Exploring Different Recombination Models @ ProtoDUNE-SP

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ProtoDUNE Sim/Reco Meeting

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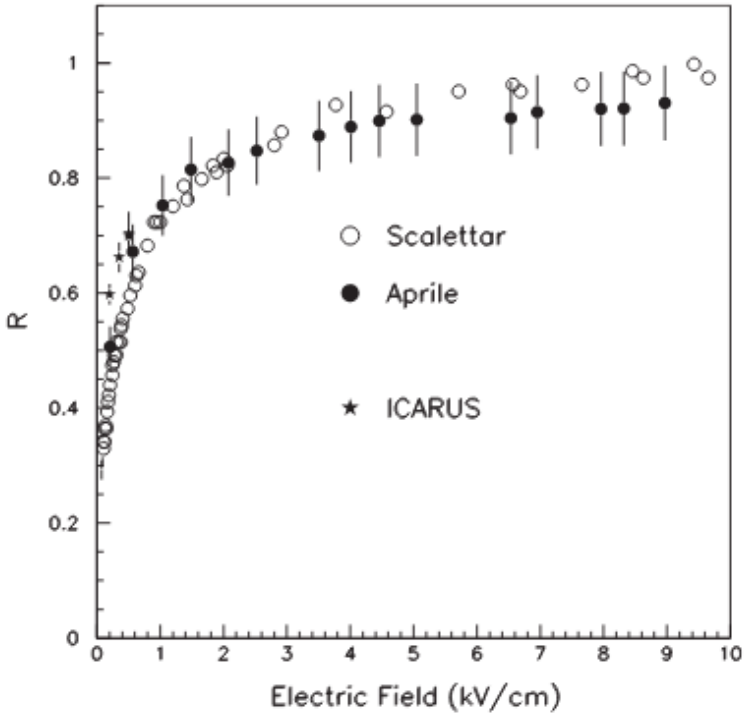
Introduction

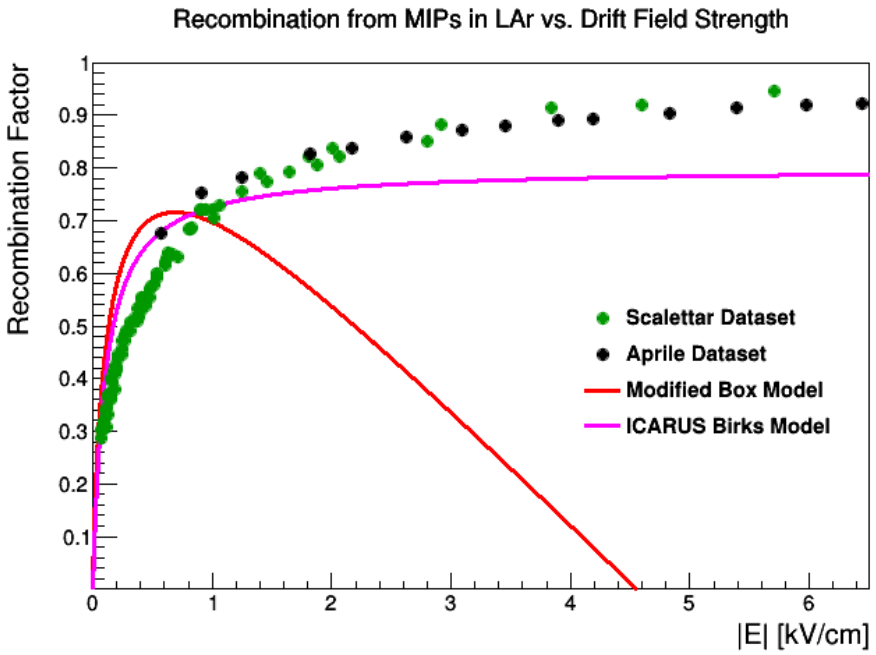
- Different LAr recombination models have been created using measurements at different experiments
  - **ICARUS**: "ICARUS Birks Model" (studies at 200-500 V/cm)
  - **ArgoNeuT**: "Modified Box Model" (studies at ~500 V/cm)
- These models include both dE/dx dependence and electric field dependence
- However, they were built using muons (ICARUS) or protons/deuterons (ArgoNeuT)
  - Should these models be used for **electron/photon showers** that are used in our analyses?
- Also, some differences between ICARUS Birks Model and Modified Box Model at our electric field
- Discuss implications for our systematic uncertainties today

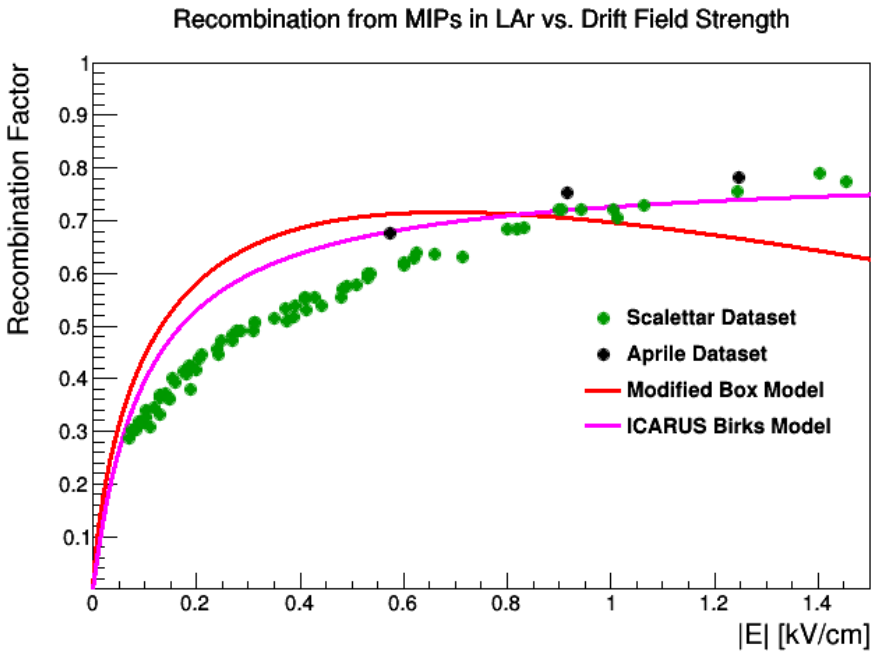
Studies at ICARUS



- ICARUS previously noticed discrepancy at lower electric fields between their measurement with muons and other measurements made with O(MeV) electrons
  - Due to non-MIP like nature of electrons at < 100 keV?
  - Due to **different microphysics** for muons? e.g. delta rays

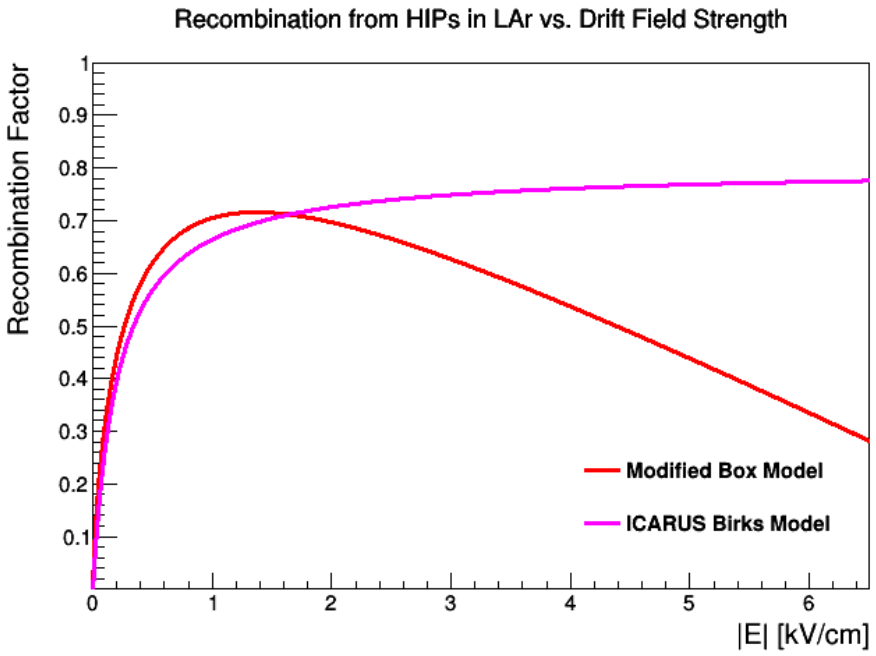
Comparison of Models (MIPs)

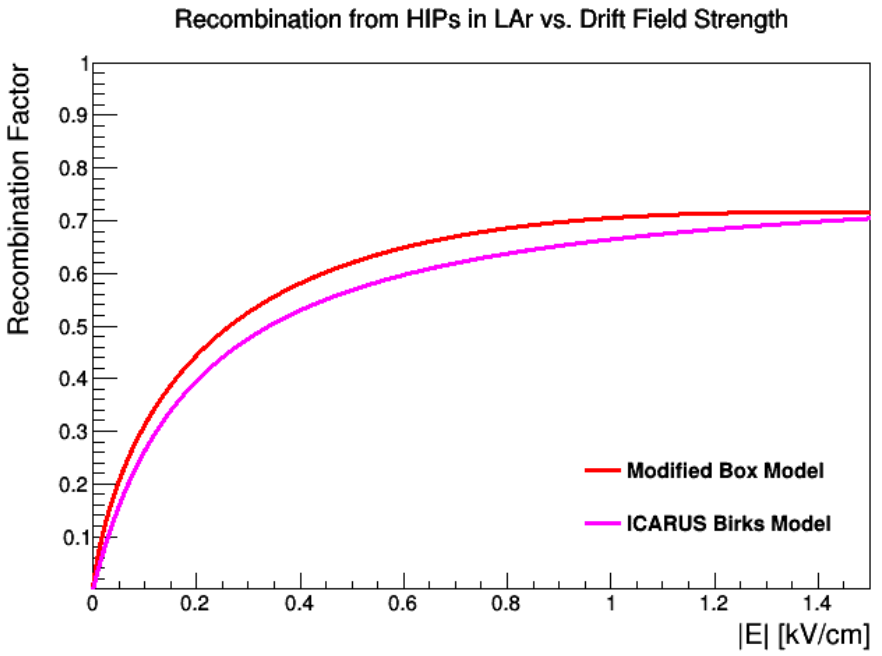




- Found Scalettar and Aprile datasets – compare to ICARUS Birks Model and Modified Box Model (dE/dx = 2.1 MeV/cm)
- Noticeable differences between electrons and muons
- Also, disagreement between ICARUS Birks Model and Modified Box Model at our electric field – O(10%)!
  - Strange behavior of Modified Box Model at high E field … ?

Comparison of Models (HIPs)





- Also compare ICARUS Birks Model and Modified Box Model for HIPs (taken as double MIP dE/dx, so 4.2 MeV/cm)
- Still disagreement between ICARUS Birks Model and Modified Box Model at our electric field – also O(10%)
- We normalize our energy scale using muons at high residual range (MIPs) so we mostly care about MIP-HIP differences

Summary of Comparisons

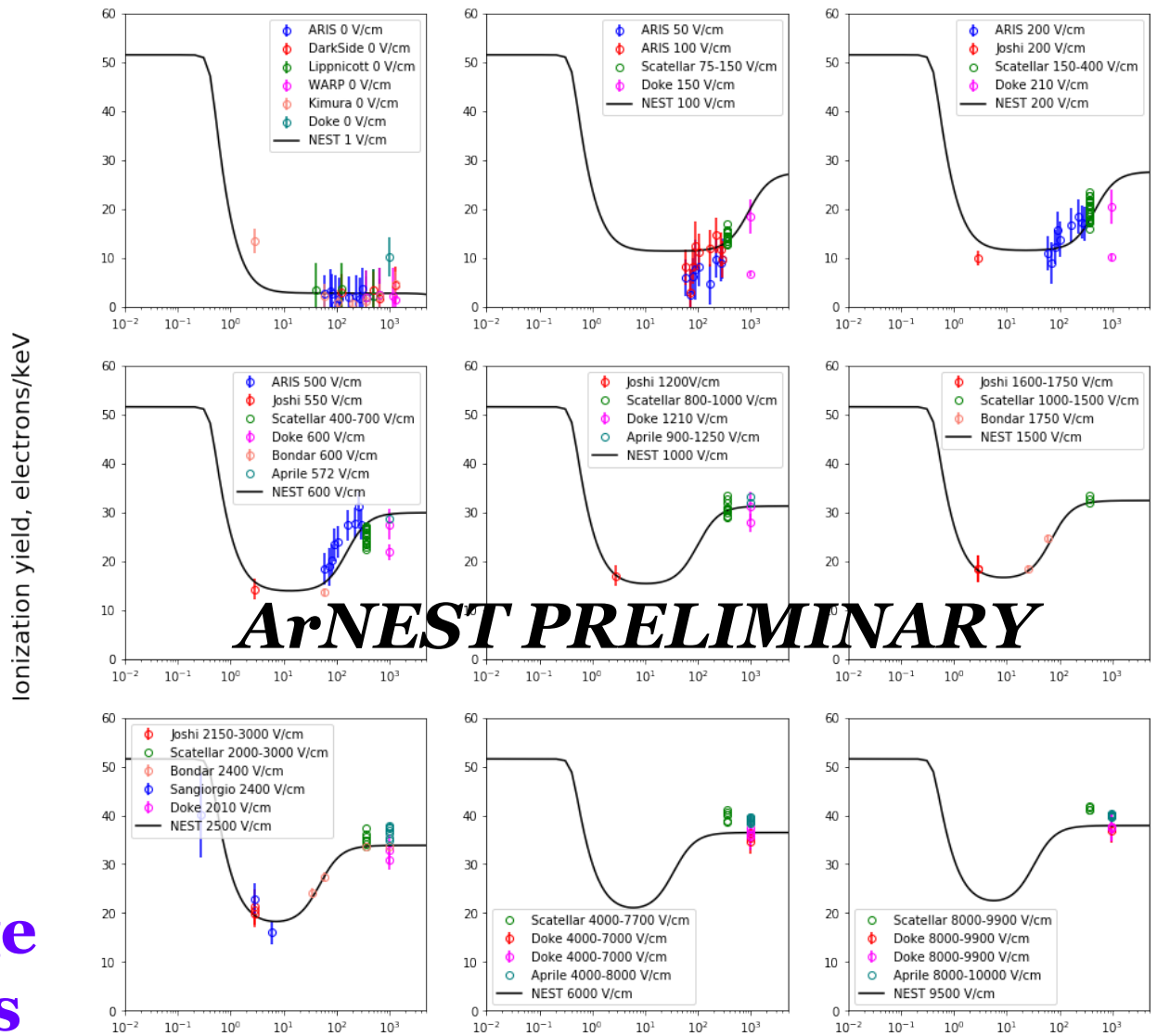
- Compare models for MIPs and HIPs (Scalettar data for electrons for now, as more points at lower E fields), using ProtoDUNE-SP E field of 486.7 V/cm
  - MIPs: 0.58 (Scalettar), 0.661 (ICARUS), 0.703 (Mod. Box)
  - HIPs: 0.564 (ICARUS), 0.616 (Mod. Box)
- Aside: also compare for MicroBooNE, with 273.9 V/cm:
  - MIPs: 0.48 (Scalettar), 0.583 (ICARUS), 0.635 (Mod. Box)
  - HIPs: 0.458 (ICARUS), 0.507 (Mod. Box)
- Normalize energy scale using MIPs (high residual range muons) so mostly care about relative MIP/HIP impact
  - If believe normalization scheme moves us to ICARUS working point, residual bias on HIPs would be **~3% overestimate of HIP dE/dx**
- But what about electrons? Data says something very different!

ArNEST for Electrons?

- Scalettar dataset uses 364 keV electrons, Aprile dataset 976 keV electrons – is non-MIP-like nature of low-energy electrons contributing to discrepancy?
- **ArNEST** (Ar Noble Element Simulation Technique) developing ionization/scintillation model using "electron recoil" data at various energies and electric fields
  - Would account for non-MIP-like features with energy dependence, which can be translated to a dE/dx dependence
  - If different microphysics at play for electrons, this model would be more appropriate to use (informed by measurements made actually using electrons)
- ArNEST being developed by CSU grad. student Justin Mueller
- Some preliminary ArNEST fit results on following slides

Prelim. ArNEST Fit Results

J. Mueller, E. Kozlova

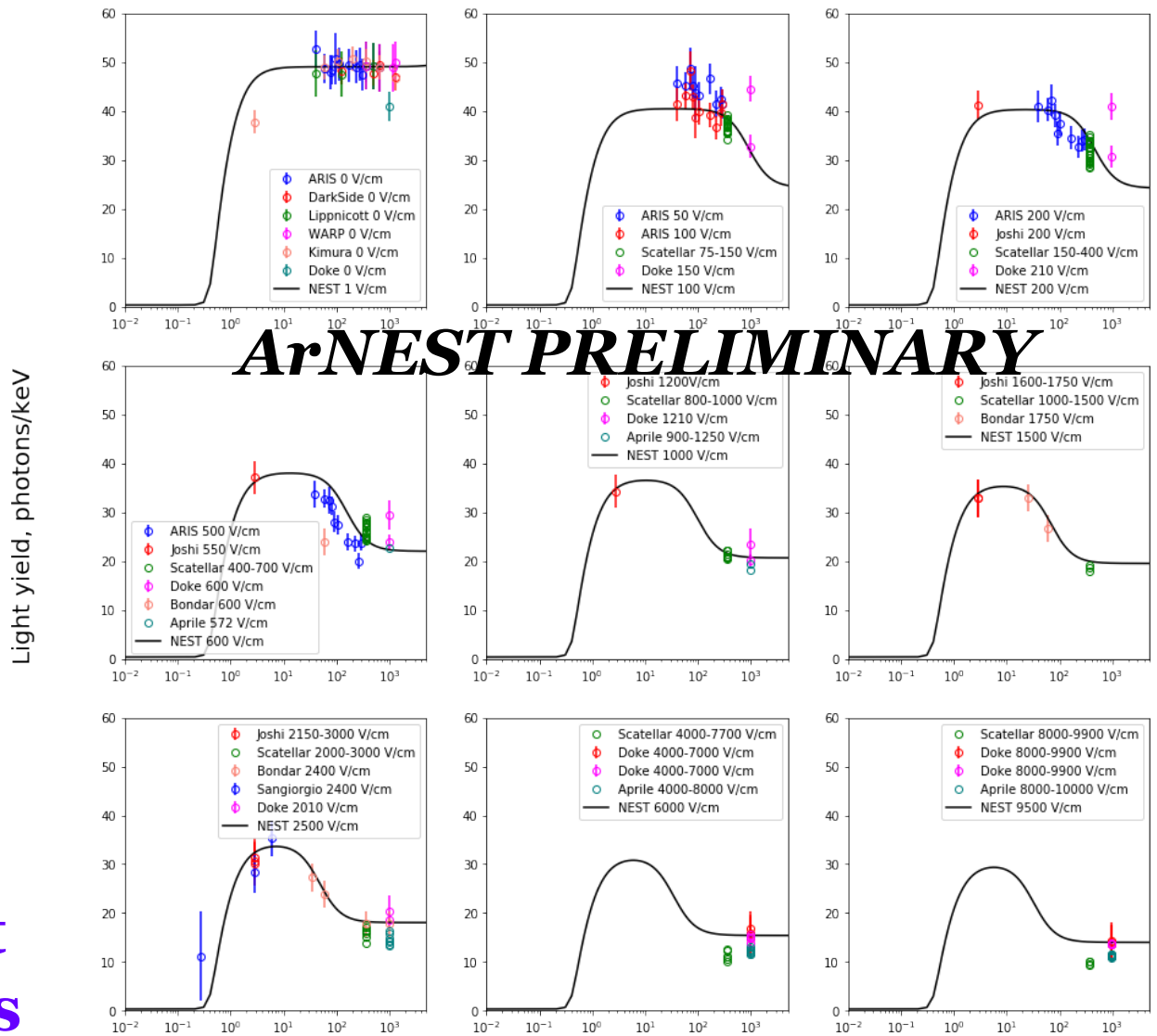


ArNEST PRELIMINARY

Charge Yields

Prelim. ArNEST Fit Results

J. Mueller, E. Kozlova



Light Yields

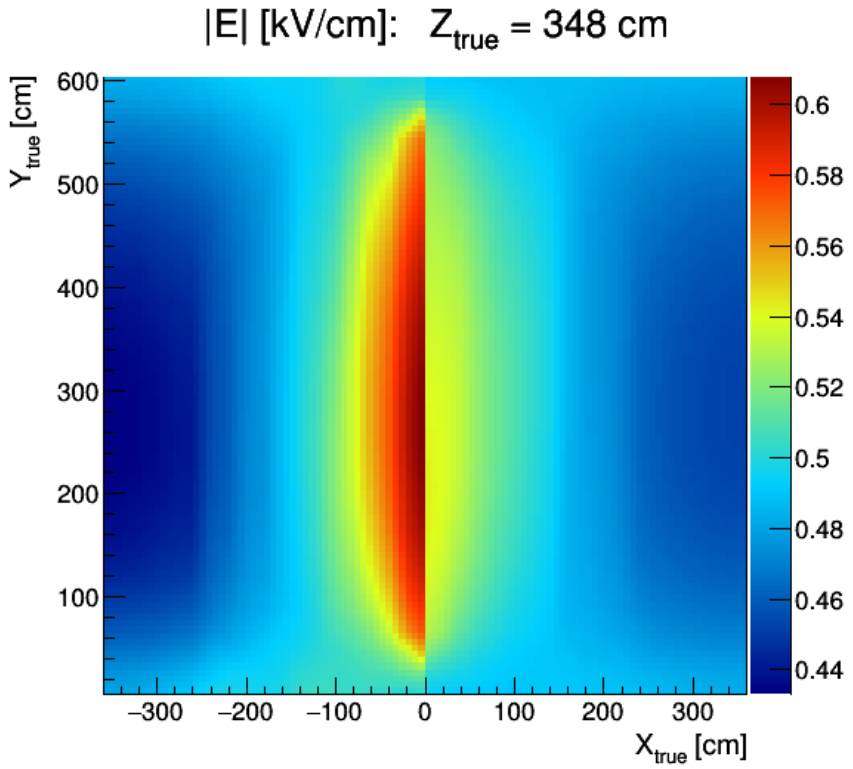
Case Study: SCE Impact on π^0

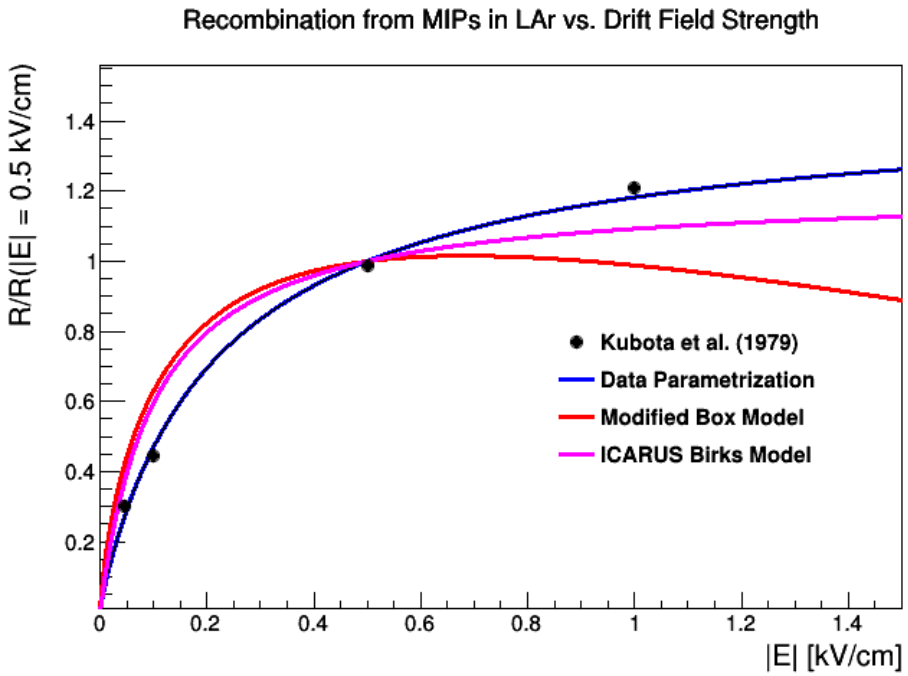
- Two space charge effect (SCE) corrections should be made to our π^0 events:
  - Spatial correction: impacts angles of photons (thus π^0 opening angle), photon dE/dx
  - E field correction: impacts photon energy (through recombination)
- Explore different recombination models we might want to use in π^0 analysis
  - **Different implications for EM shower energy scale**
- Also discuss first studies of impact of SCE on reco. π^0 mass
  - Assumes we are using knowledge of π^0 decay point and photon shower start points to determine opening angle (should give best mass resolution)

Methodology

- Making use of a sample of roughly 2300 π^0 events (from beam π^+ interactions), including location of π^0 decay, location of each photon interaction start point, and energy of each photon
  - Select only candidates with exactly two photon daughters
- Reconstruct π^0 mass for four cases:
  - No SCE simulation included
  - Only E field SCE simulation included (impacts photon energies)
  - Only Spatial SCE simulation included (impacts opening angle)
  - Full SCE simulation included (impacts both)
- Repeat above study for three different recombination models:
  - Modified box model
  - ICARUS Birks model
  - Scaling from Kubota data (charge yield from ~1 MeV beta decays)

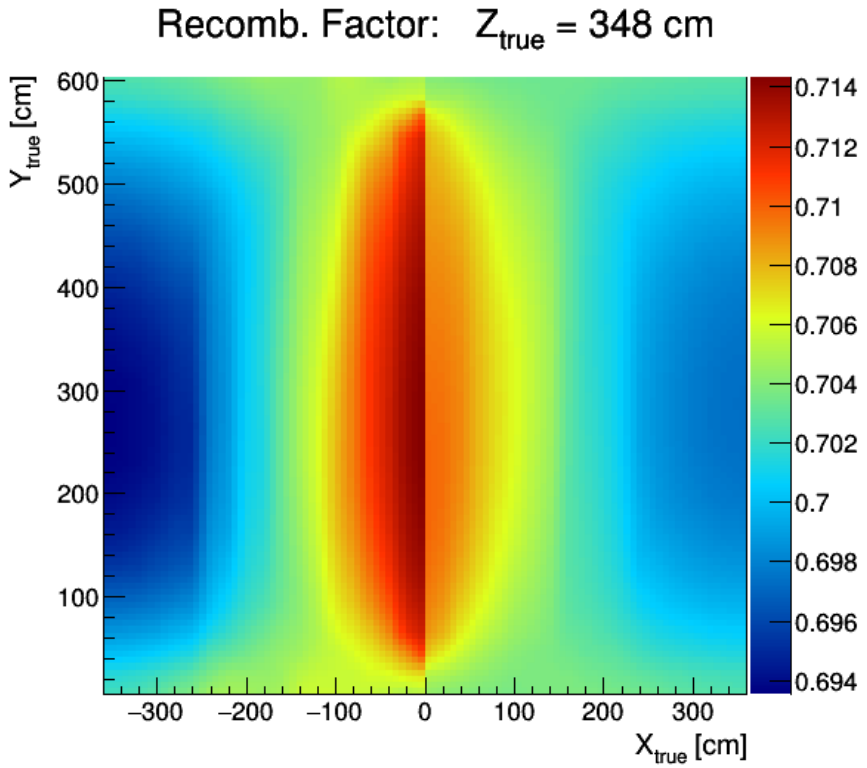
E Field SCE Corrections

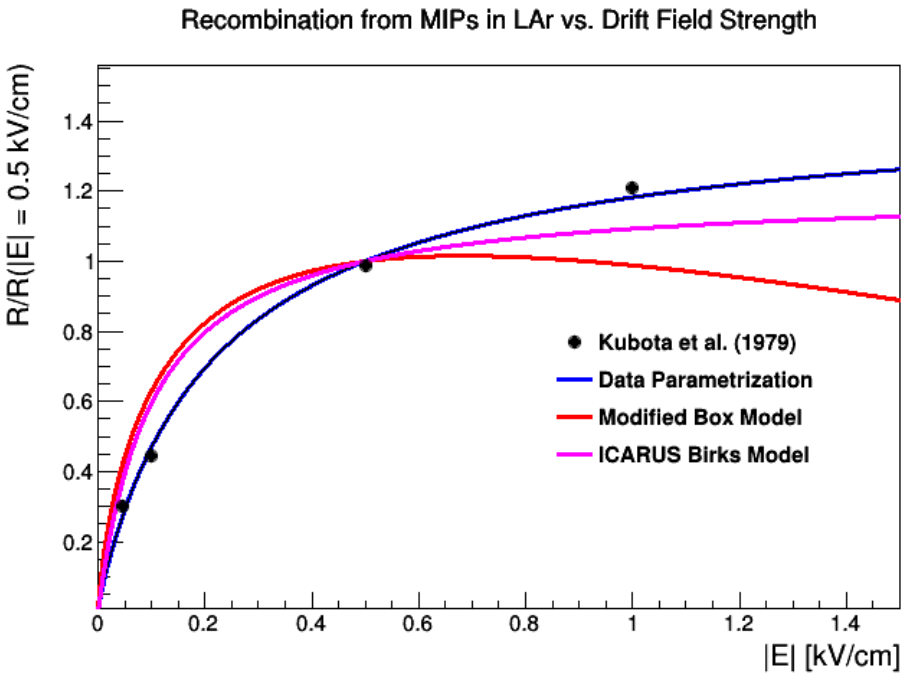




- Can both simulate and correct for impact of E field through recombination → impacts charge/energy scale
  - However… which recombination model to use?
  - Complicated question… use different models for different parts of shower, based on topology?

Modified Box Model





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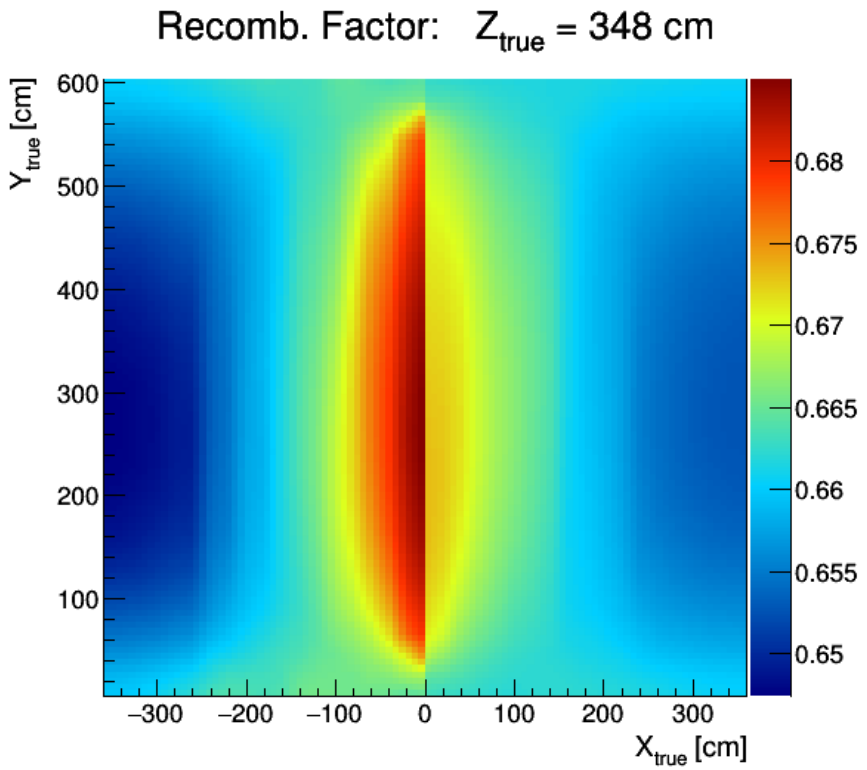
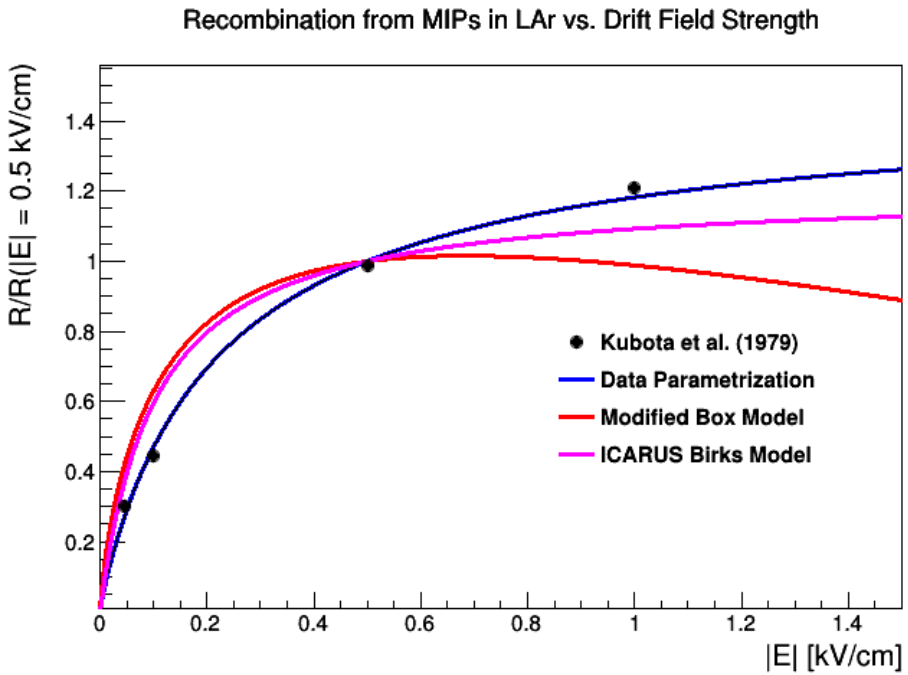
ICARUS Birks Model





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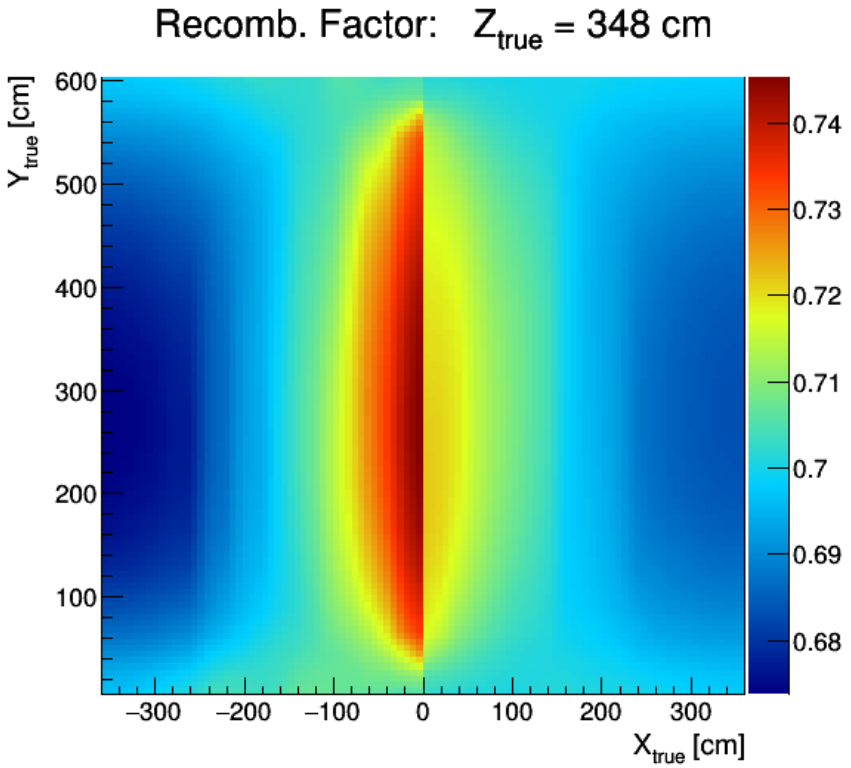
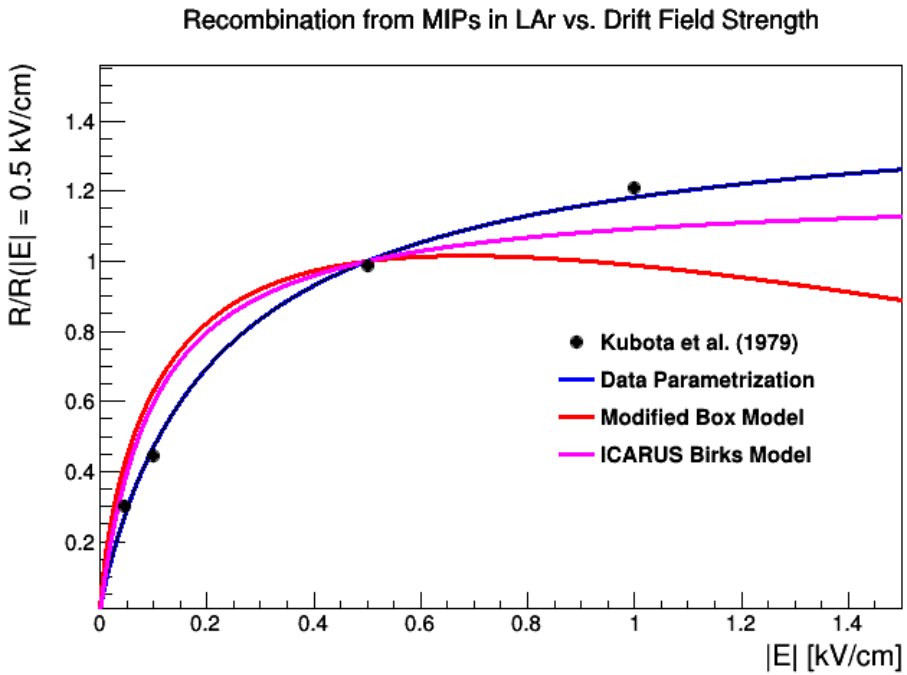
Mod. Box w/ Kubota Scaling





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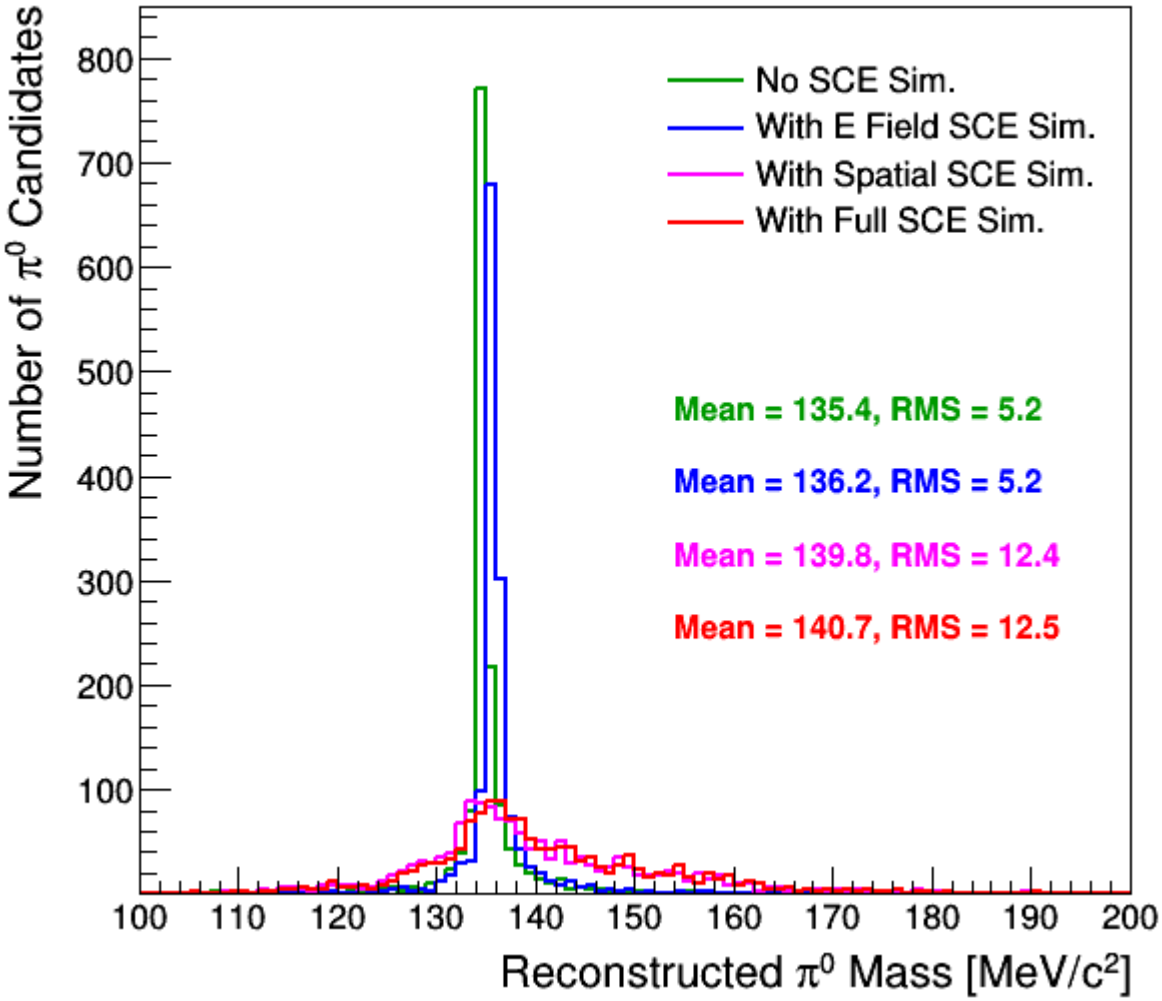
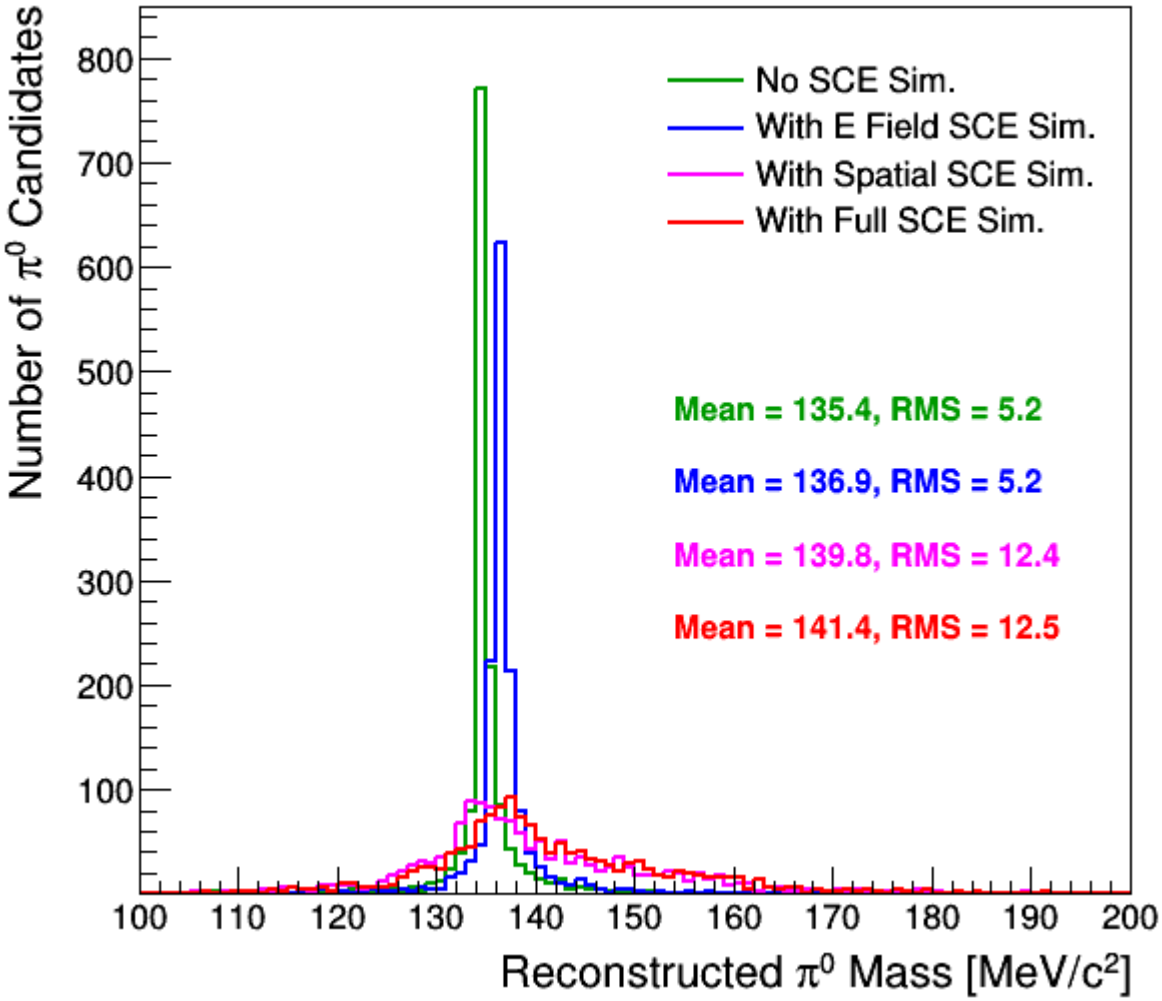
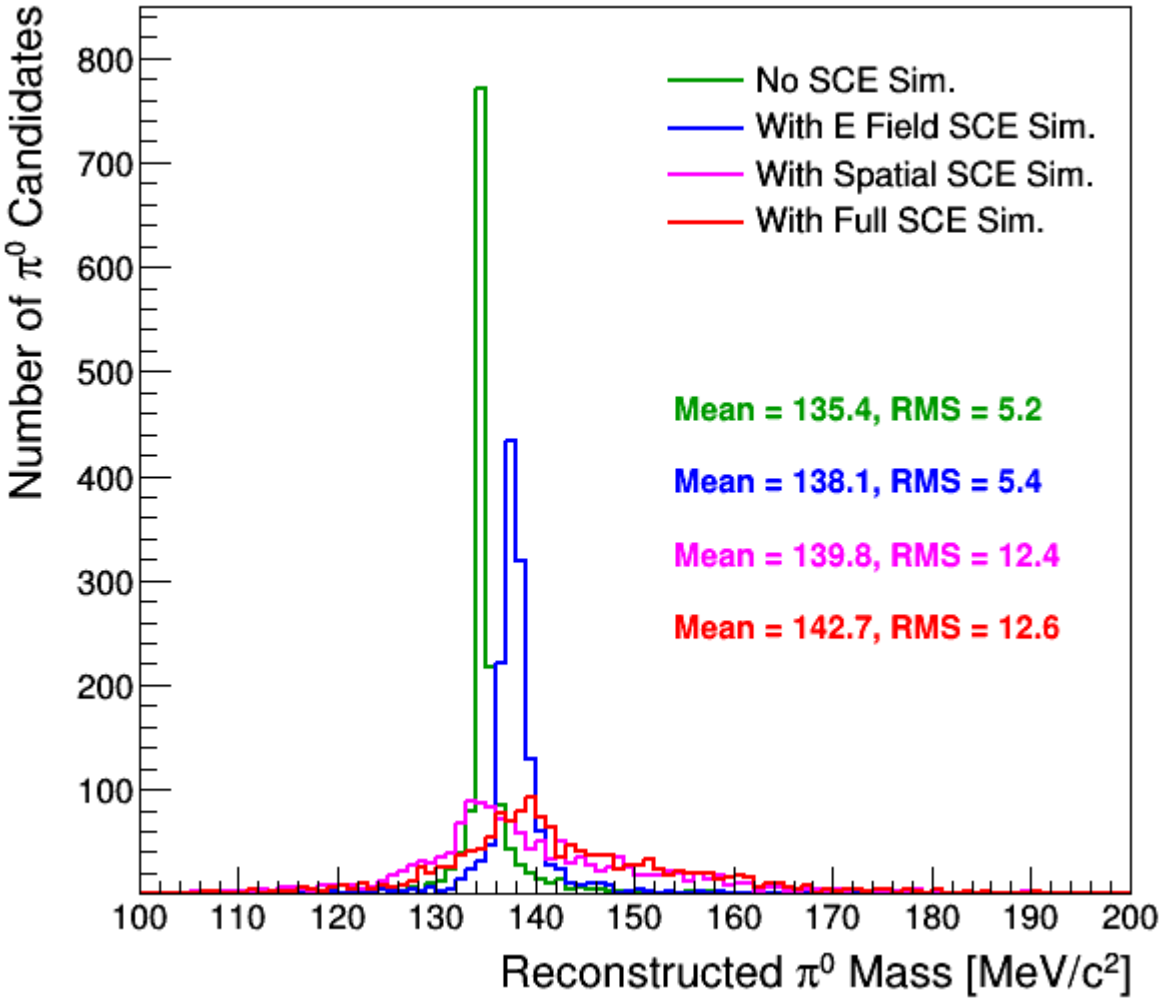
Results: Mod. Box Model



Results: ICARUS Birks Model



Results: Kubota Scaling



Discussion

- Different recombination models make predictions that vary by up to **10%** in predicted MIP, HIP free charge scale
  - Given how we determine energy scale using muons in data, MIP/HIP ratio most important → difference of **3%** comparing Birks, Box models
- Low-energy electron data suggests story could be much different for electrons → *study in ProtoDUNE-SP using data!*
  - **Use beam electrons, π^0 photons, Michels, and ^{39}Ar beta decays**
- Use ArNEST For electron/photon shower recomb. model?
  - Preliminary version soon (end of year) available for us to study and compare to electron/photon measurements w/ data
- As a case study, impact of SCE non-negligible to π^0 analysis, and different impact for different recombination model choice
  - Spatial SCE impact more important in general
  - E field SCE impact becomes more important for certain recombination models (ICARUS Birks model, measurements with beta decays)

BACKUP SLIDES