Stability of ASM and Minuit Based Vertex Reconstructions

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Motivation

- Wanted to study the stability of Analytic Sphere Method (ASM) and Minuit based reconstructions with:
  - Different ice models
  - Ray tracing vs. Ara default (straight line) approximation
- A secondary objective was to study the structures of the reconstruction. From the structures we can make conclusions about how UNL's calibration routine might be affected.

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Outline

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Introduction

In this talk:

- A look at a few ice models found from data in the RICE paper located:
  - http://icecube.wisc.edu/~mnewcomb/radio/index/rice_refraction.pdf
- Effect on different reconstructions (testbed,ara02)
- Comparison of a straight line approximation of hit times to ray traced hit times

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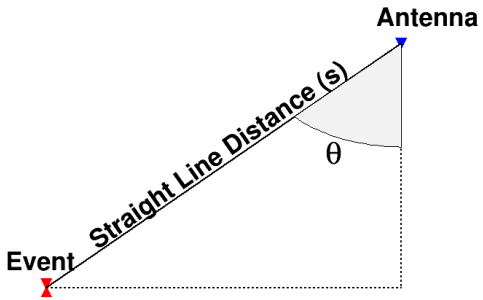
Straight Line Approximation (NTime)



- Ara standard ice model: $n = A - B * e^{C*z}$

  A = 1.78, B = 0.43, C = 0.016 or 16.0 (for meters or kilometres respectively)

- Approximation:

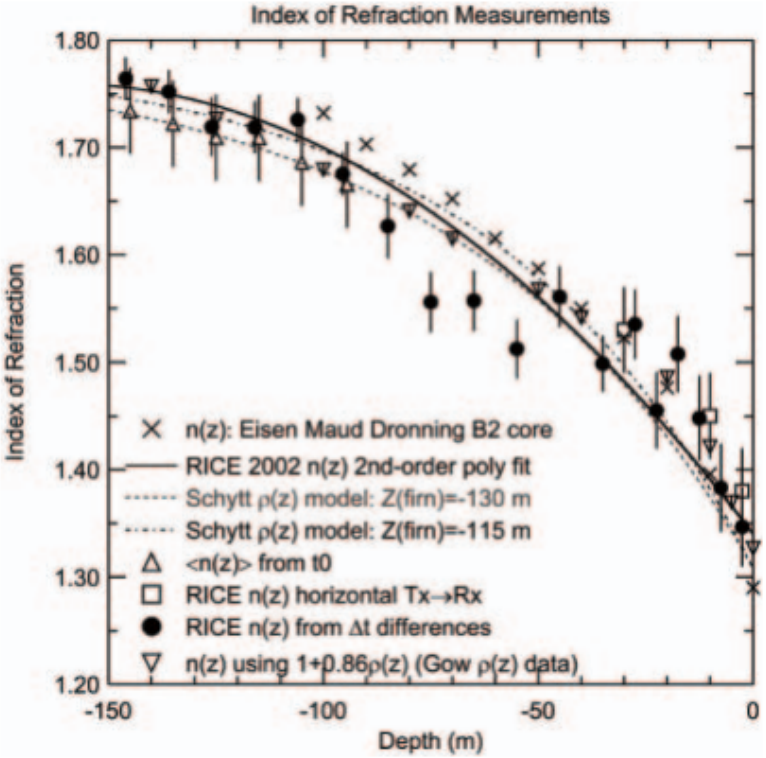
$$T = \int dT = \int_0^s \frac{n(z)ds}{C_{ice}} = \frac{1}{C_{vac} * cos(\theta)} \int_{Z1}^{Z2} n(z)dz$$

- After Integration:

$$T = \frac{A(Z_2 - Z_1) - \frac{B}{C} * (e^{(C*Z_2)} - e^{(C*Z_1)})}{C_{vac} * cos(\theta)}$$

$$cos(\theta) = \frac{Z_2 - Z_1}{SLD}$$

Data Used For Ice Models



- Data points obtained using a plot digitizer
- Used data:
  - Black Dots with errors
  - Downward pointing triangles with no errors (inverted triangles)
  - Crosses with no errors
  - All data points and associated errors

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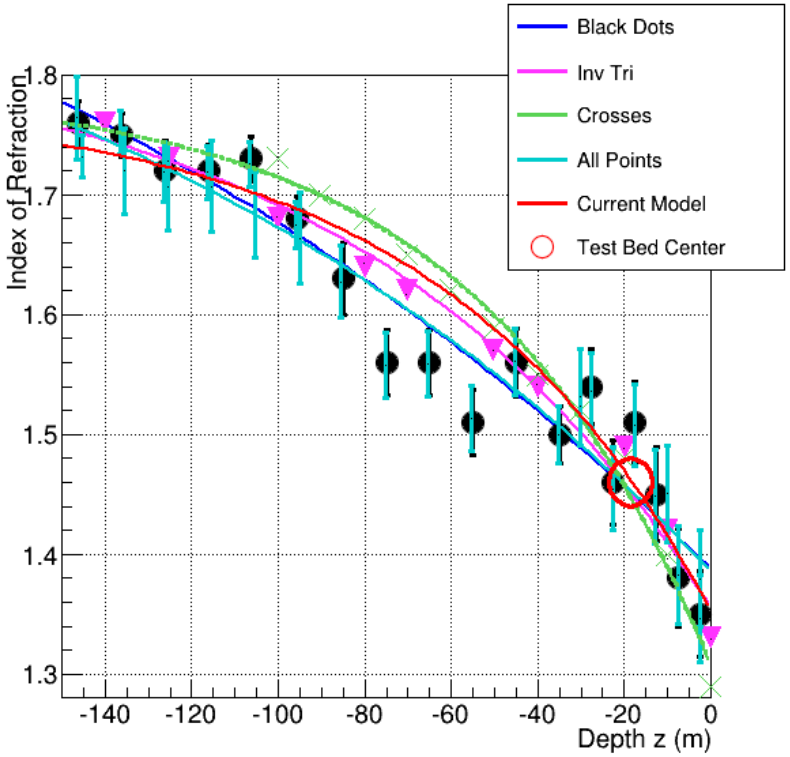
Fit Equation

- After looking into existing research on the current model(s) used by various sources an exponential decay function of the form:

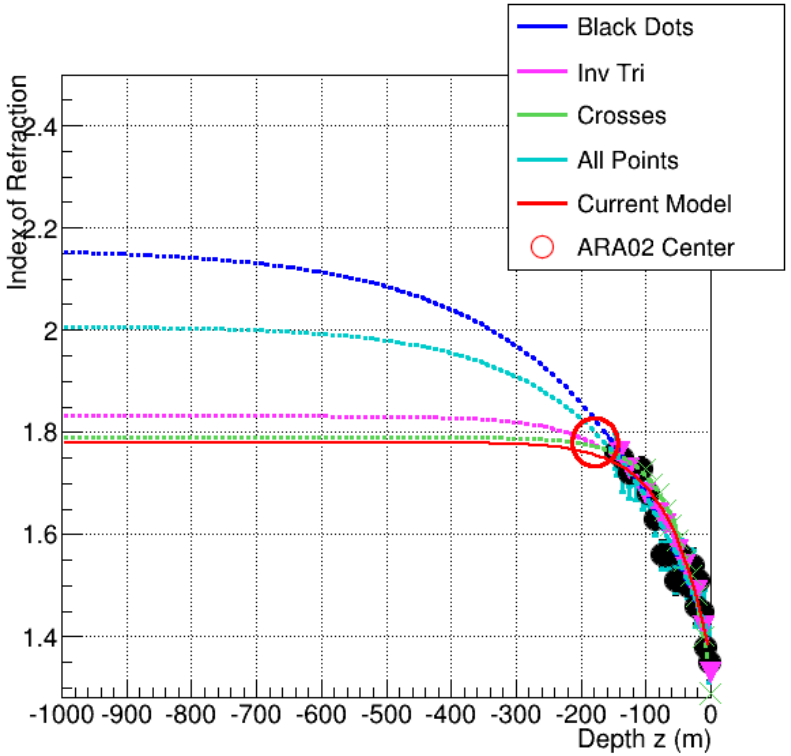
$$n = A - B * e^{C*z}$$

appears to be the best function to fit the data to.

Ice Models



- Lines shown are fits to respective data



- Zoom out of left plot

Testbed Reaction, 2011 data, Pulser: C2V

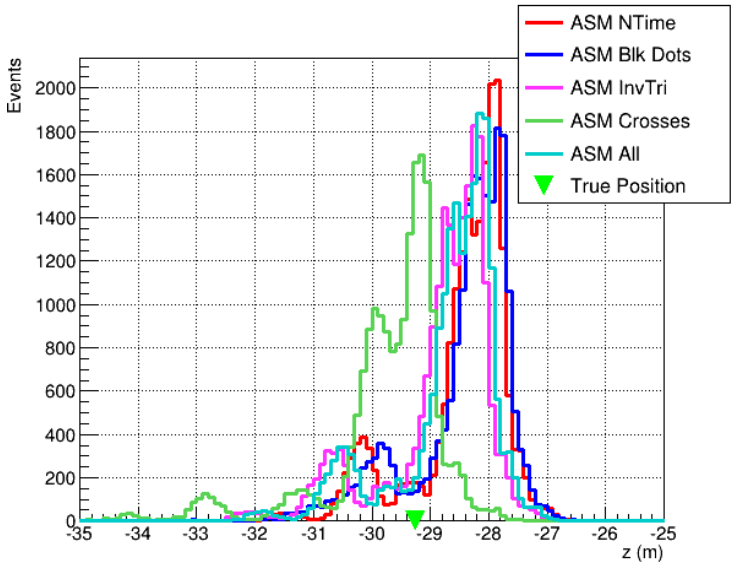


Figure: Analytic Sphere Method

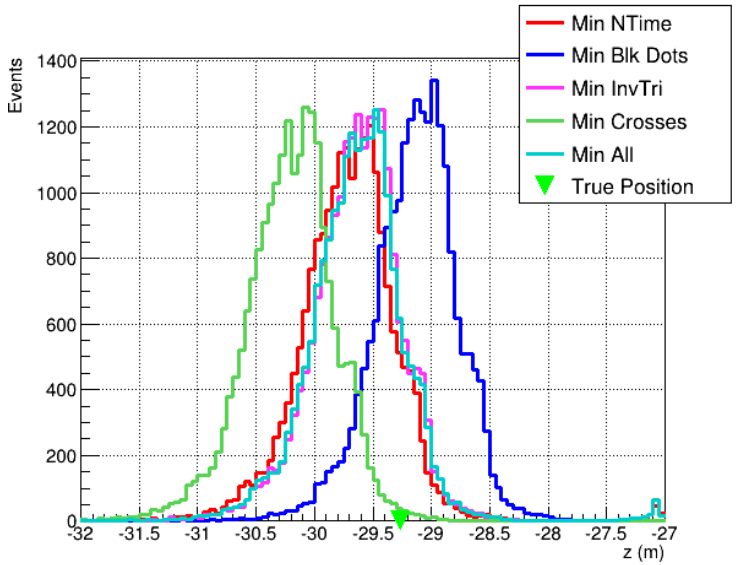


Figure: Minuit

- Small shifts in structure position with small changes in structure shape (Biggest shift $\approx$ 1m)

Testbed Reaction, 2012 data, Pulser: C1H

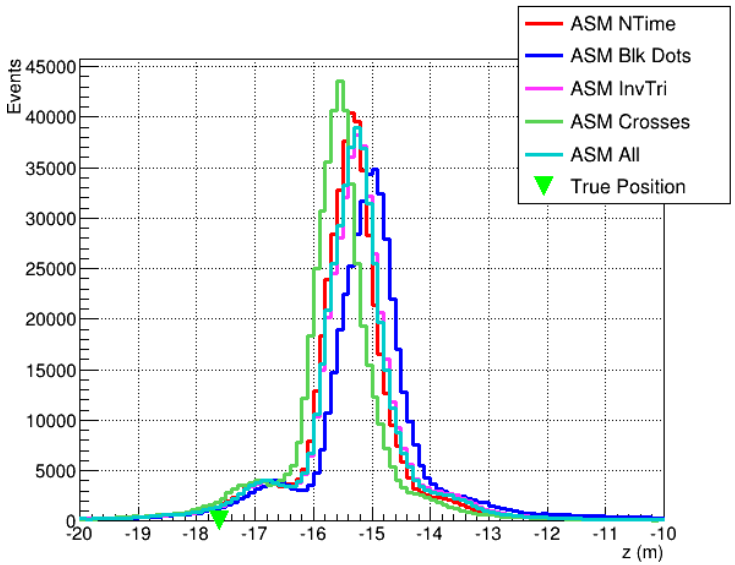


Figure: Analytic Sphere Method

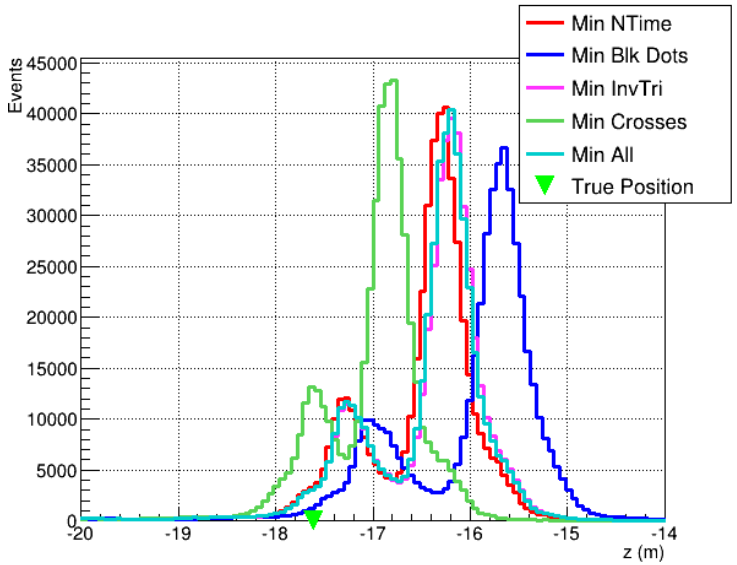


Figure: Minuit

- ASM is very stable with C1H
- Structure shifts < 1m, tiny differences in shape

ARA02 reaction, 2013 data, Pulser: D6V

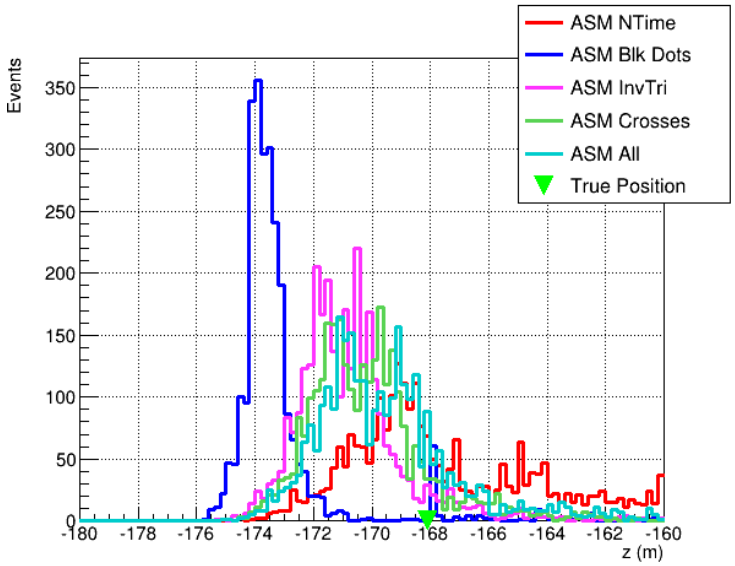


Figure: Analytic Sphere Method

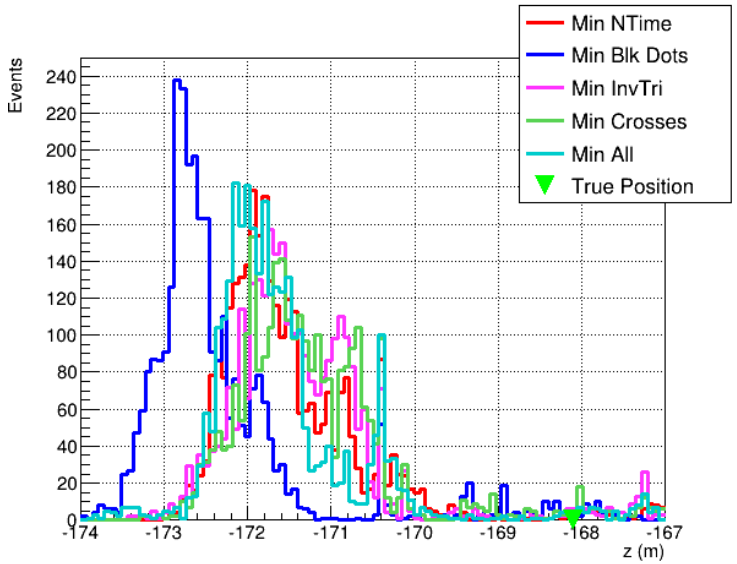


Figure: Minuit

- Apparent improvement in shape, larger shifts (1m-2m)
- Structure shifts $<$ 1m, some differences in shape

Ice Model Conclusion

- Shallow ice antennas have more stability in reconstruction from the different ice models
- Deep ice antennas have questionable reconstruction stability
- Questionable deep ice reconstruction stability with varied ice models might warrant more research time

Ray Tracing

- Used my own code
- Code used has been verified against a similar one from Dave Besson
- Code used:
  - Finds shortest path (time-wise)
  - Uses our current ice model for predicted n(z)
- Compared against a straight line approximation using the current ice model (NTime)

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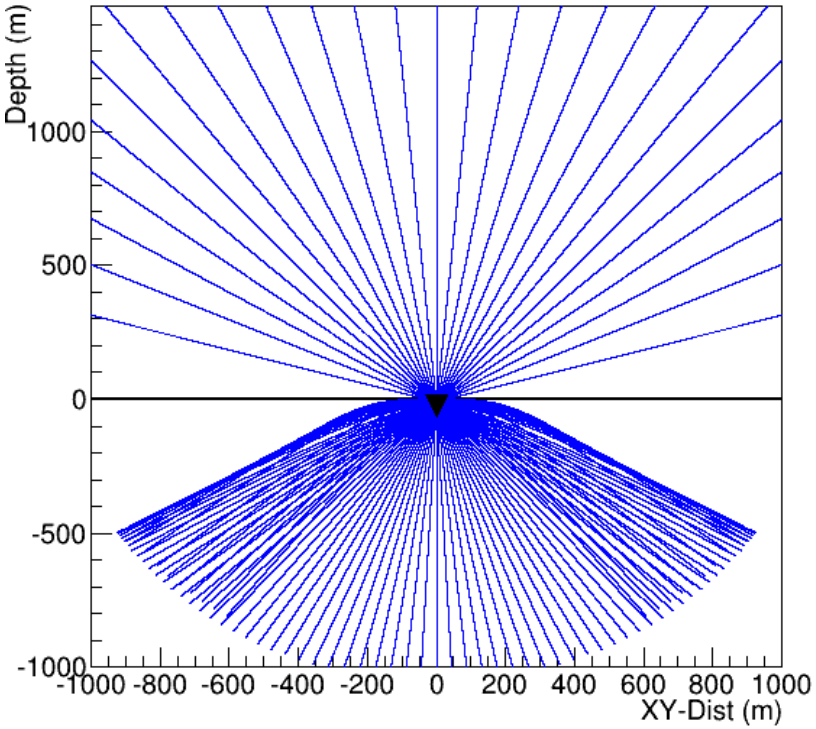
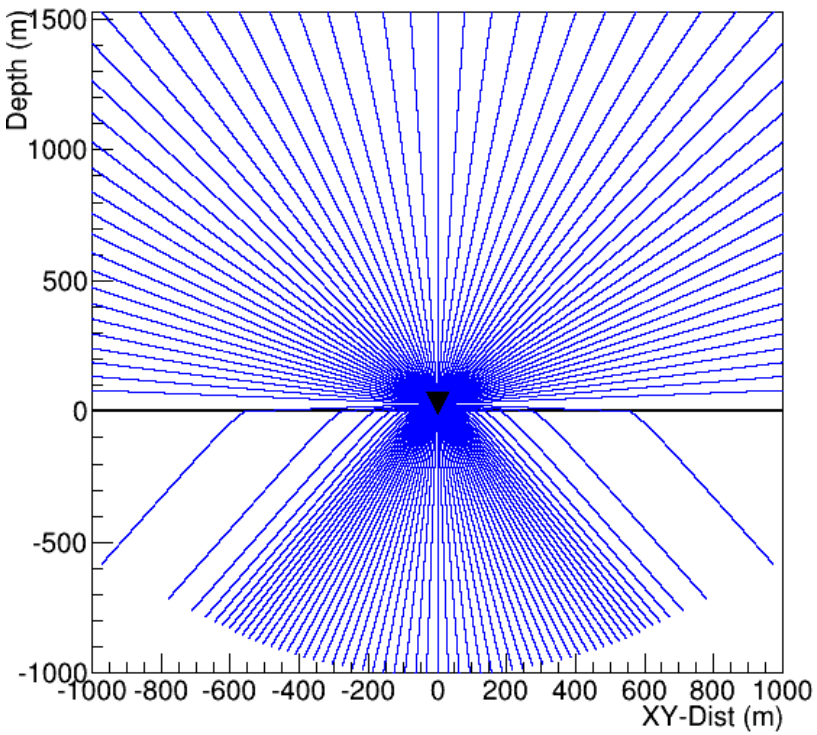
Example Ray Traces





- Path of light from Testbed pulser C2V after 6000ns
- Path of light from 30m above ice after 6000ns

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Ray Traced Times, Testbed Pulser C2V

Antenna Name	Ray Time (ns)	Ntime (ns)	dT	Error (%)
H1	138	138	-0.034	0.024
H4	205	205	-0.106	0.052
V2	99.9	99.9	-0.009	0.009
V1	133	133	-0.025	0.019
V3	133	133	-0.028	0.021
H2	95.2	95.2	-0.008	0.008
V4	205	205	-0.116	0.057
H3	136	136	-0.032	0.024
V5	194	194	-0.087	0.045
H6	194	194	-0.085	0.044
V7	214	214	-0.187	0.088
H5	191	191	-0.082	0.043
H7	174	174	-0.066	0.038
H8	174	174	-0.060	0.035

- Minuscule error from all ray traces

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Ray Traced Times, Testbed Pulser C1H

Antenna Name	Ray Time (ns)	Ntime (ns)	dT	Error (%)
H1	131	131	-0.042	0.032
H4	147	147	-0.042	0.028
V2	182	182	-0.108	0.059
V1	137	137	-0.037	0.027
V3	204	204	-0.137	0.067
H2	188	188	-0.102	0.054
V4	138	138	-0.040	0.029
H3	198	198	-0.148	0.075
V5	153	156	-3.490	2.280
H6	172	180	-7.770	4.520
V7	153	156	-3.350	2.190
H5	153	154	-1.420	0.931
H7	107	107	-0.016	0.015
H8	117	117	-0.015	0.012

- Only a few notable errors: V5, H6, V7, and H5. These antennas are surface antennas and land in a "reflection zone". There was poor convergence from the ray trace for these antennas, meaning the ray times might actually be closer to NTime.

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Ray Traced Times, ARA02 Pulser D6V

Antenna Name	Ray Time (ns)	Ntime (ns)	dT	Error (%)
TV1	195	195	0.005	0.002
TV2	274	274	0.010	0.004
TV3	192	192	0.006	0.003
TV4	272	272	0.006	0.002
BV1	231	231	0.008	0.004
BV2	302	302	0.009	0.003
BV3	229	229	0.005	0.002
BV4	300	300	0.008	0.003
TH1	194	194	0.009	0.005
TH2	274	274	0.009	0.003
TH3	192	192	0.006	0.003
TH4	272	272	0.009	0.003
BH1	222	222	0.007	0.003
BH2	294	294	0.012	0.004
BH3	220	220	0.004	0.002
BH4	292	292	0.007	0.002

- Tiny error from all ray traces

Ray Tracing Conclusion

- NTime appears to be a very accurate means of estimating in ice travel time for light
- With such low error between NTime and Ray time, reconstruction stability is relatively unaffected
- Thus, NTime can be relied on for our reconstructions

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Conclusion

- Both:
  - varied ice models
  - ray tracing

  do not seem to hold a solution to our reconstruction difficulties.
- Open for suggestions where sources of reconstruction instability might be.

Backup

Ice Models

$$n = A - B * e^{C*z}$$

Model	A	B	C
NTime	1.78	0.43	.016
Black Dots	2.16	0.78	.0045
Inverse Triangle	1.83	0.48	0.012
Crosses	1.79	0.48	0.019
All	1.81	0.46	0.013