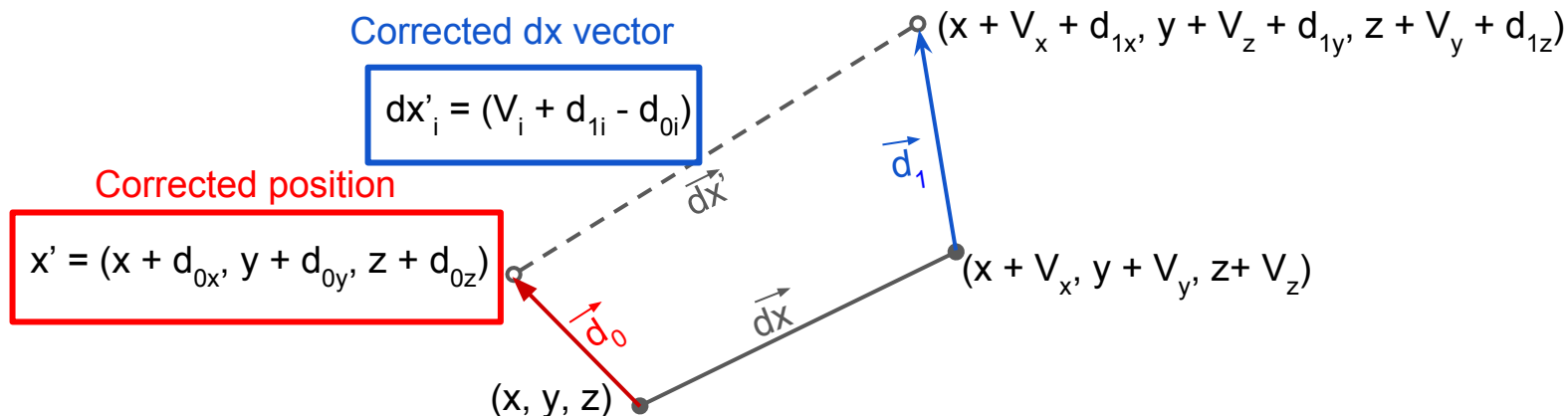# SCE-Corrected dE/dx Calculation in dunetpc

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February 27, 2019 - *ProtoDUNE Sim/Reco Meeting*

Calibration Corrections

- Spatial corrections for **dE/dx** or **dQ/dx** applied in larreco/Calorimetry/Calorimetry_module.cc
  - Both position and dx vector must be corrected

Corrected dx vector

$$dx'_i = (V_i + d_{1i} - d_{0i})$$

Corrected position

$$x' = (x + d_{0x}, y + d_{0y}, z + d_{0z})$$

$(x + V_x + d_{1x}, y + V_z + d_{1y}, z + V_y + d_{1z})$

$\vec{d_1}$

$\overrightarrow{dx'}$

$(x + V_x, y + V_y, z + V_z)$

$\vec{d_0}$

$\overrightarrow{dx}$

(x, y, z)

- Electric field corrections for **dE/dx** applied in dunetpc/Protodune/singlephase/dEdxcalibration/CalibrationdEdxPDSP_module.cc
  - Already spatially corrected (from Calorimetry_module.cc)
  - Corrected electric field used to calculate new recombination parameters from modified box model

Test of Implementation

- Use 1000 isotropic, high-energy (1000 GeV), quiet muons to cover detector
  - Each trajectory point should have same deposited energy (dE/dx = 2 MeV/cm)
- Compare 5 data sets:

| Set	SCE in sim?	SCE in reco?
1	No	No
2	Yes	No
3	Yes	Spatial only
4	Yes	E-field only
5	Yes	Yes (both)
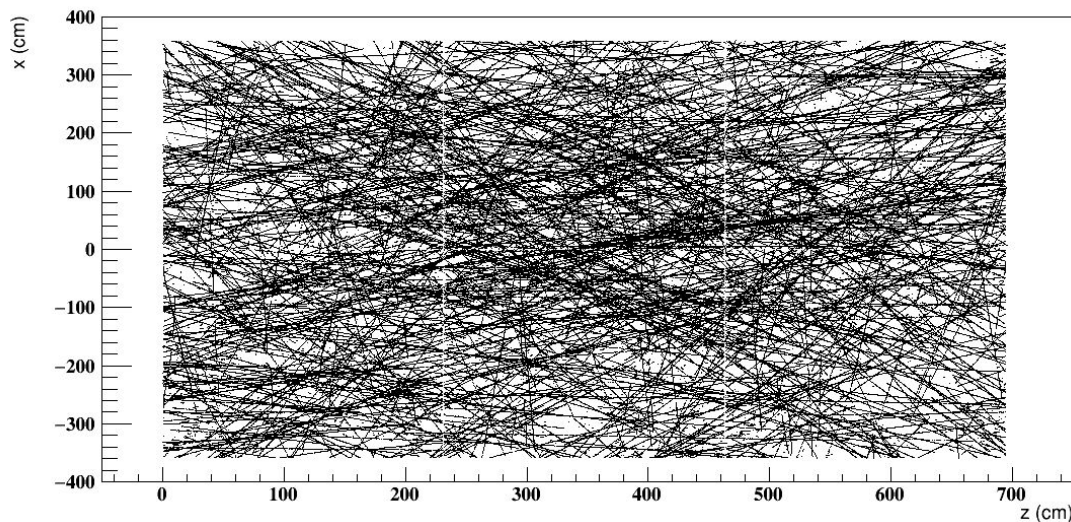
dE/dx with no simulated SCE

- Two peaks seen in dE/dx
  - Higher peak follows expected decay from electron lifetime
  - Lower peak is flat in x
- Lower peak due to tracks parallel to collection plane
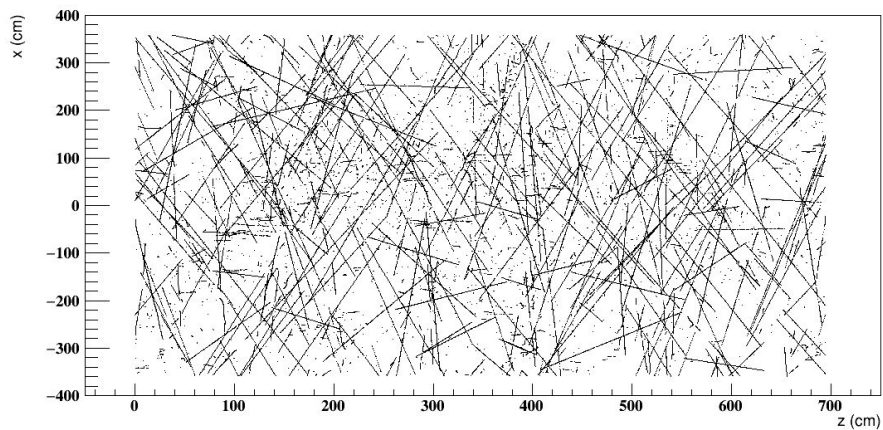 - Angle cut suggested
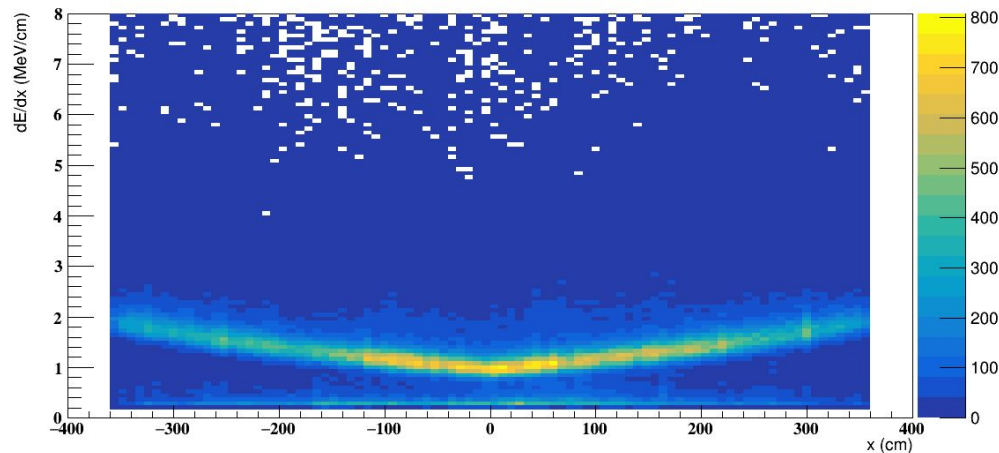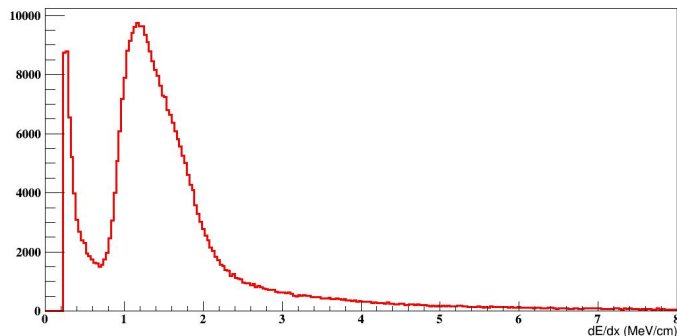
Angle Cut Definition

- Define Θ_{XZ} and Θ_{YZ}: Angle between Z-axis and projection onto XZ or YZ plane
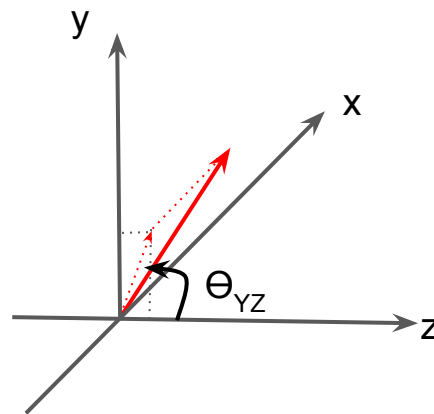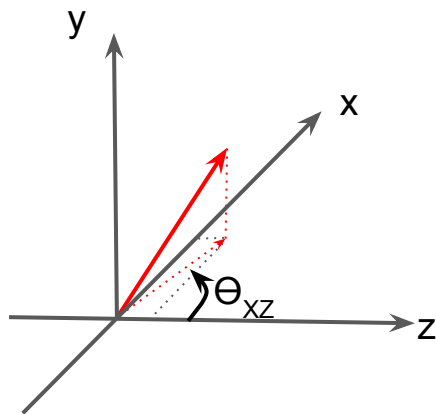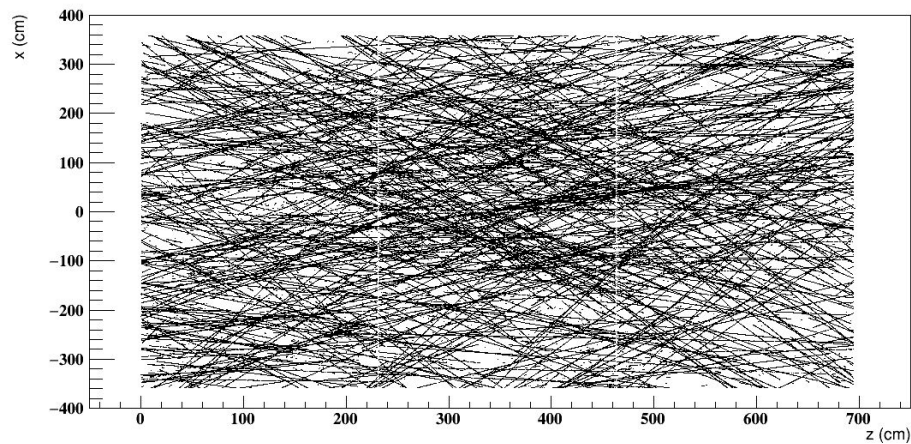

- Remove tracks with $|\Theta_{XZ}| = (1.13, 2.0)$ OR $|\Theta_{YZ}| = (1.22, 1.92)$
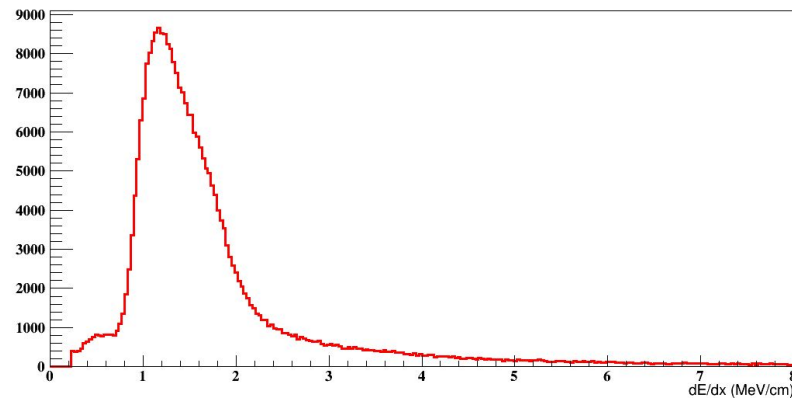
Defined Angle Cut

Tracks removed:
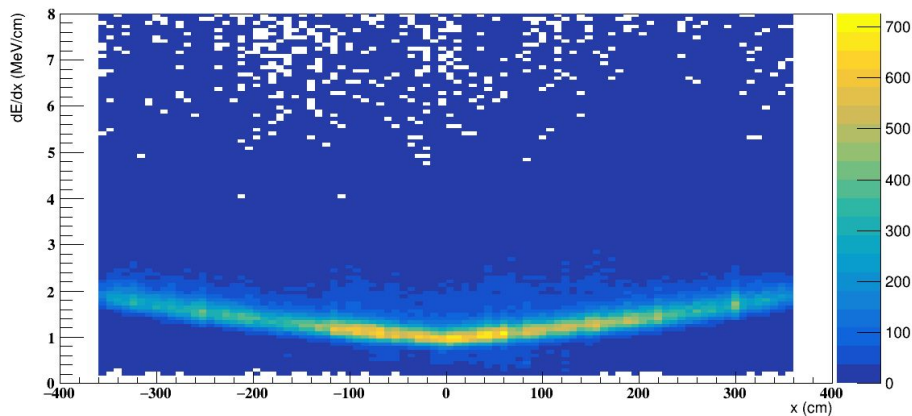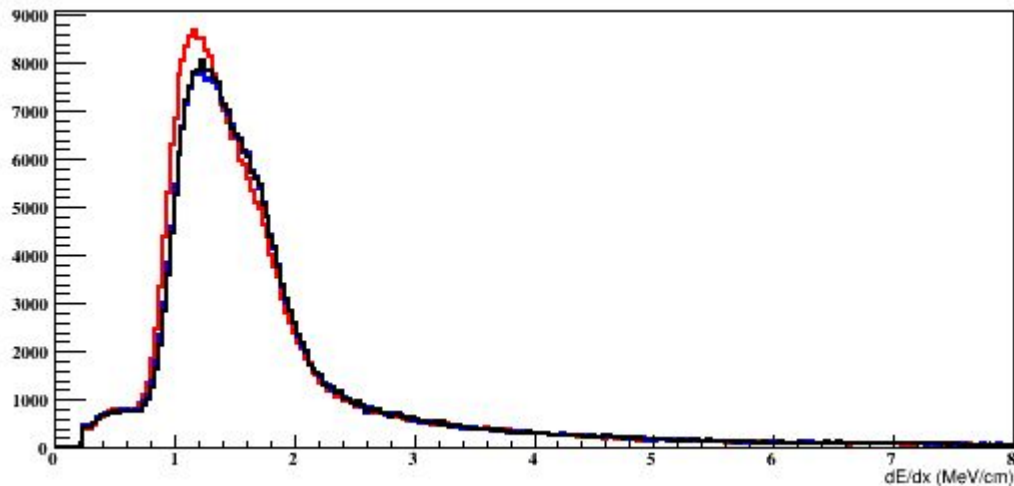
Tracks kept:

Angle Correction

- Angle cut successfully removes lower dE/dx peak

Comparison between Samples

- Effect of SCE in simulation visible
  - Slight shift
  - Broadening could be more obvious with infinite electron lifetime
- SCE correction in reconstruction not working?

- Red = no SCE in simulation
- Blue = SCE in sim / no SCE in reco
- Black = SCE in sim / full SCE in reco

Double Check Using Simple Muon

- Simulated quiet muon down the center of one set of APAs
- In all plots:
  - Red = no SCE in sim
  - Blue = SCE in sim / no SCE in reco
  - Black = SCE in sim / full SCE in reco
- Spatial correction look correct
  - Track location and pitch (dx)
  - dE/dx "blob" width doesn't change
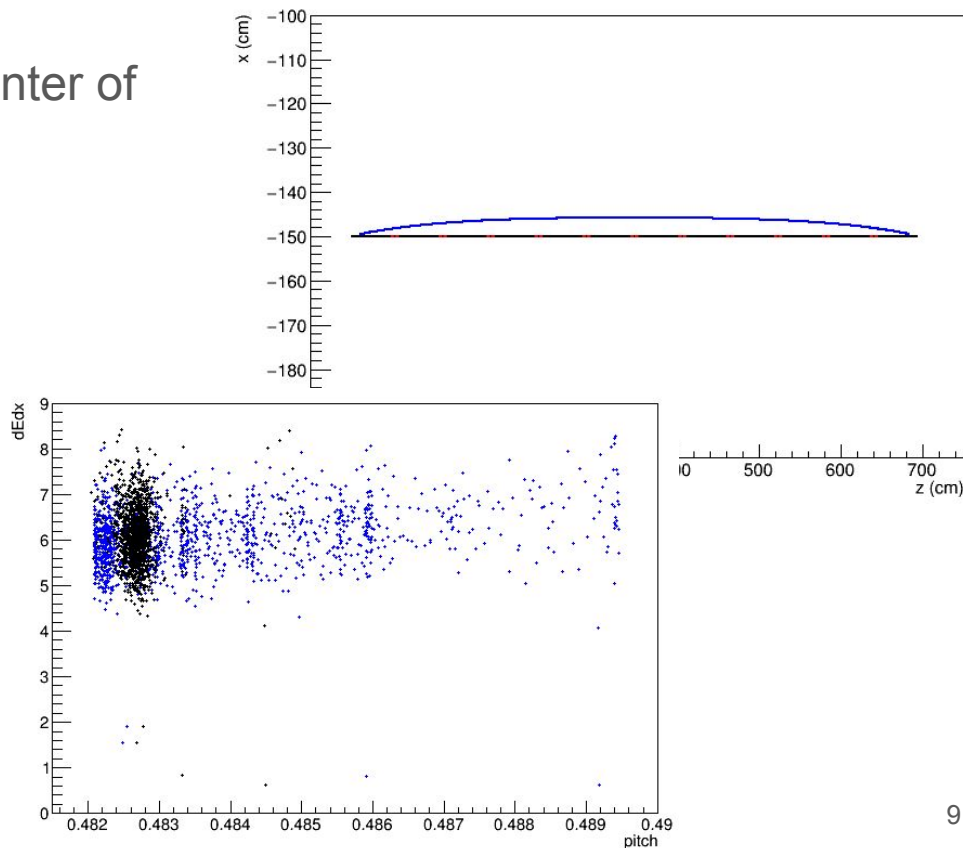
Double Check Using Simple Muon

- ● dE/dx vs. residual range:
  - ○ dx correction increased length of muon
  - ○ No change to dE/dx from spatial or electric field corrections?
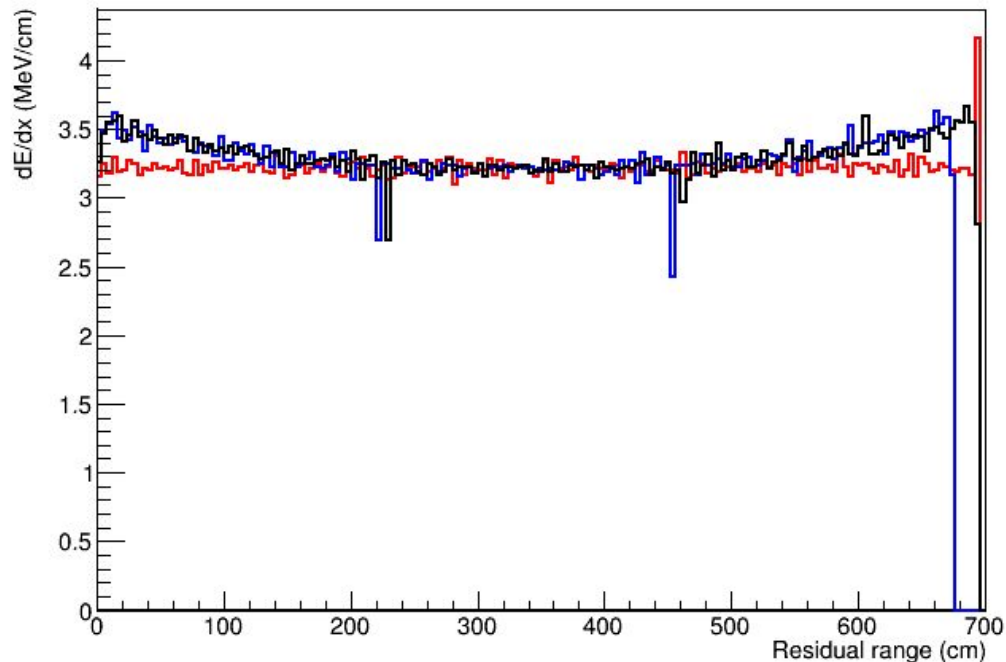
dE/dx calculation in Calorimetry_module.cc

1. Calculate dQ/dx from hit information (dx can be SCE corrected)
2. Use CalorimetryAlg.cc to calculate dQ/dx_e from dQ/dx
   a. Convert dQ/dx to dQ/dx_e (ADC/cm to e/cm) using CalAreaConstants: [4.833e-3, 4.815e-3, 4.966e-3] in calorimetry_dune10kt.fcl
   b. Apply lifetime correction based on hit time and track t_0
      i. Controlled by fcl parameter (default *true* for uboonecode and dunetpc)
3. Use DetectorPropertiesService to calculate dE/dx from dQ/dx_e
   a. Uses modified box model with nominal electric field

dE/dx calculation in CalibrationdEdxPDSP_module.cc

1. **Use dQ/dx as calculated in Calorimetry_module.cc**
2. Use CalorimetryAlg.cc to calculate dQ/dx_e from dQ/dx
   a. Convert dQ/dx to dQ/dx_e (ADC/cm to e/cm) using CalAreaConstants: [4.833e-3, 4.815e-3, 4.966e-3] in **calorimetry_pdune.fcl** *(values chosen to match Calorimetry_module.cc)*
   b. ~~Apply lifetime correction based on hit time and track t_0~~
3. Calculate dE/dx from dQ/dx_e
   a. *Method matches that of DetectorPropertiesService except:*
   b. ~~Applies dQ/dx uniformity calibration~~ *(Turned off for now)*
   c. Uses modified box model with **SCE-corrected electric field**

Excerpt from CalibrationdEdxPDSP_module.cc

```
178            //Calculate dE/dx uisng the new recombination constants
179            double dQdx_e = caloAlg.ElectronsFromADCArea(vdQdx[j], planeID.Plane);
180            double rho = detprop->Density();           // LAr density in g/cm^3
181            double Wion = 1000./util::kGeVToElectrons;  // 23.6 eV = 1e, Wion in MeV/e
182            double E_field_nominal = detprop->Efield(); // Electric Field in the drift region in KV/cm
183
184            //correct Efield for SCE
185            geo::Vector_t E_field_offsets = {0., 0., 0.};
186
187            if(sce->EnableCalEfieldSCE()&&fSCE) E_field_offsets = sce->GetCalEfieldOffsets(geo::Point_t{vXYZ
    [j].X(), vXYZ[j].Y(), vXYZ[j].Z()});
188
189            TVector3 E_field_vector = {E_field_nominal*(1 + E_field_offsets.X()),
    E_field_nominal*E_field_offsets.Y(), E_field_nominal*E_field_offsets.Z()};
190            double E_field = E_field_vector.Mag();
191
192            //calculate recombination factors
193            double Beta = fModBoxB / (rho * E_field);
194            double Alpha = fModBoxA;
195            vdEdx[j] = (exp(Beta * Wion * dQdx_e) - Alpha) / Beta;
196
```

Conclusions

- SCE corrections don't seem to change dE/dx
  - I've shown this to work at MicroBooNE; very little change from MicroBooNE code
- I've confirmed the following:
  - The dE/dx value calculated matches expectation from new electric-field using modified box model for recombination
  - The electric field distortions match from simulation, reconstruction, and expectation
  - Modified box model for recombination gives ~2.5% change in dE/dx for ~10% change in electric field
- Any suggestions?