Motivations for a CRT

J. Klein, Penn, DUNE CTF Workshop

Parameter Classes

1. **Universal: Completely determined *ex situ***
   - Ionization energy
   - Wire field response?
   - ADC response? (not yet)
   - Electronics transfer function?
   - Recombination?

2. **Calculable: Completely determined by others**
   - $v_d(E(x,y,z,t), T(x,y,z,t))$
   - Overall energy scale (=dQ/dx)?
   - $E(x,y,z,t)=E=\Delta V/d$?
   - Diffusion?

3. **Measured: Requires *in situ* measurement**
   - $T(x,y,z,t)$
   - $E(x,y,z,t)$ probably
   - Diffusion probably
   - t_0 Offsets
   - Wire positions and geometry
   - Electronics noise and pickup

Assumptions about 1 and 2 and ignorance of those under 3 are OK if there is a **<u>precision, relevant test</u>** of the model that provides acceptable agreement. If it does not---prepare to figure out why.

Examples of "Tests" (SNO)
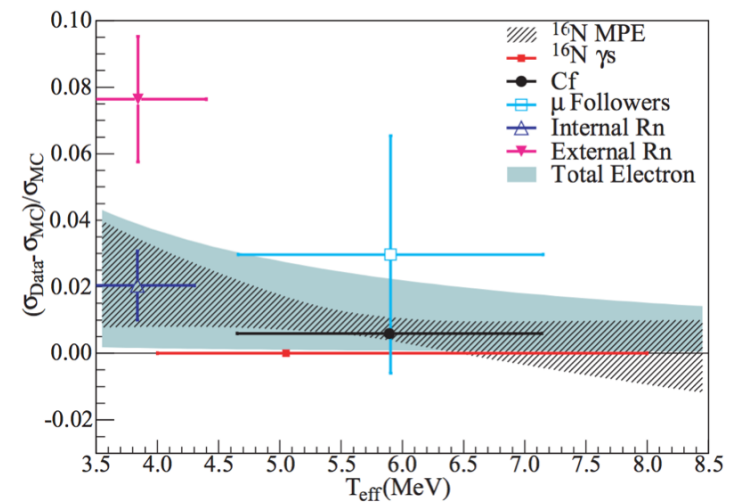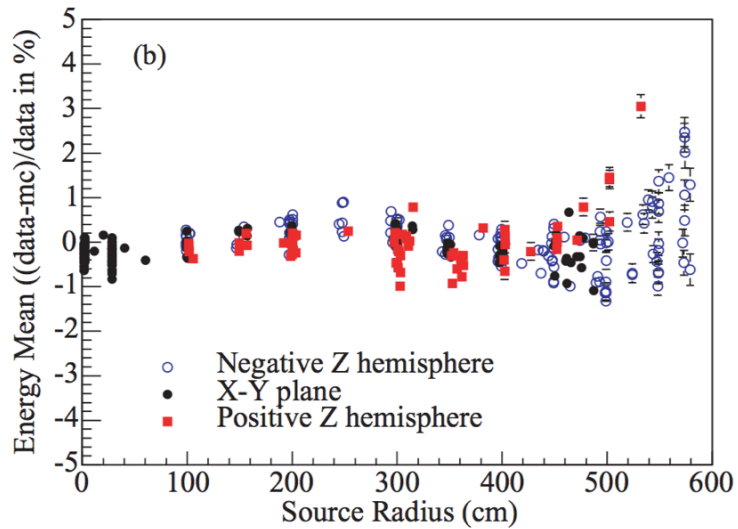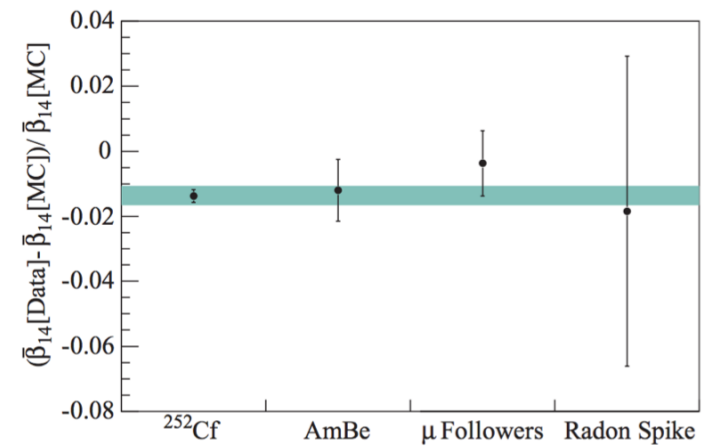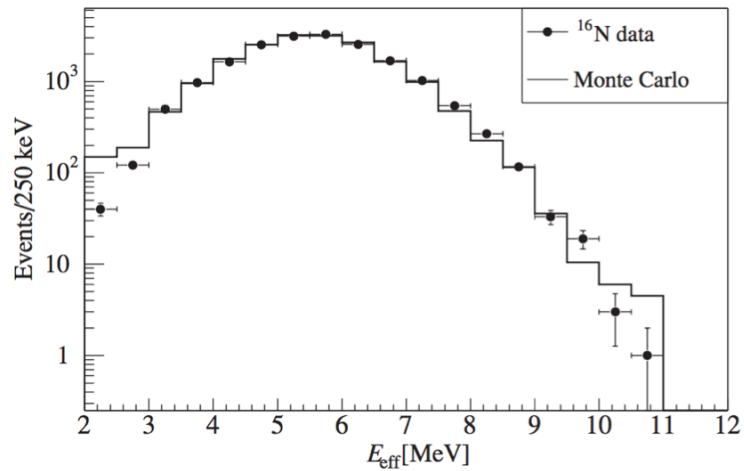
Examples of "Overconstraining the Model"

TABLE I. Primary calibration sources.

Calibration source	Details	Calibration	Deployment Phase	Ref.
Pulsed nitrogen laser ("laserball")	337, 369, 385, 420, 505, 619 nm	Optical & timing calibration	I & II	[26]
^{16}N	6.13-MeV γ rays	Energy & reconstruction	I & II	[27]
^{8}Li	β spectrum	Energy & reconstruction	I & II	[28]
^{252}Cf	Neutrons	Neutron response	I & II	[25]
Am-Be	Neutrons	Neutron response	II only	
^{3}H$(p, \gamma)^{4}$He ("pT")	19.8-MeV γ rays	Energy linearity	I only	[29]
Encapsulated U, Th	$\beta - \gamma$	Backgrounds	I & II	[25]
Dissolved Rn spike	$\beta - \gamma$	Backgrounds	II only	
In situ ^{24}Na activation	$\beta - \gamma$	Backgrounds	II only	

Various energies, particle types, and source systematics

The basic idea is to have information external to the events of interest (energy, tags, known position) and to have systematically different types

(These are the "controls" you learned about in 2nd grade science).

Boy, wouldn't it be nice if we had a test beam right there at the DUNE FD...?

Results of Calibration "Tests" for DUNE

I.   Position reconstruction biases and uncertainties compared to MC model
II. Direction reconstruction biases and uncertainties
III. Energy scale biases and uncertainties
IV. Energy resolution biases and uncertainties
V.   …?

Results of Calibration "Efficiencies"

I.   Particle ID efficiencies and purities
II. Noise removal efficiencies
III. Other instrumental effect removal efficiencies

Cosmic "APA/CPA Crossers"
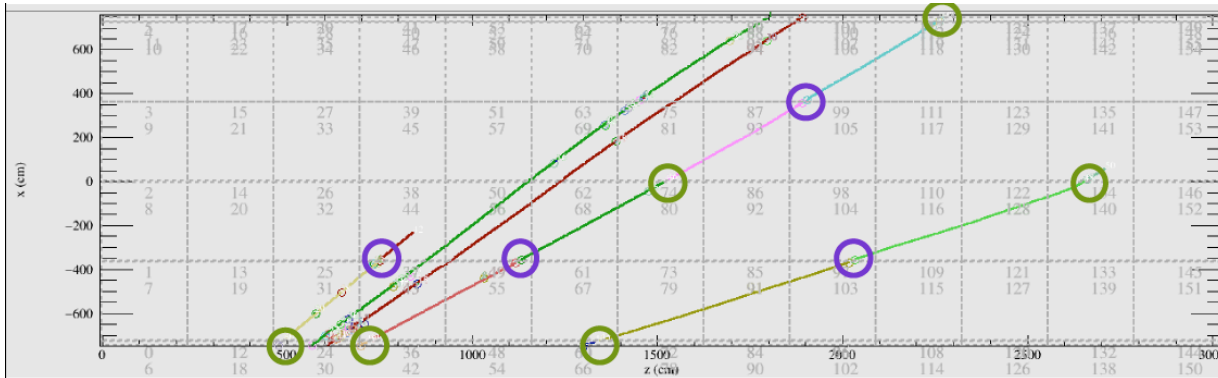
L. Whitehead

Essentially these give us x-x0 for a wide range of z—

x=x0+vΔt

But we don't necessarily know x, x0, or v(x,y,z,t) without other information

We can use these for
- CPA/APA distortions (a la Junk) if we know t0 and field map
- PDS-determined t0 (a la 35 t)
- Electron lifetime if we know diffusion and recombination
- Drift velocity if we know CPA/APA distortions and partial field map
- Diffusion if we know electron lifetime and distortions and drift velocity

We can also use these to test our overall calorimetry, but not detailed track reconstruction and not for events that "look like" our signal.
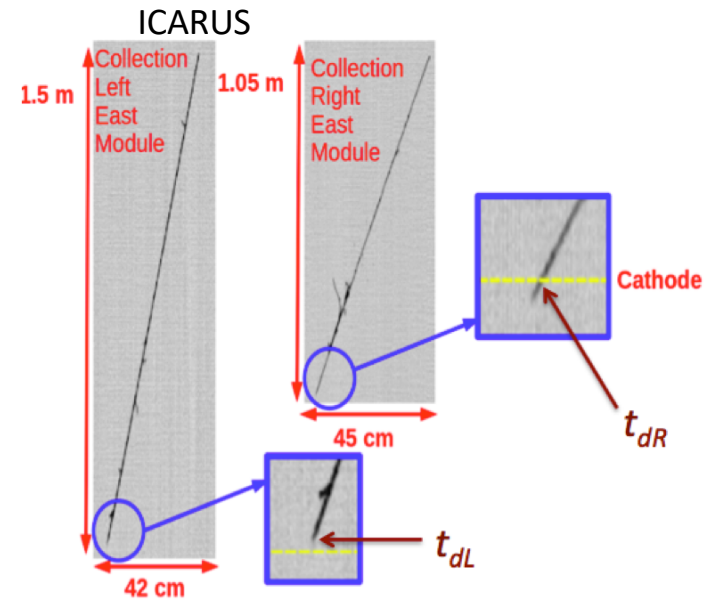
Yellow line marks nominal cathode position($\Delta y=0$)

Do We Care about x0 (where track is)?

Maybe we can do entire analysis with a fiducial area*time?

APA/CPA crossers give us max Δt---why bother converting to distance?

- Because physics cares about Δx: distance for gamma conversions, for example.

- And because we don't know distance between APA and CPA we don't know the actual volume even if we know $\Delta t/t_{max}$ and hence don't know $N_{targets}$.

- And because v_d might not be uniform over x, we also don't know where things are relative to APAs and CPAs.

Absolute position matters!

CRT?

What would a CRT buy us?

- Independent definition of t0 (to be compared to PDS and beam)
- "Truth" information for beam-like data, to compare to MC recon and PID
- At least one x,y,z position (depending on where and how much CRT coverage there is).

CRT?

What would a CRT buy us?

- Known t0 and (initial) position gives drift velocity as a function of x,y
- Extended tracks test field map from laser in regions not illuminated well
- Measurement of MIP dE/dx integrating over many other model parameters
- Beam-like tests of reconstruction and PID (for muons)

But really, a CRT is not so much for parameter measurement as it is a "test" of high-level systematic uncertainties: reconstruction biases and resolutions.
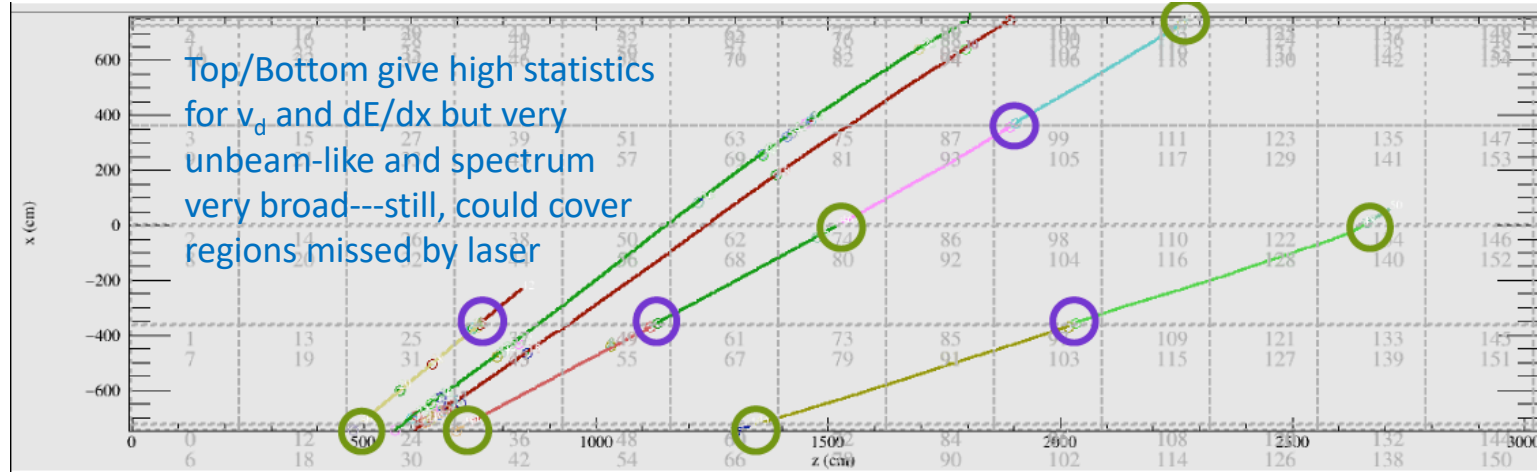
In other words, once (we think) we've measured all the model parameters, we can test whether we've gotten it right, for an admittedly limited set of data.

Where to put a CRT?

Exit point for internal exiting μs

Dirt muons very useful!

Test beam!

Top/Bottom give high statistics for v_d and dE/dx but very unbeam-like and spectrum very broad---still, could cover regions missed by laser

Beam comes in from sides and bottom too! (TRJ)

- Most useful is probably front to catch both cosmics and dirt muons
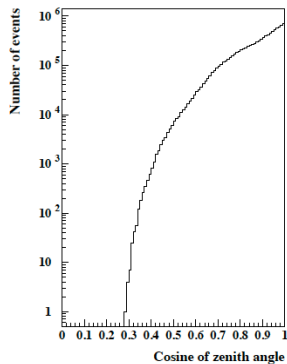
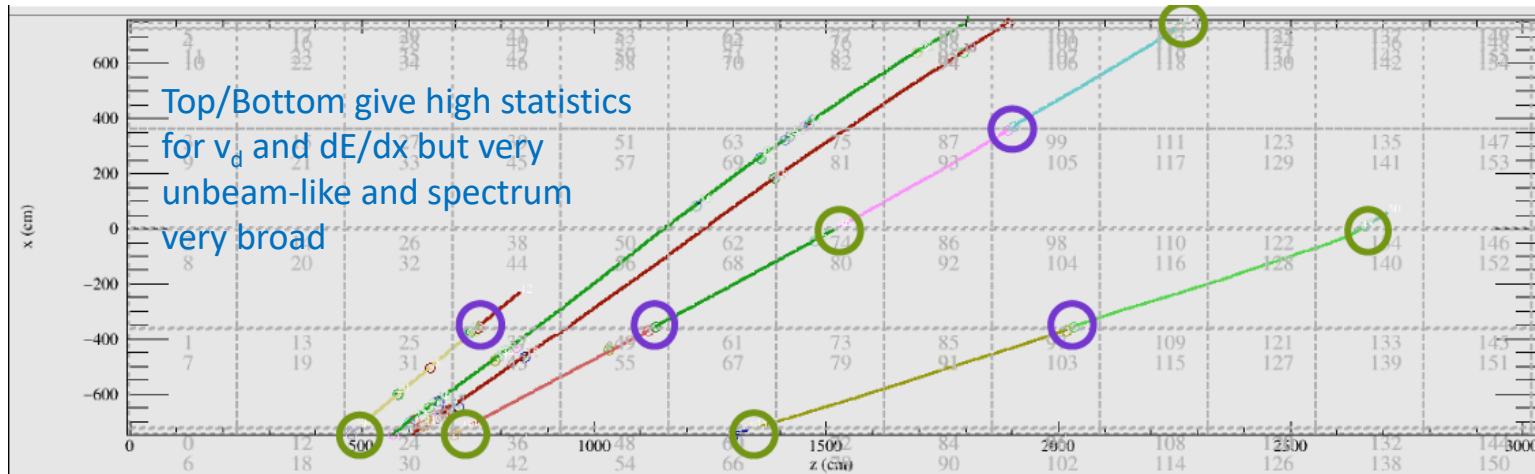Unfortunately cosmics probably never make it through both ends---Zenith angle is 78 degrees (cos(θ)=0.2)!

But side-going muons could make it all the way through: cos(θ)=0.6

Where to put a CRT?

Beam comes in from sides and bottom too!

Dirt muons very useful!

Exit point for dirt μs for recon tests

Top/Bottom give high statistics for v_d and dE/dx but very unbeam-like and spectrum very broad

Beam comes in from sides and bottom too!

- Small area on top could be valuable, perhaps moveable?

Provides high(est) statistics and if we illuminate regions laser is partially blind to, this could be valuable. Probably need some telescopic lever arm---is there room? (How about bottom?)
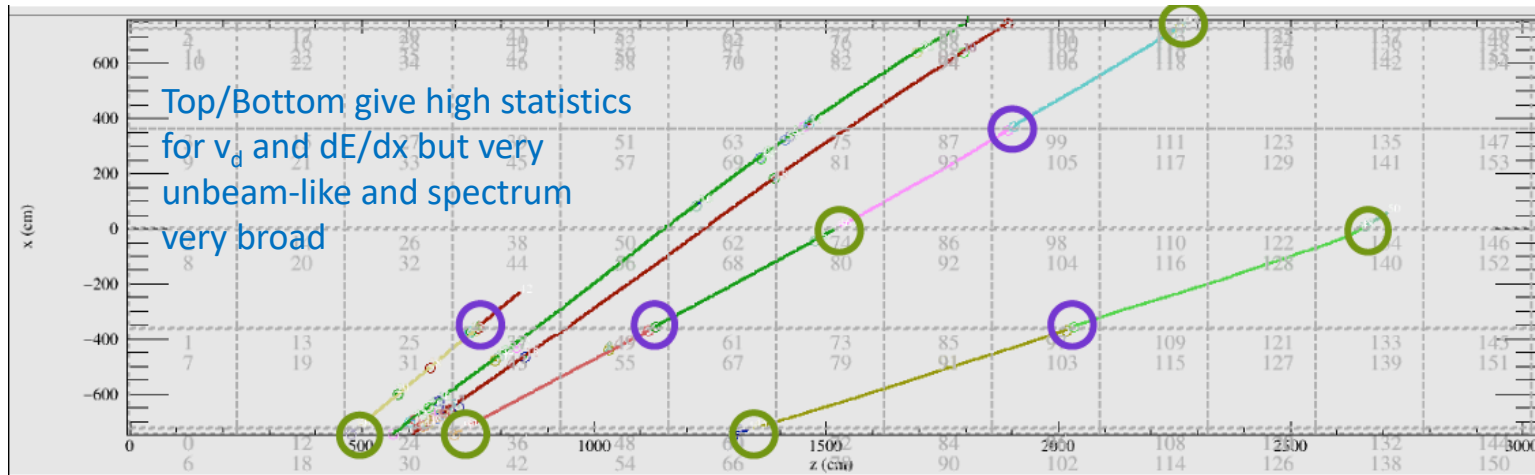Get immediately vd (if t0 for CRT is calibrated!)
Get field map after enough of these cross

Where to put a CRT?

Beam comes in from sides and bottom too!

Top/Bottom give high statistics for v_d and dE/dx but very unbeam-like and spectrum very broad
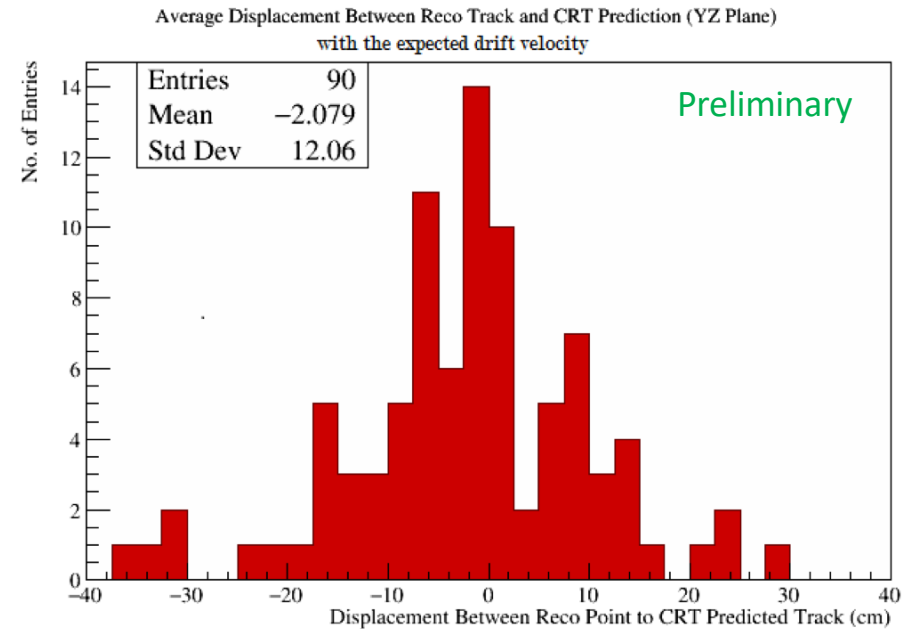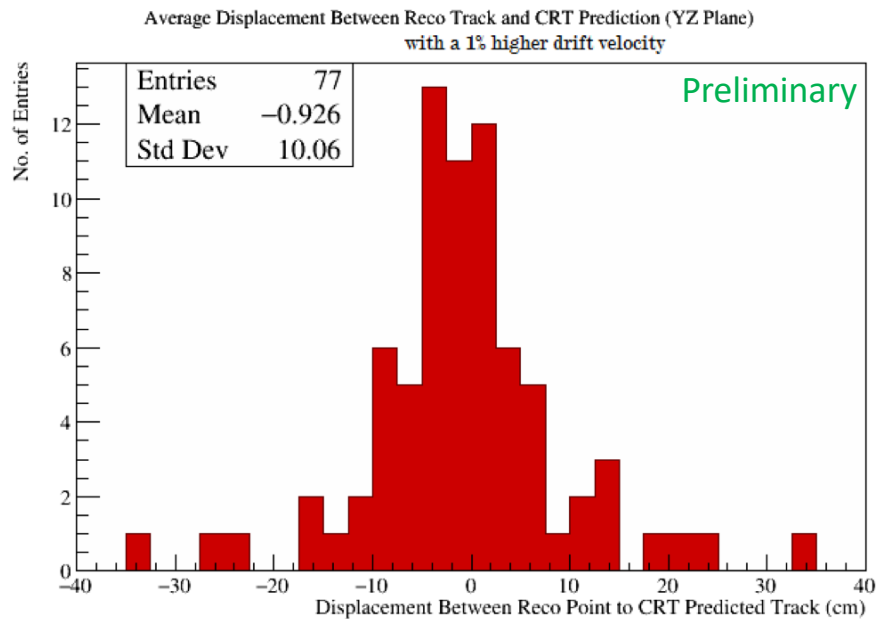
Beam comes in from sides and bottom too!

- Pixel size

This is mostly a question of statistics and known detector uniformity. Could use uniformity of all cosmics to make the same measurements, but pixels allow us to discriminate position-dependent scenarios.

Example CRT Test of v_d

Average Displacement Between Reco Track and CRT Prediction (YZ Plane) with a 1% higher drift velocity

Entries	77
Mean	−0.926
Std Dev	10.06

Preliminary

Average Displacement Between Reco Track and CRT Prediction (YZ Plane) with the expected drift velocity

Entries	90
Mean	−2.079
Std Dev	12.06

Preliminary

Richie Diurba (Penn)

So roughly 1% sensitivity to v_d with just 80 or so dirt muons
But this depends on where APAs are…what should the CRT
be registered to? FC, cryostat, TPC?

And how much of cryostat can be measured this way?

Example CRT Test of v_d

Richie has put a CRT "telescope" with 1 m distance in front
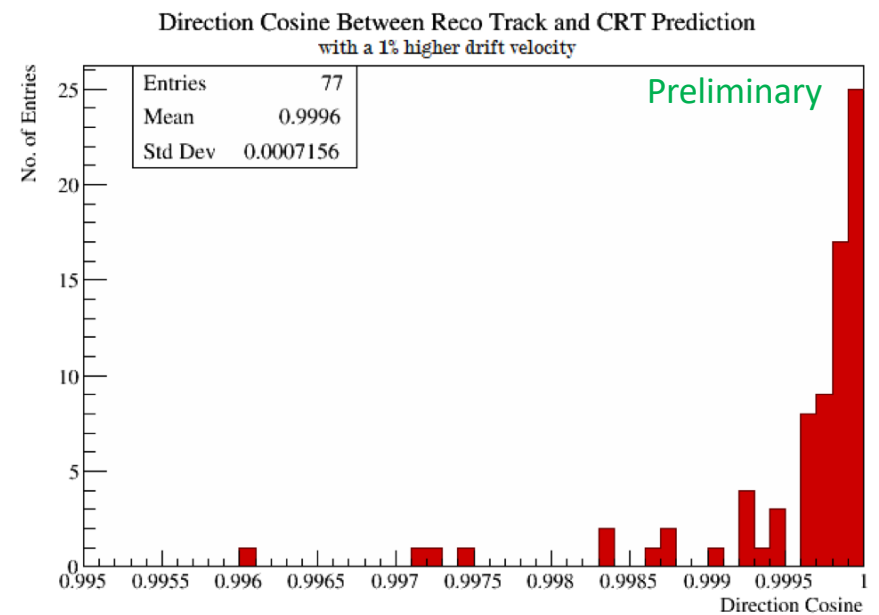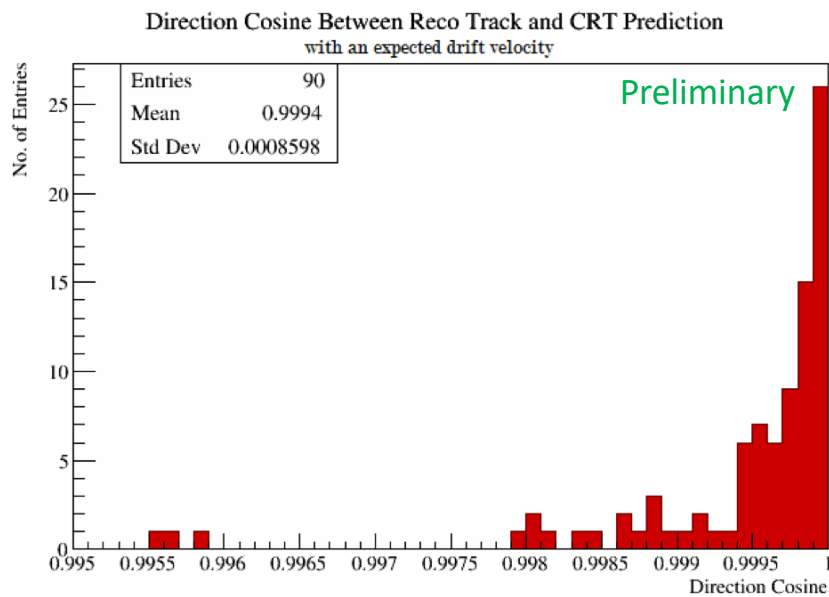
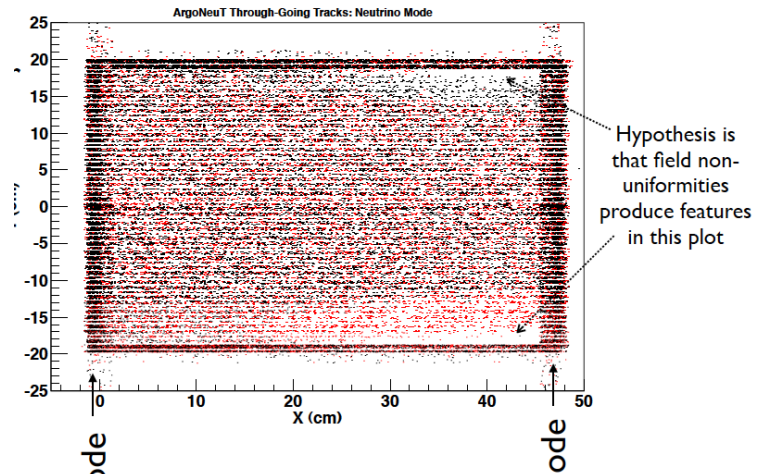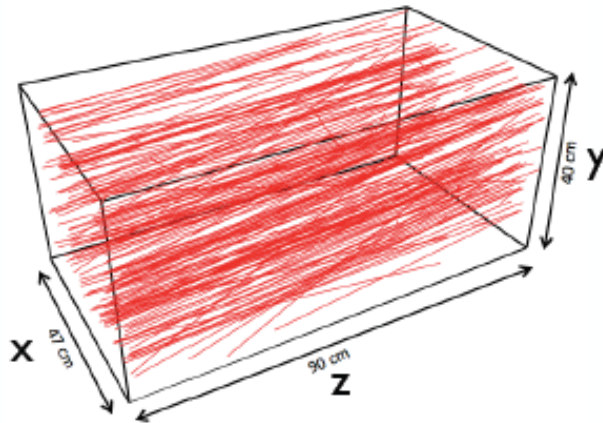Not surprisingly, v_d hardly affects direction at all---that's good!

Summary

- CRT could provide beam-like tests of reconstruction and PID (for ν_μ CC events)
- A measurement of v_d as a function of x
- Also a measurement of dE/dx without t0 and v_d covariances
- Work to be done
  - Where is biggest bang for the buck---how many dirt μs from sides?
  - Can we calibrate t0 of CRT independently?
  - Can we use old counters (e.g., MINOS?)
  - Is there space? (Richie has looked at this---there's about 1 m in front and back)
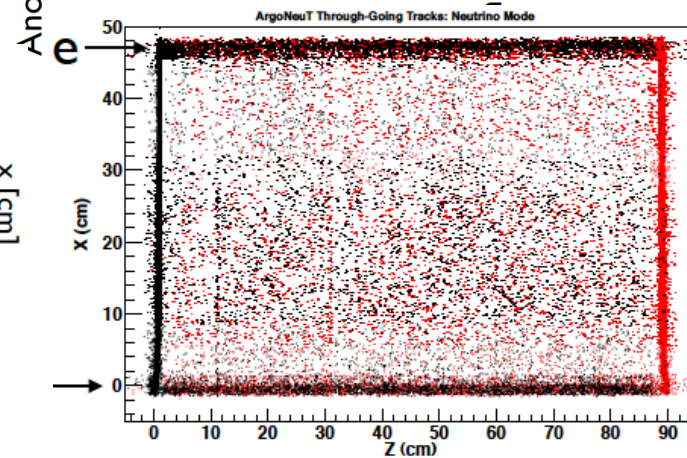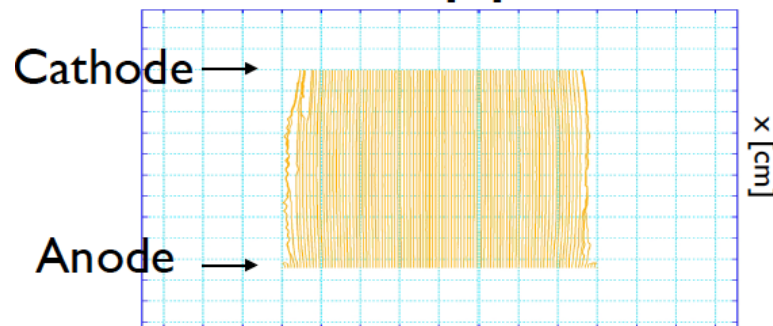 - What are realistic costs?

Backups

Meeting Discussions to Date

4. ARGONEUT (etc.) Calibrations (Soderberg)

ArgoNeuT Through-Going Tracks: Neutrino Mode

Hypothesis is that field non-uniformities produce features in this plot

Anode

ode

Garfield calculation

Cathode →
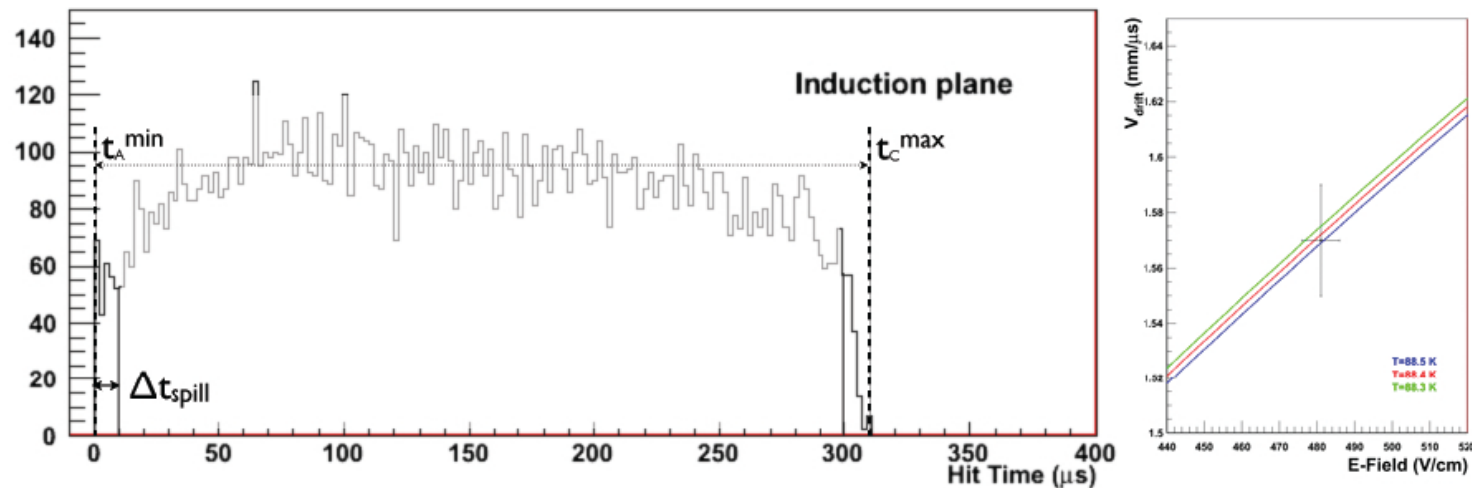
Anode →

e

ArgoNeuT Through-Going Tracks: Neutrino Mode

Meeting Discussions to Date

4. ARGONEUT (etc.) Calibrations (Soderberg)

$$t_d = t_C^{max} - t_I^{min} - \Delta t_{spill} = 300.5 \, \mu s \qquad\qquad v_d = \frac{\ell_d + \ell_g/r_{T1} - \Delta\ell}{t_d} = 1.57 \pm 0.02 \, mm/\mu s$$

Average drift velocity using through-going muons known to better than 2%.