Energy Reconstruction of Low Energy Events in LArTPC

LeRayah Neely-Brown
GEM Fellow: Purdue University
Supervisors: Joseph Zennamo + Fernanda Psihas
Final SIST/GEM Talk
08.08.2022
Liquid Argon Time Projection Chamber

- Detectors where interactions between neutrinos and Argon atoms are observed
  - The energy & trajectory from these interactions are measured via the charge and light emitted

LArTPC @ BNL Animation: https://lar.bnl.gov/home/img/signal.gif
LArTPCs + Low Energy

LArTPCs are designed to effectively study high energy events ranging from 0.1-10 GeV.

Typically, any event below 5 MeV will only reach 1 or 2 of the anode wire planes.

Also, the light is collected with low efficiency.

This will result in small signal readouts for these low energy events.
Introducing Photosensitive Dopants to LArTPCs

This project’s aim is to observe how well low energies are detected when photosensitive doping is added to the LArTPC.

- The dopants’ purpose are to convert the scintillation light emitted into ionization charge.
- We want to measure how doping will improve the detection and collection of charge and the energy resolution for low energy events.

Fernanda Psihas, 2022
**Summer Research Goals & Objectives**

**Main Objective:** Take low energy simulations from the LArTPC and view how well the energy of the particles can be reconstructed **with and without** photosensitive doping.

**Goals To Meet Objective:**

- Analyze simulated electrons from 2 samples:
  - Monoenergetic 2.5 MeV
  - 0-10 MeV
- Make energy distribution plots to understand energy reconstruction & resolution
  - Use full LArSoft reconstruction
  - Use stored data products from the interactions in the LArTPC to create ROOT Ttrees to make plots depicting the interactions **and** true deposited energy
  - Ultimately, these plots will measure energy resolution at low energies.
Spread of Normalized Charge from Wire Q & Charge from Light

\((\text{true}_Q/\text{true}_\text{Edep}) : (\text{true}_L/\text{true}_\text{Edep})\)
Spread of Charge from Wire Q & Light Combined

True Wire Q + True L Spread
Current Spread of Reconstructed Wire Q

reco_tot_wire_Q
Importance of Comparing Energy Spreads

Full Half Width Maximum (FWHM) is defined as the spread of energy for the specific variables we study in LArTPCs.

Energy Resolution is defined by FWHM/maximum energy detected
Importance of Comparing Energy Spreads

Full Half Width Maximum (FWHM) is defined as the spread of energy for the specific variables we study in LArTPCs.

Energy Resolution is defined by $\text{FWHM}/\text{maximum energy detected}$
Importance of Comparing Energy Spreads

Full Half Width Maximum (FWHM) is defined as the spread of energy for the specific variables we study in LArTPC.

Energy Resolution is defined by FWHM/maximum energy detected.
Importance of Comparing Energy Spreads

Full Half Width Maximum (FWHM) is defined as the spread of energy for the specific variables we study in LArTPCs.

Energy Resolution is defined by FWHM/maximum energy detected

Smaller FWHM = Improved Energy Resolution
Importance of Comparing Energy Spreads

Full Half Width Maximum (FWHM) is defined as the spread of energy for the specific variables we study in LArTPCS.

Energy Resolution is defined by $\frac{\text{FWHM}}{\text{maximum energy detected}}$

Smaller FWHM = Improved Energy Resolution
Determining Figures of Merit

Using True Energy Deposited \((\text{True\_Edep})\), True Energy \((\text{True\_E})\), Hit Q \((\text{Reco\_Tot\_Hit\_Q})\), and Wire Q \((\text{Reco\_Tot\_Wire\_Q})\) variables are essential in energy reconstruction and resolution as they explicitly define the detected energy charge and number of low energy events in LArTPCs.

As a result, 4 distinct figures of merit were formulated and used to determine how well the energy resolution can be improved in terms of low energy events:

1) \((\text{Reco\_Tot\_Wire\_Q})/\text{True\_Edep}\)
2) \((\text{Reco\_Tot\_Hit\_Q})/\text{True\_Edep}\)
3) \((\text{Reco\_Tot\_Wire\_Q} - \text{True\_Edep})/\text{True\_Edep}\)
4) \((\text{Reco\_Tot\_Wire\_Q} - \text{True\_E})/\text{True\_E}\)
Ratio Figure of Merit Plots

Energy Resolution Comparison Between HitQ F.O.M. and WireQ F.O.M.

Energy Resolution at 2.5 MeV [%]

F.O.M.: reco_tot_hit_q/true_Edep
Fitted Fxn: $y = 0.9 + e^{1.5 + 0.02x}$

F.O.M.: reco_tot_wire_q/true_Edep
Fitted Fxn: $y = 0.7 + e^{1.4 + 0.02x}$

Dopant Quantum Efficiency [%]
Ratio and Percent Difference Figure of Merit Plots

Comparison of Energy Resolution For All F.O.M. Variations

- F.O.M.: reco_tot_hit_q/true_Edep
  Fitted Fxn: $y = 0.9 + e^{1.5 + 0.02x}$

- F.O.M.: reco_tot_wire_q/true_Edep
  Fitted Fxn: $y = 0.7 + e^{1.4 + 0.02x}$

- F.O.M.: (reco_tot_wire_q - true_E)/true_E
  Fitted Fxn: $y = 0.3 + e^{1.5 + 0.01x}$

- F.O.M.: (reco_tot_wire_q - true_Edep)/true_Edep
  Fitted Fxn: $y = 0.5 + e^{1.4 + 0.02x}$

Energy Resolution at 2.5 MeV [%]

Dopant Quantum Efficiency [%]
Energy Scan for F.O.M. \( \frac{\text{Reco}_\text{Tot}_\text{WireQ} - \text{True}_\text{Edep}}{\text{True}_\text{Edep}} \)

- Pure Liquid Argon
- with P.S. Dopant, 25% Q.E.
- with P.S. Dopant, 100% Q.E.
Energy Scan for F.O.M. (Reco_Tot_HitQ - True_Edep)/True_Edep

- Pure Liquid Argon
- with P.S. Dopant, 25% Q.E.
- with P.S. Dopant, 100% Q.E.

Energy Resolution [%]

Energy Deposited [MeV]

0 1 2 3 4 5 6 7 8 9 10

Fermilab

08/08/22 LeRayah Neely-Brown | Energy Reconstruction of Low Energy Events in LArTPC
Energy Scans for Energy Resolutions

• Although we found both F.O.M. incorporating the **True Energy Deposited variable** to be close in resolution percentage, the True Energy Deposited & Wire Q F.O.M. appeared to be more effective when dopants were added.
Energy Scans for Energy Resolutions

• Although we found both F.O.M. incorporating the **True Energy Deposited variable** to be close in resolution percentage, the True Energy Deposited & Wire Q F.O.M. appeared to be more effective when dopants were added.

• However, the True Energy Deposited & Hit Q F.O.M. showed improved energy resolution in undoped conditions (Pure Liquid Argon).
Overall, these energy distribution plots have given us confidence to select 1 figure of merit to utilize when measuring the energy of low energy events in LArTPCs.

As we fully dope the LArTPCs with the \( \frac{\text{Reco}_{\text{Tot}} \text{Wire}_{\text{Q}} - \text{True}_{\text{Edep}}}{\text{True}_{\text{Edep}}} \) figure of merit, the energy resolution percentage is seen to reach 1%-3.5%. This improvement in resolution will result in enhanced energy measurement for low energy events.
Conclusion + Future Progress

Overall, these energy distribution plots have given us confidence to select 1 figure of merit to utilize when measuring the energy of low energy events in LArTPCs.

As we fully dope the LArTPCs with the \( \frac{\text{Reco}_\text{Tot}_\text{Wire}_Q - \text{True}_\text{Edep}}{\text{True}_\text{Edep}} \) figure of merit, the energy resolution percentage is seen to reach 1%-3.5%. This improvement in resolution will result in enhanced energy measurement for low energy events.

In the near future, we will revisit one more figure of merit, conduct another energy scan, and make the decision for which figure of merits to utilize when dopants are present or absent in LArTPCs.
I would like to extend my thanks to the following for their support this summer:

- Joseph, Fernanda, Raofa & William
- Mentor Group #1
- Neutrino Division
- SIST/GEM Committee & Fermilab
- The National GEM Consortium
- Purdue University
Appendix for Energy Reconstruction Plots
Defining Variables for Energy Reconstruction (Undoped)

True Energy vs Sum of Wire Charge
Defining Variables for Energy Reconstruction (Undoped)

Energy Deposited Into Detector vs Raw Wire Sum of Charge

FWHM vs $E_{dep}$ [MeV]

0 1 2 3 4 5 6 7 8 9 10

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

0 1 2 3 4 5 6

Fermilab
Defining Variables for Energy Reconstruction (Doped)

Doped True Energy vs Sum of Wire Charge

WireQ (FWHM) vs True Energy (MeV)

Fermilab
Defining Variables for Energy Reconstruction (Doped)

Doped Energy Deposited Into Detector vs Raw Wire Sum of Charge

FWHM vs E_{dep} [MeV]

Fermilab
Defining Variables for Energy Reconstruction (Doped)

Doped True Energy vs HitQ

HitQ [MeV]

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

True Energy [MeV]

0 1 2 3 4 5 6 7 8 9 10

Fermilab