IMAGING COSMIC AND RARE UNDERGROUND SIGNALS

Data vs. MC comparison of light signal from cosmic rays in the ICARUS detectors

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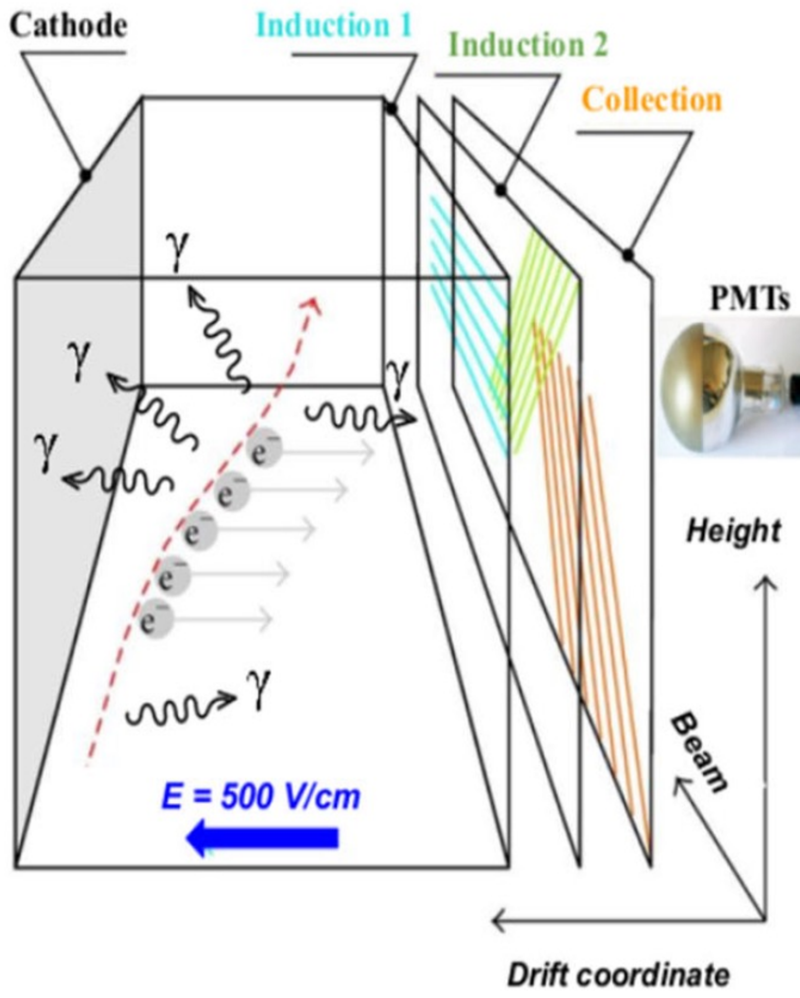
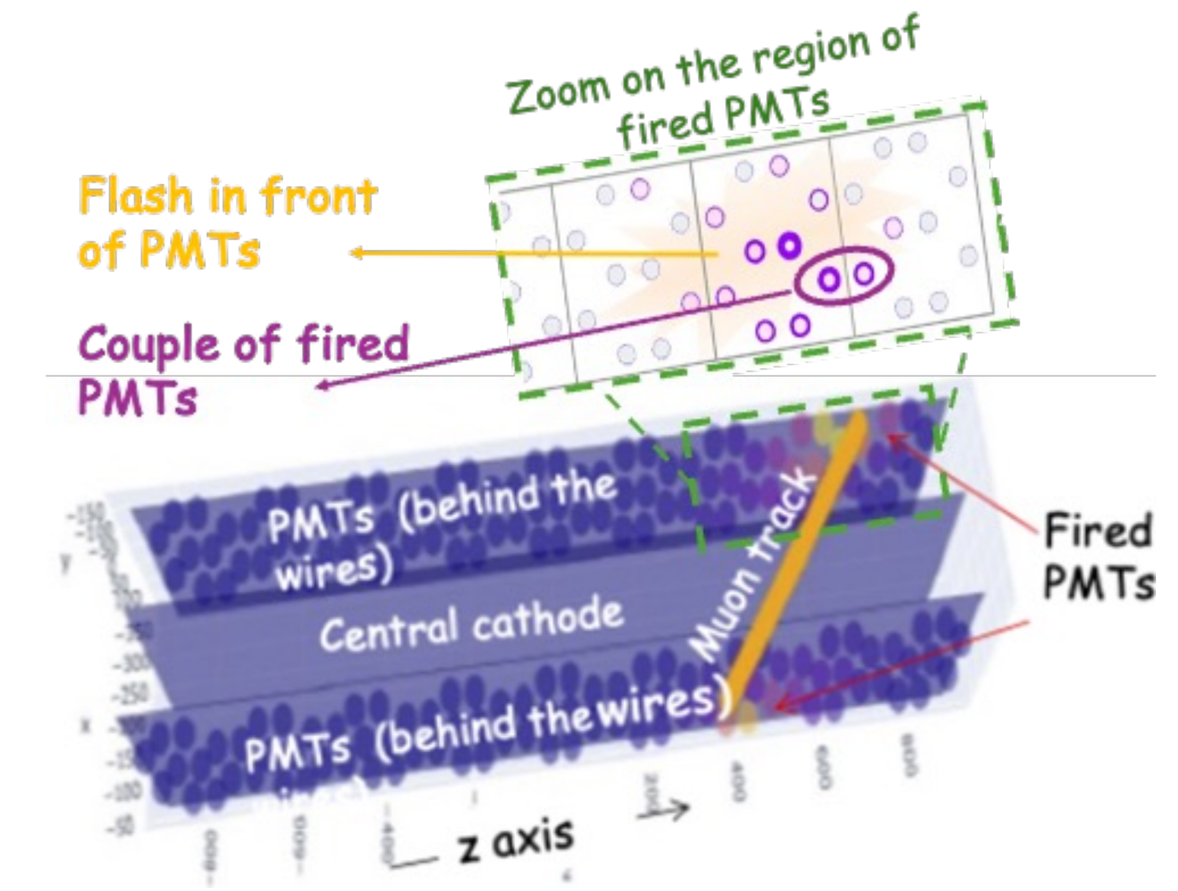


Schematic view of the ICARUS-T600 readout principle, shown for one TPC§

The ICARUS PMTs mounted behind the wires of one TPC§



The PMTs associated with a cosmic ray muon crossing the cathode §

1 – The ICARUS detectors system

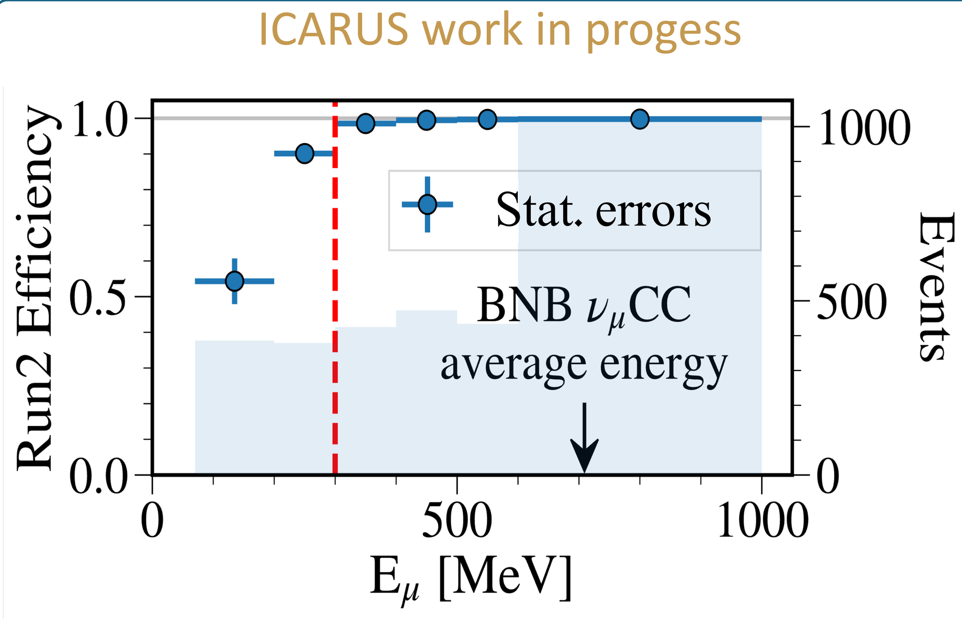
ICARUS§,* is collecting data exposed to BNB and Numi off-axis beam within the SBN program at Fermilab; due to its operations at shallow depths, it is also exposed to a huge flux of cosmic rays, which is exploited for detectors calibration. It is composed of two identical cryostats, surronded by the Cosmic Ray Taggers (~95% efficiency tagging cosmics rays).

In each cryostat two Liquid Argon TPC with a common cathode are placed. The electrons ionized in TPC are continuosly detected by 3 non-destructive readout planes with different orientation (0º, ±60º).

1.1 – Scintillation light detection system

Behind the wires plane, 90 PMTs per TPC (5% coverage, 15 ph.e./MeV) provide the scintillation detection system §,† to detect vacuum ultraviolet photons produced by ionizing particles in LAr and allowing to:

- identify the interaction time (*time resolution ~ns*).
- Localize events in PMT plane (*spatial resolution <50cm*).
- Roughly determine the event topologies.
- Generate a trigger signal:
  - ICARUS main trigger signal✦ = light signals from PMTs in coincidence with beam spills.
    - Beam events are collected requiring at least 5 fired PMT pairs (Mj = 5) inside one of 6 m longitudinal slices equipped with 30+30 opposite PMTs.
  - MinBias : minimum-bias triggers with out requesting scintillation light a priori; the timing is provided by CRT. It provide the sample for trigger efficiency study: the trigger is emulated starting from recorded PMT waveforms, and the logic is evaluated for each stopping muon.



The trigger efficiency as function of muon energy for a highly-pure sample of stopping cosmic muons (MinBias data from Run2) selected based on topology and calorimetry (Bragg peak). Courtesy of Riccardo Triozzi.

2 – MC simulation of the light signal

The *simulation of the scintillation photons* are generated with a Monte Carlo✦: (i) photons are generated based on energy deposition and particle type, and (ii) are propagated through the liquid argon; (iii) all their information are stored; (iv) photon by photon, the sigle photon response is added. (v) The simulated noise is added to the waveforms. (vi) If the signal exceed a threshold (~0.6 ph.e.) on a channel, the waveform is recorded in a 4μs time window.

3 – Preliminary study of light signal: comparison data vs. MC

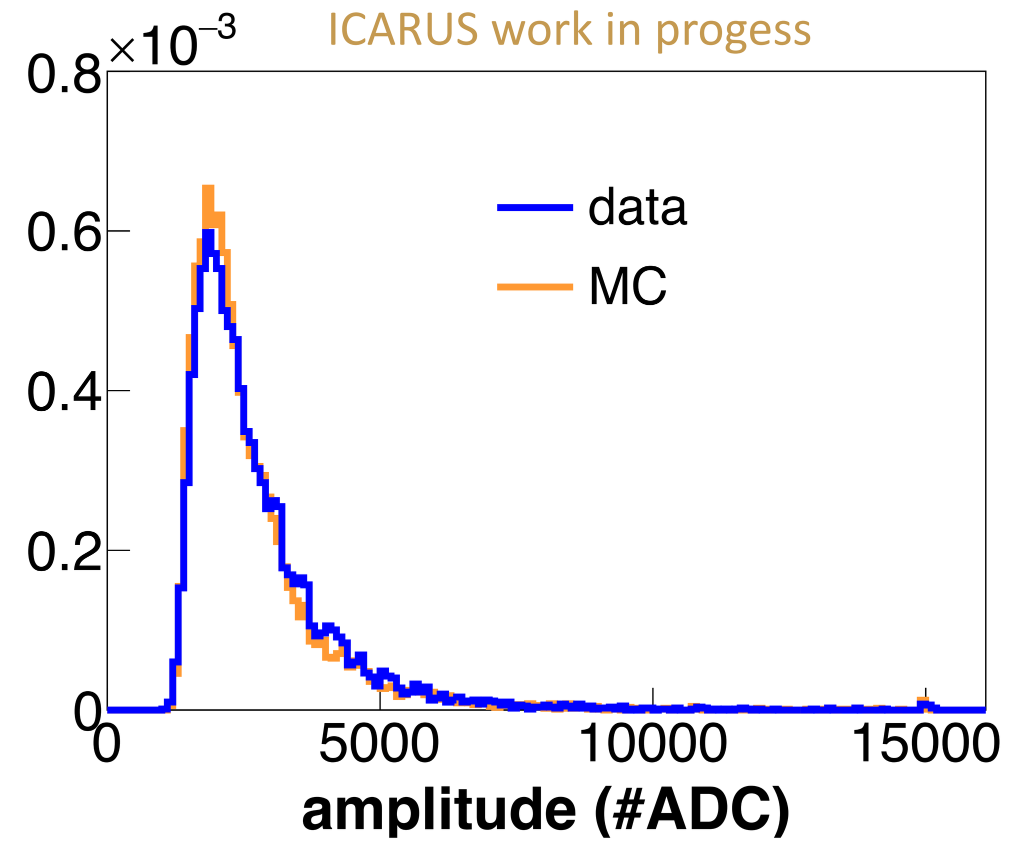
The MC simulation has been data-based optimized tuning the simulation's parameters related to the gain and to the quantum efficiency. The data sample is a run of about 15 k-events from the Run2 collected with BNB-majority.

3.1 - Samples' selections: the brighest light signal in coincidence with cathode crossing vertical tracks

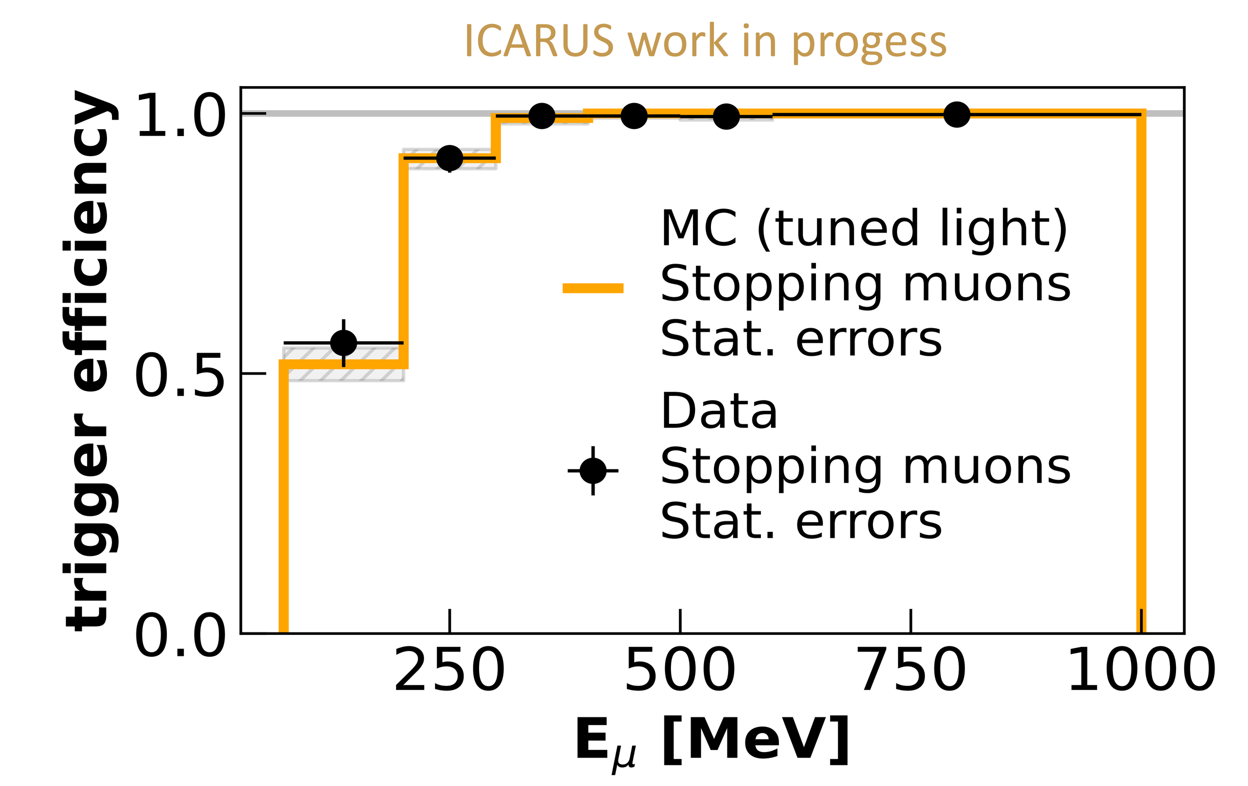
1. The cathode crossing vertical tracks were selected → sample completely under control in time and position;
2. Only the first flash (i.e. collection of light signals in the time window of 40ns in at least 5 PMT) in coincidence (in time and in spatial barycenter along beam direction) with selected tracks was consider;
3. the first optical hits (i.e. light signal) looking along the time for each PMT are recognized
4. the 10 with the highest amplitude are selected: brightest signals.

3.2 – Good agreement between data and MC amplitude

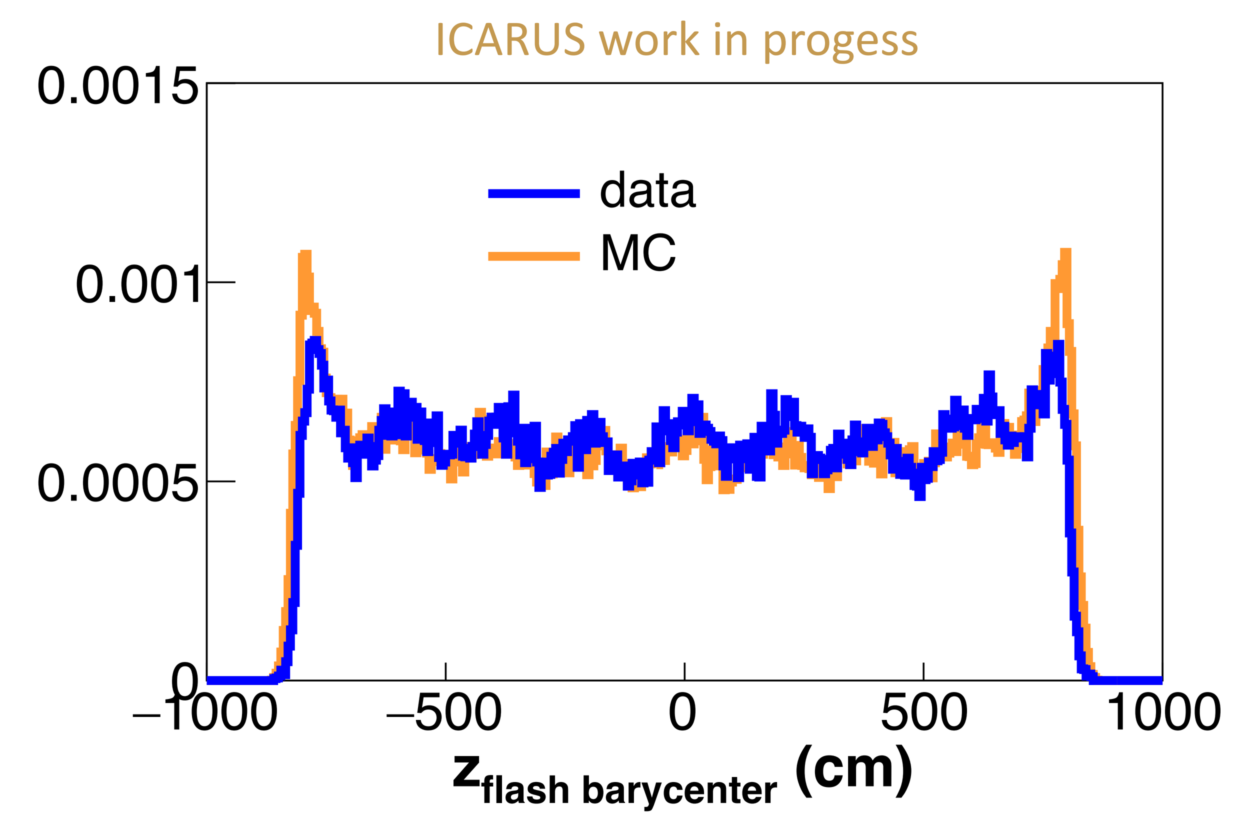
The tuned MC well reproduce the data amplitude of the brightest light signals.



Comparison of data vs. MC amplitude of the brightest light signals.



Comparison of trigger efficiencies (data vs. MC) for single tracks with majority 5 (Mj=5). Courtesy of Riccardo Triozzi.



Comparison of data vs. MC light barycentre along the beam direction.

4.1 – Validation of the trigger efficiency.

The data trigger efficiency (Mj=5) for single track is well matched using data-based tuning of the MC parameters.

4.2 – Validation of the light position

The data flash barycentre along the beam direction is quite well reproduced by MC one. It is important in the analysis ✿ to select the track-flash match (and assign a time to non-cathde-crossing tracks).

References:

§ P. Abratenko *et al.*, *ICARUS at the Fermilab Short-Baseline Neutrino program: initial operation.* EPJ C 83, 467 (2023).

† B. Ali-Mohammadzadeh et al., *Design and implementation of the new scintillation light detection systemofICARUST600.* Jol 15, T10007 (2020).

✦ C. Farnese *et al.*, *Implementation of the trigger system of the ICARUS-T600 detector at Fermilab.* NIM A 1045, 167498 (2023).

✦ E. Snider and G.Petrillo, *LArSoft: toolkit for simulation, reconstruction and analysis of liquid argon TPC neutrino detectors.* JoP Conf. Series 898, 042057 (2017). S. Agostinelli *et al.*, NIM A 506, 250 (2003). C. Andreopoulos *et al.*, NIM A 614, 87 (2010). C. Andreopoulos *et al.*, preprintarXiv:1510.05494 (2015).

For more details:

* *ICARUS at the Short-Baseline Neutrino program: first results* D. Gibin **plenary talk**.

✿ *Neutrino reconstruction analysis at ICARUS detector* M. Artero Pons **poster #51**.