The "Online Method" of Purity Monitoring at the ICARUS T600 Detector

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New Perspectives 2.0

24th August, 2020

FERMILAB-SLIDES-20-105-ND

Talk Overview

1. Background:

   - The ICARUS Detector and SBN Program*
   - Introduction to monitoring with liquid argon
   - Process on performing the "online method"

2. Results:

   - Results using TPC noise variations and space charge effect parameters
   - Discussion on the robustness of the purity algorithm

3. Summary

   - Recap and future studies ahead of final detector commissioning

*see Justin's slides for an excellent deeper discussion from New Perspectives 1.0

ICARUS and the Short Baseline Neutrino (SBN) program

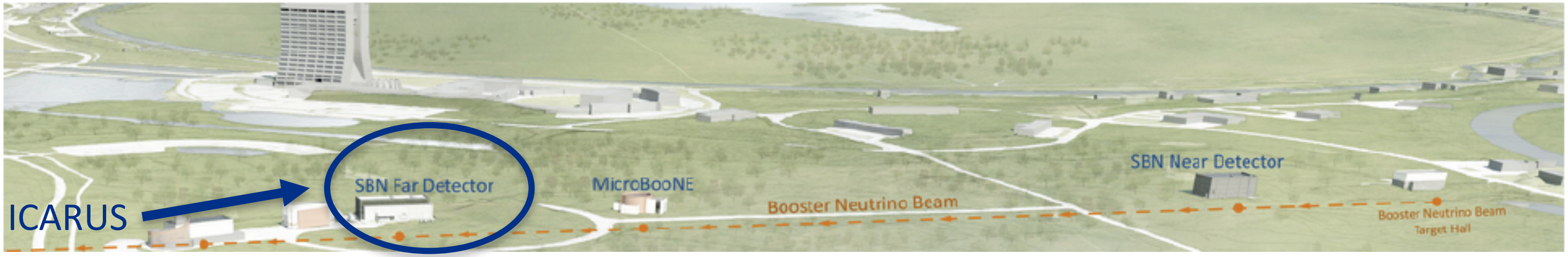

Figure 1: The three detectors of the SBN program at Fermilab. All are situated along the booster neutrino beamline.

- SBN program at Fermilab:
  - Consists of three detectors SBND, MicroBooNE, ICARUS, which all utilize liquid argon technology (LAr) - improving reconstruction techniques
  - ICARUS plans to study the experimental neutrino anomalies found in oscillations of the $\nu_\mu \rightarrow \nu_e$ measurements, such as probing into the existence of sterile neutrinos
- ICARUS:
  - Comprised of two cryostats where each half-module is filled with 760 tons of ultra pure LAr.
  - There will be an electric field of $E_D = 500 \frac{V}{cm}$ after turning on the high voltage.
  - Status updates: all TPC electronics and cryogenics have been installed and tested (Also, as of April 19th, 2020 – the filling of the two cryostats is completed).

Figure 2: Installation of the two modules of ICARUS.

Liquid Argon Technology

- Neutrino event:

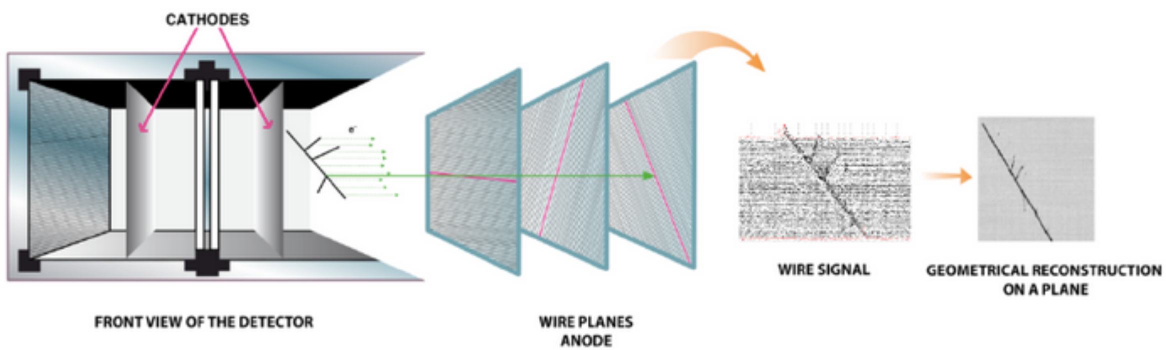

Figure 3: A neutrino event reconstructed from the signals recorded on the time projection chamber (TPC) wire planes.

Figure 4: A single module comprising two TPCs.

- The ultra-pure LAr produces more accurate event displays following reconstruction.
  - It is crucial to be ultra-pure since the presence of electronegative impurities produces an exponential attenuation of the electron signal collected in the wire planes.
  - The purity of the LAr is kept high to minimize this effect.

- A correction for the effect due to the impurities can be obtained from the study of the wire signal attenuation along through-going cosmic muon tracks in the LAr-TPC, providing a measurement of the purity level.

- Factors such as the noise level on the TPC wires and space charge* can bias the purity measurements still further. (subject of the simulation studies)

* M. Mooney, *The MicroBooNE Experiment and the Impact of Space Charge Effects*, 2015 [arXiv:1511.01563v1].

Lifetime Measurements - 1

- To monitor purity, we perform measurements of the drift electron lifetime τ_{ele} as a parameter in the following formula:

$$Q(t) = Q_0 e^{\frac{-t}{\tau_{ele}}}$$

- $Q(t)$ is the measured charge arriving at the wire planes, Q_0 is the initial free charge prior to drift in the electric field within the TPC, and t is the drift time*

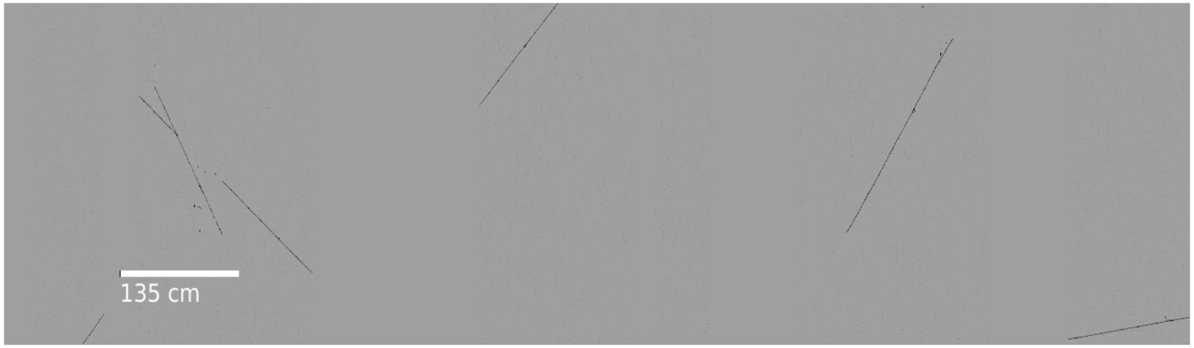

Figure 5: A cosmic MC simulation from ICARUS of the collection plane on one side of the TPC in one of the two cryostats. This image is after deconvolution.

* B Baibussinov et al, *Free electron lifetime achievements in liquid Argon imaging TPC*, 2010 JINST 5 P03005 [arXiv:0910.5087v2].

Lifetime Measurements - 2

- There are two approaches that we will be using for measurements:
  - Offline method – very precise and slow to be used with the full calibration
  - Online method – a quick measurement without a detailed reconstruction (will be used in the website monitor)
- We start with calculating the attenuation $\lambda = \frac{1}{\tau}$ from raw wire signals and using simple hit/cluster identification tool. (no noise filtering, no full track reconstruction)
- The attenuation is measured from cosmic muon tracks in a simplified one step process*.
  - The fluctuations due to the asymmetric Landau tail of $\frac{dE}{dx}$ distribution were reduced.
  - Average over tracks with minimal purity change.

* M. Antonello et al, *Experimental observation of an extremely high electron lifetime with the ICARUS-T600 LAr-TPC*, 2014 JINST 9 P12006 [arXiv:1409.5592].

Lifetime Measurements - 3

- From the purity algorithm, critical information such as the run, sub-run, event, TPC, and attenuation number after each event is stored to be used in performing the final results.
  - We take the average attenuation across all 4 TPCs with a simple arithmetic mean calculation, and this found for a spectrum of lifetimes where we apply different noise and space charge factors.
  - Then, the electron lifetime is displayed as the inverse of the average attenuation

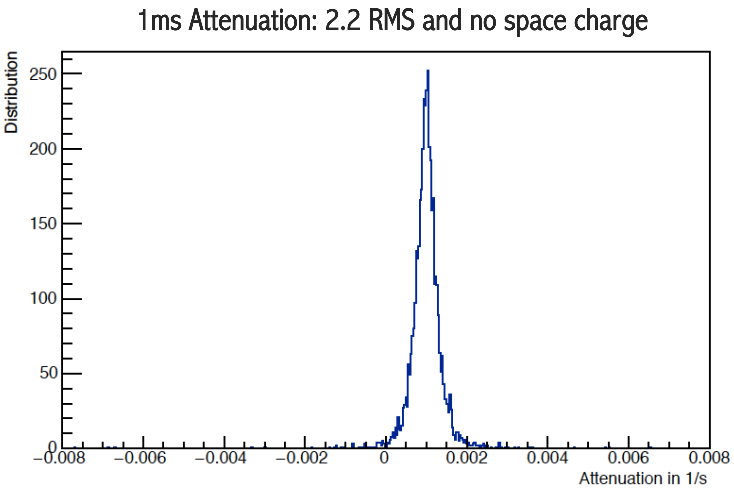

Figure 6: A sample attenuation distribution for a 1ms lifetime with 2.2 RMS noise and no space charge.

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Lifetime Results

- The first study performed on the purity showed a high linearity across a whole spectrum of lifetimes. Therefore further studies were performed with more realistic factors: noise and space charge.

- The lifetimes presented are 1ms, 2ms, 4ms, and 10ms:

  - Noise configurations are the RMS measurements of 2.2 ADC, 3.2 ADC, and 5.0 ADC

  - Space charge off and on where "space charge on" means double space charge effects (2x the expected effects)

- Another study dedicated to the robustness of the purity algorithm is also discussed. (more later)

❖ Note: The following results are based upon official simulation productions.

Space Charge Off

- We see that at low lifetimes, the noise variations are minimal.

- However, there is a significant increase in noise contribution at higher lifetimes.

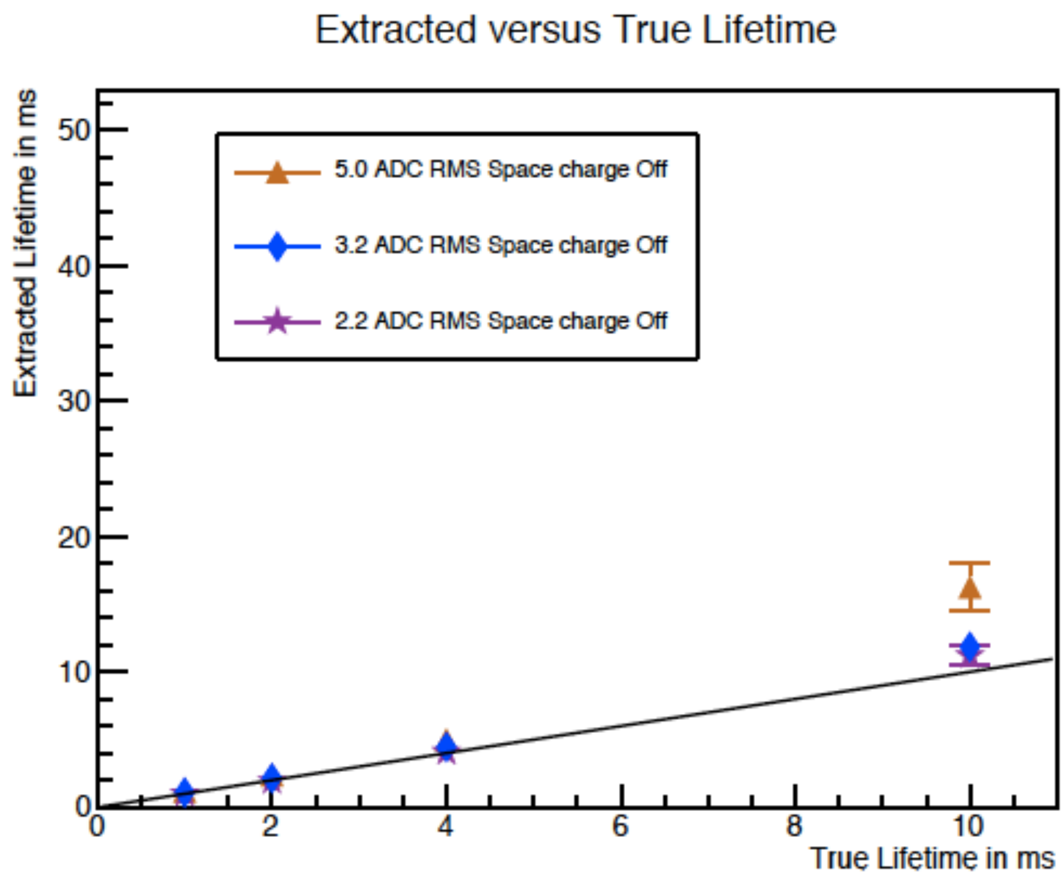


Figure 7: “Space charge Off” results for 1-10ms lifetimes.

Space Charge On

- At low lifetimes, space charge has an effect on the deviation, albeit small compared to noise effects.
- However, the space charge plays the more dominate effect at higher lifetimes.
- These are 2X the expected space charge effects and this offset will be taken into account during data analysis.

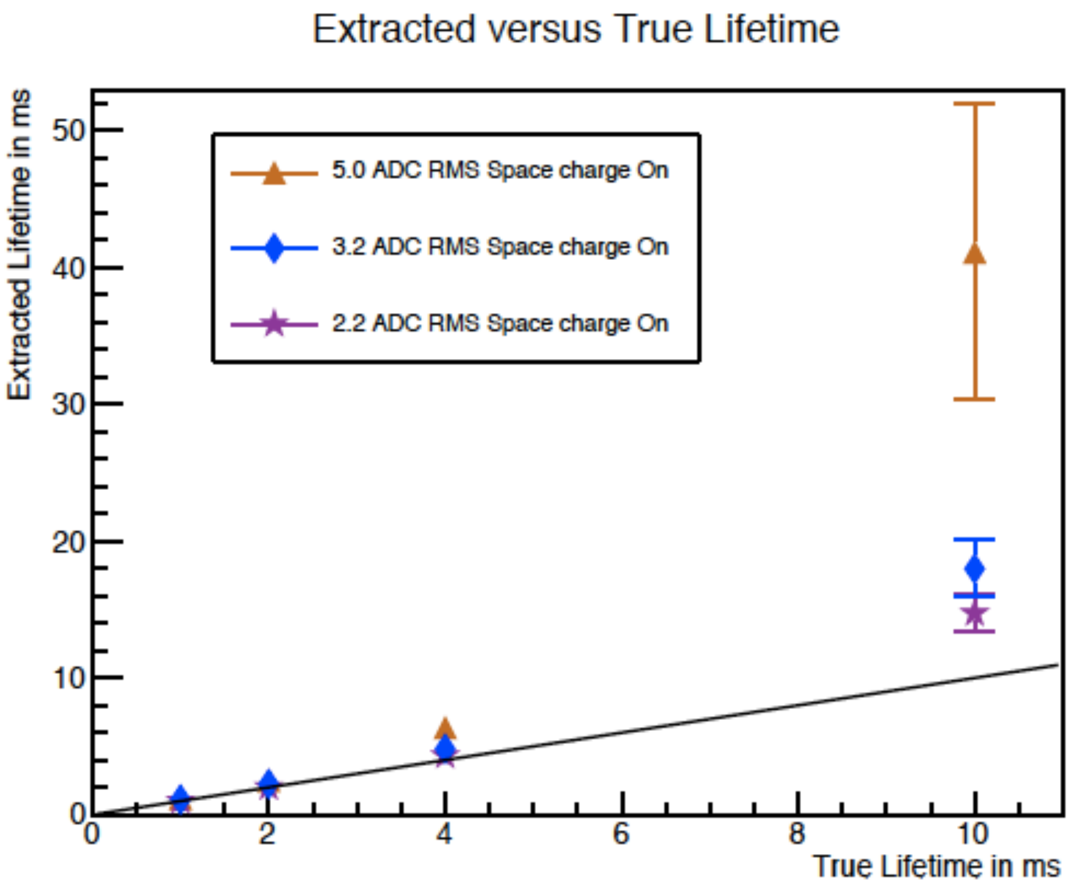
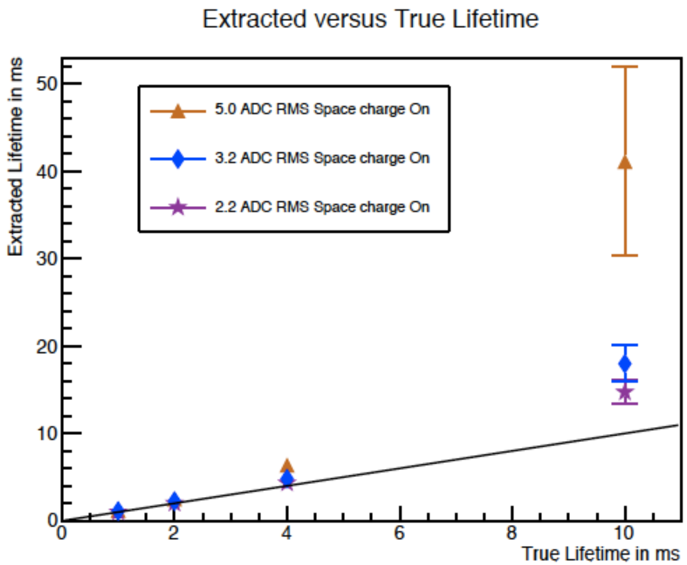


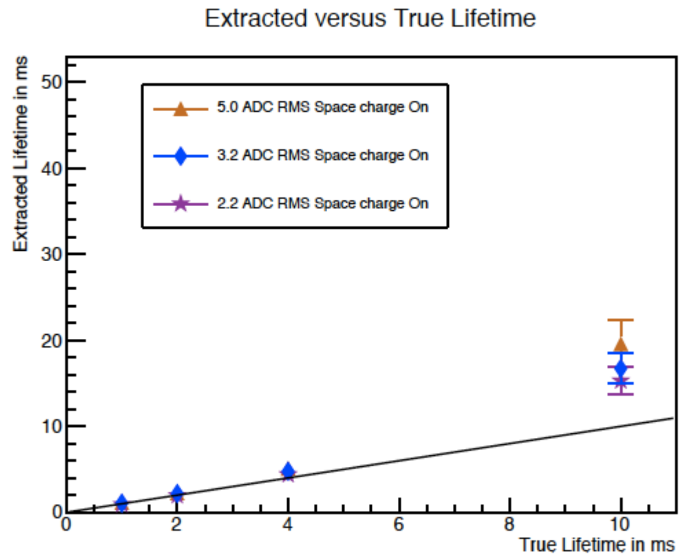
Figure 8: "Space charge On" results for 1-10ms lifetimes.

Robustness of the Purity Algorithm

- To decrease the high biases, we look into the effects of changing the hit threshold parameter which sets the minimum threshold to determine physical hits in the "online method."
  - We classify a "hit" as the detected charge deposits on the TPC wires that is above a given noise value.
- By lowering it from N = 5 ADC to N = 3 ADC we can reduce the overall biases from the high noise samples because we are increasing our statistics by lowering the threshold, leading to a better more robust measurement.



N = 5 ADC, "space charge on"



N = 3 ADC, "space charge on"

Hit Threshold: Space Charge Off

- There is a decrease in the overall noise contributions.
- Lowering the threshold shifts the values down across all lifetimes and leads to a better measurement.
- However, there remains some small deviations at higher lifetimes.

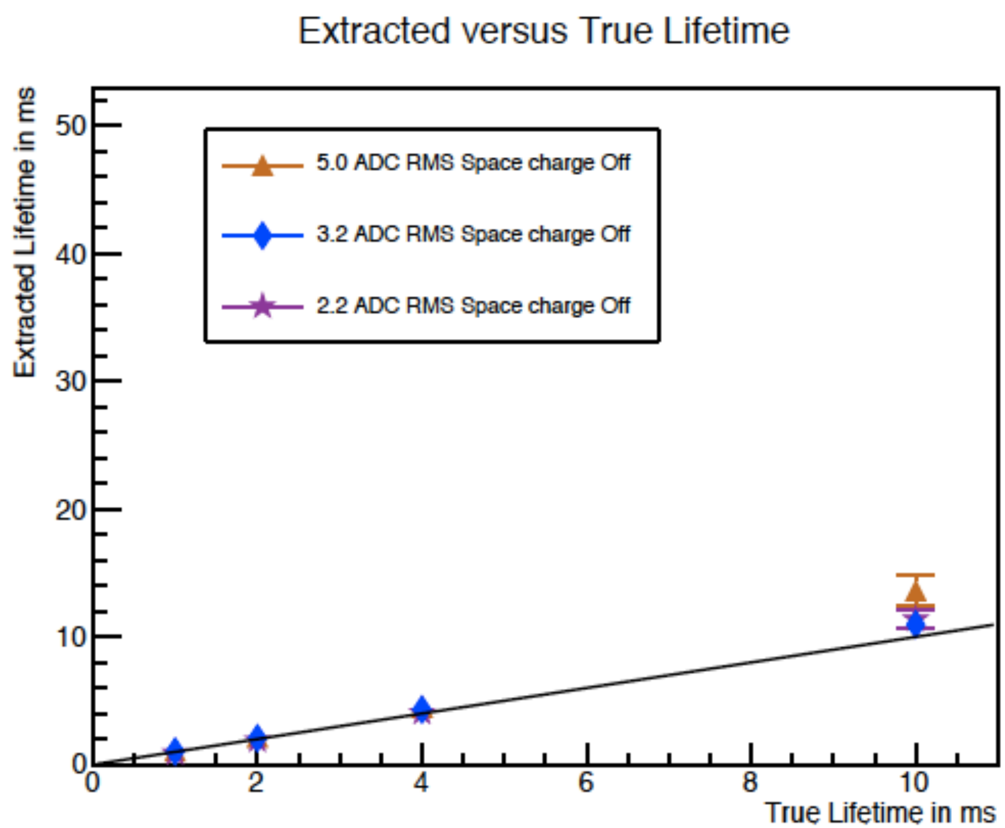


Figure 9: “Space charge Off” results for 1-10ms lifetimes with the lowered hit threshold.

Hit Threshold: Space Charge On

- The space charge effects cause less deviation when the hit parameter is lower.
- However at high lifetimes, there remains a small deviation.
- We also lowered to N = 2 ADC, however, the results indicated very little change, so N = 3 ADC insures the results to be the most robust for various noise configurations across the range of lifetimes.

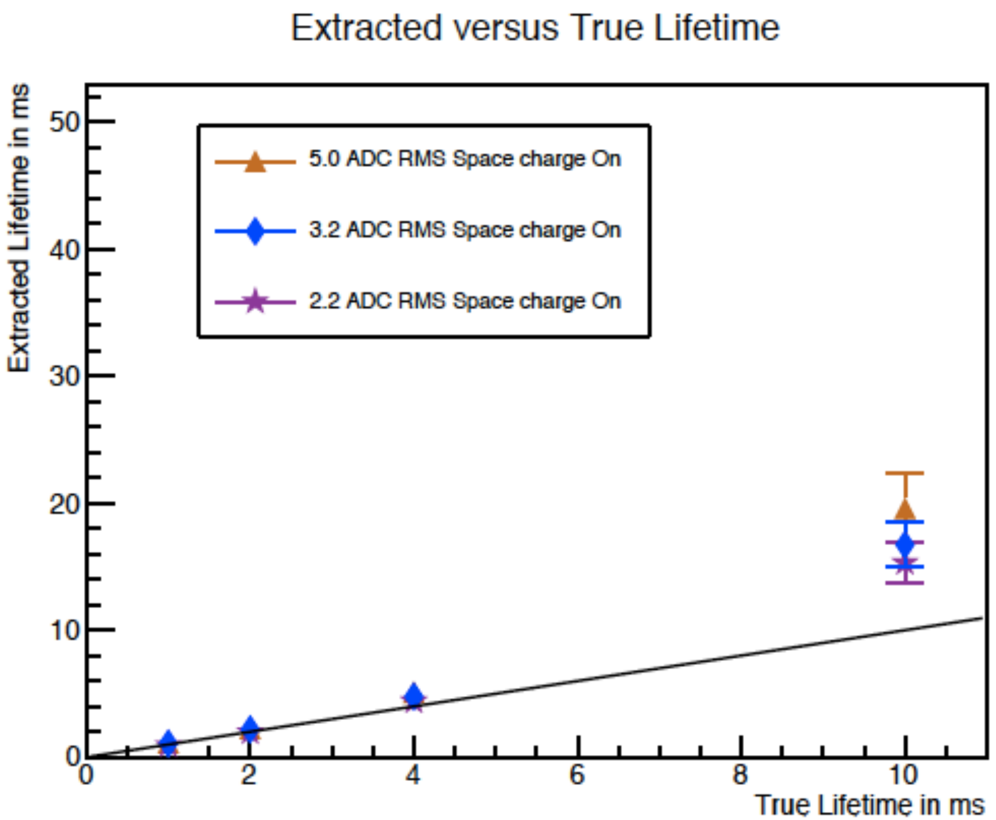


Figure 10: “Space charge On” results for 1-10ms lifetimes with the lower hit threshold.

Summary

- Since the simulations discussed used the "online method" for the purity measurement, in real time, the presence of a bias is not so dramatic as it appears.
  - ➢ It is also important to note that the space charge effects simulated are twice what we expect.

- The large deviations at higher lifetimes will be accounted for in any analysis of the data.
  - ➢ However, the code does provide us with information on the trend where the conditions are good for the physics we expect to see.

- The important takeaways:
  - ➢ For low lifetimes, space charge effects were subdominant to the noise effects at each lifetime measurement. However at higher lifetimes these effects became more dominant.
  - ➢ The noise effects from each configuration have more of an impact as the lifetime itself increases.
  - ➢ Changing the hit threshold to a lower minimum increases our statistics to make the results more robust to the changes in the noise at every lifetime.

Future Studies

- Optimization of the purity measurement is ongoing which includes implementing a form of the “online method” into the ICARUS monitoring website ahead of operations.

- A new set of studies is under way simulating single space charge effects. We are also looking at other lifetimes such as 6, 8, and 12 ms to fully explore the effects of noise variations and space charge on a spectrum of lifetimes.

- And a study is also underway to make appropriate cuts to the tracks used in the lifetime calculation as another way of improving the measurement by reducing biases.

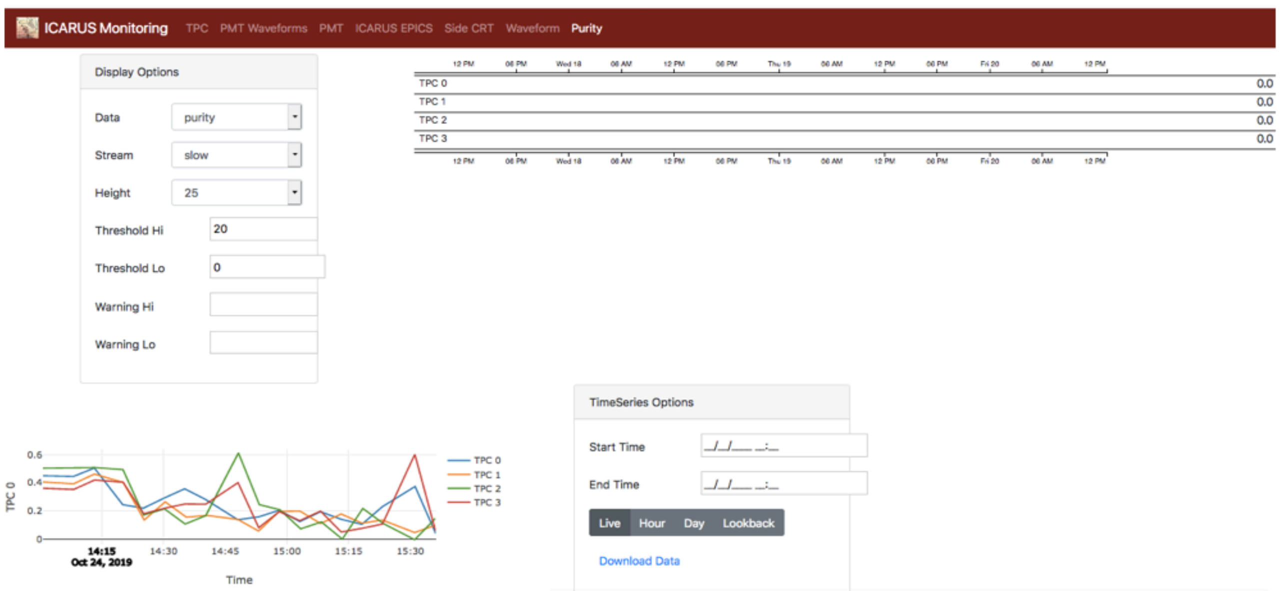
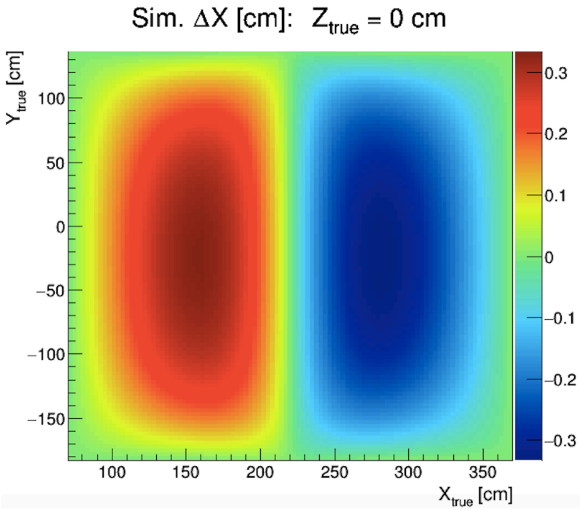


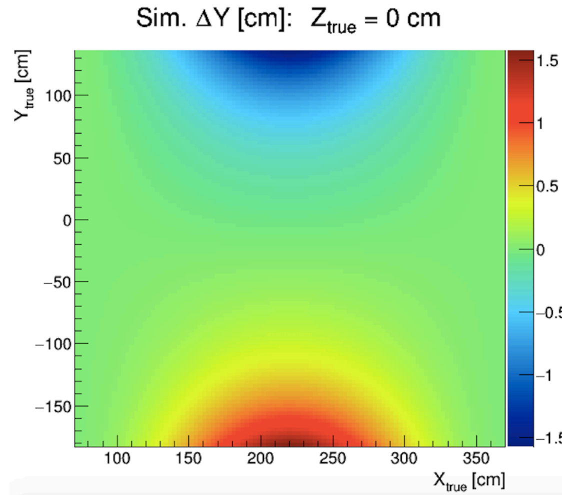
Figure 11: A sample webpage displaying the purity values for each of the four TPCs during a previous simulation in October, 2019.

Thank You!

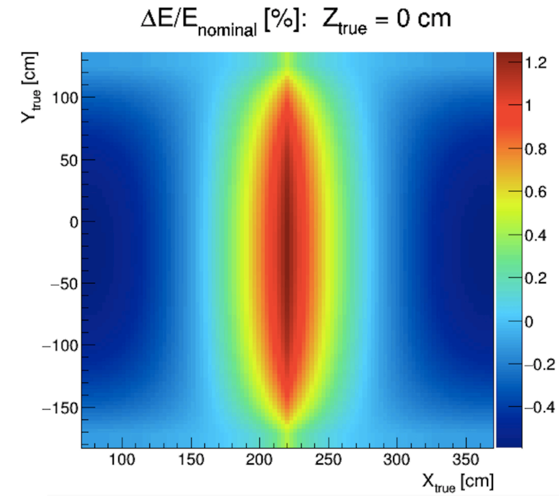
Amount of Space Charge used in the simulations



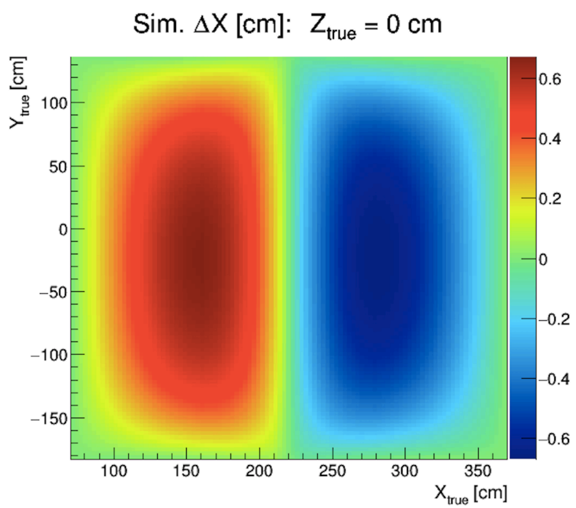
Single Space Charge: migration of charge in x plane



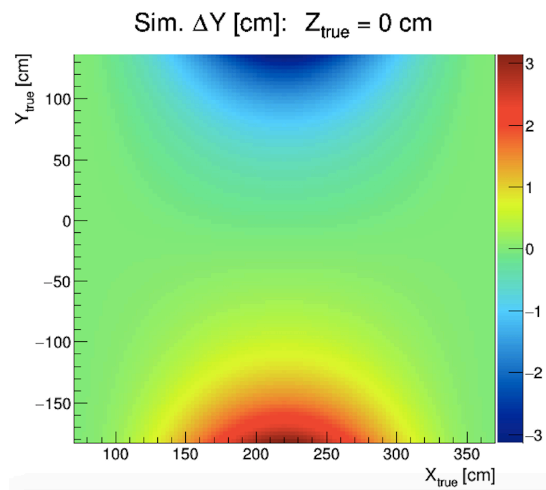
Single Space Charge: migration of charge in y plane



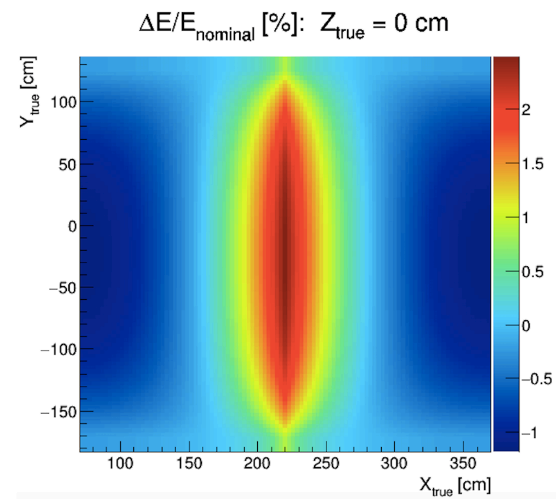
Single Space Charge: change in the $|E_D|$ within the detector



Double Space Charge: migration of charge in x plane



Double Space Charge: migration of charge in y plane



Double Space Charge: change in the $|E_D|$ within the detector

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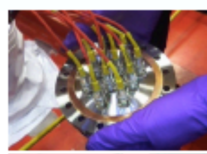
ICARUS Status Updates -1

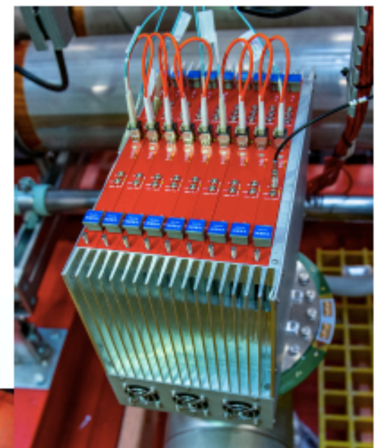
Status on ICARUS Installation

Placement of ICARUS inside the warm vessel after the overhauling at CERN (August 2018)

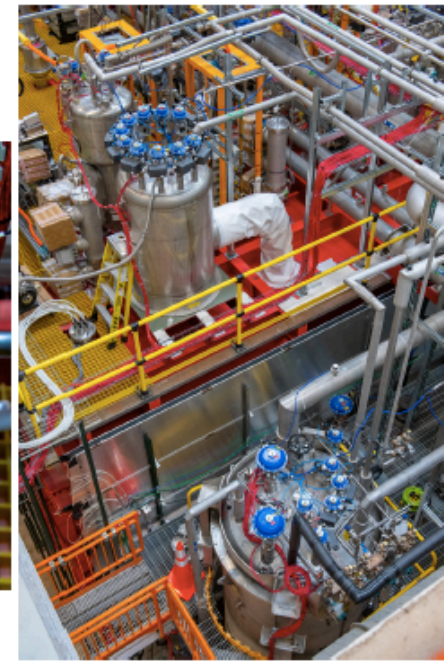
Feedthrough TPC/PMT/laser flanges installation (December 2018)



All TPC readout electronics installed and tested



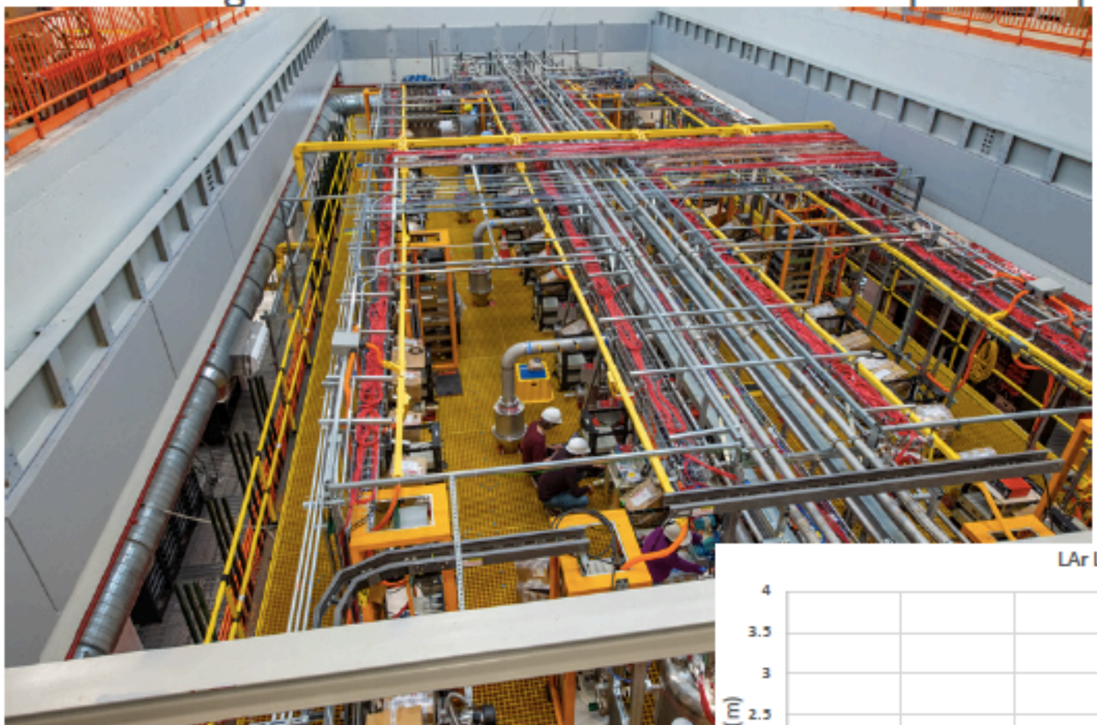
All cryogenic equipment installed, welded and tested (May 2019)

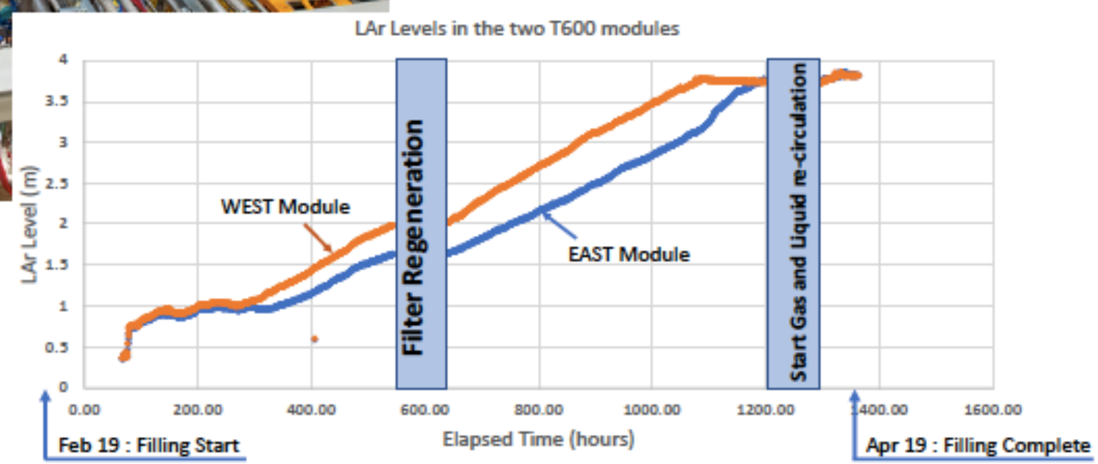


*Slide courtesy of Minerba Betancourt

ICARUS Status Updates -2

- LAr filling started on Feb19-2020 and completed Apr 19-2020





*Slide courtesy of Minerba Betancourt