Charge and Light study for ν_e events in the HD – Far Detector

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Charge+Light Energy Estimation

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

Charge: $Q = N_e = N_i R$

Light: $L = N_y = N_{ex} + N_i (1-R)$ *R=Recomb. Factor*

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

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

Energy from Charge:

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

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

So we need:

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

L = N_y = Calculated **number of scintillation gammas** **from reconstructed OpDet PE**

Our Simulation

- FarDet Horizontal Drift
- Event Samples: **500 Beam ν_e events** → this presentation
  Beam ν_μ, single electrons, single muons analyses on the way
- Far Detector **refactored geometry**
- Reconstruction: **Pandora**
- Analysis using → **All charge hits of the event**
  → **All PE reco of the events**
- **Containment** = spacepoints in fiducial volume: |x| < 310, |y| < 550, 50 < z < 1250 cm

  → CC contained events are 20% of the total

Charge And Light

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

  $q_i\, e^{(ti/\tau)}$ = 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 $\quad L = \text{Total PE} / (0.03 * Fvis)$

  3% Quantum Eff

  The visibility function

  $$Fvis = \frac{\gamma \text{ expected @ OpDet}}{\gamma_{Ion\&Scint}}$$

  → Wee need a **Visibility Map**

Light – The Visibility Map (1)

D. Guffanti

- **Light map:** Reverse the simulation of the Semi-analytical propagation model

Nr. of photons ↓ | Transport effects ↓ | PD eff. ↓

$$N_{\text{hits}} = \boxed{E_{\text{dep}} \cdot S_{\text{ph}}(\mathscr{E}) \cdot Q} \cdot \boxed{Q_{\text{abs}} \cdot Q_{\text{trans}} \cdot G(d,\theta) \cdot T(d,\theta)} \cdot \boxed{\text{QE}_{\text{eff}}}$$

Diego Garcia-Gamez, Patrick Green, Andrzej M. Szelc – Eur.Phys.J.C 81 (2021) 4, 349

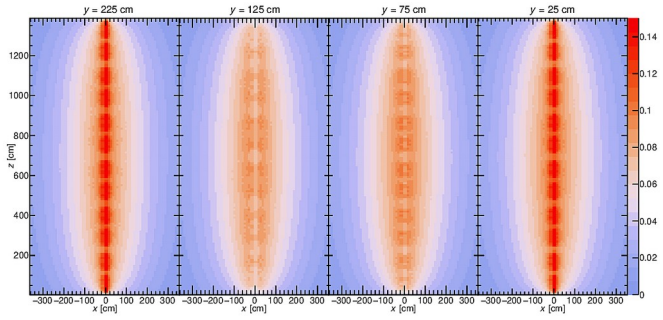
Propagation effects (absorption, transmission, rayleigh…) included together with geometrical extrapolation in our computation of scintillation y

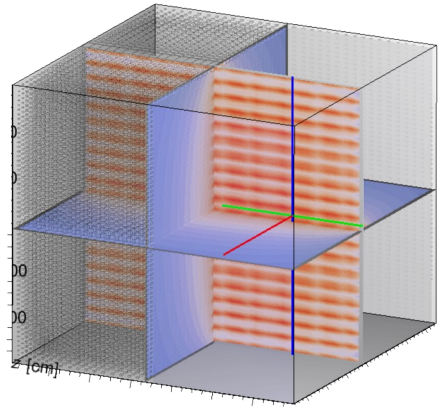
$$f_{\text{vis}} = Q_{\text{abs}} \cdot G(d,\theta) \cdot Q_{\text{trans}} \cdot T(\theta)$$
$$= \boxed{e^{-d/\lambda_{\text{abs}}} \cdot \frac{\Omega}{4\pi}} \cdot \boxed{\Gamma(d|\cos\theta)\cos^{-1}\theta}$$

Geometry + Abs. | Rayleigh

- Formatted as 3D histogram [x, z, y] (other format possible if needed)

Visibility at different *y*





Light – The Visibility Map (2)

- To apply the map:

  1) Get the space points in the event

  2) Require the charge hits associated with the spacepoints to be collection plane hits

  3) For each spacepoint position $p_i=(x_i, y_i, z_i)$

  → Get the associated hit charge q_i

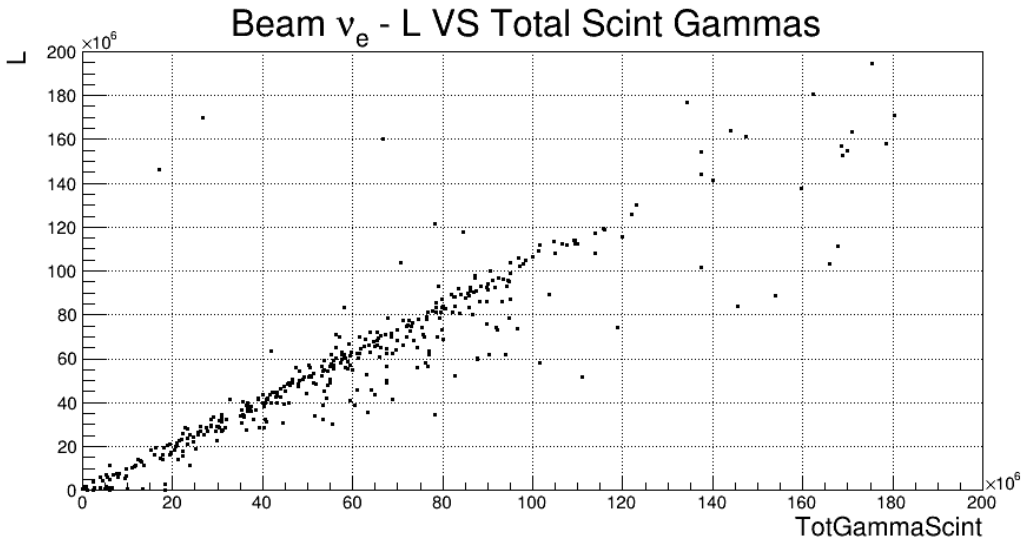
  → Find the corresponding bin in the map → content gives $f_{vis}(p_i)$

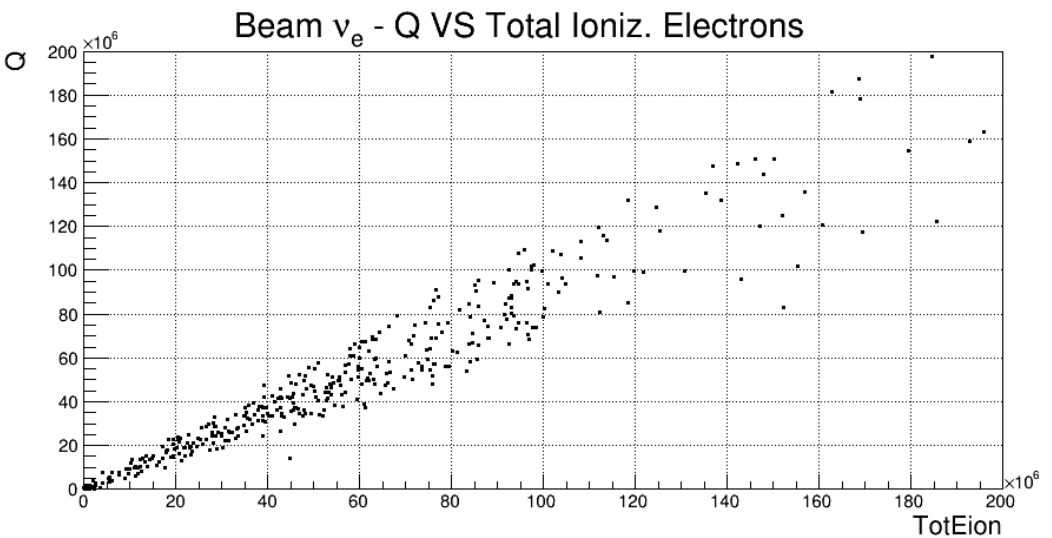
→ $\mathbf{F_{vis} = (\Sigma f_{vis}(p_i) q_i) / \Sigma q_i}$ = Charge weighed **visibility function of the event**

Value from light map in $p_i = x_i, y_i, z_i$ = Pandora SPACEPOINT

Beam ν_e events – Q & L

- If we have done our calulation correctly Q should correspond to the number of ioniz. electrons and L to the number of scint. gammas produced
  → Check **Q VS Ioniz. Electrons** & **L VS Scint. Gammas** from Ion&Scint

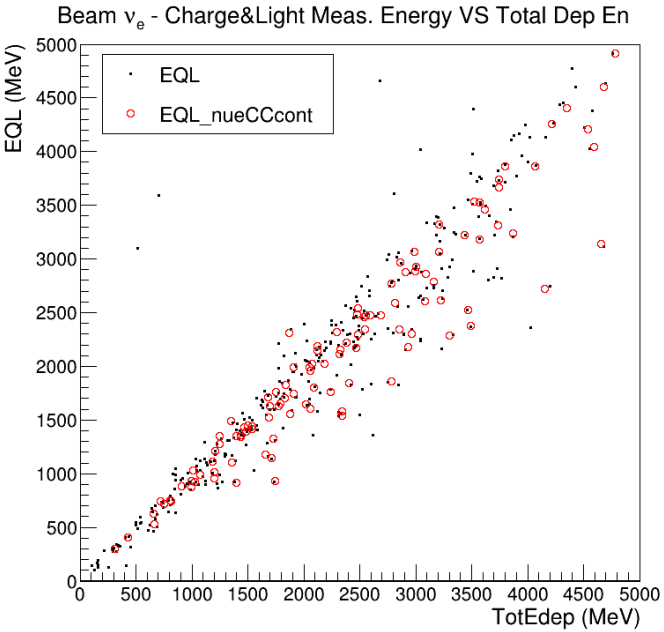




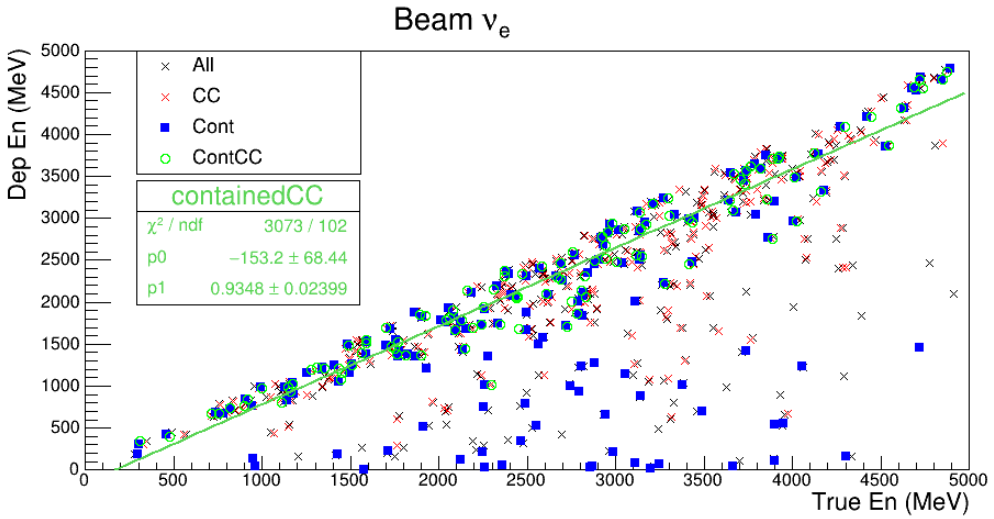
Beam ν_e events – EQL

- W_{ph} * (Q+L) = EQL, should correspond to the Deposited Energy

→ Check EQL VS the Total Deposited Energy from Ion&Scint →



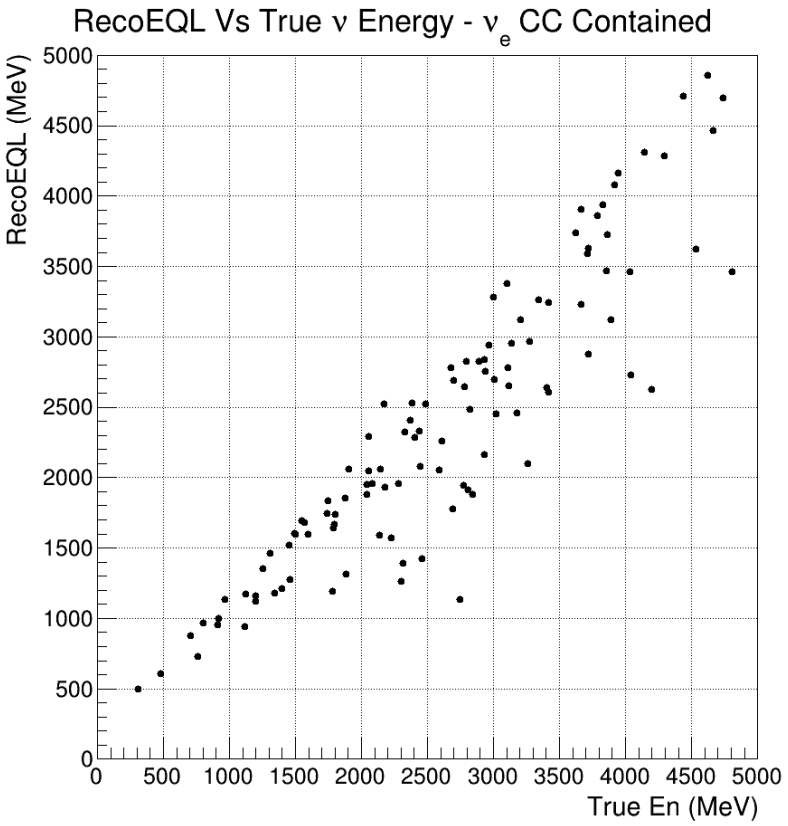
- To evaluate the True Energy:
  Fit the deposited energy vs True Neutrino Energy (CC contained ev.)
  → get gradient and intercept ...

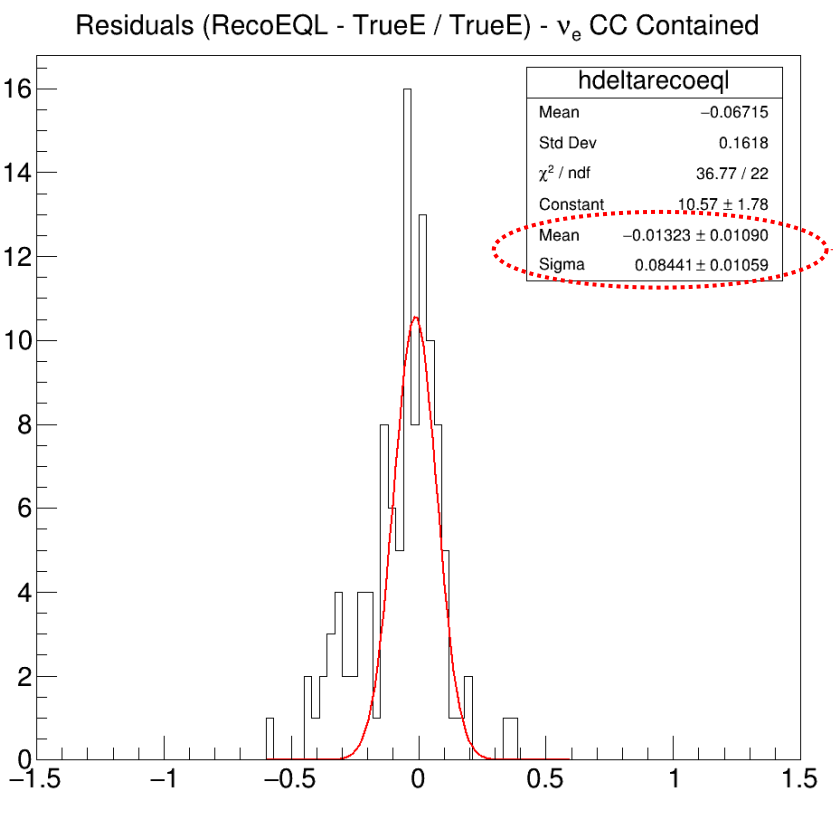


→ ...Apply correction to EQL

→ Check Reconstructed Energy VS True Energy

Beam ν_e events – RecoEQL vs True Energy





8% overall energy resolution for ν_e CC events

Conclusions & Next Steps

- **First energy estimation** for beam **ν_e events** in the HD-FD **combining Charge+Light**
- For ν_e CC contained events **σ(EQL)=8.4%**
- Better compared to current observed neutrino energy resolution of 15%-20% for 0.5 - 4 GeV neutrino energies estimated using only charge information
- **Next**:
  - Complete the analysis also for beam ν_μ events
  - Check Resolution VS Energy using single electrons and single muons samples