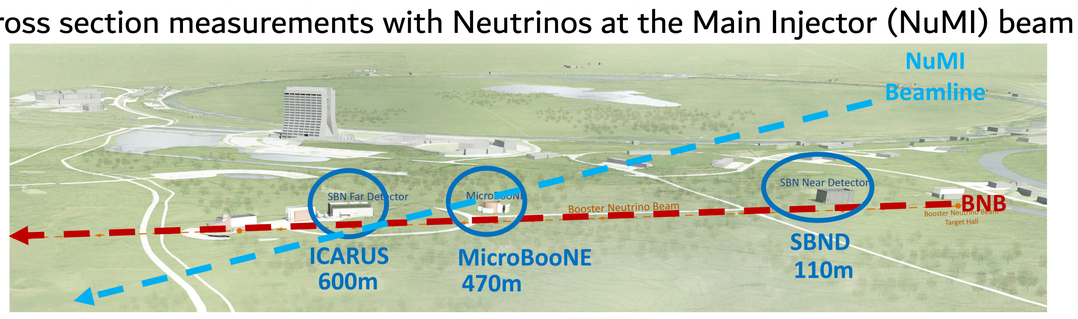
Enhancing Neutrino Event Simulation through Overlays at the ICARUS Experiment on the Short-Baseline Neutrino Program

Ivan Caro Terrazas, on behalf of the ICARUS Collaboration
icaro@colostate.edu
Neutrino 2024 – Poster #433
COLORADO STATE UNIVERSITY

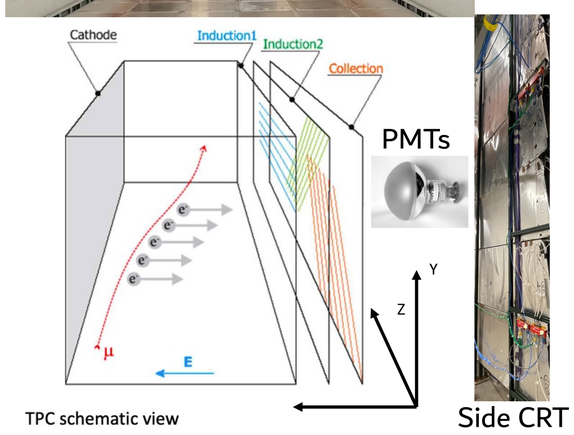
1. Short Baseline Neutrino Program in a Nutshell

- Three detectors on the same beamline to investigate short-baseline anomalies
  - **Main goal:** search for sterile neutrino oscillations with Booster Neutrino Beamline (BNB)
- **ICARUS:** Rich Physics program including study of Neutrino-4 anomaly and ν-Ar cross section measurements with Neutrinos at the Main Injector (NuMI) beam



Top CRT

- **ICARUS** started taking data in August 2020
- Comprised of **three data-taking subsystems** required for physics measurements
  - Liquid Argon Time Projection Chamber (LArTPC)
  - Photomultiplier tubes (PMT)
  - Cosmic ray tagger (CRT)

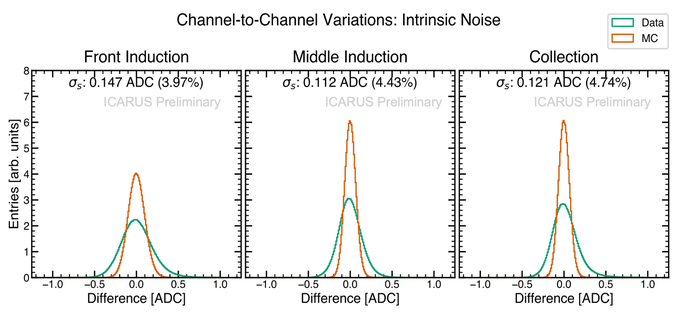


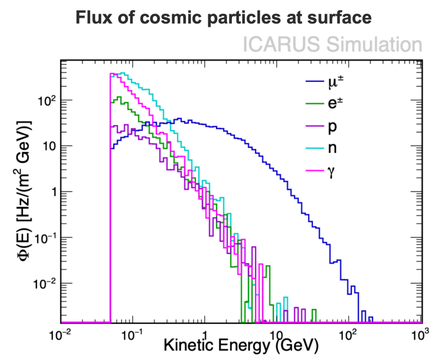
TPC schematic view

Side CRT

2. Noise and Backgrounds Simulation at ICARUS

- Understanding noise within the TPC is important for spatial resolution and calorimetric reconstruction. Noise characterization (parameterized as σ_s) shows inefficiency in simulating spatial variations with our current noise model



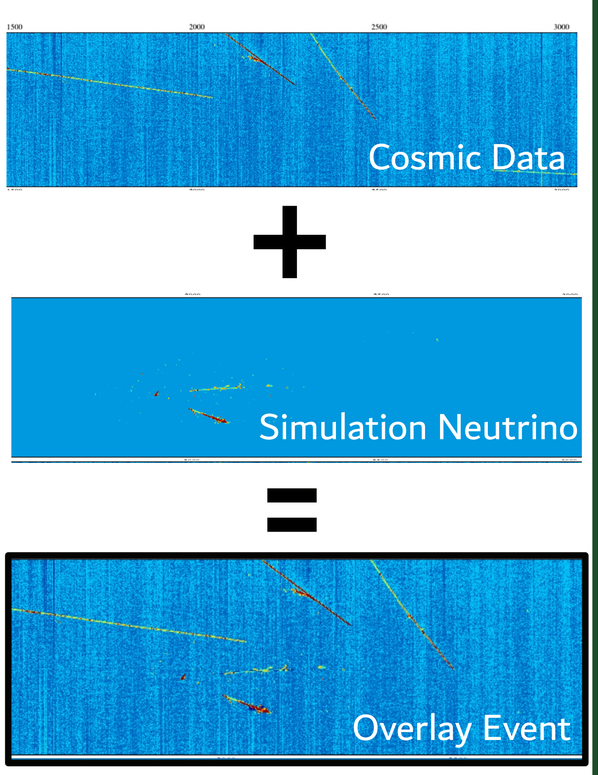


- ICARUS is operating on the surface at Fermilab and exposed to a high flux of cosmogenic particles
  - ~10 cosmic muon tracks in detector per ~1ms drift time in each readout
- Cosmic flux is currently modeled using CORSIKA

- Overlays allow for a **data-driven modeling of backgrounds and noise sources**
  - **Captures noise** from TPC, PMTs and CRT

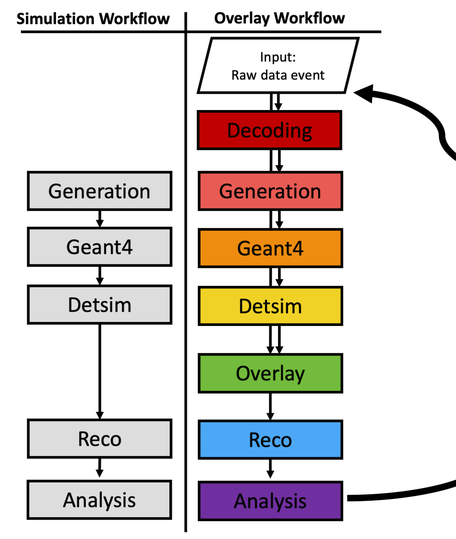
3. What are Overlays?

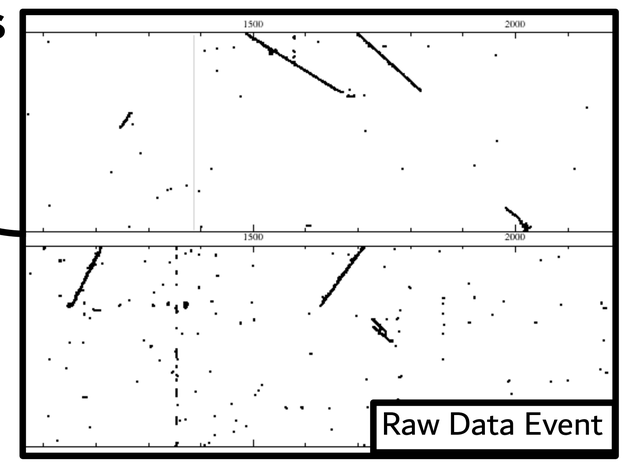
- Using a method developed by MicroBooNE[1] and NOvA[2], we overlay **simulated neutrino events on real cosmic data** collected by the ICARUS detector
- Allows for use of real detector data to model our backgrounds and evaluate detector systematics
- Requires **complete calibration** of TPC, PMT and CRT subsystems
- Reduced dependence on detector noise or background generators from simulation
  - CORSIKA or other cosmic ray generators may have different composition or flux compared to reality
  - Reduced computing time spent simulating cosmic backgrounds
  - Get radiological or other backgrounds that aren't modeled for free
- Require ~10x the neutrino beam triggered data to overcome statistical uncertainties in simulation

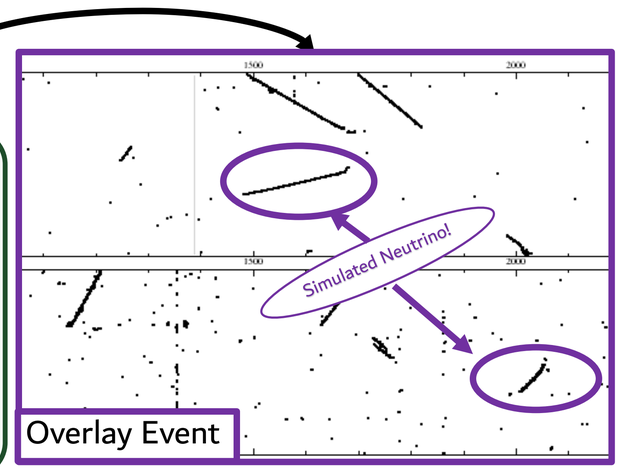


- **Goal: Make simulation look as data-like as possible**

4. Making Overlays Events





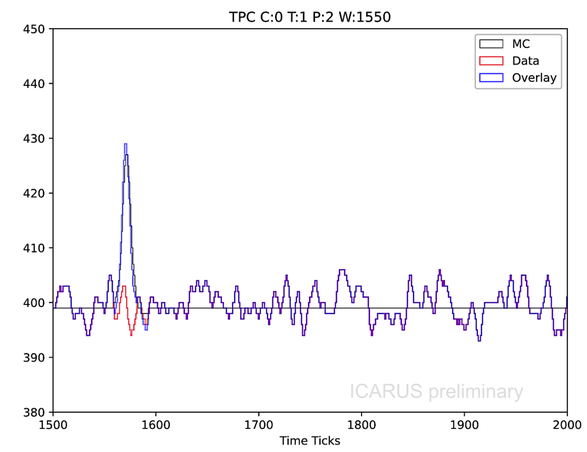


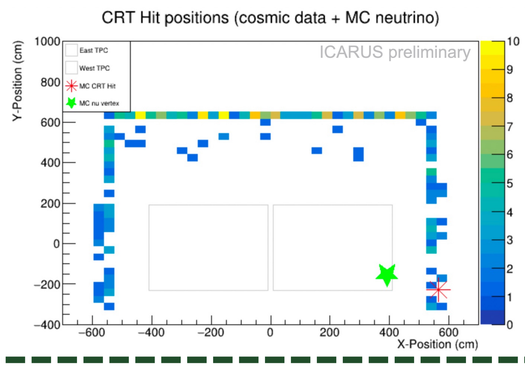
- Decoding stage: Decode raw data fragments into data products
- Detsim stage: remove noise simulation
- Overlay stage:
  - Adding PMT and TPC wire waveforms to the corresponding one from data
  - Add simulation CRT hits to data

5. Overlaying Signals

TPC Waveforms

- Here we see a raw waveform from a single TPC wire in off-beam data overlayed with simulated neutrino
- See that the raw TPC signals are correctly being merged from data and simulation





CRT Hits

- Example of merging collections of CRT Hits from simulation and data
- Plot shows CRT Hit positions from a single off-beam cosmic data event
  - Green star: neutrino interaction
  - Red star: CRT Hit from neutrino

PMT Waveforms

- Effort is ongoing to merge PMT simulated and data waveforms

6. Conclusion and Future Work

- Overlays are a data-driven method to control for noise sources and backgrounds
- ICARUS has a workflow dedicated for making overlays and is planning on using overlays for future analyses
- Implementing changes in off-beam triggering: increasing the maximum rate for both BNB and NuMI data streams to achieve the 10x data needed
- Validation of CRT and TPC data/simulation overlay signals is ongoing with PMT signal overlay in the works

References:
[1] Novel Approach for Evaluating Detector-Related Uncertainties in a LArTPC Using MicroBooNE Data, https://link.springer.com/article/10.1140/epjc/s10052-022-10270-8
[2] The NOvA simulation chain, https://iopscience.iop.org/article/10.1088/1742-6596/664/7/072002

This work was supported by the Office of High Energy Physics within the U.S. Department of Energy Office of Science under Award Number DE-SC0017740