Charge and light studies in the FD-HD

***M.Torti**, G.Brunetti*

Università di Milano Bicocca and INFN Milano Bicocca

FD Sim/Reco meeting 21st November 2022

Our simulation

- Far detector Horizontal Drift with refactored geometry, LarG4 algo: IonAndScint Correlated, reconstruction: pandora
- Event samples:
  - 500 beam ν_e
  - 300 beam ν_μ

  } Q+L energy reconstruction → resolution wrt deposited and true energy

  monoenergetic single muons

  ```
  Vertex: x = [-330, 330], y = [-570, 570], z = 30;
  Angle: θxz = [-30,+30], θyz = [-30,+30]
  E = 350 MeV, 500 MeV, 750 MeV, 1 GeV, 1.5 GeV, 2.0 GeV
  → 300 events for each energy
  ```

  monoenergetic single electrons

  ```
  E = 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 GeV
  → 500 events for each energy
  ```

  }
  - Check Charge-Light anticorrelation → this presentation
  - Resolution VS energy → in progress
- Analysis using: all collection plane charge hits of the event
  all PE reco of the events
- To compare reconstructed energy to the true energy → Containment cut: pandora spacepoints of the event in fiducial volume: $|x| < 310$, $|y| < 550$, $50 < z < 1250$ cm

Energy estimation with Charge and Light (Recap)

The energy deposited in the detector goes into 2 observables, **Charge and Light**

Charge: $\mathbf{Q = N_e} = N_i R$

Light: $\mathbf{L = N_\gamma} = N_{ex} + N_i (1\text{-}R)$ *R = Recomb. factor*

$\mathbf{Q+L} = N_i + N_{ex} = \mathbf{\Delta E / W_{ph}}$

$\mathbf{W_{ph} = 19.5\ eV}$ = average amount of energy deposited by a charged particle to produce an ion or exciton

→ Charge and Light Sum is directly proportional to the energy deposited
→ one can perform a calorimetric measurement by-passing the correction for recombination that is no longer necessary

$$\mathbf{EQL = W_{ph} * (Q+L)}$$

Energy from Charge:

$$EQ = Q*R/W_{ion}$$

W_{ph} is related to the ionization work function, W_{ion} through the excitation ratio α: W_{ion}=23.6eV=(1-α)W_{ph}*

So we need:

Q = N_e = Calculated number of ioniz. Electrons from reconstructed charge

L = N_γ = Calculated number of scintillation gammas from reconstructed OpDet PE

Charge and Light

- **Q ↔ Ioniz. Electrons** $Q = C^{e}_{cal} \Sigma_i (q_i\, e^{(ti/\tau)})$

  $q_i\, e^{(ti/\tau)}$ = Charge corrected by electron lifetime
  = Sum of all collection plane hits corrected by electron lifetime
  C^{e}_{cal} = ADC to electron calib. const→ In the fcl files we found:
  `ElectronsToADC: 6.8906513e-3` → $1/6.89e^{-3}$

- **L ↔ Scint. Gammas** $L = \text{Total PE} / (0.03 * F_{vis})$

  3% Quantum Eff
  $F_{vis} = (\Sigma f_{vis}(p_i) q_i)/\Sigma q_i$ = Charge weighed **visibility function of the event**
  ↓
  light map value in $p_i = x_i, y_i, z_i$ = Pandora SPACEPOINT

- If calculation is done correctly:

  Q should correspond to the number of ioniz. electrons and

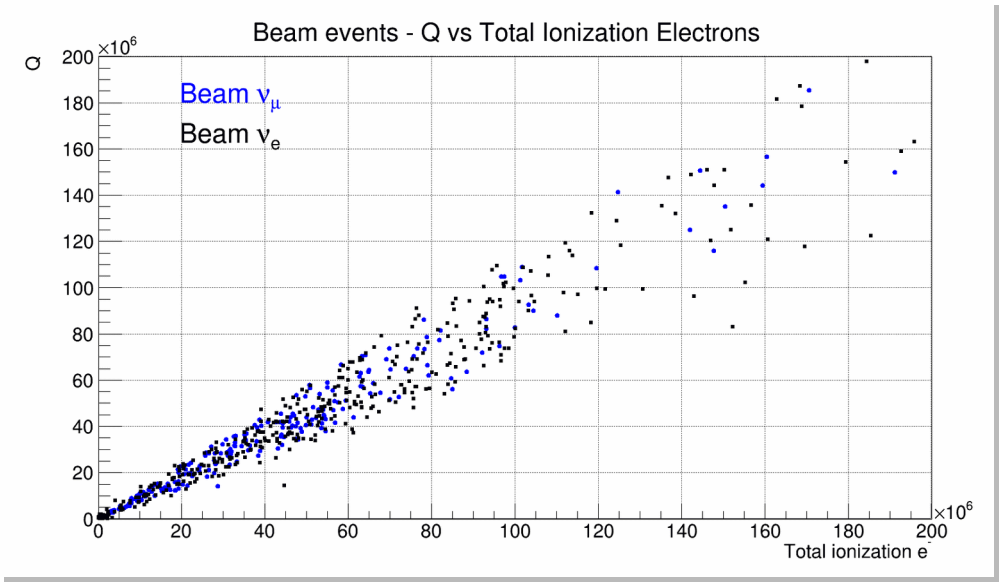
  L to the number of scint. gammas produced by Ion&Scint

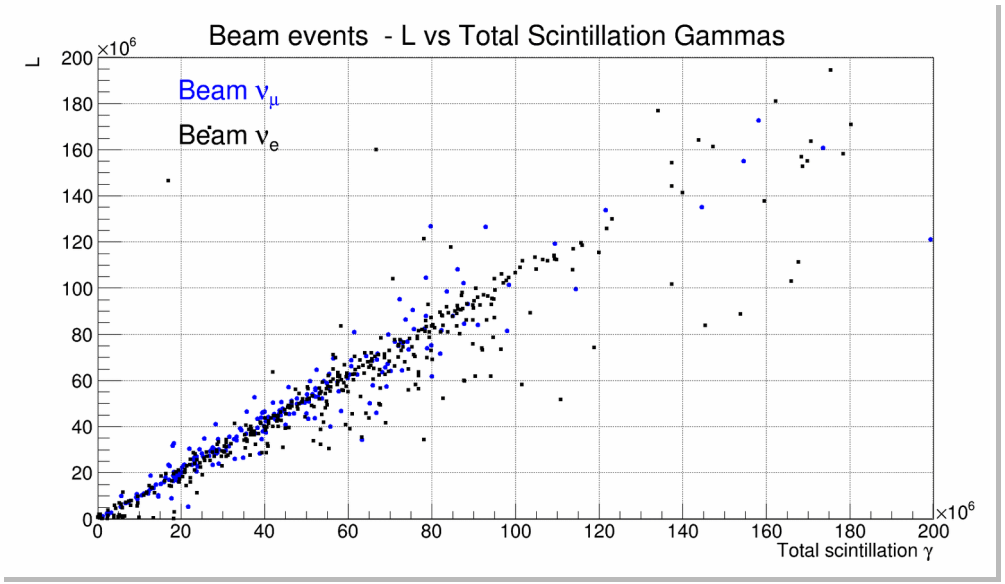
More details in https://indico.fnal.gov/event/56743/contributions/252933/attachments/160820/212011/brunetti_charge_light_fd.pdf

Beam ν_μ and ν_e events - Q and L

- If calculation is done correctly, Q should correspond to the number of ioniz. electrons and L to the number of scint. gammas produced by Ion&Scint

→ Check Q vs Ioniz. Electrons and L vs Scint. Gammas from Ion&Scint

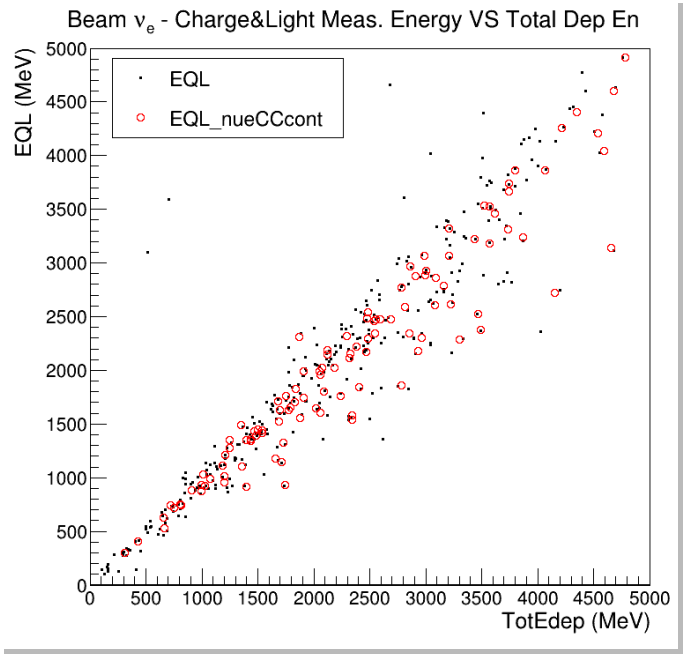




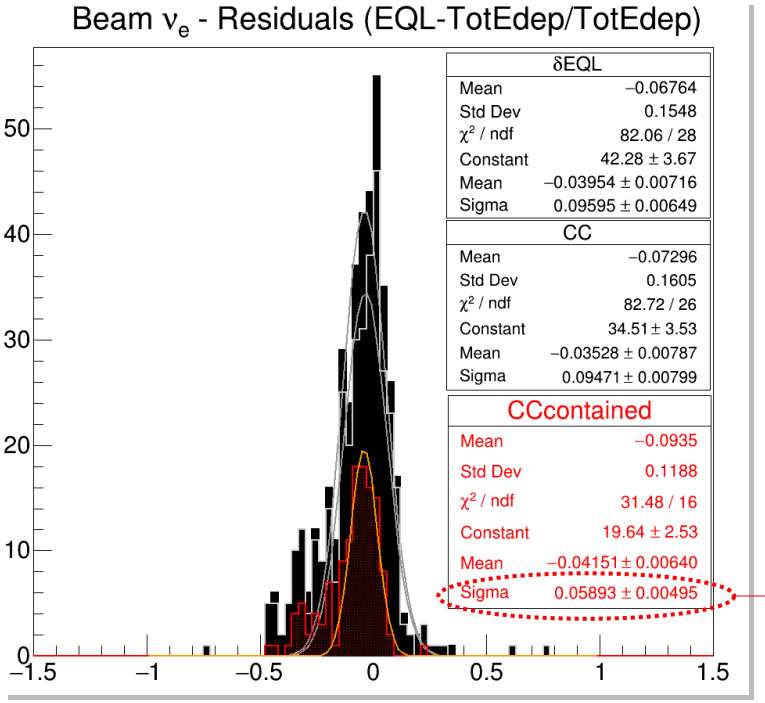
Beam ν_e events – EQL vs Deposited Energy

$$EQL = W_{ph} * (Q+L) \rightarrow$$

EQL vs Total Deposited Energy from Ion&Scint



Residuals



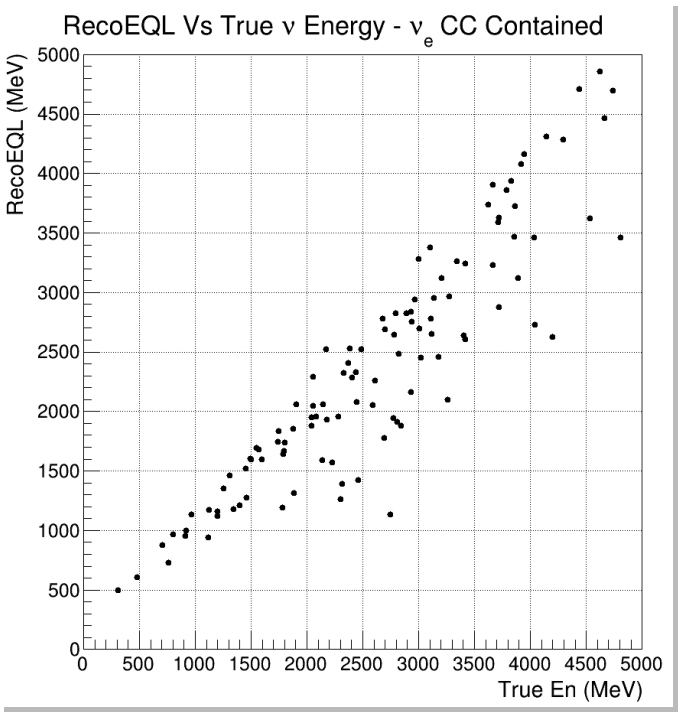
6% resolution for ν_e CC contained events

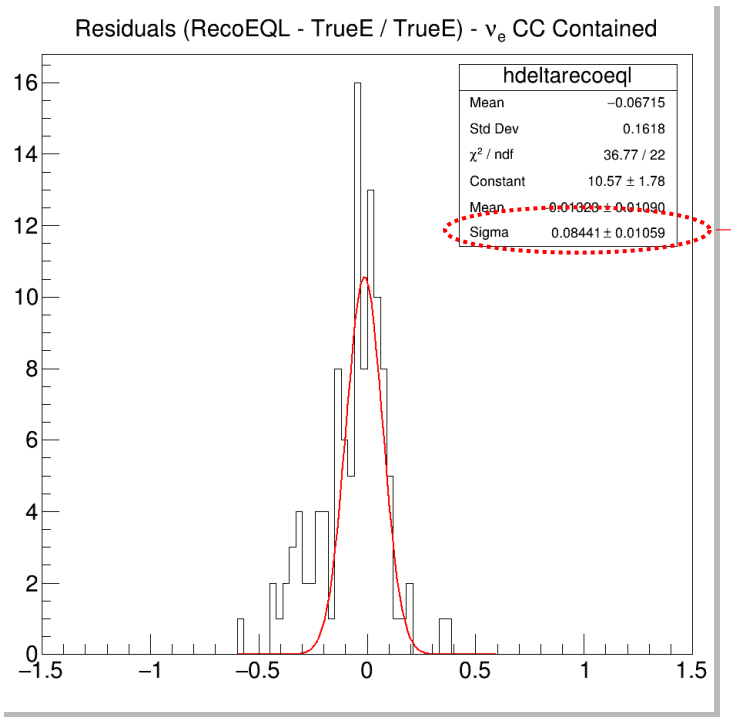
Details at: https://indico.fnal.gov/event/56743/contributions/252933/attachments/160820/212011/brunetti_charge_light_fd.pdf

Beam ν_e events – RecoEQL vs True Energy

1) Fit Deposited energy vs True Neutrino Energy → apply correction with fit params
   (see: https://indico.fnal.gov/event/56743/contributions/252933/attachments/160820/212011/brunetti_charge_light_fd.pdf)

2) Apply containment cut



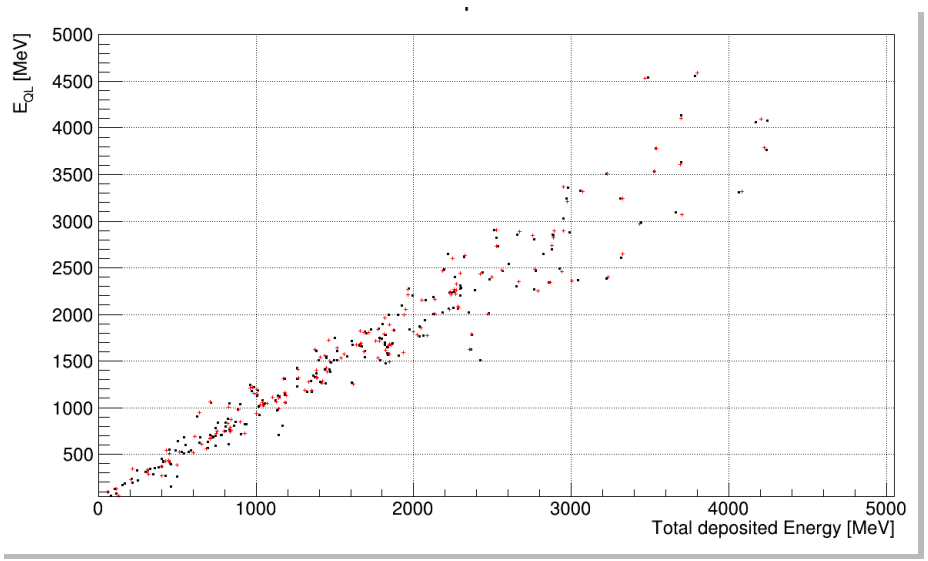


8% resolution for ν_e CC contained events

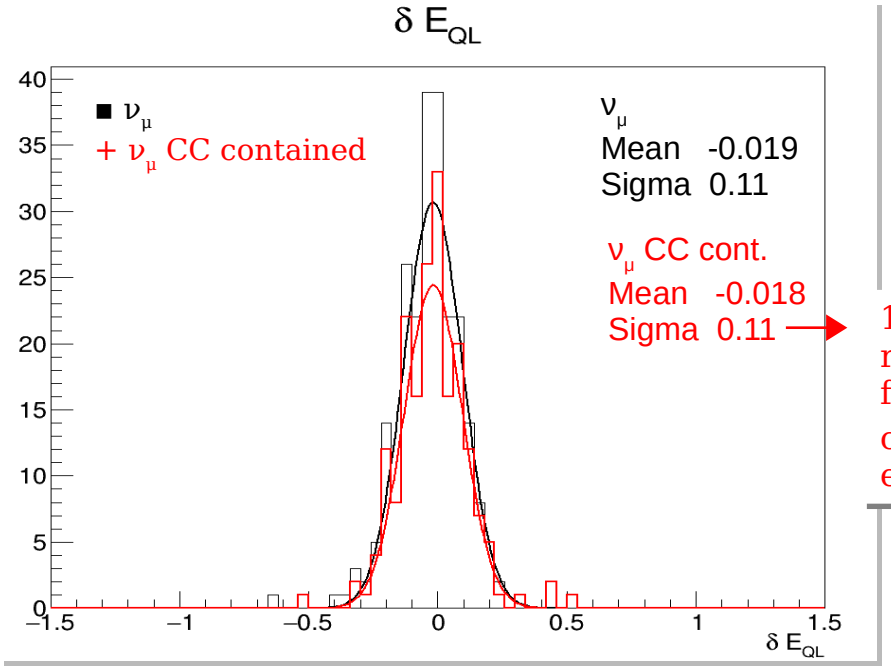
Beam ν_μ events – EQL vs Deposited Energy

$$EQL = W_{ph} * (Q+L) \rightarrow$$

EQL vs Total Deposited Energy from Ion&Scint



Residuals

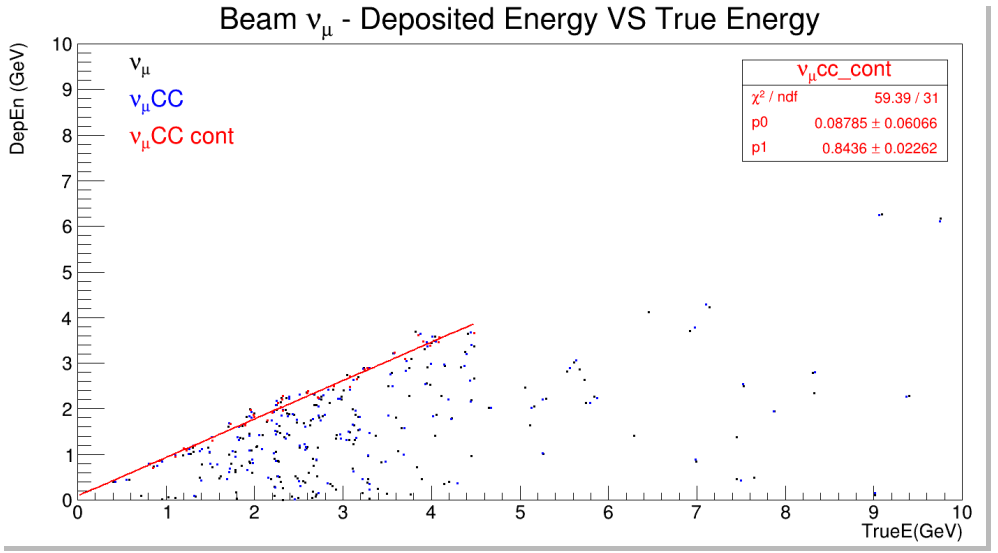


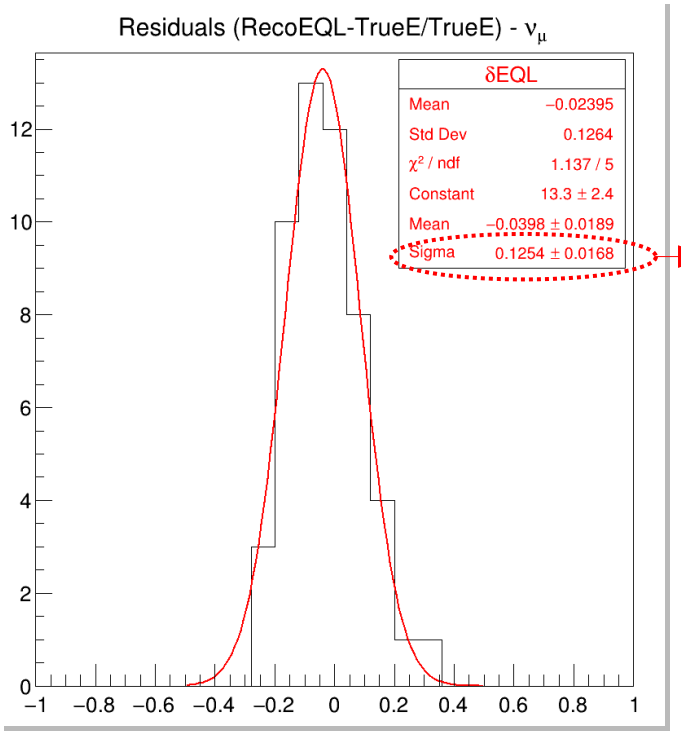
11% resolution for ν_μ CC contained events

Beam ν_μ events – RecoEQL vs True Energy

1) Fit Deposited energy vs True Neutrino Energy → apply correction with fit params

2) Apply containment cut



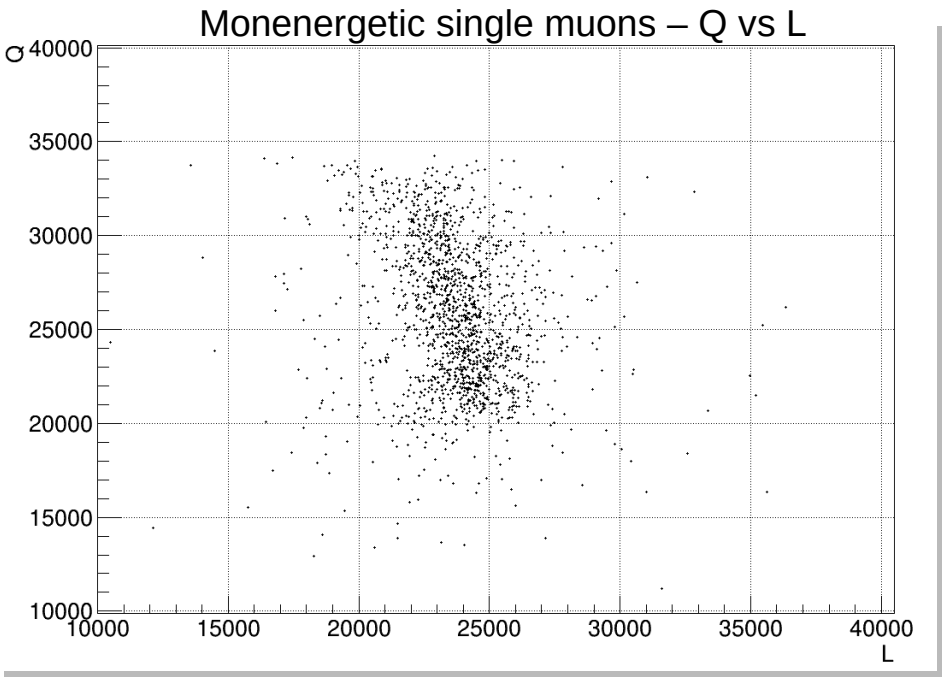


12.5% resolution for ν_μ CC contained events

Single muons & single electrons - Charge and Light anticorrelation

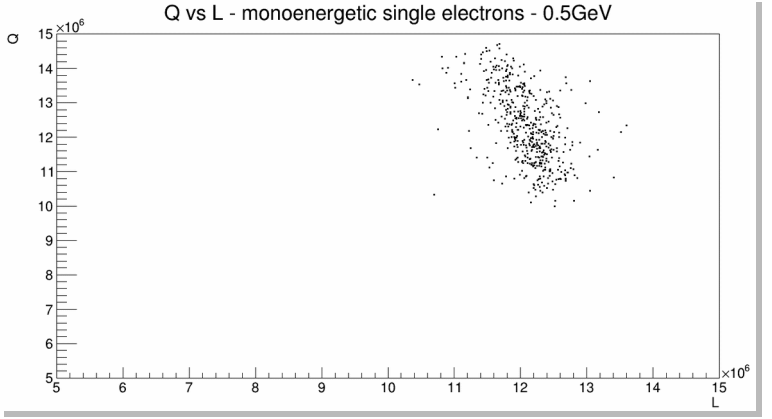
Single Muons:

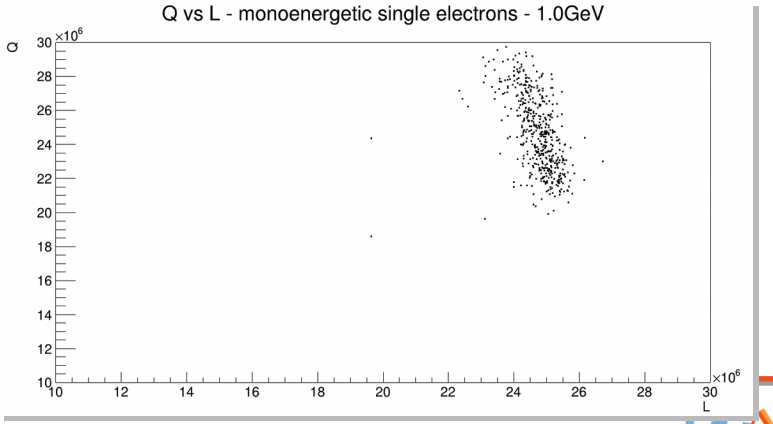
- All energy samples: Q & L normalised for deposited energy



Single Electrons:

- Q & L anticorrelation for 0.5 & 1.0 GeV samples (other samples on the way)





Conclusions & Next Steps

- First energy estimation for beam events in the HD-FD combining Charge+Light
- For ν_e CC contained events
  - σ(EQL)=6% residuals wrt deposited en.
  - σ(EQL)=8.4% residuals wrt true en.
- For ν_μ CC contained events
  - σ(EQL)=11% residuals wrt deposited en.
  - σ(EQL)=13% residuals wrt true en.

Neutrino energy resolution estimated using only charge information: 15%-20% for 0.5 - 4 GeV neutrino energies

(Low exposure long-baseline neutrino oscillation sensitivity of the DUNE experiment, Phys. Rev. D 105, 072006 (2022))

- We are able to see the anticorrelation between charge and light using monoenergetic single particle samples of muons and electrons
- Next: Check Resolution vs Energy using single muons & single electrons

Stay tuned!