ν_e CC Event Identification Based on Shower Energy Profiles in LArTPCs

Diego Lopez Gutierrez

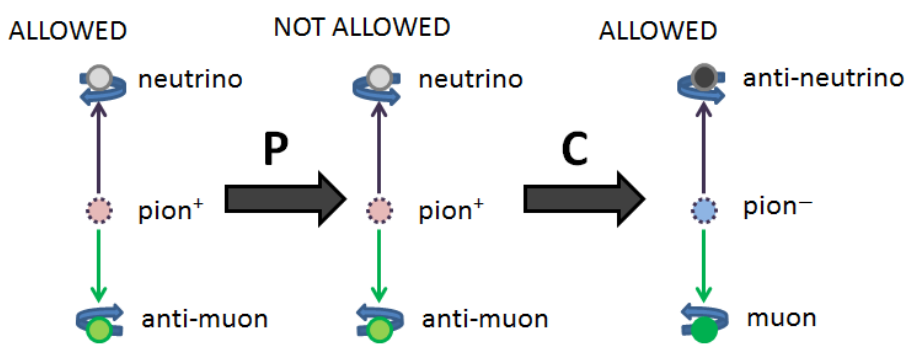
Supervisor: Dr. Wanwei Wu

SIST 2019 Summer Intern

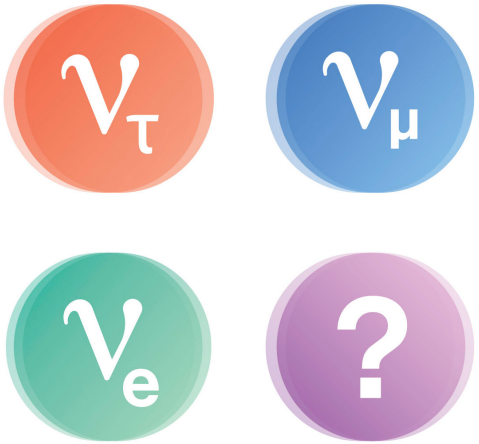
5 August 2019

Why do we care about neutrinos?

- Standard Model: Neutrinos have no mass
- Super-Kamiokande/SNO: Neutrino oscillations → Neutrinos have mass
- Neutrinos could give us insight into physics beyond the SM:
  - The matter/antimatter asymmetry in the universe (CP violation)
  - The nature of dark matter (sterile neutrinos)

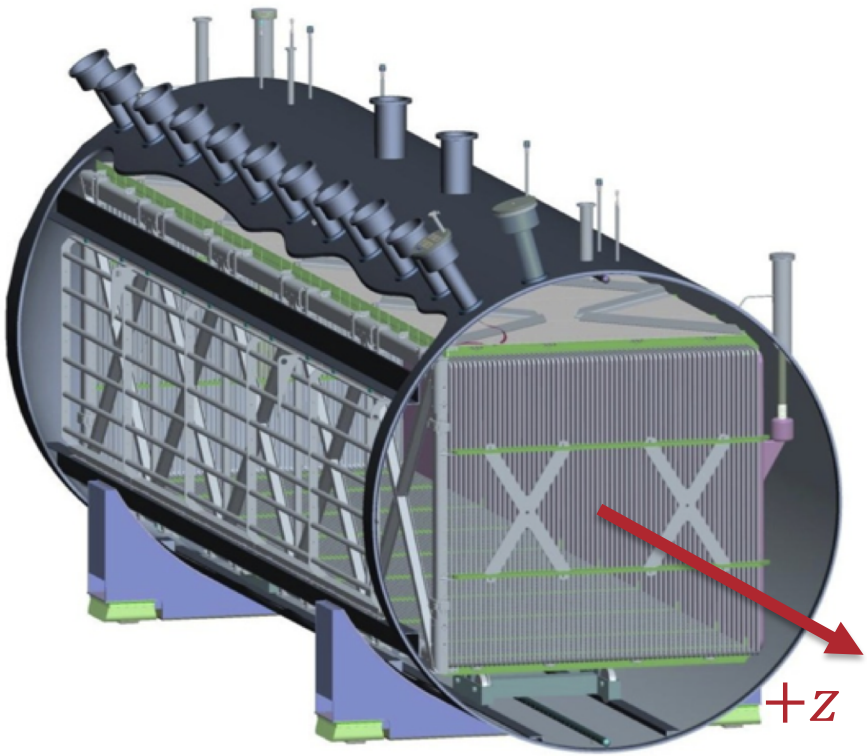


M. Strassler 2013



Liquid Argon Time Projection Chambers as Neutrino Detectors

MicroBooNE Detector

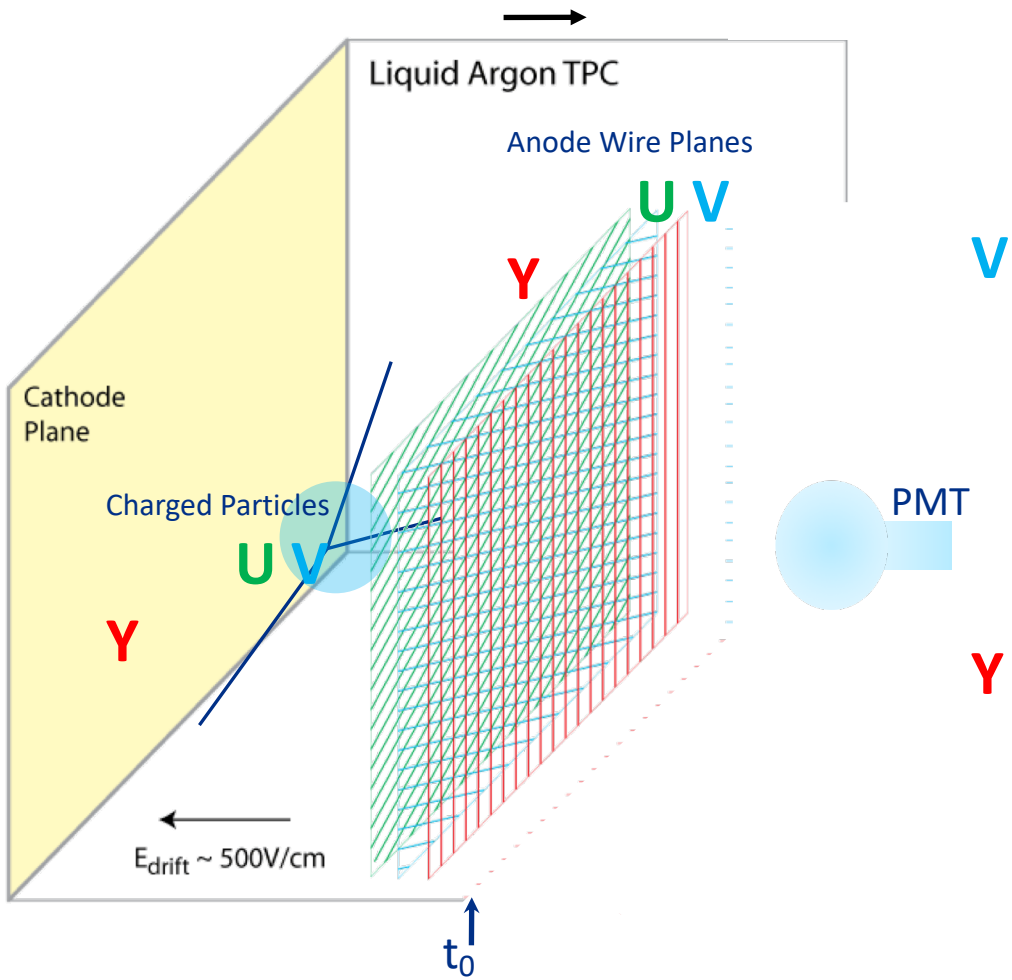


- Short-baseline Neutrino LArTPC experiments:
  - SBND
  - MicroBooNE
  - ICARUS
- Long-baseline Neutrino LArTPC experiments:
  - DUNE

Liquid Argon Time Projection Chamber (LArTPC)

- Why LArTPC?
  - Exceptional calorimetry and tracking capabilities.
  - Differentiate between $e^{\pm}$ and γ showers.
- How does LArTPC work?
  - ν + Ar → particles such as $e^{\pm}, \pi^{\pm}, \gamma, p$
  - Excited Ar nuclei release scintillation photons detected by photomultipliers (PMT) at the detector.
  - Charged particles ionize Ar nuclei→ e^{-}
    - e^{-} drift to anode by electric field.
    - e^{-} induce currents in the anode wires.
    - Wires store charge information (hits)
  - Events are reconstructed using light and charge signals.

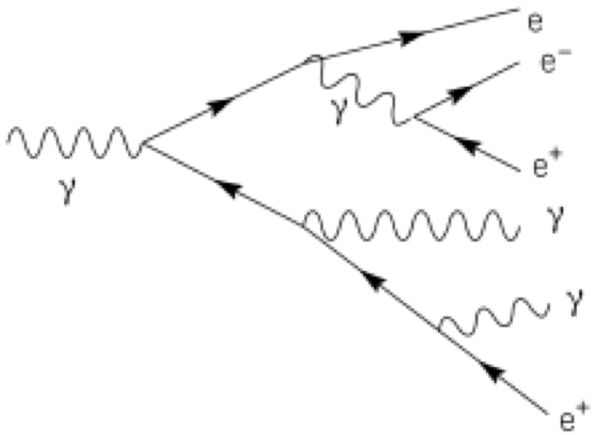
Liquid Argon Time Projection Chamber

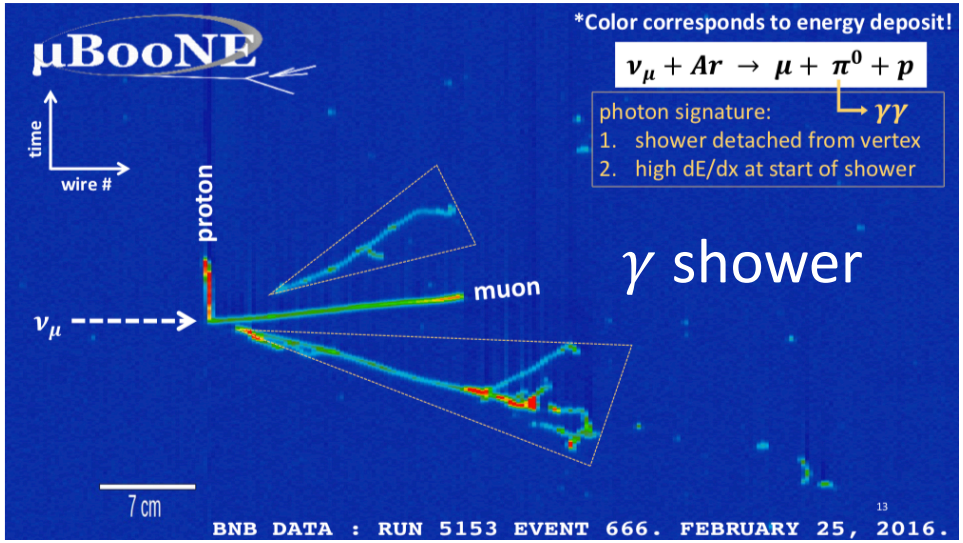


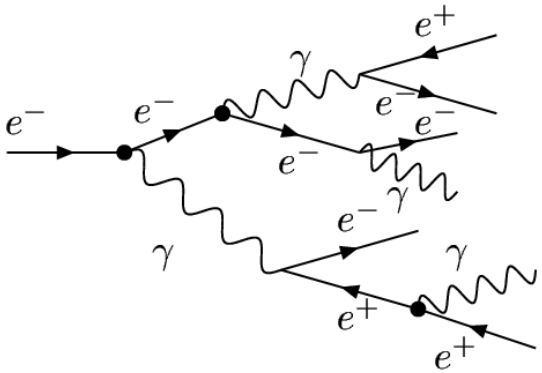
What is a Charged Current Neutrino Interaction?

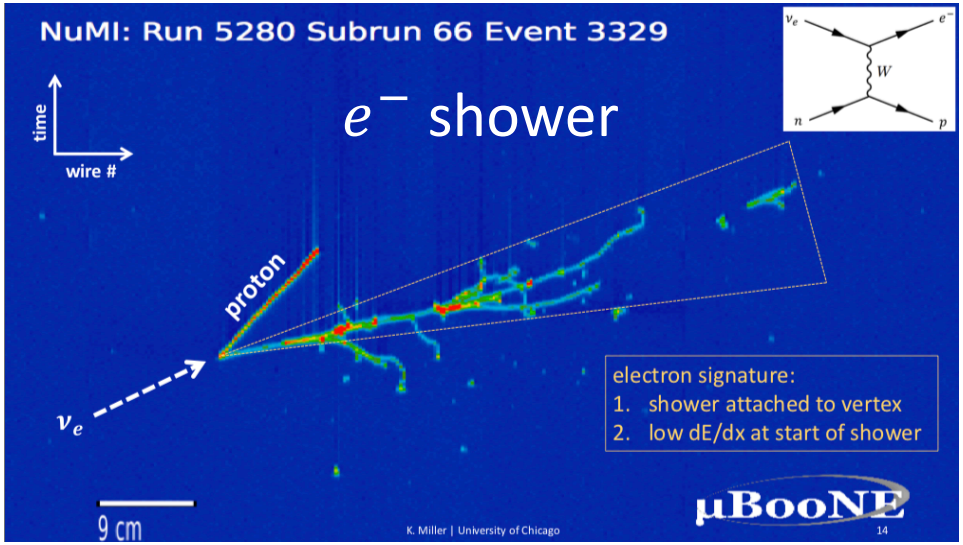
- ν_e , ν_μ ($\bar{\nu}_e, \bar{\nu}_\mu$) Interactions:
  - Neutral current (Z^0): $\nu_e + n \rightarrow \nu_e + n \mid \nu_\mu + n \rightarrow \nu_\mu + n$
  - Charged current ($W^\pm$): $\nu_e + n \rightarrow e^- + p \mid \nu_\mu + n \rightarrow \mu^- + p$
    - If CC final state identified, then mother neutrino identified
- Neutrino oscillations:
  - Change flavor. Example: $\nu_\mu \rightarrow \nu_e \mid \bar{\nu}_\mu \rightarrow \bar{\nu}_e$
- ν_e CC event important to study oscillations
  - MicroBooNE and DUNE beams contain many $\bar{\nu}_\mu, \nu_\mu$

Showers and Event Displays







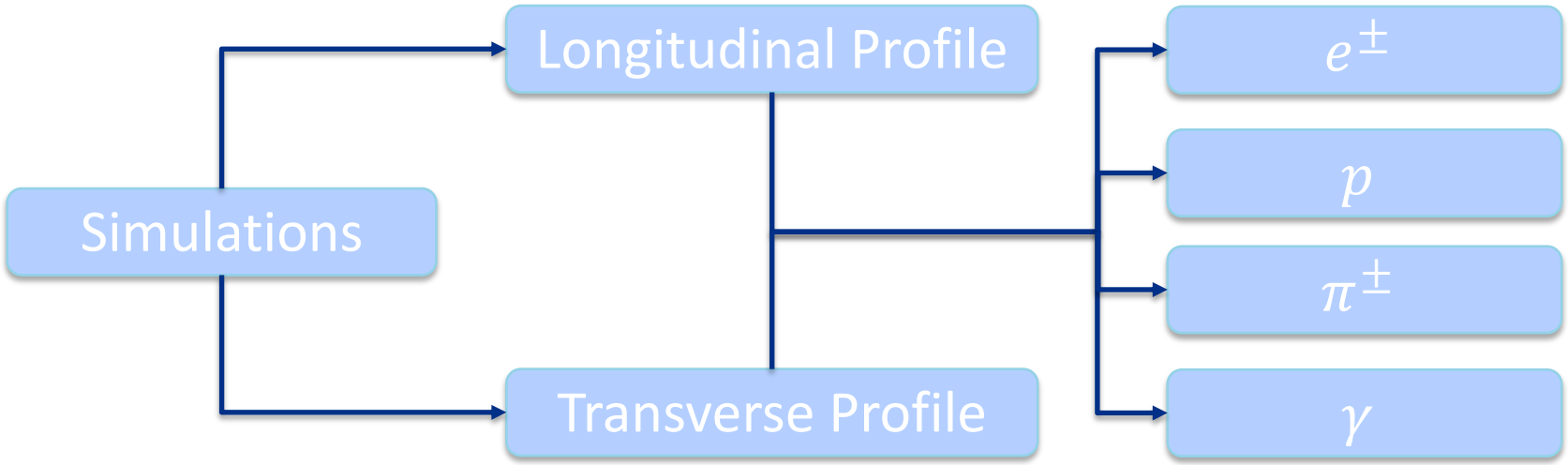


Electron Identification Using Shower Energy Profiles

- Physics goal:
  - Identify and select e^- showers to do ν_e CC analysis
- Motivation:
  - By studying ν_e CC, we learn more about neutrino oscillations, neutrino cross sections, etc.
  - Different particles → Different energy depositions in LArTPCs. We use this fact to perform shower profile analysis to identify the showers.
- Method:
  - Produce shower energy profile templates for particles such as $e^{\pm}, p, \pi^{\pm}, \gamma$.
  - Calculate electron likelihood based on shower energy profiles.
  - Feed likelihoods into an Artificial Neural Network to train and determine e^- showers.

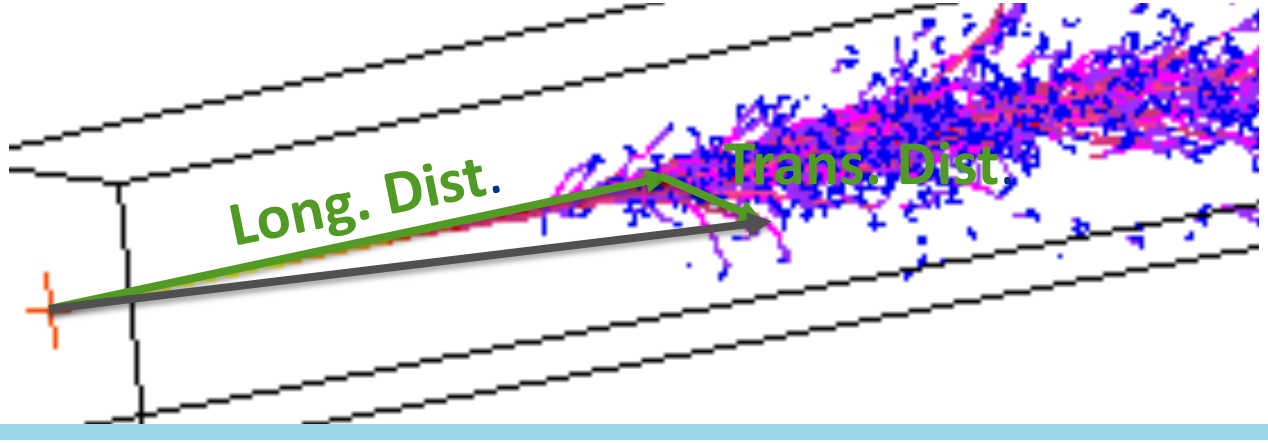
Shower Profile Templates

- We use DUNE Far Detector simulations of reconstructed showers to produce our shower templates.
- For each shower, we calculate the longitudinal and transverse profiles.
- We store the shower profiles from different particles as templates.

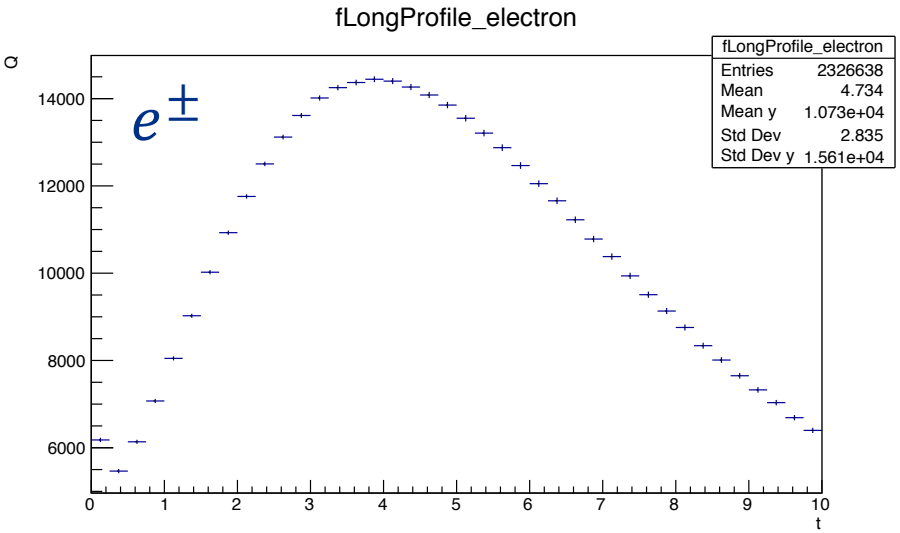


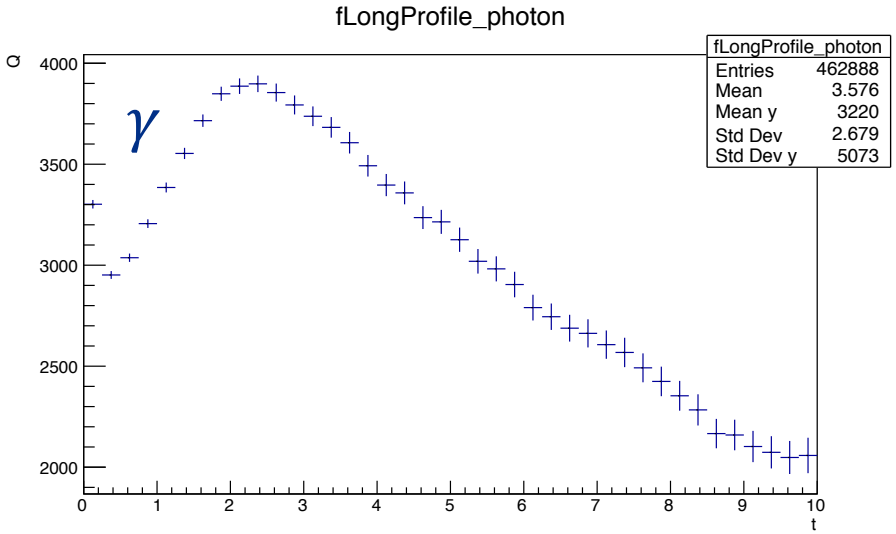
Shower Profiles

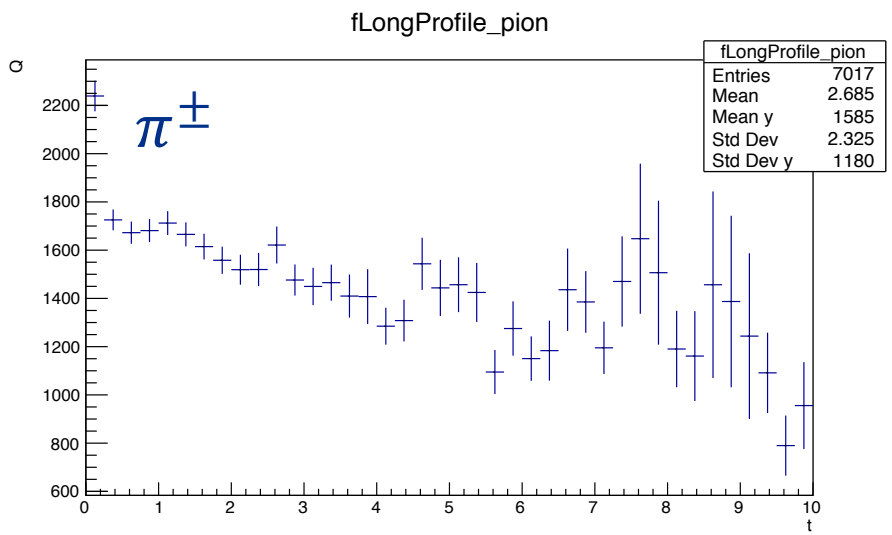
- From simulation information, we get shower's vertex and direction.
- We use these to calculate longitudinal and transverse distances:
  - Longitudinal: along shower's direction
  - Transverse: perpendicular to shower's direction.
- From hits, we calculate charge.
- We save charge vs. distance information in different longitudinal and transverse plots.

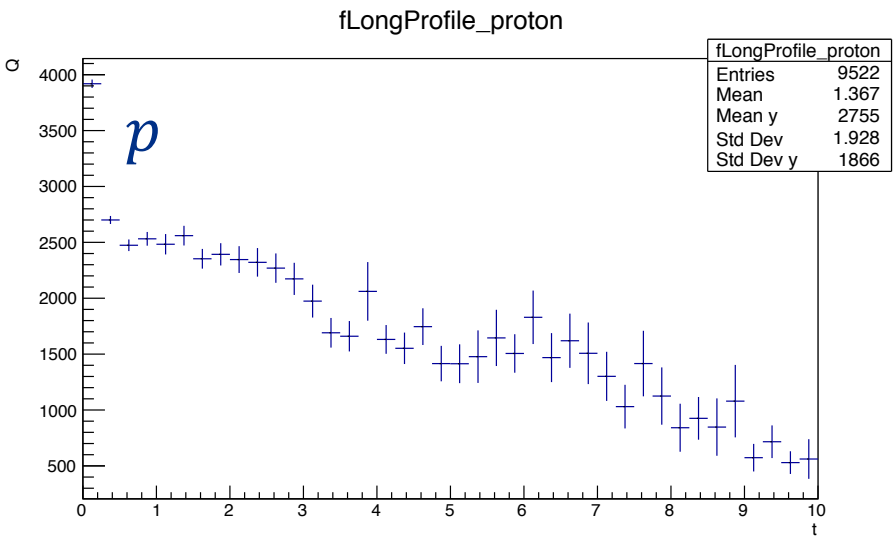


Longitudinal Shower Profile

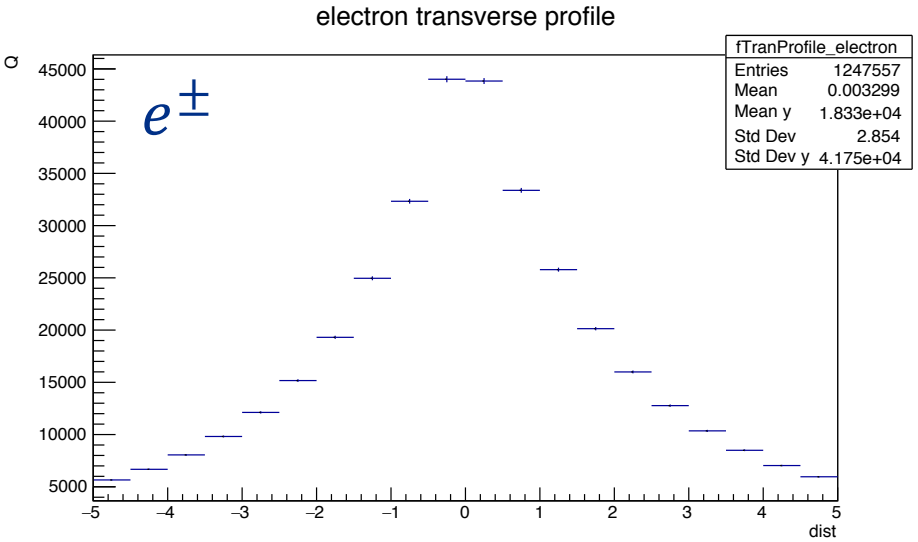


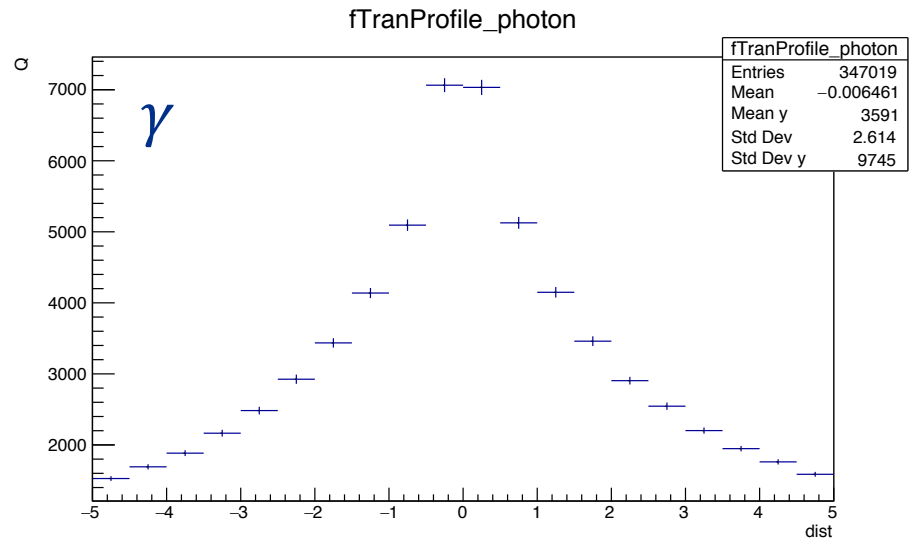


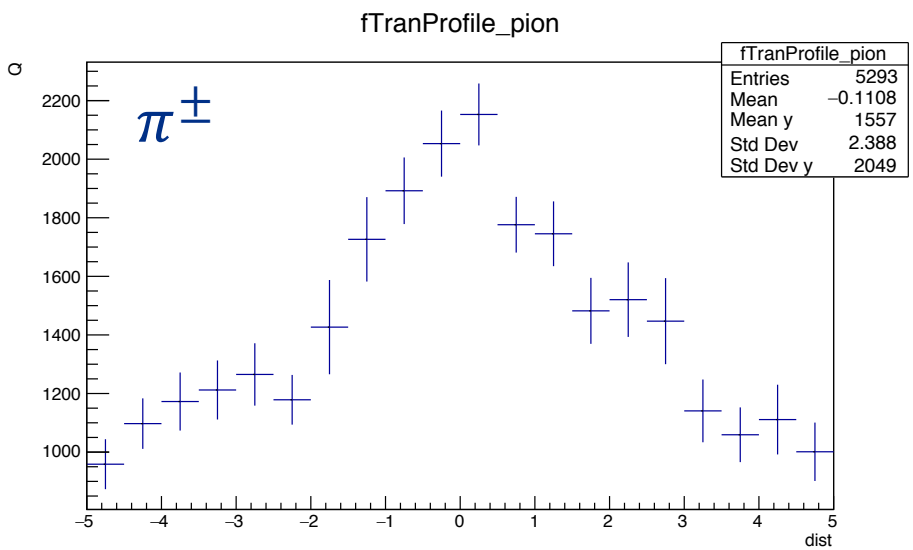


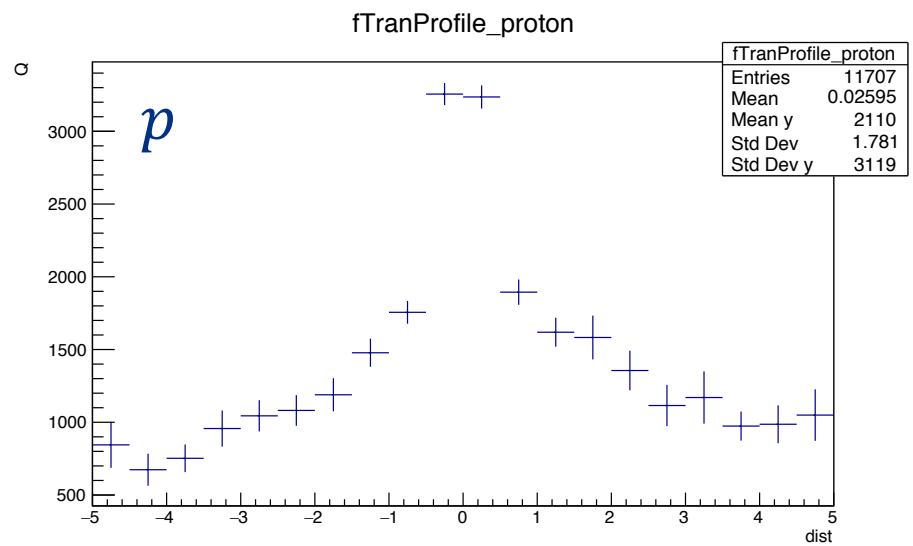


Transverse Shower Profile

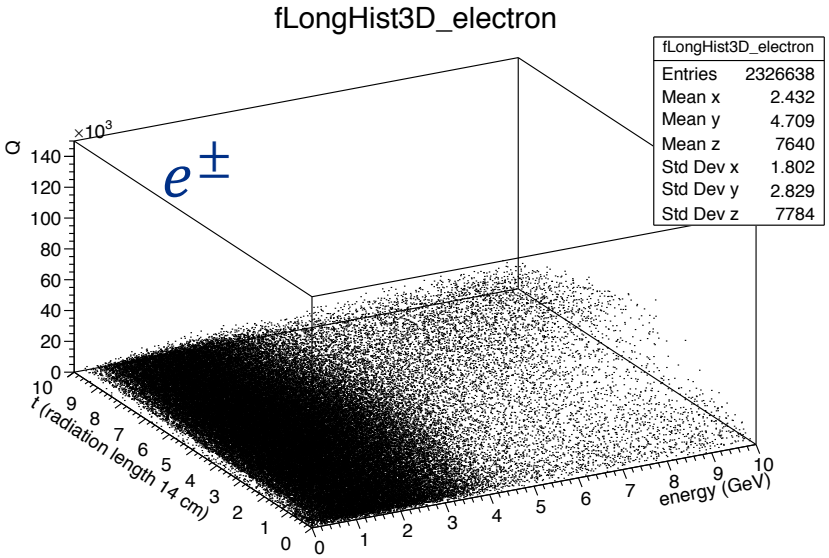


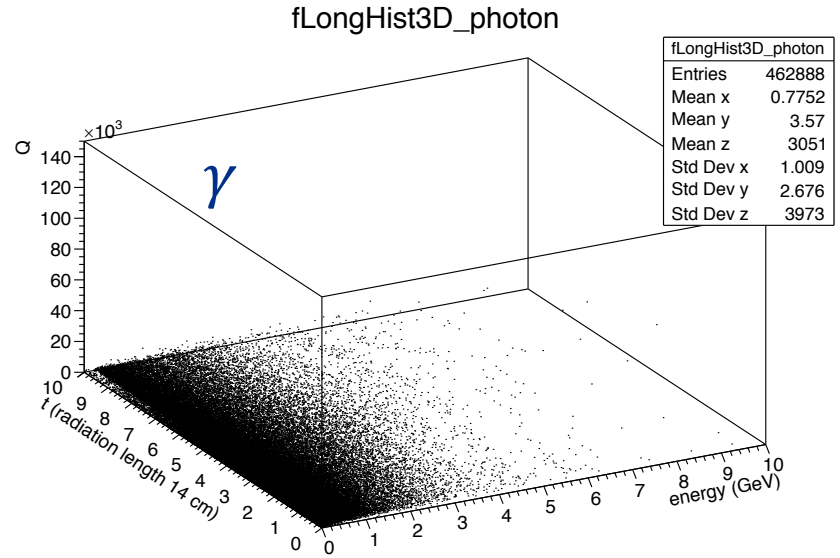


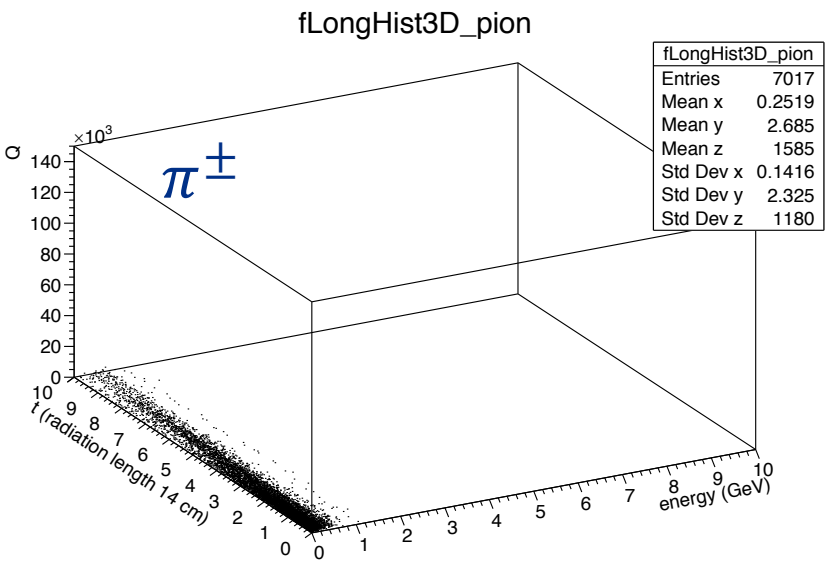


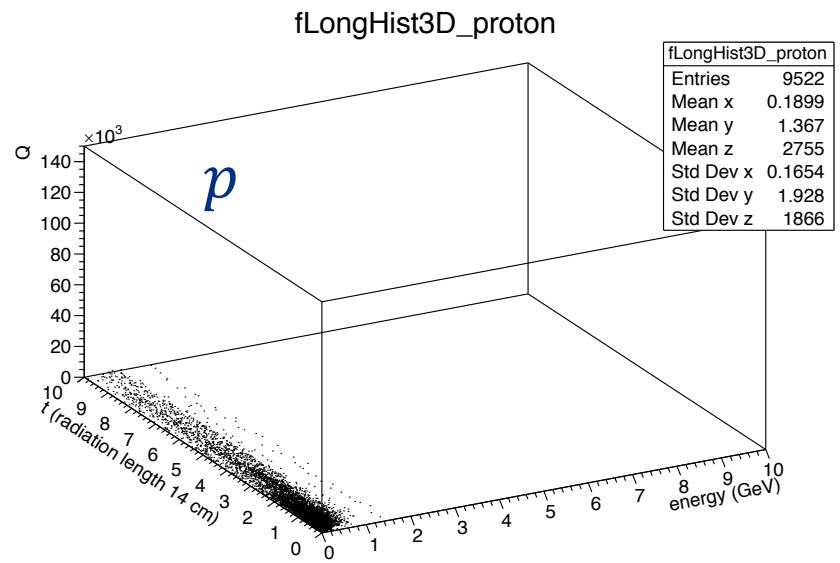


3D Longitudinal Histogram as Template

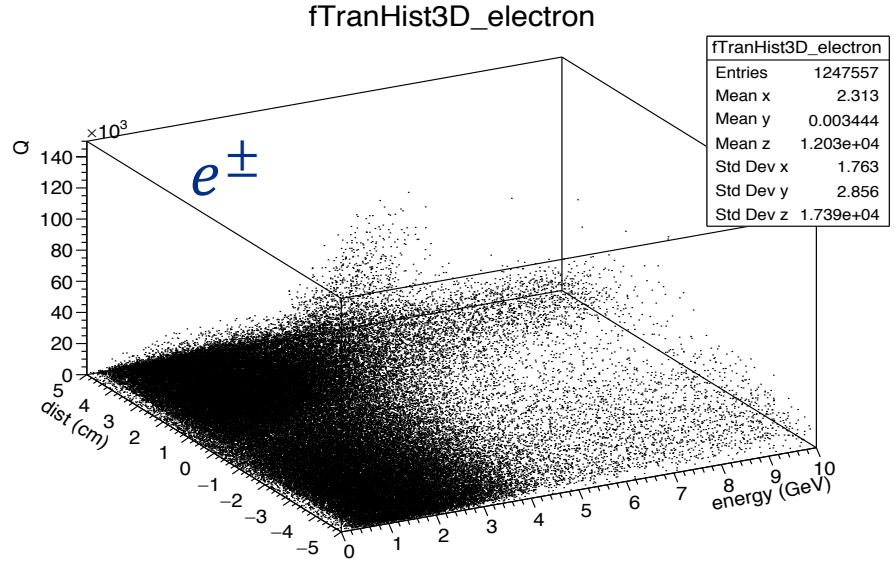


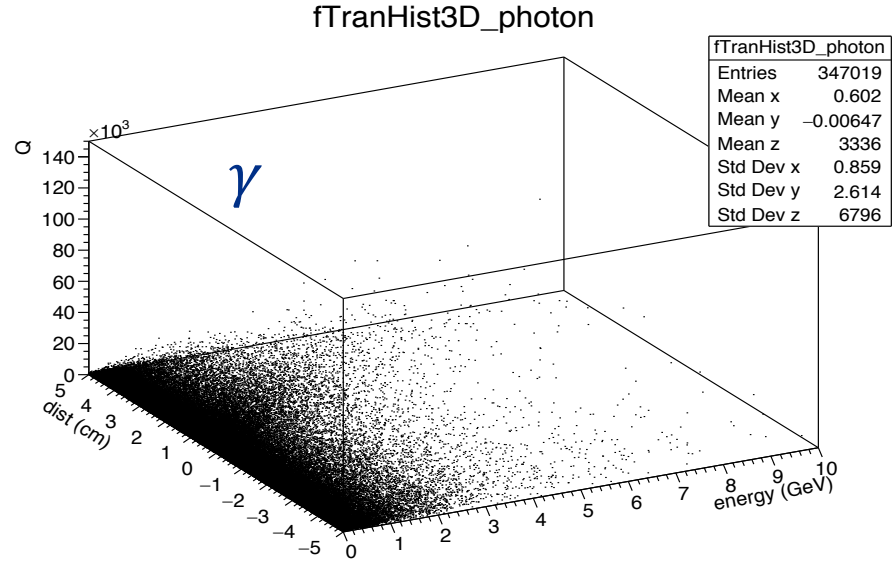


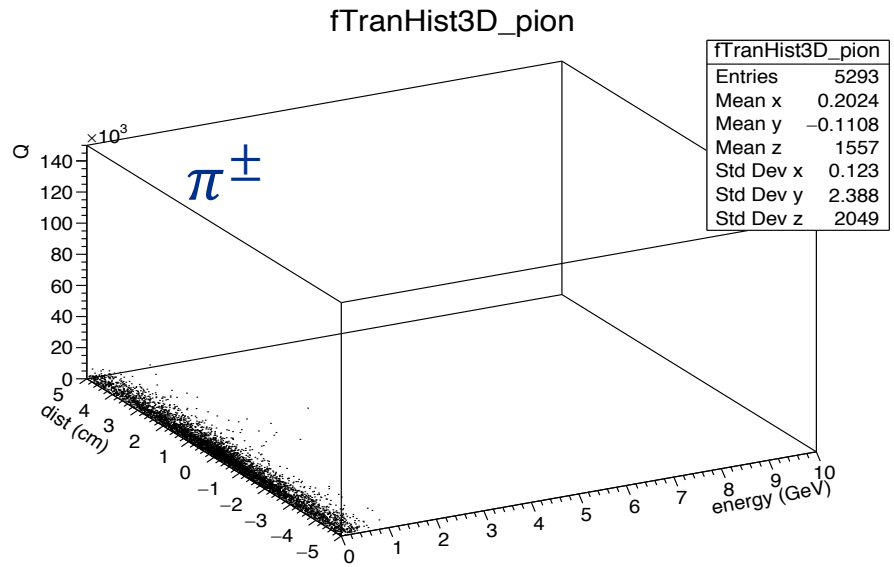


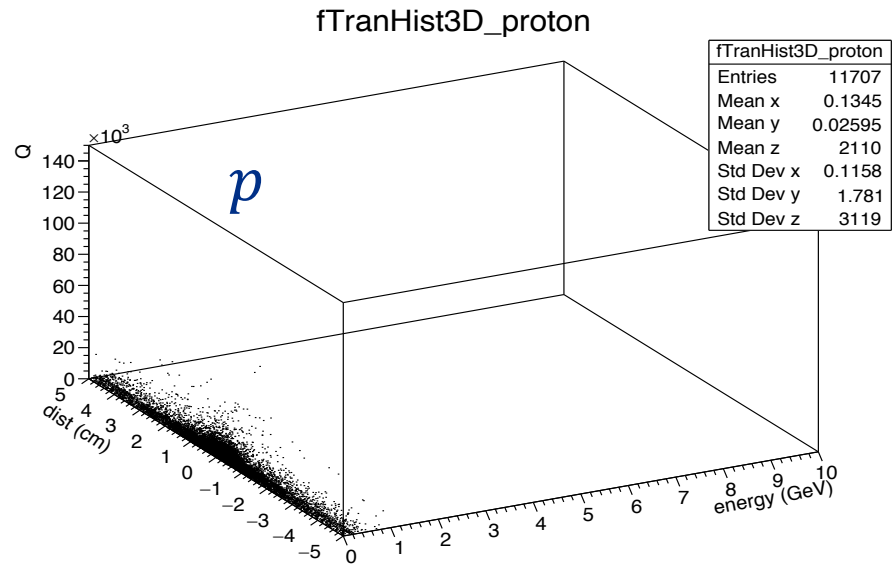


3D Transverse Histogram as Template









Likelihood Calculation

- For a given test shower, we calculate the longitudinal and transverse shower profiles.
- According to the templates, we calculate the probability for each type of particle.
- The probability for the particle is given by:

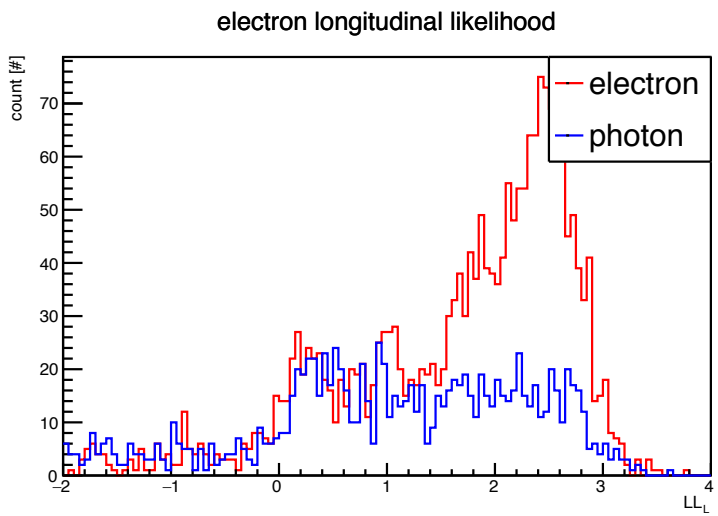
$$P_i = \frac{N}{N_{tot}}$$

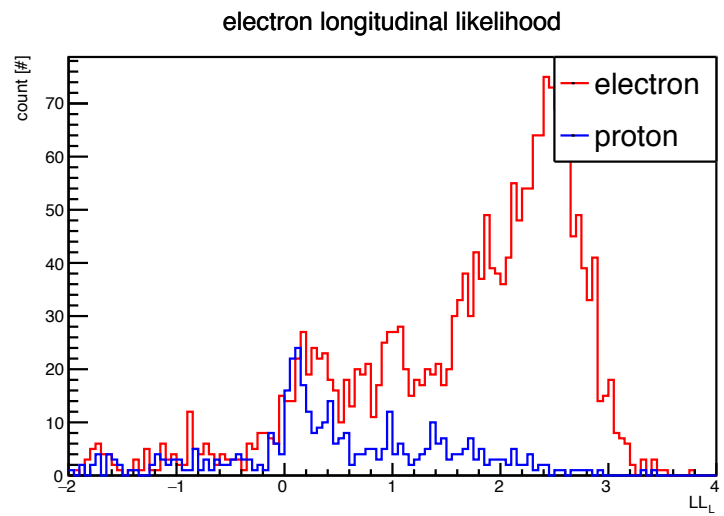
Where N is the number of entries of the bin found in the template histogram and N_{tot} is the total number of entries of the template histogram.

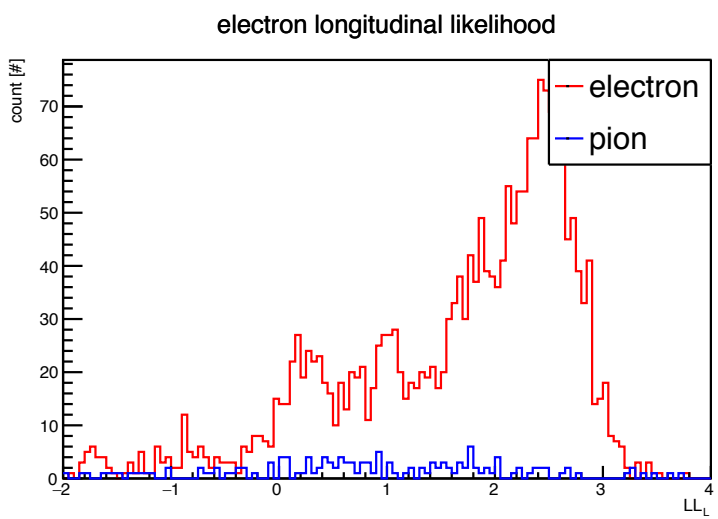
- The likelihood is defined as

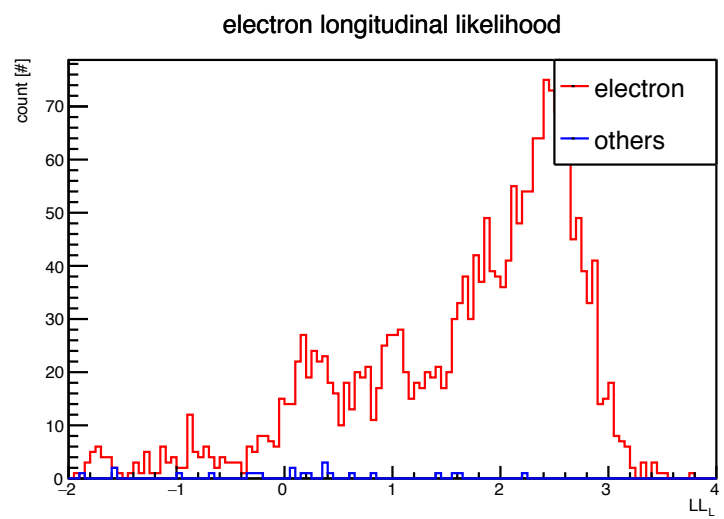
$$LL_{L/T} = \frac{1}{BINS}\sum_i LL_i = \frac{1}{BINS}\ln\left(\prod_i P_i\right) = \frac{1}{BINS}\ln P$$

Likelihood Calculation









Conclusion and Future Work

- We are able to get shower profiles for different particles.
- Using these templates, we are exploring the likelihoods for different showers.
- Next steps:
  - Feed the likelihoods into an Artificial Neural Network that will determine whether the shower is an electron shower.
  - Apply this technique to MicroBooNE, DUNE and other LArTPC experiments.

Acknowledgment

- Thank you to Dr. Wanwei Wu and Dr. Tingjun Yang for their encouragement and guidance throughout this summer.
- Thank you to Ms. Sandra Charles, Dr. Laura Fields and the SIST committee for giving me the opportunity to work and learn at Fermilab.
- Thank you to my mentors Alexander Martinez, Raul Campos and Matthew Alvarez for their assistance throughout my internship here.
- And thank you to all my fellow SISTers for their friendship and support during our twelve weeks working here.