radiospline:
fast raytracing spline tables for radio event reconstruction

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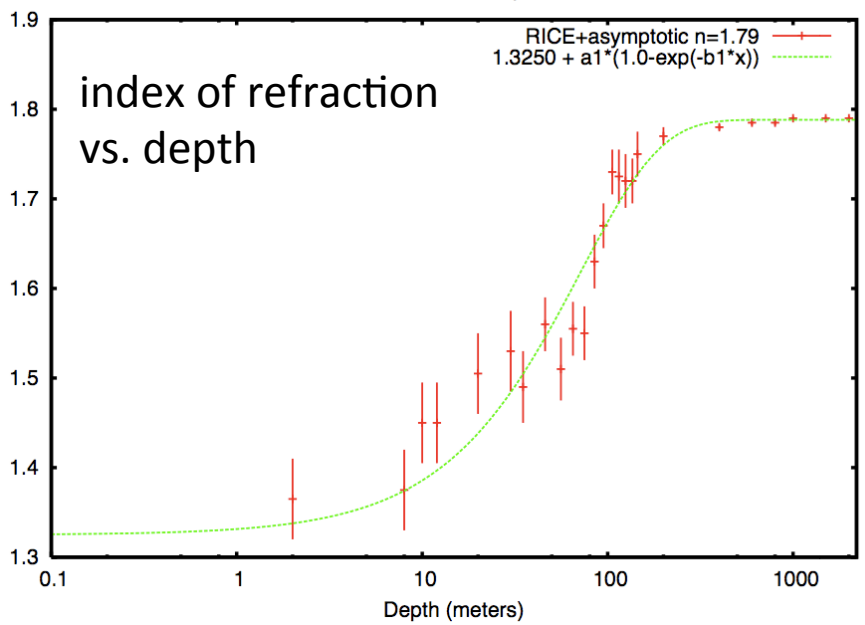
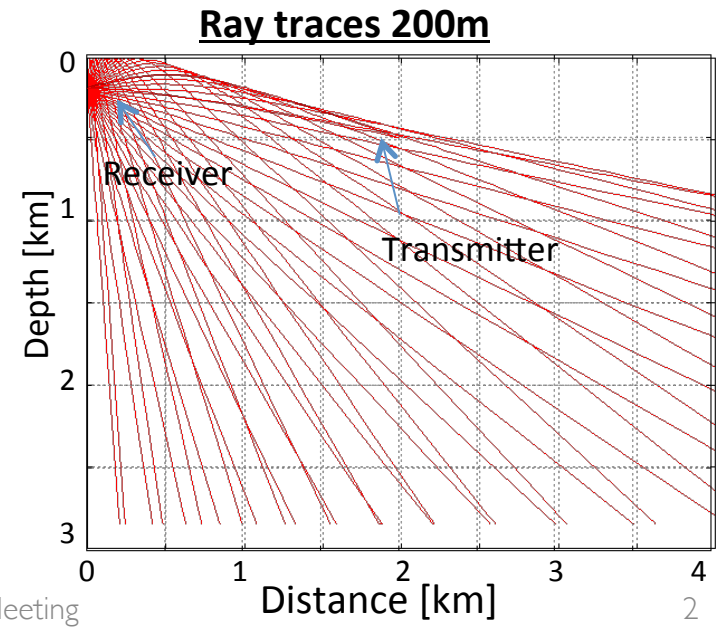
Radio Propagation in Ice

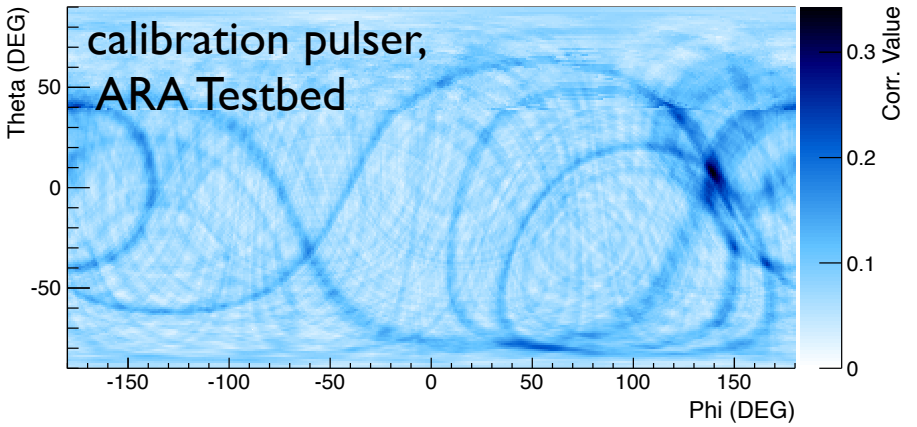
- Index of refraction in South Pole ice not uniform (firn layer)
- Spherical wave reconstruction: large systematic zenith angle errors
- Full ray-tracing code used for simulation; slow for reconstruction



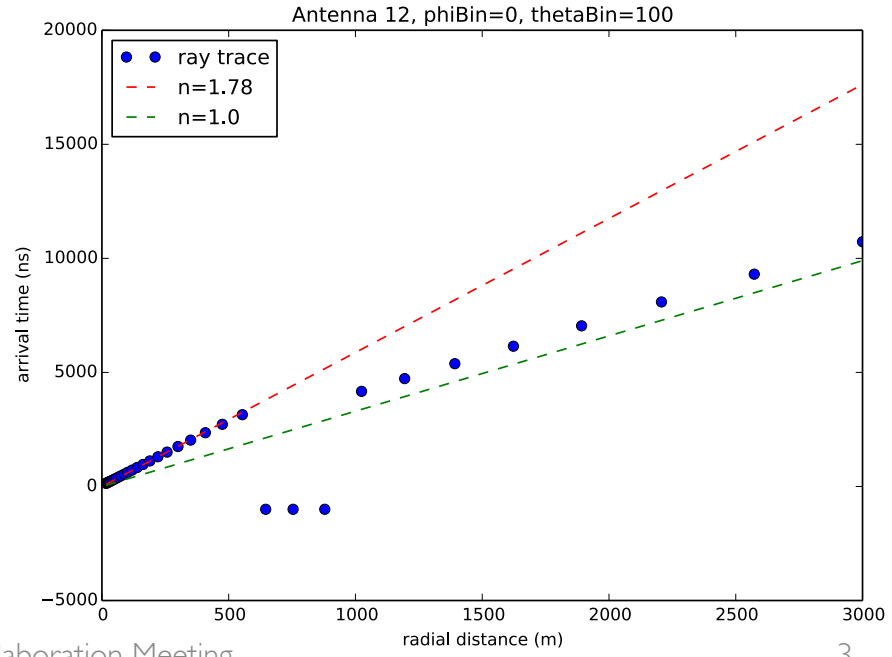


Beamforming-based Reconstruction

- All-sky beamforming for directional reconstruction
  - arXiv:1404.5285
  - discrete tables of ray-tracing solutions
  - only two distances



tabulated raytrace time delays (C. Pfendner)

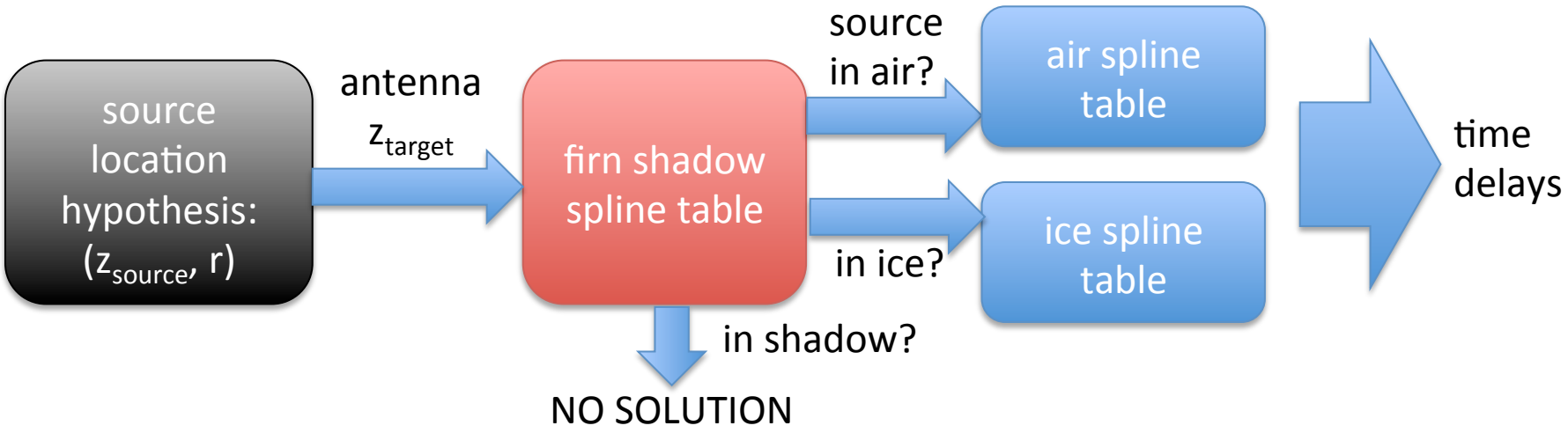


- Goal: full ray-trace-based beamformed reconstruction
  - speed up beamforming with GPUs
  - smoothly interpolated raytrace solutions for fast time-delay lookup

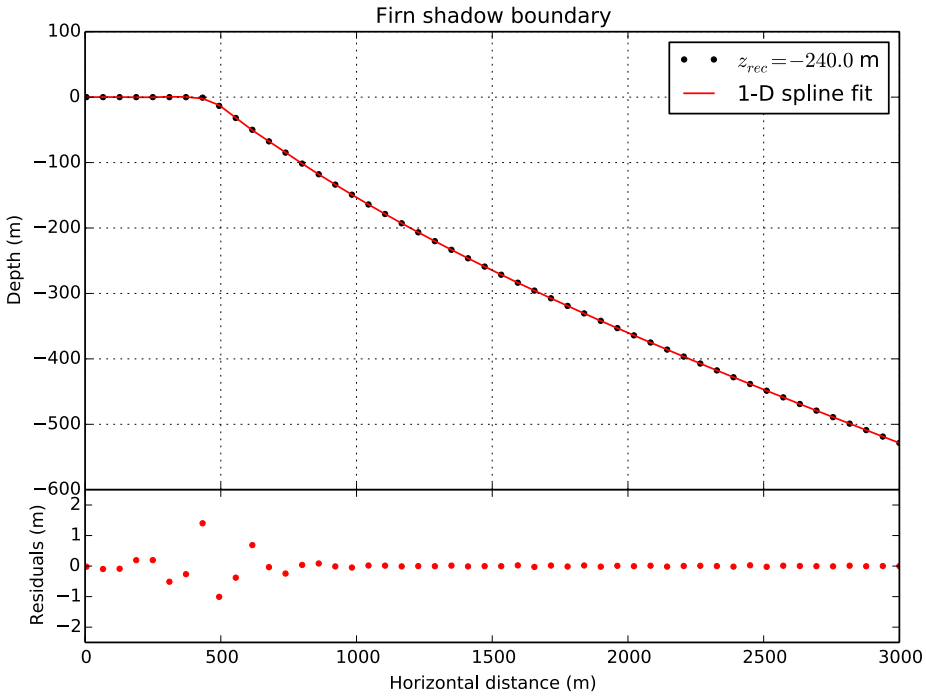
Spline-Fitted Raytrace Tables

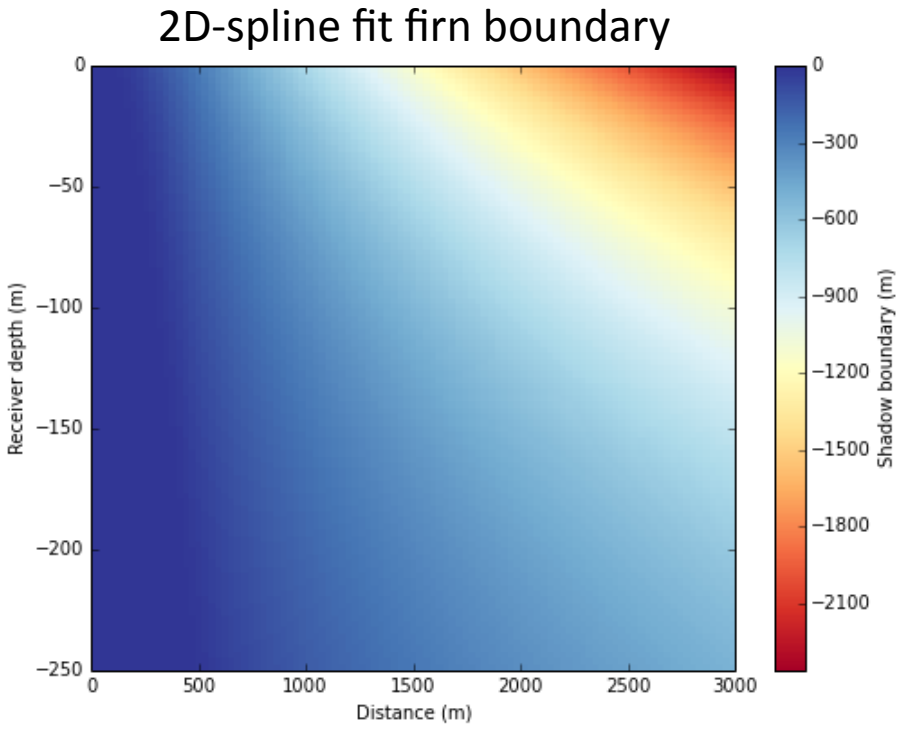
- Smoothly interpolating many-dimensional tables solved for IceCube (B-splines)
  - photospline [CPC 184, 2214 (2013)]

- Technical challenges
  - discontinuities due to firn shadow, air/ice boundary
  - reflected solutions in addition to direct ray (deferred)
  - solution: cylindrical coordinates + multi-step table lookup



Firn Boundary Spline Table

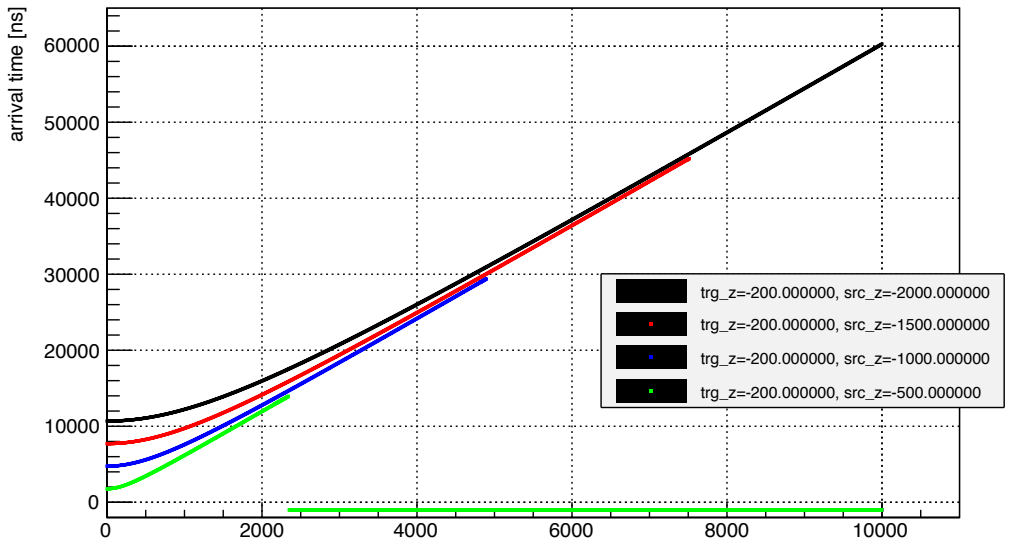


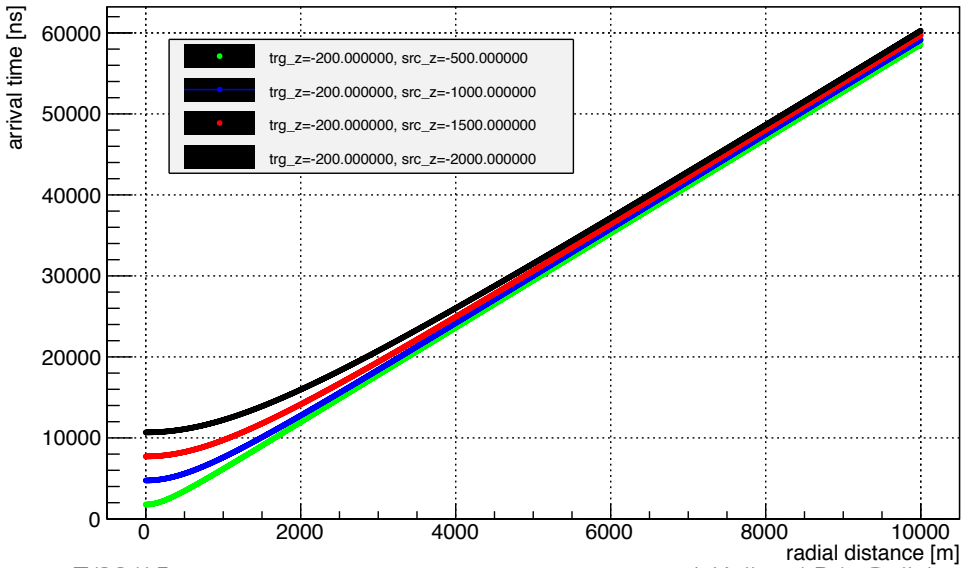


Firn boundary table: fast determination if source / receiver solution possible

Cylindrical Raytrace Table

M.-Y. Lu





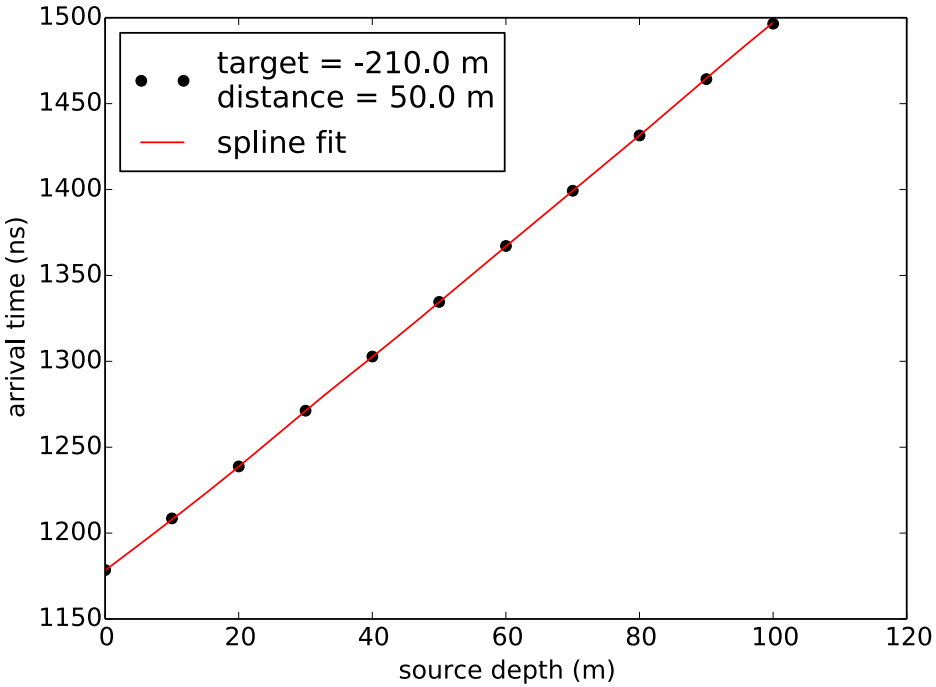
- Produce raytrace table $t\ (\ r, z_{target}, z_{source})$ using ray solver (C. Weaver)

- For smooth spline fit, linearly extrapolate past firn shadow boundary

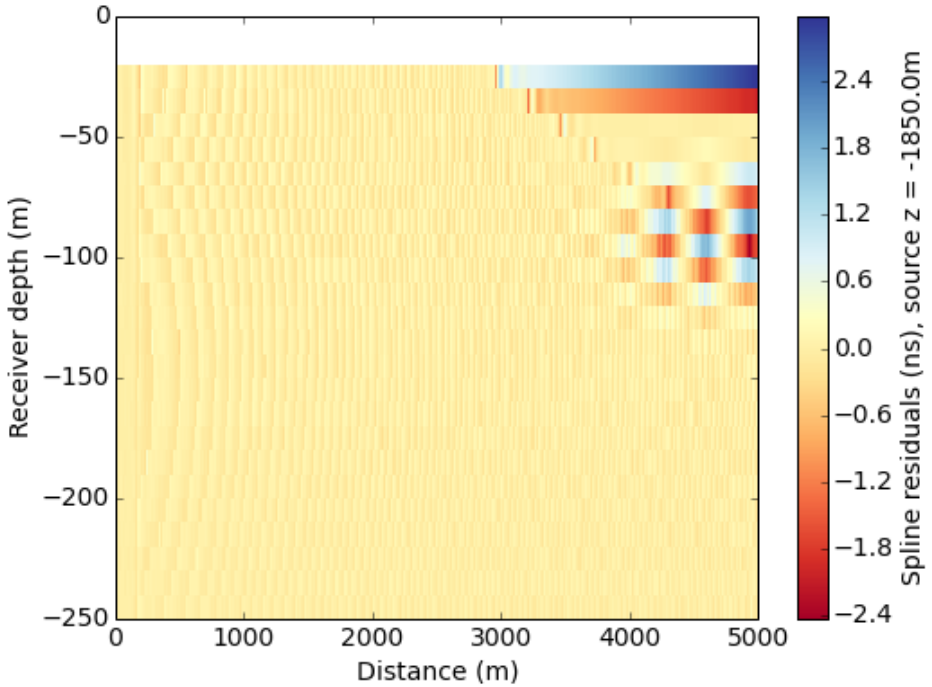
- Time delays beyond shadow boundary will be discarded as previously described

Example raytrace spline fits

source in air: table points with fit

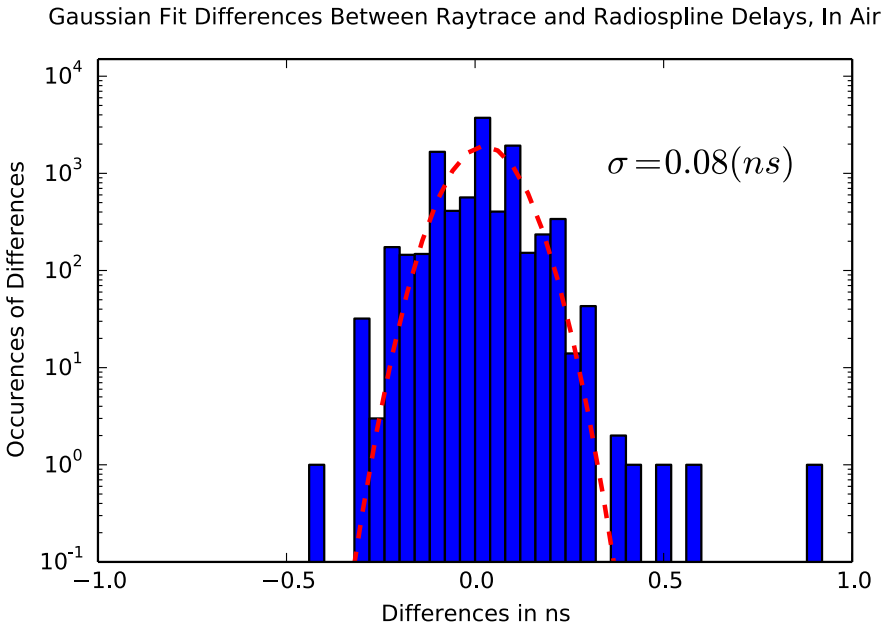


source in-ice: 2D residuals

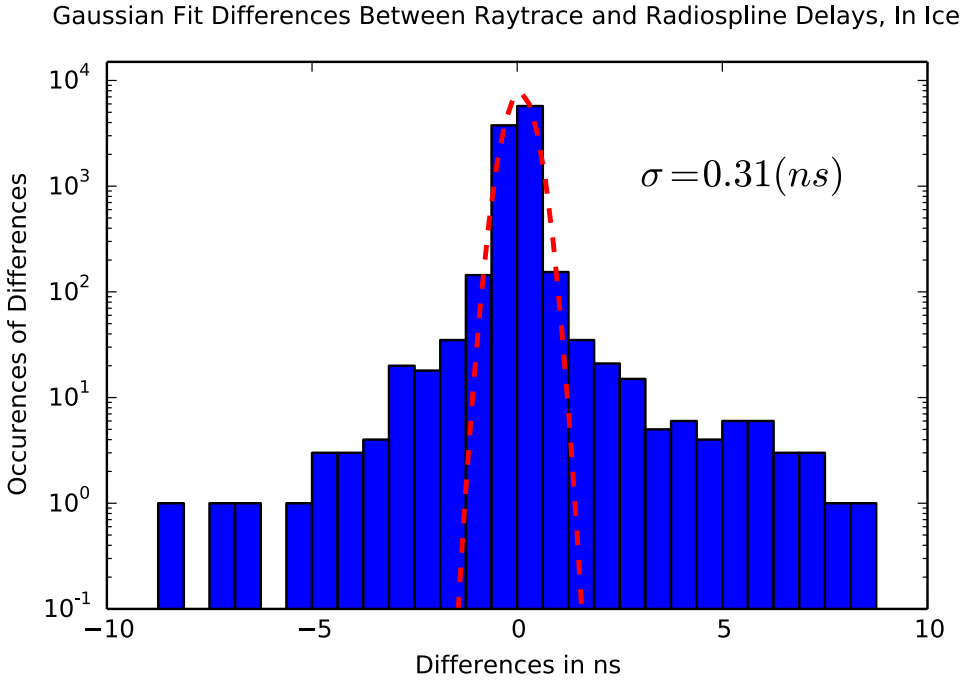


Errors relative to raytracer

random sources in air



random sources in ice



M. Beydler

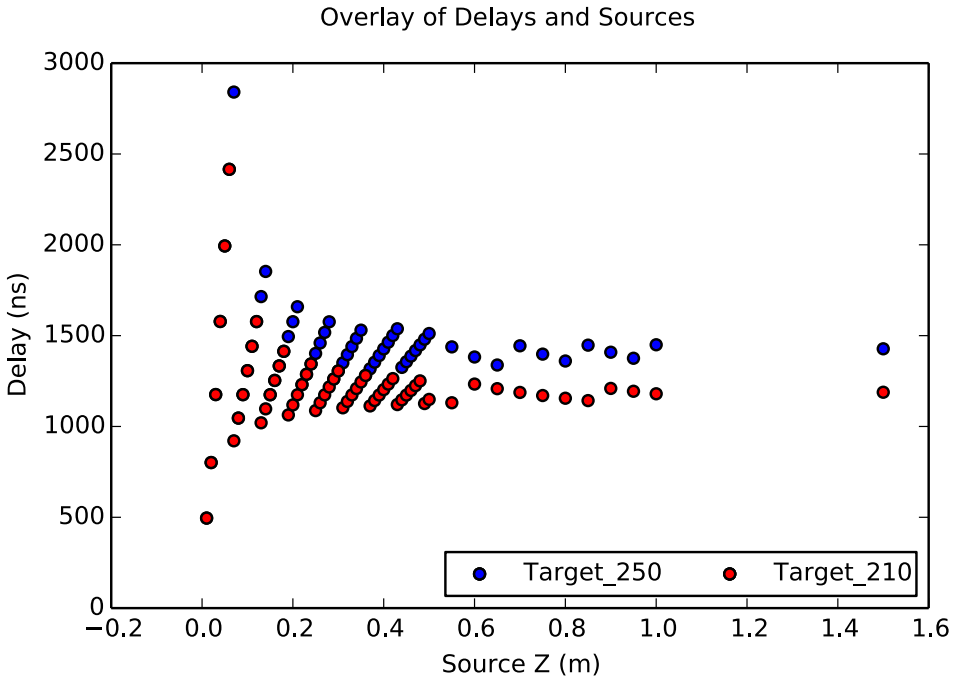
Agreement of in-air tables excellent;
some outliers in ice (known issue with spline fits)

Aside: minor AraSim bug

- Large raytrace errors for sources just above firn surface ($0 < z < \sim 1$ m) when target is in the ice
  - could impact surface pulser analysis / simulation

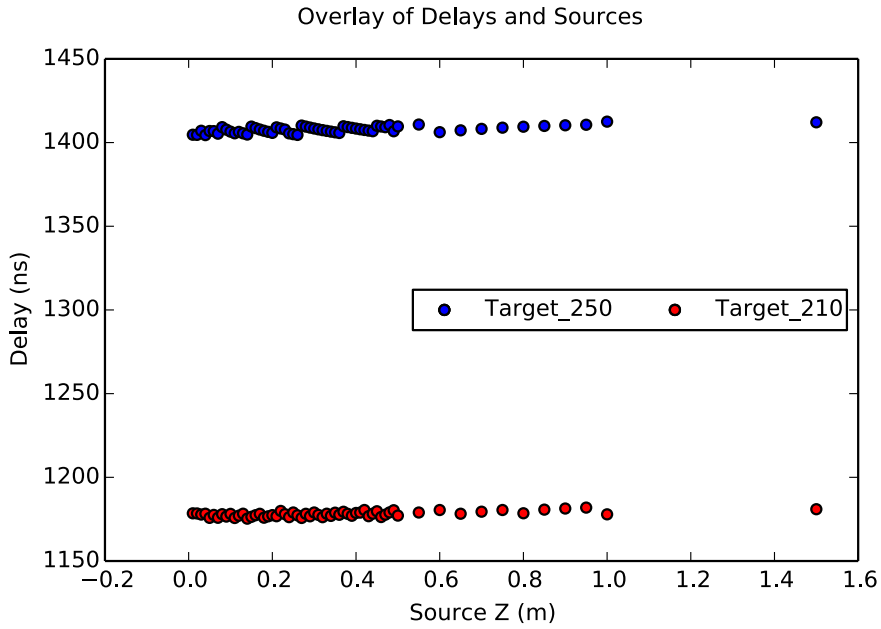
- Patch sent to OSU

before fix



after fix

M. Beydler



radiospline Performance

Random source/target locations (2.3 GHz Core i7)

Method	Average computation time / ray (ms)
AraSim raytracer	0.21
radiospline	0.00037

Spline lookup+evaluation is > 500 times faster than full raytrace calculation

Status and Next Steps

- Current version has sufficient accuracy for interferometry (see talk by M.-Y. Lu)
- Rerun in-ice fits with more spline knots
  - technical challenges: requires ~50GB of RAM and a different linear algebra library
- Fully decouple from IceCube repository
  - photospline is published but hidden behind CPC paywall
- Improve documentation, self-testing
- Release on WIPAC GitHub and/or ARA SVN
- What to do about 2nd solution (reflected ray?)