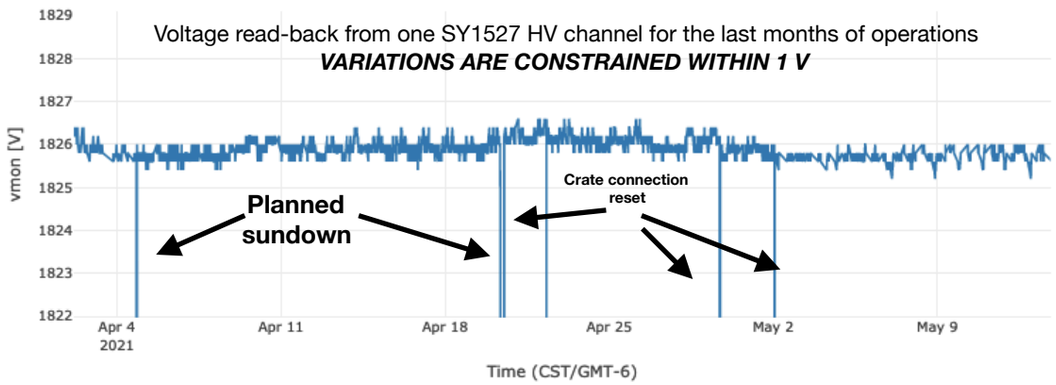


The 8” HAMAMATSU R5912-MOD

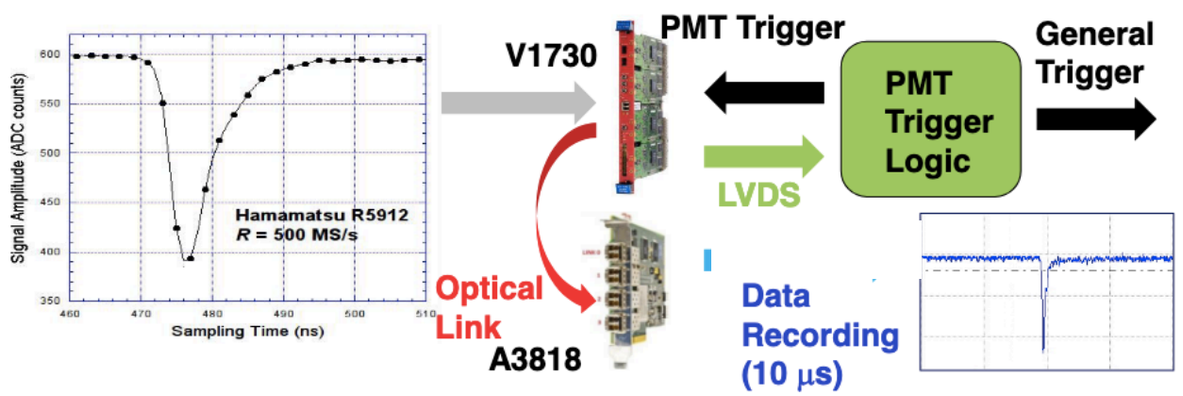
POWER SUPPLY AND DATA ACQUISTION



- **The Power supply system**
  - Primary PS (BERTAN 210-02) **2000 V max** (100 mA)
  - 4 High density distributors (CAEN A1932AN): 45 independent channel (**1 V precision**) distributed the voltage to the 360 PMTs
  - The CAEN SY1527LC crate allows control and monitoring. Included in the ICARUS Slow Control system



- **The data acquisition system**
  - 24 CAENV1730 digitizers x 15 channels each
  - Waveform digitization and read by a Flash ADC, 2Vpp dynamic range, 14-bit resolution and **500 MHz sampling rate (2ns /sample)**
  - Discriminated output pulses are presented in 8 programmable outputs (1 every 2 channels) using *LVDS (Low Voltage Differential Signaling)* standard **used for the ICARUS trigger logic**



TIMELINE OF COMMISSIONING @FNAL

First lockdown

BNB Activated

FY 2018-2019

Winter 2020

Spring 2020

Summer 2020

Fall 2020

Winter 2021

Spring 2021

Test stand @CERN and installation @ FNAL

Detector Filling and cooling down

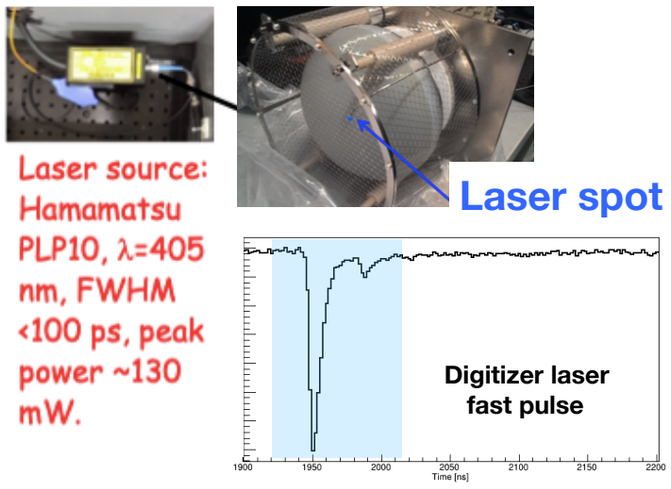
Noise stability

Begin of operation at cold TPC and PMT High Voltage commissioning

PMT calibration at cold

Trigger commissioning

CALIBRATION AT COLD

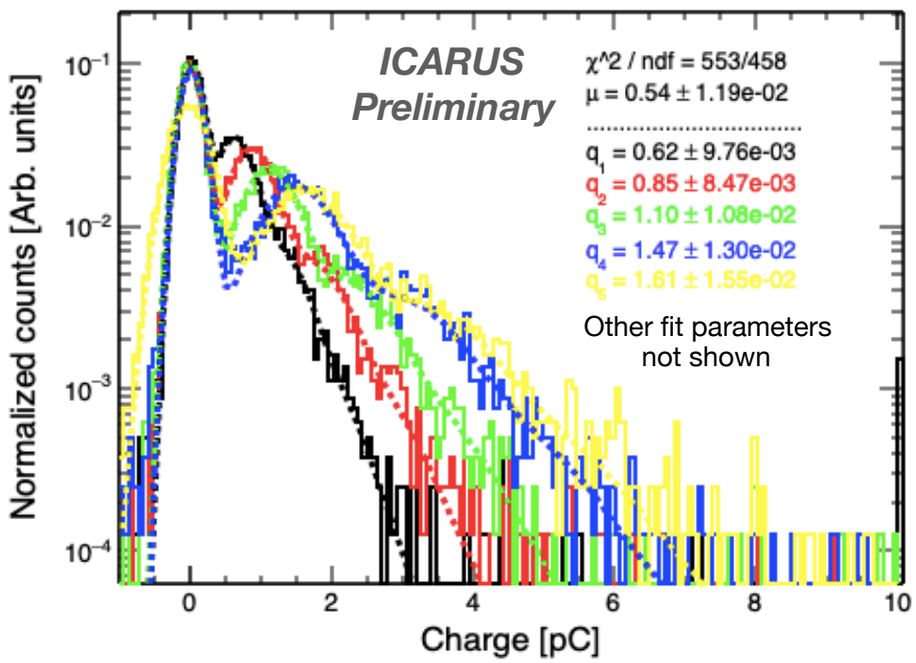


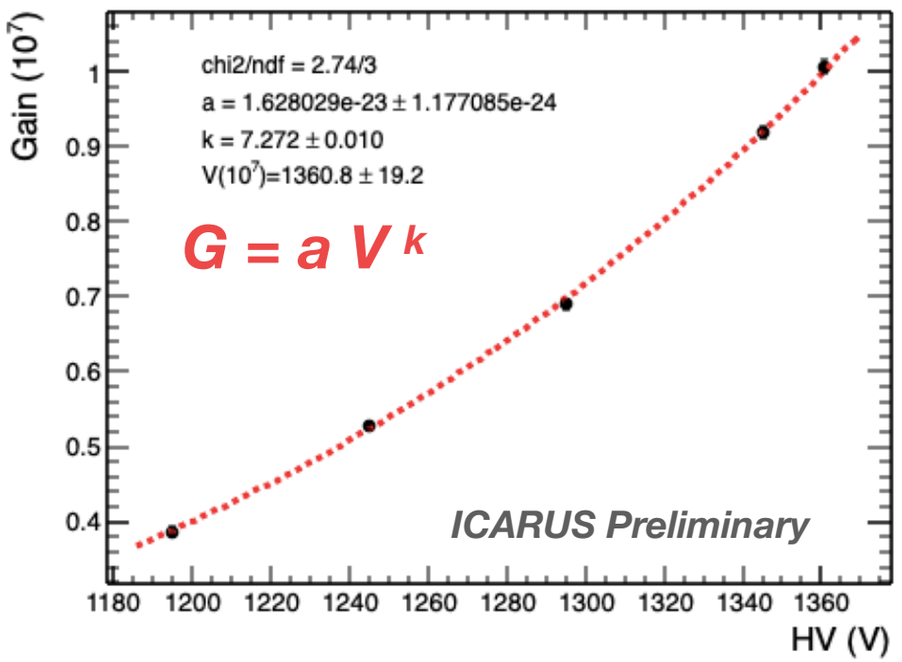
- **Calibration in situ done using an external fast (~ns) laser pulser** flashed on each pmt by dedicated optical fibers
- Charge integrated in a 100 ns window timed with the laser pulse. Expected 0.005 dark rate pulses per event
- **The PMT Response function is fitted simultaneously for 5 different voltage values** to constrain μ (mean number of photoelectron, fixed per PMT). *Laser fluctuations: 5:1000 for > 4 hours*

Pedestal modeled using an ExpNormal function:
Due to the low dark rate expected the noise is considered decoupled from the "signal" part

$$S_i(x) = a_0 E_N(x, q_0, \sigma_0, \tau_0) + a_i \sum_{n=1}^{100} \frac{1}{\sqrt{2\pi n \sigma_i}} \frac{\mu^n e^{-\mu}}{n!} \exp\left(\frac{-(x - q_i n)^2)}{2n\sigma_i^2}\right)$$

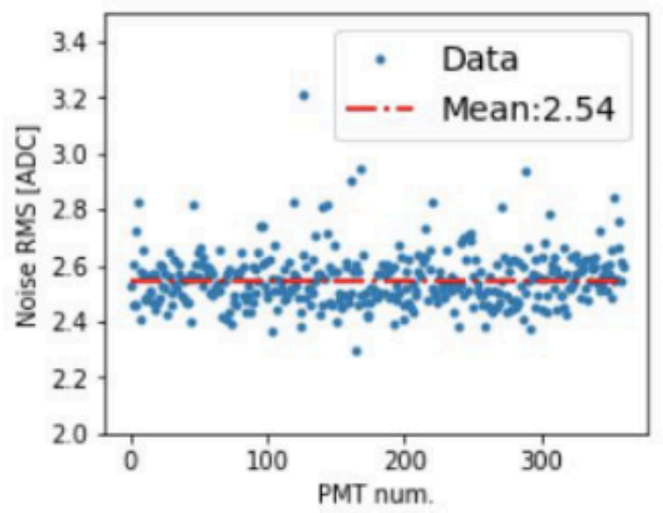
- E. H. Bellamy NIM A399 (1994) 468-476
- M.V. Diwan 2020 JINST 15 PO2001



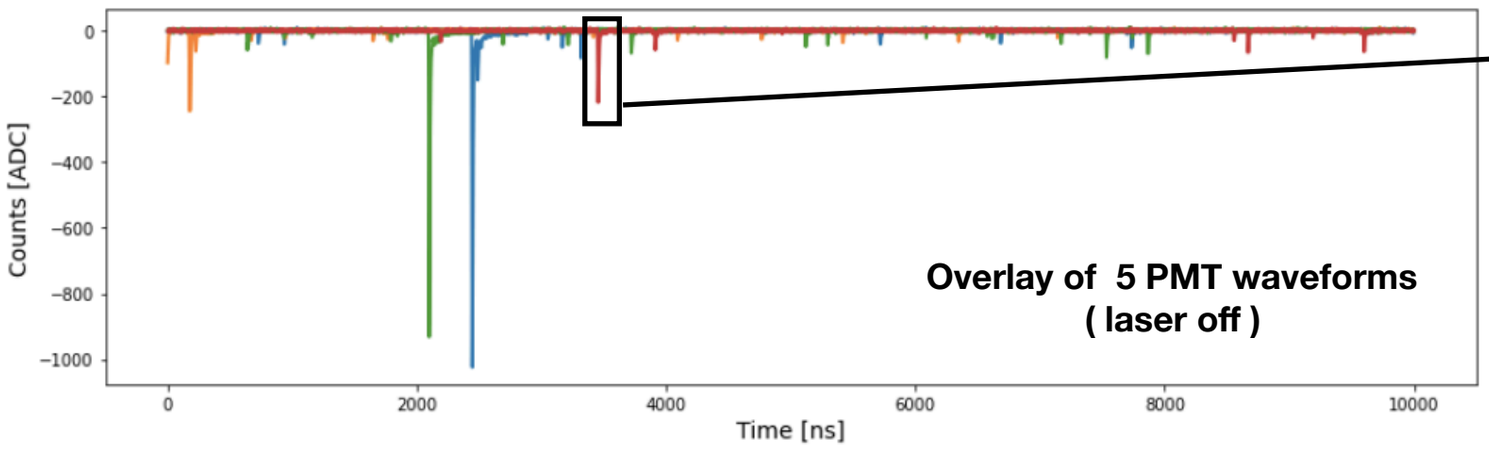


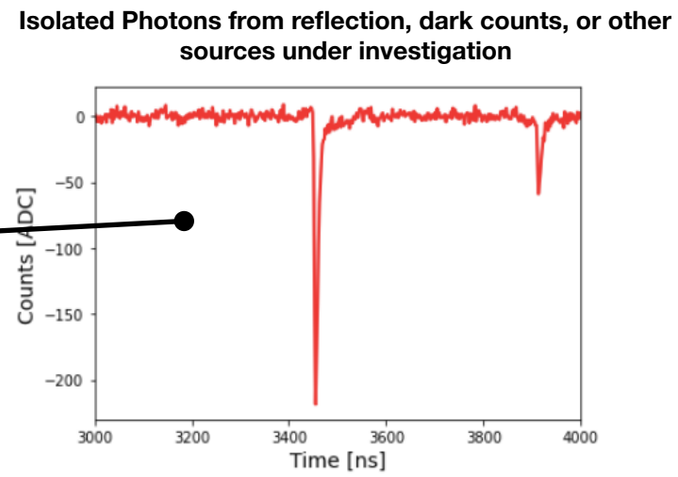
- Phototubes equalized to the value of **G=10⁷** using the ***Power Law*** fitted from the 5 gains as function of the applied voltage

NOISE AND EQUALIZATION OF THE PMTs

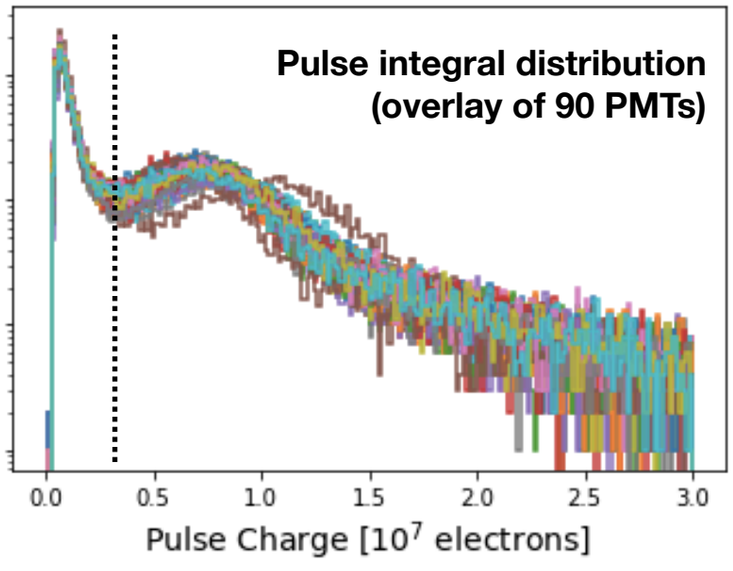


- Electronic noise has been measured at cold and room temperature. Uniform on all channels. Expected S/N with PMT at G=10^7 is **20 for a single photoelectron (SP)**
- *Isolated* photons activity is present normally in large quantity



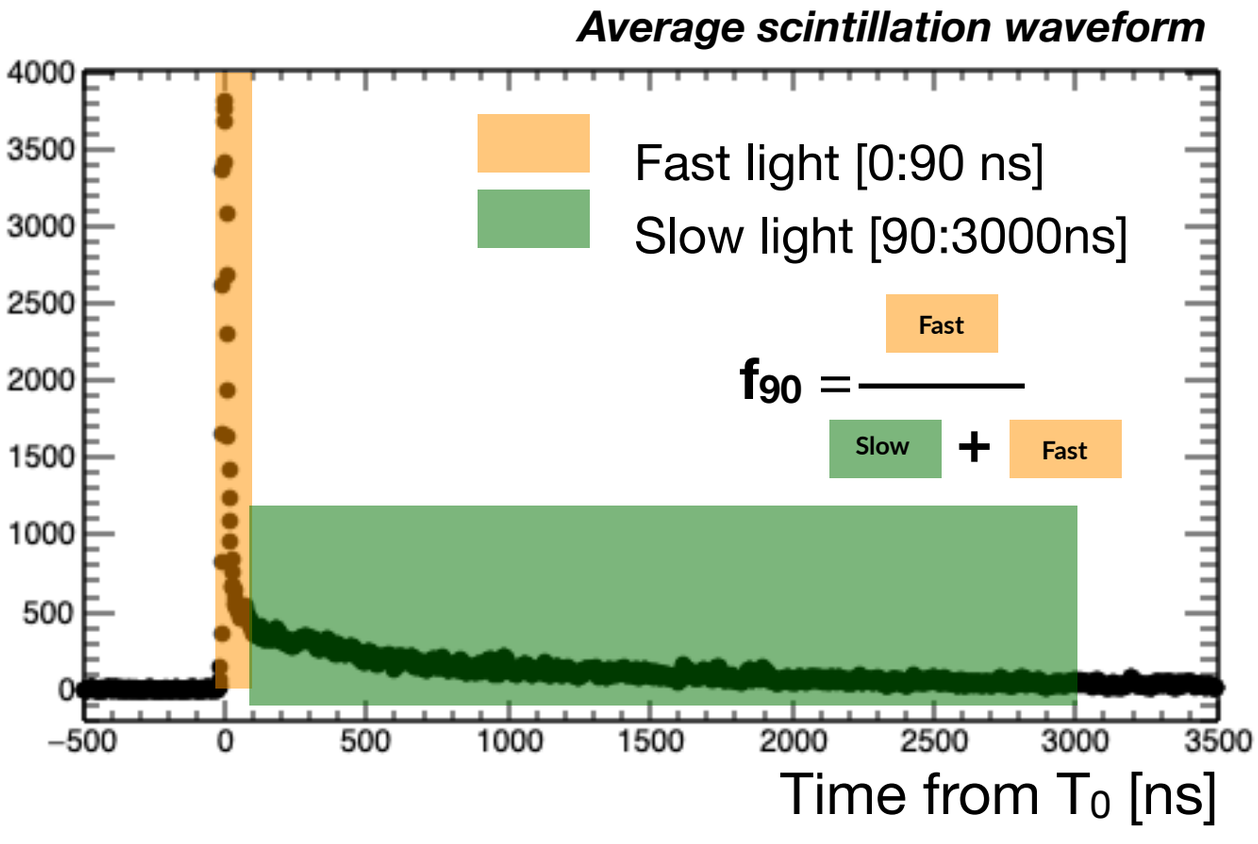


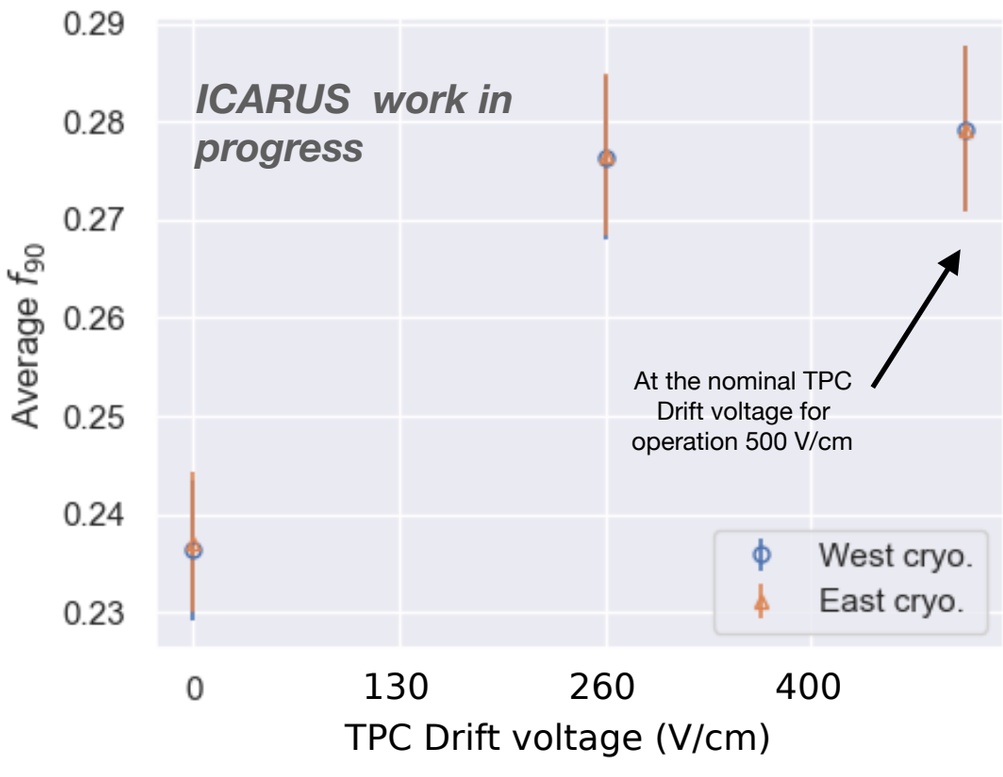
- Use isolated photoelectron pulses to probe the PMT system status and confirm the relative PMT response equalization
- May be done without the necessity of dedicated downtime (as happens for the laser)



EARLY STUDIES OF SCINTILLATION LIGHT

- **Argon scintillation profile has been observed**
  - Both **fast (τ ~ 6 ns)** and **slow (τ ~ 1.6 μs)** light components are visible from the two de-excitation times of argon excimers
  - Study of a sample of cosmics at reduced drift voltage collected during commissioning seems to indicate a variation of the light profile similar to what observed by other experiment (B. Aimard *et al* 2021 *JINST* **16** P03007), which is not yet entirely understood. This requires more work and in particular a better control of the level of impurity of Argon.

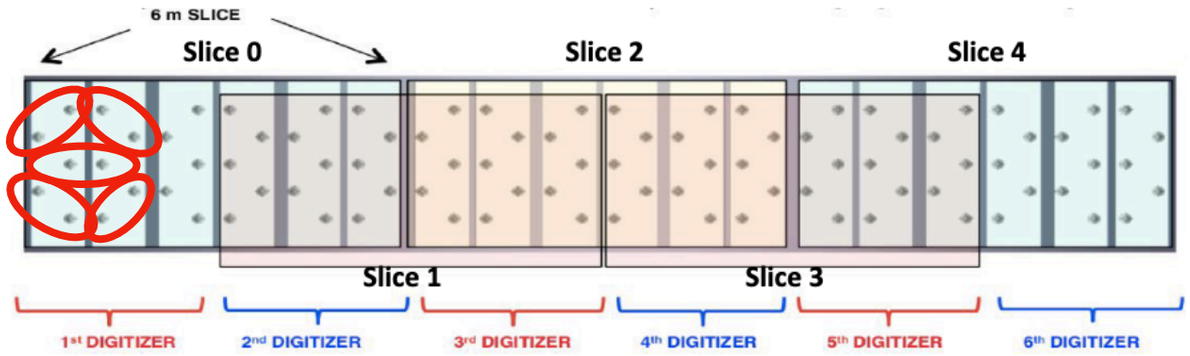


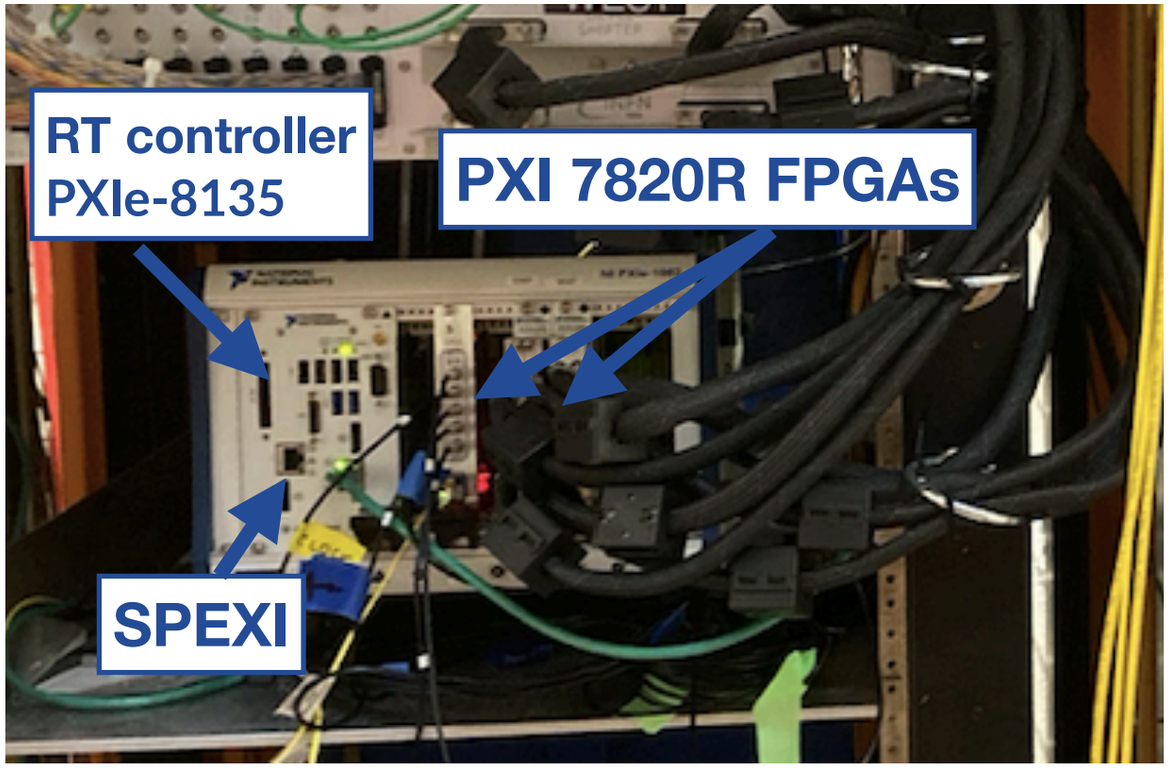


- **Quite limited sample at reduced TPC drift voltage due to the commissioning schedule, studies may be enriched during the detector summer shutdown**

THE TRIGGER SYSTEM

- **The prompt scintillation light from physical events is used for the trigger system of ICARUS**
  - Beam extraction signals at 5 Hz (BNB) and 0.7 Hz (NUMI), but **total physical events rate ~0.27 Hz**
  - **0.17 Hz are in-time cosmic rays and 0.08 Hz from beam neutrino**

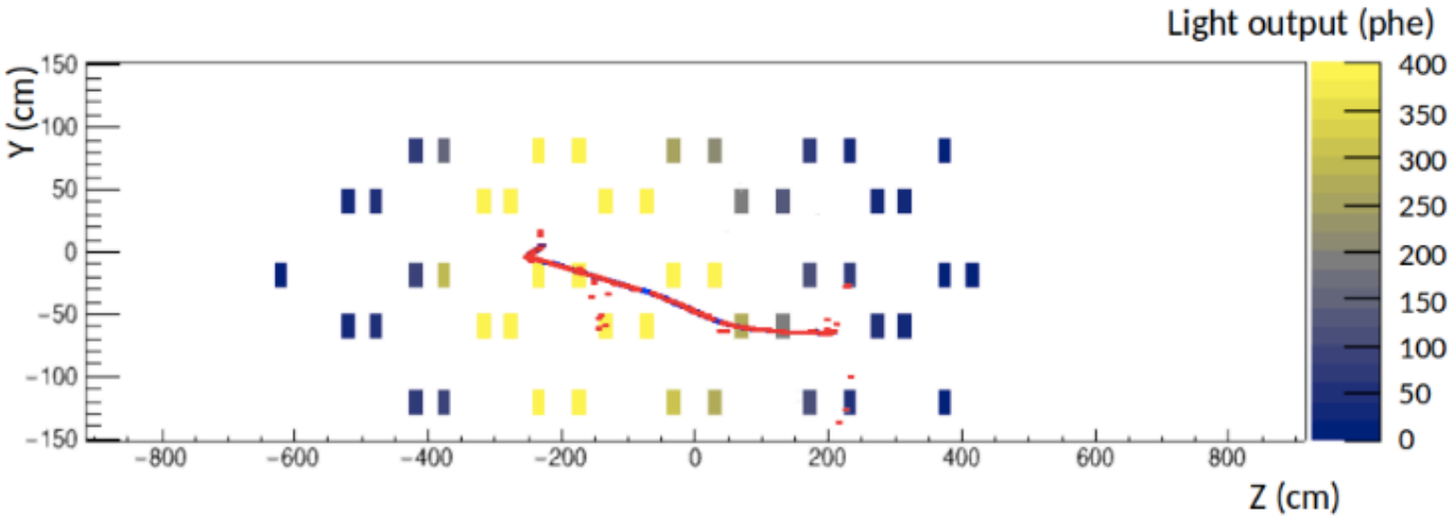


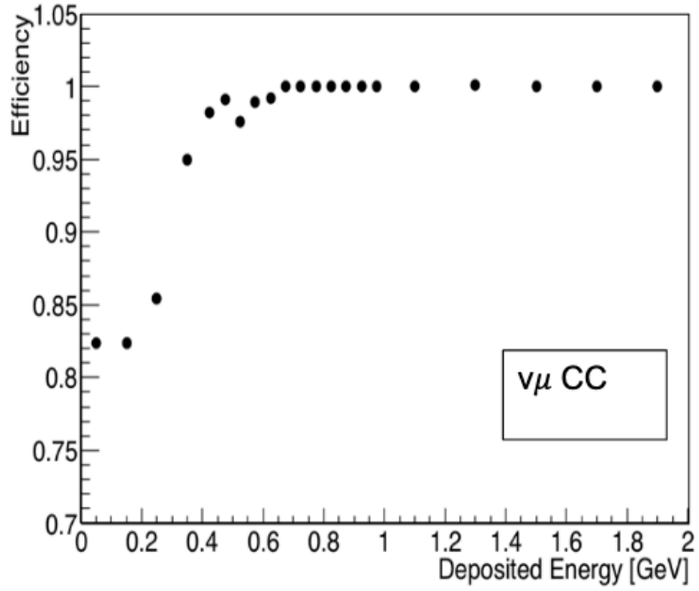


- **The trigger is designed to maximize the capture of localized light activity in coincidence with the beam spill window time**
  - Trigger logic based on combinations of PMT LVDS pairs over a certain threshold
  - The trigger system use the NI-PXIe instrumentation with FPGAs to customize different settings and logics
  - Precision information of the beam extraction timing are transmitted to the system through a *White Rabbit network* with sub-ns accuracy synchronization

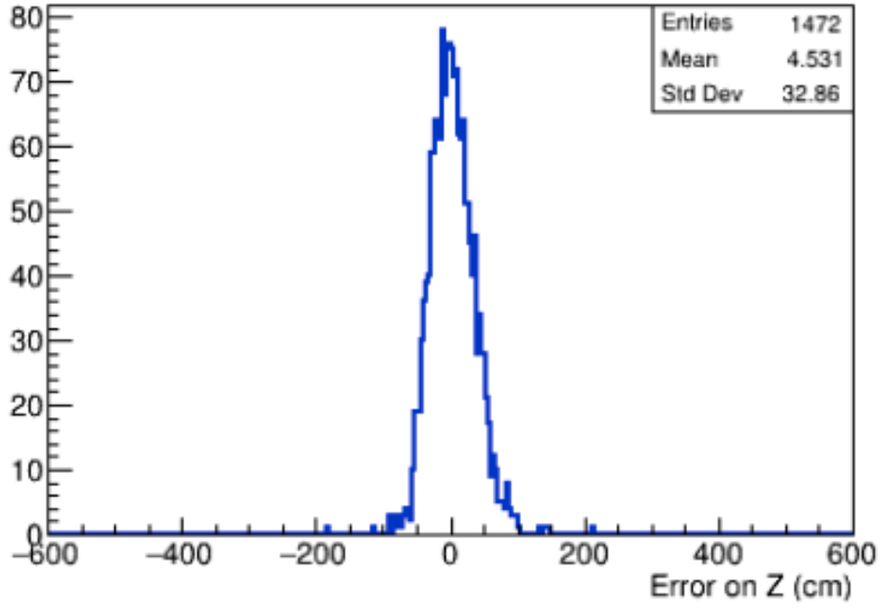
TRIGGER: MONTECARLO STUDIES

- **Efficiency studies implementing different combination of threshold discriminations and local PMT trigger logics are carried out with a detailed Monte Carlo simulation**
  - Studies to be refined with data-driven inputs





- **Optimization of the light reconstruction and identification of the vertex of the neutrino candidates is also in progress**
  - Preliminary simulation studies suggest vertex resolution ~ 30 cm to be confirmed also with data



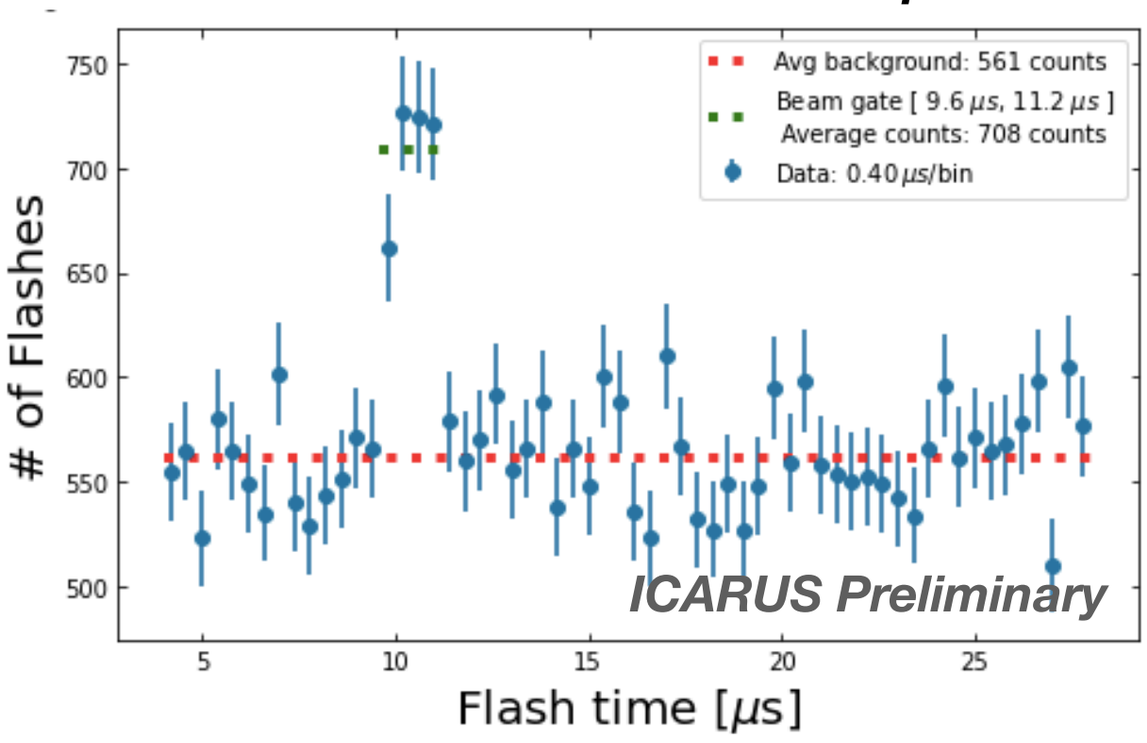
- B. Ali-Mohammadzadeh et al JINST 15 (2020) 10, T10007

BEAM SPILLS IDENTIFICATION

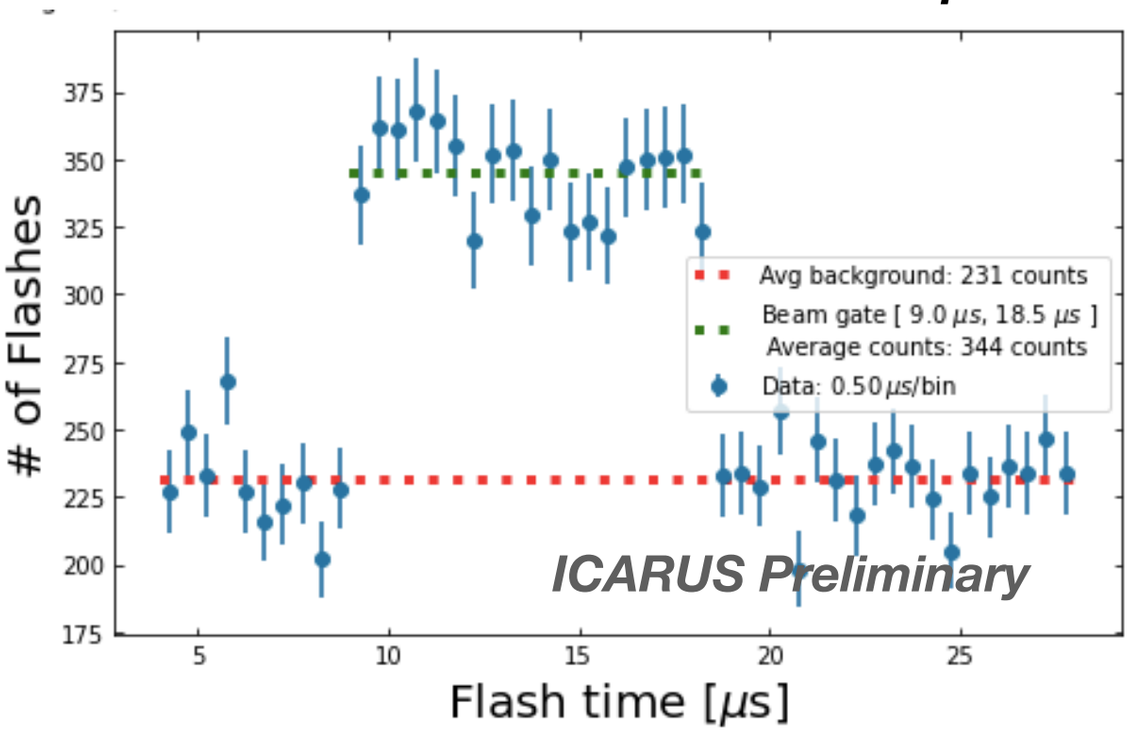
- **Example of a trigger commissioning exercise: identify timed light activity in coincidence with the beam extraction signals**

  - Offline selection: Flashes are defined as the 100 ns coincidence between pulses on 3 PMTs with more than 10 PE. Only events with flashes with 10 PMTs for two front-facing walls are kept

BNB SPILL WINDOW 1.6 μs



NuMI SPILL WINDOW 9.5 μs



- **Background represented by cosmic activity. The excess of flashes is timed and compatible with the presence of neutrinos from the beam spill window**

SUMMARY AND OUTLOOK

- **The photodetector system is a fundamental part of the LArTPC technology allowing the precise timing and interpretation of a TPC event**
- **The ICARUS photodetection system is fully commissioned and in good shape:**
  - The characterization of the PMTs in a test and and in-situ has terminated
  - The calibration of the system is completed and stability proven
  - Supports the Trigger commissioning activities
- **Outlook**
  - The final timing resolution of the system is targeting a *ns* resolution. This aspect is currently under study
  - Analysis of the scintillation light from both cosmic and neutrino interaction is in progress to provide data-driven inputs to the detailed Monte Carlo simulation and trigger efficiency studies
  - ***ICARUS is planning to start physics data collection as early as September!***

Thank you!