Interferometric Reconstruction with Radiospline

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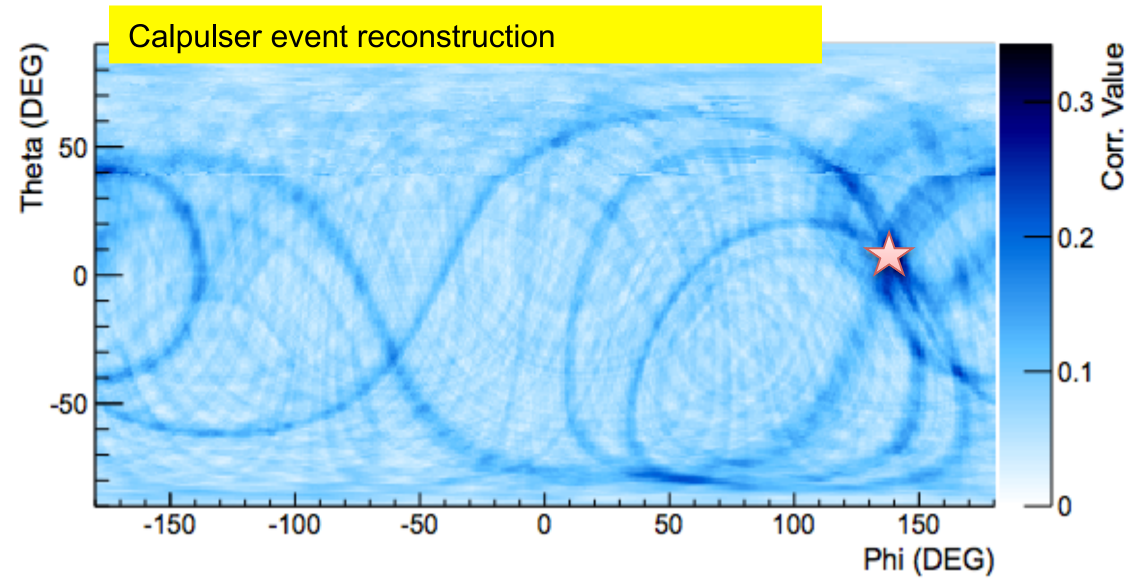
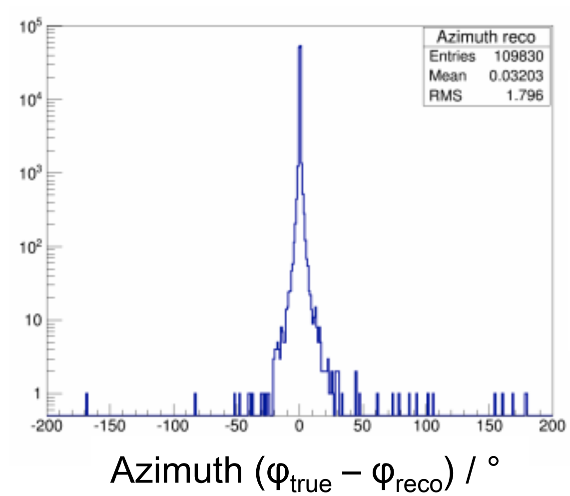
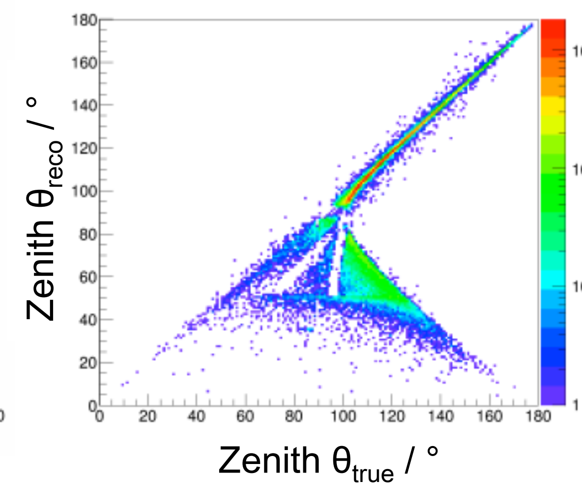
2015 ARA Collaboration Meeting

Brief review of reconstruction methods so far

- Interferometric reconstruction with 2 hypothesized distances (30m & 3km)
- Matrix-based plane-wave reconstruction
- In general ~1° angular resolution can be achieved by both methods

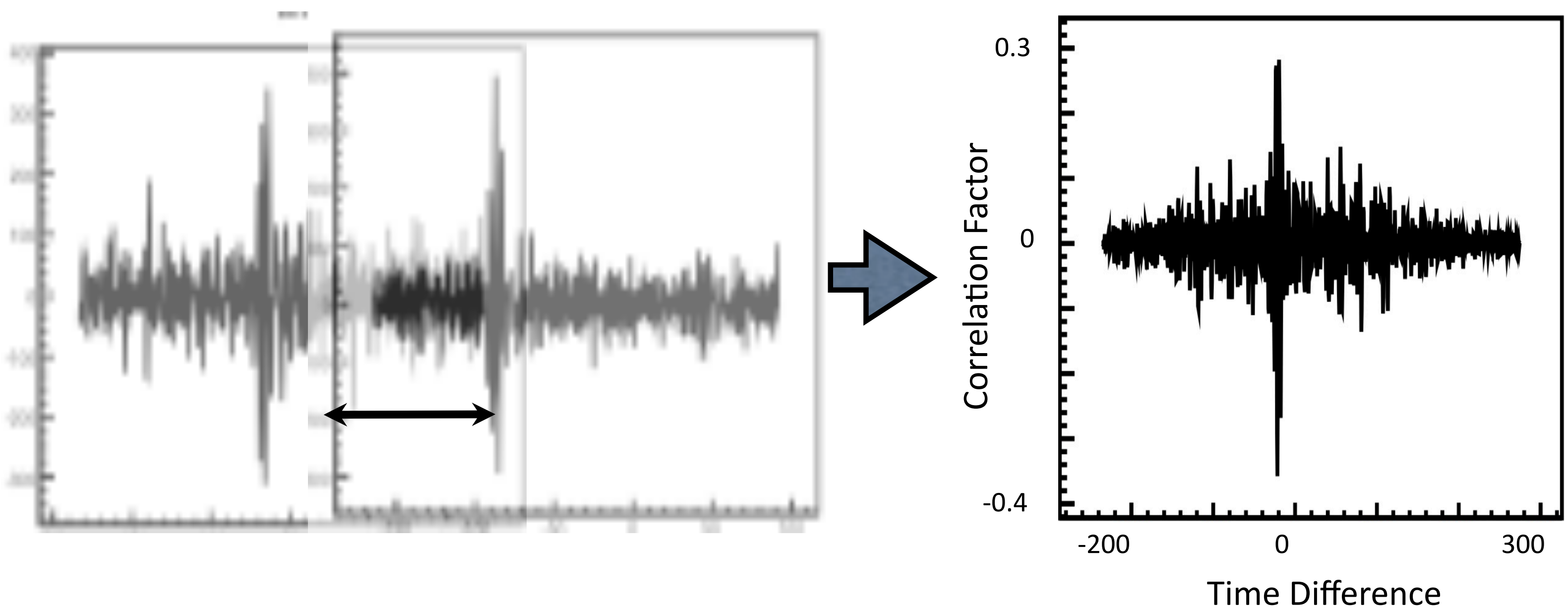






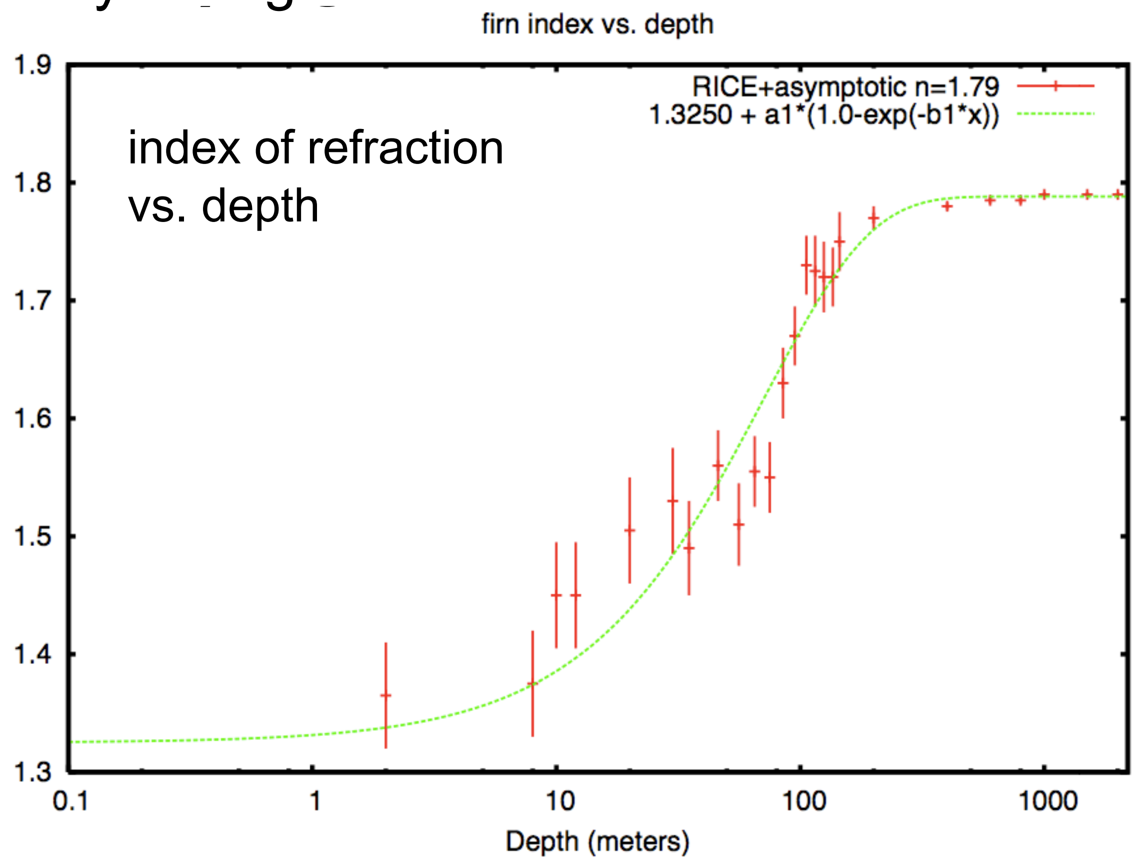
Interferometric Reconstruction

- Attempt vertex reconstruction using relative timing information from hypothesized source positions
- Waveforms time-shifted according to computed delays



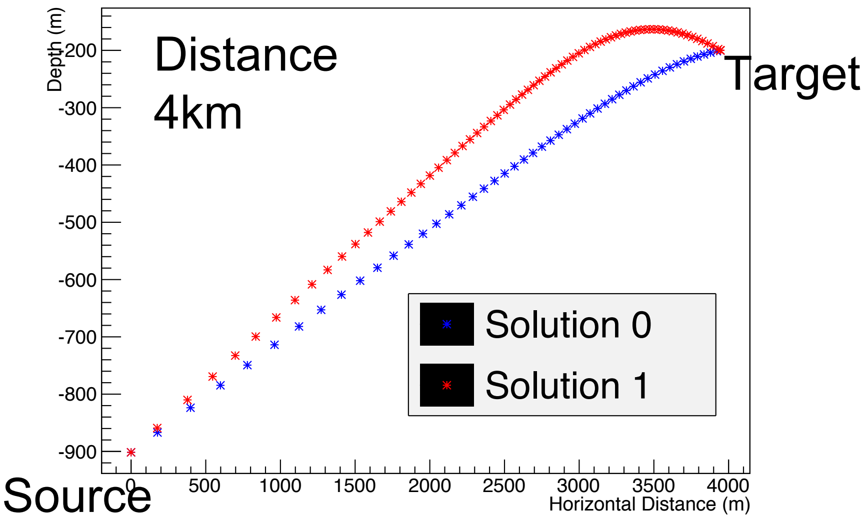
Where to Get Delays?

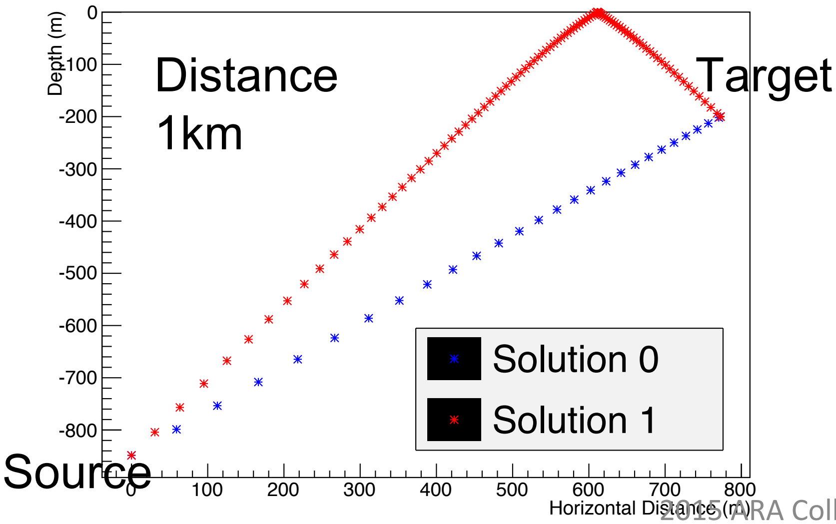
- Ice index of refraction varies with depth. Change is most drastic near surface (firn). As a result, EM waves travel in curved paths – raytracing
- Ideal direction/distance reconstruction need to take into account raytracing effect



Raytracing and Radiospline

- Semi-analytic approach to compute ray paths by C. Weaver. Delays computed by this approach tabulated and fitted with B-Spline



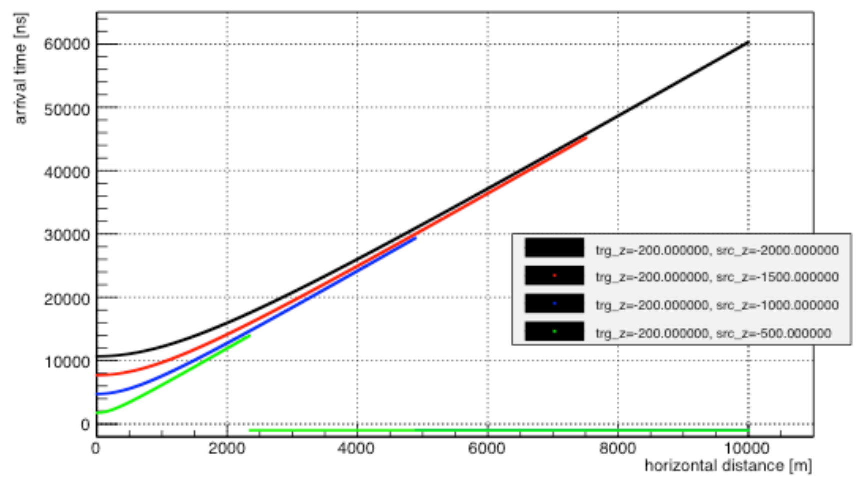


Radiospline (See J. Kelley talk)

Determining shadow boundary

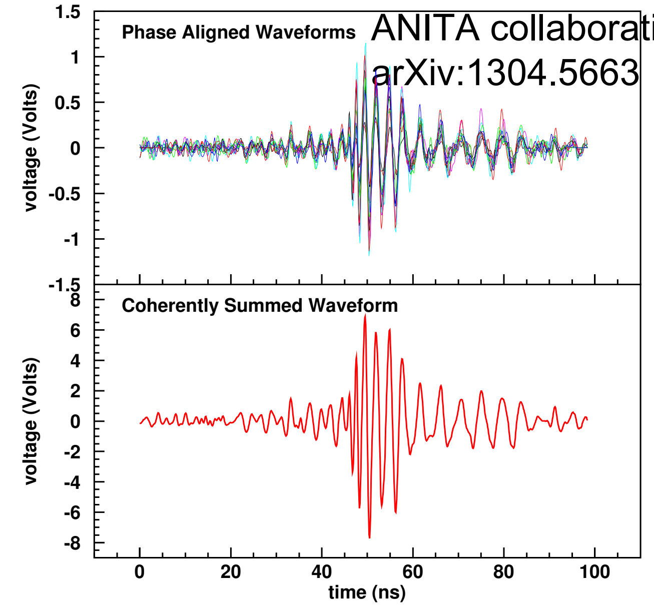
⇩

Determining delay



Coherently Summed Waveforms

$$P_\Sigma(\hat{r}) = \frac{1}{Z_L T}\int_0^T \sum_{i=1}^{N_A}\sum_{j=1}^{N_A} dt\cdot v_i(t+\tau_i(\hat{r}))v_j(t+\tau_j(\hat{r}))$$



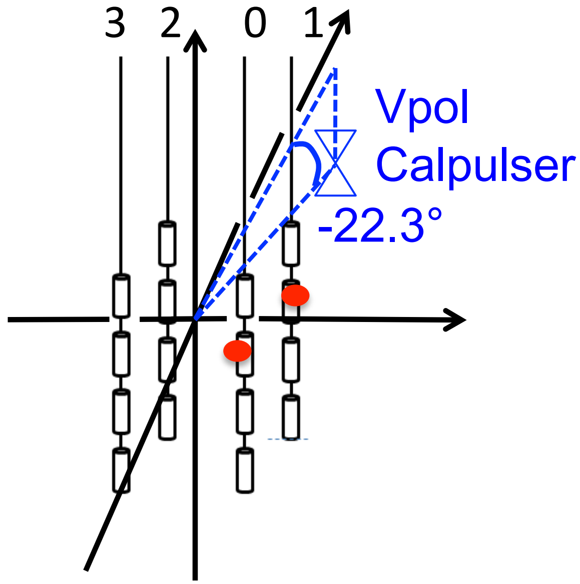
ANITA collaboration
arXiv:1304.5663

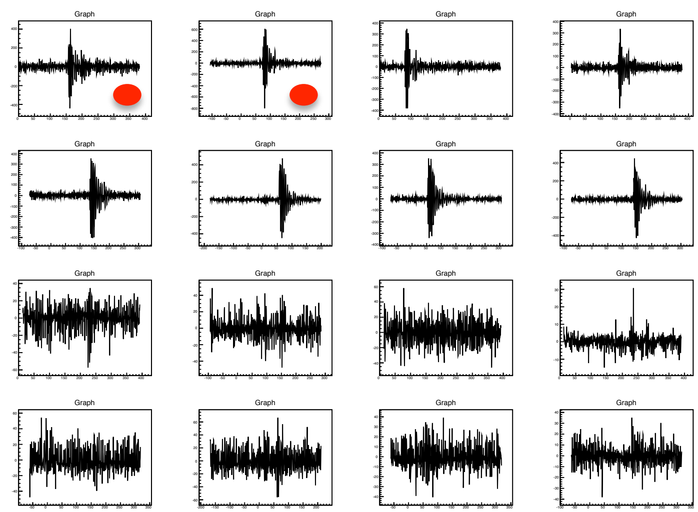
Cross Correlation

$$P_\Sigma(\hat{r}) = \sum_{i=1}^{N_A} P_i + \frac{1}{Z_L T}\sum_{i=1}^{N_A}\sum_{j\neq i} v_i \otimes v_j(\hat{r}),\qquad P_i = \frac{1}{Z_L T}\int_0^T dt\cdot v_i^2(t)$$

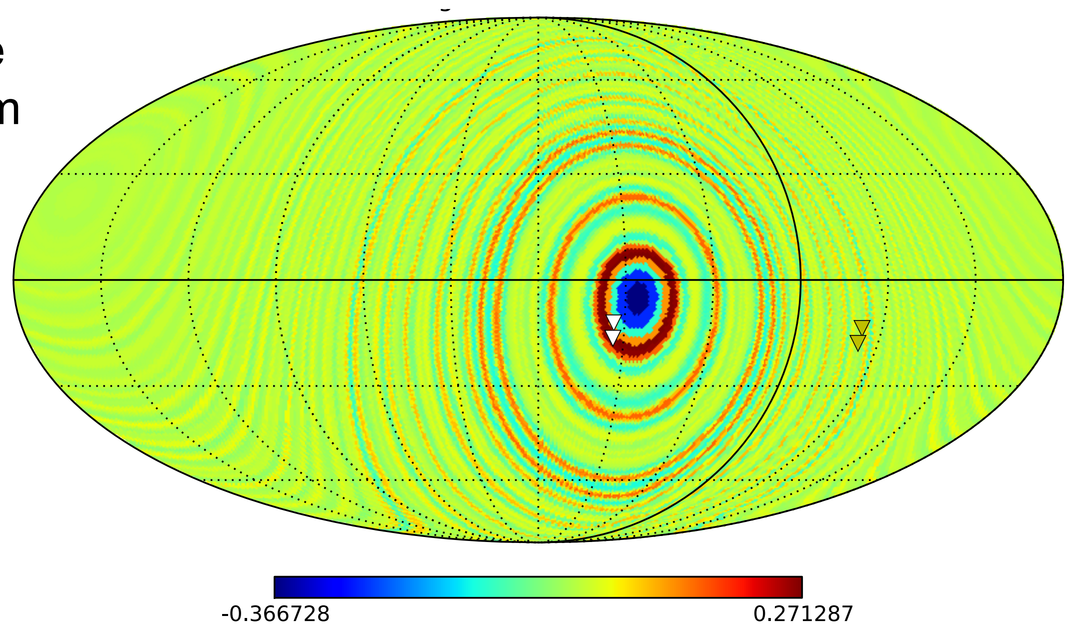
Directional information
“Coherence”

Cross Correlation (A3 Calpulser)





Assume true distance 42m



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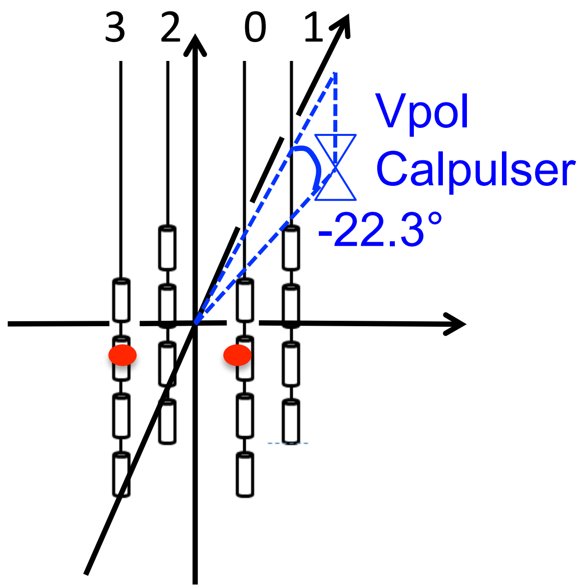

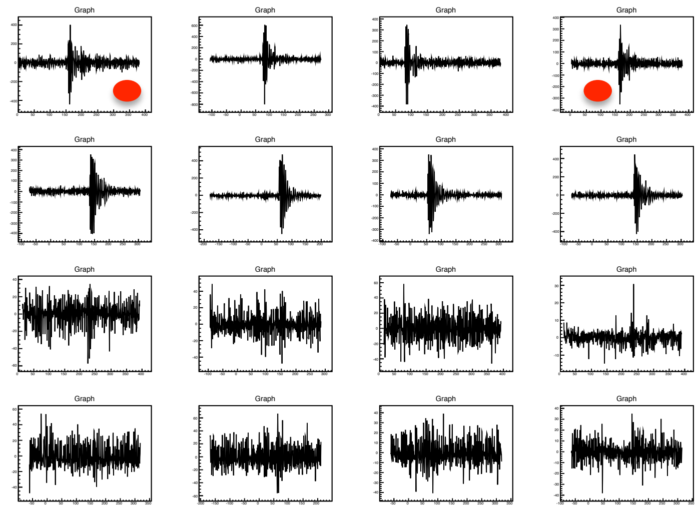

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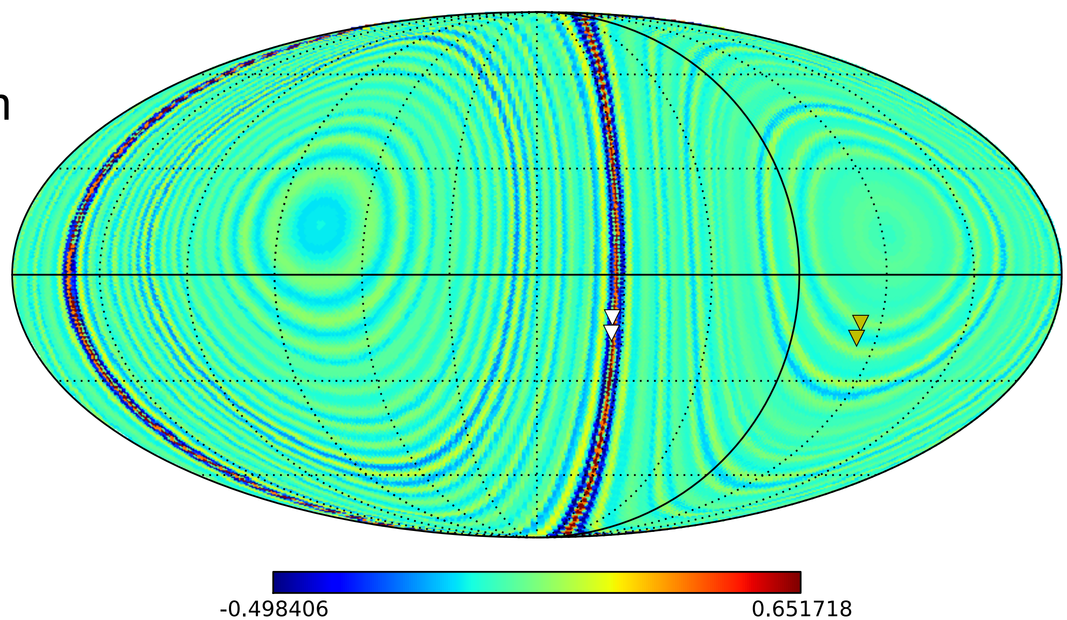

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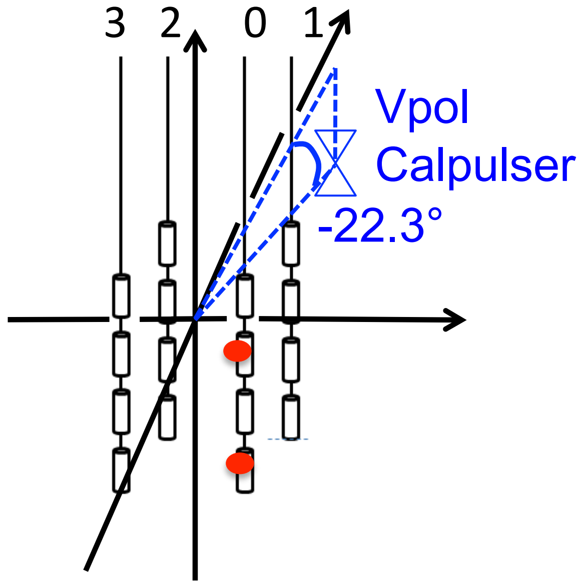
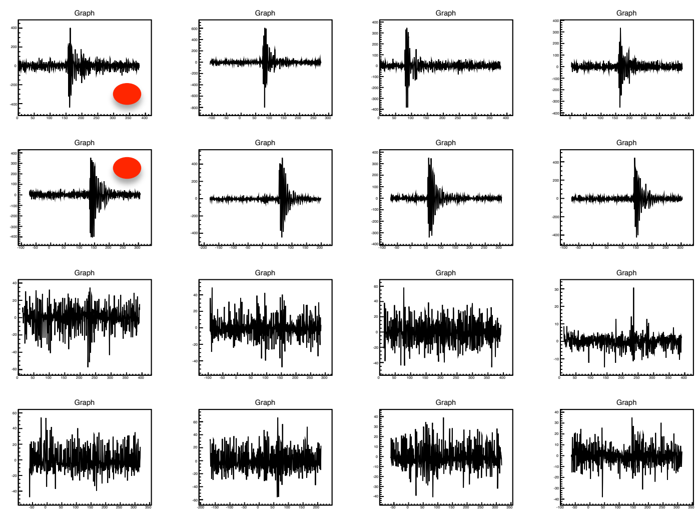
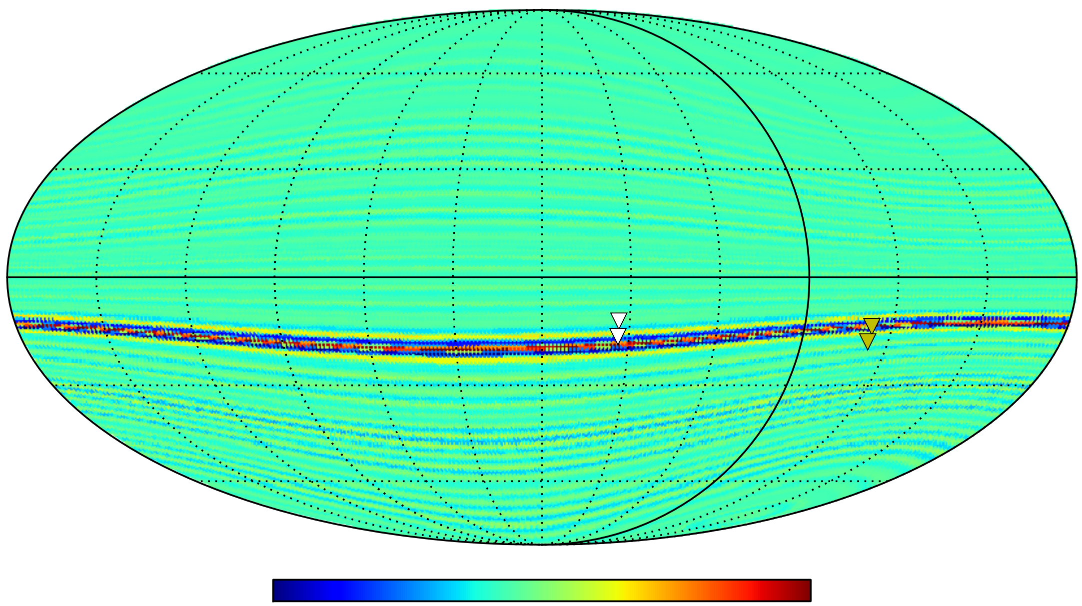


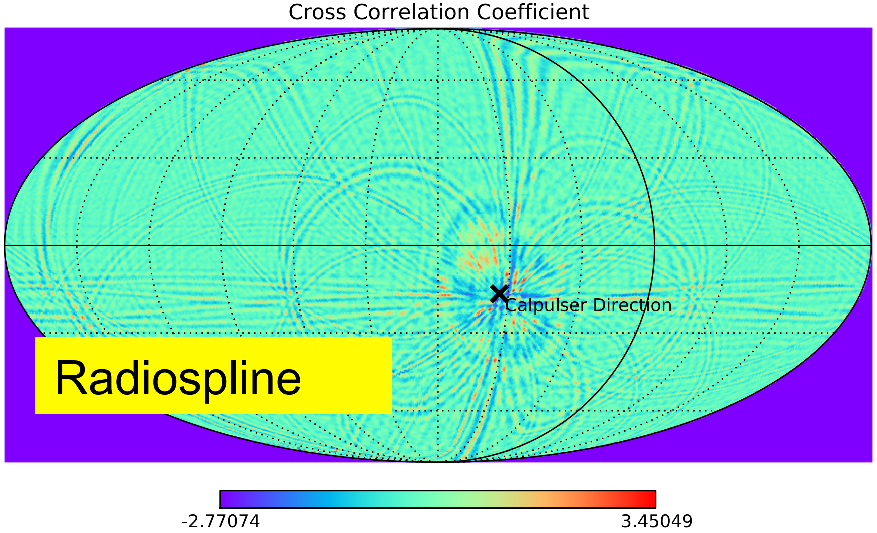


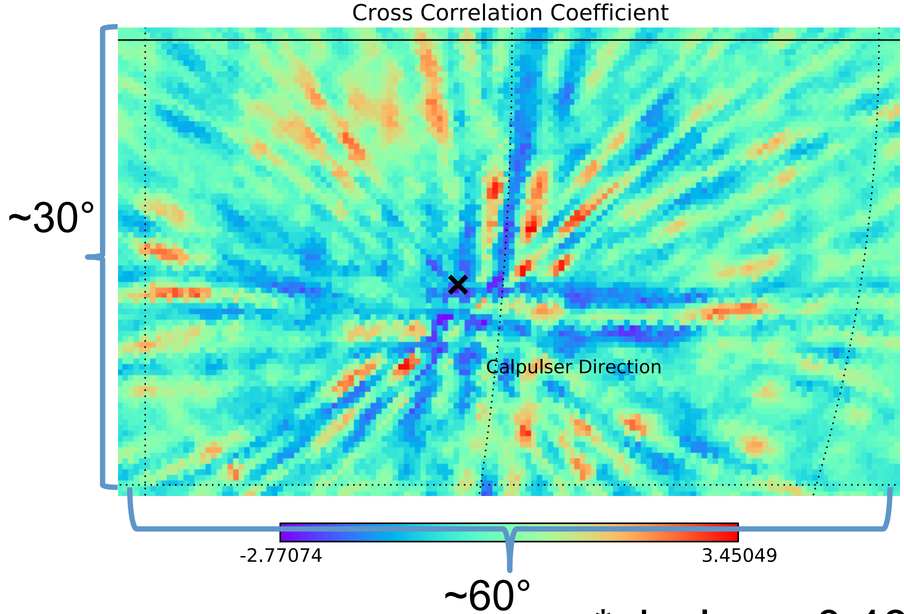
Assume true distance 42m



Full Cross Correlation Skymap

- All 8 Vpol channels used
- ARA3 Vpol calpulers reconstruction assuming 42m distance (=true distance)
- 2013 run673 cal event #2

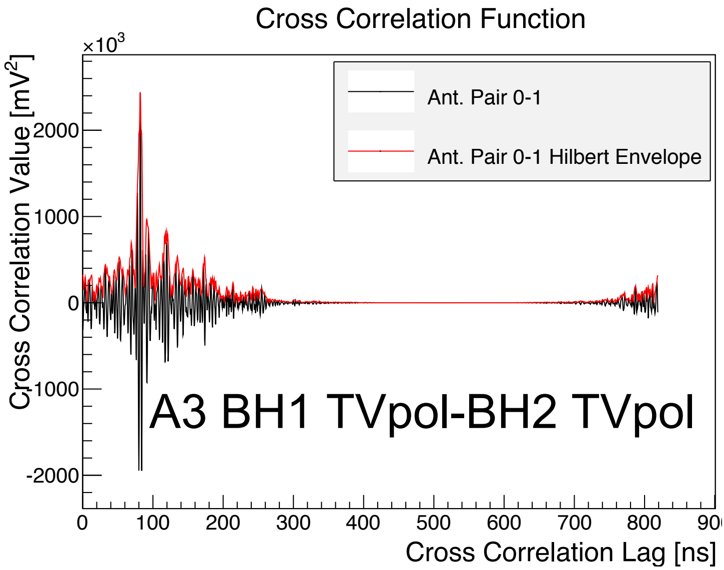


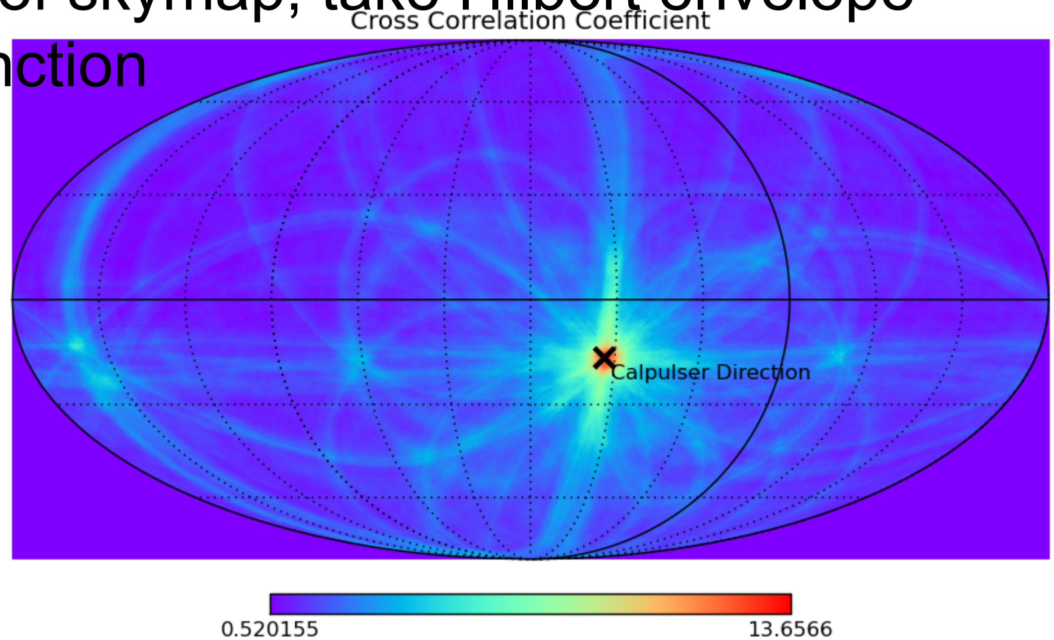


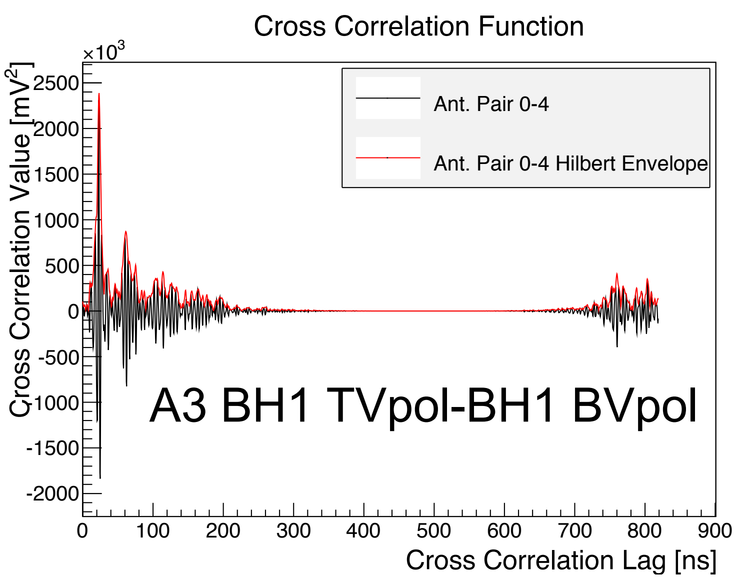
*pixel res.:0.46°

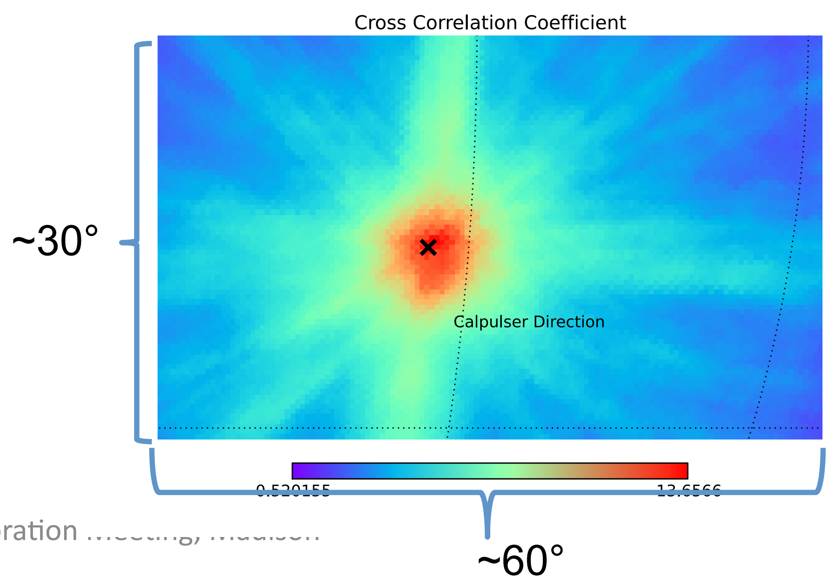
Hilbert Envelope

- To remove graininess of skymap, take Hilbert envelope of cross-correlation function



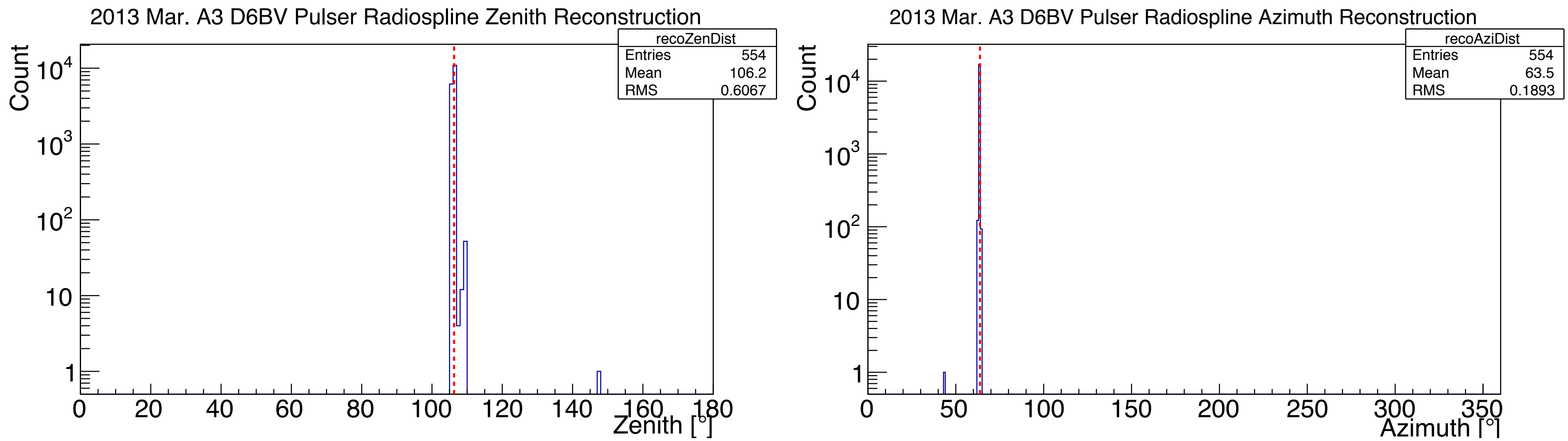






Calpulser Reconstruction

- A3 2013 March filtered events –D6BV pulser
- Calpulser distance fixed as known value (42m)

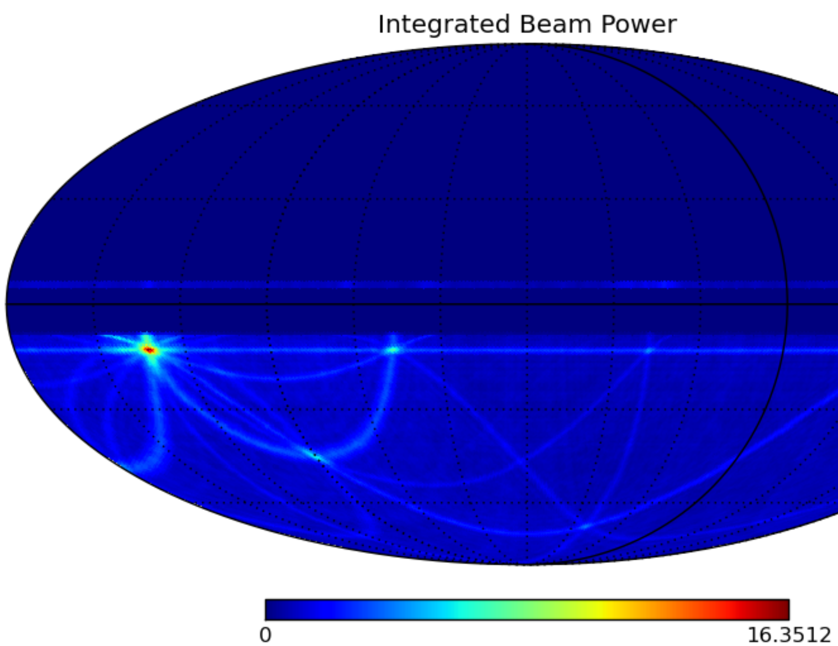


True Pulser Distance: 42m			
	True	Reco Mean	Diff.
Zenith	106.3°	106.2°	-0.1°
Azimuth	63.8°	63.5°	-0.3°

Angular Reconstruction

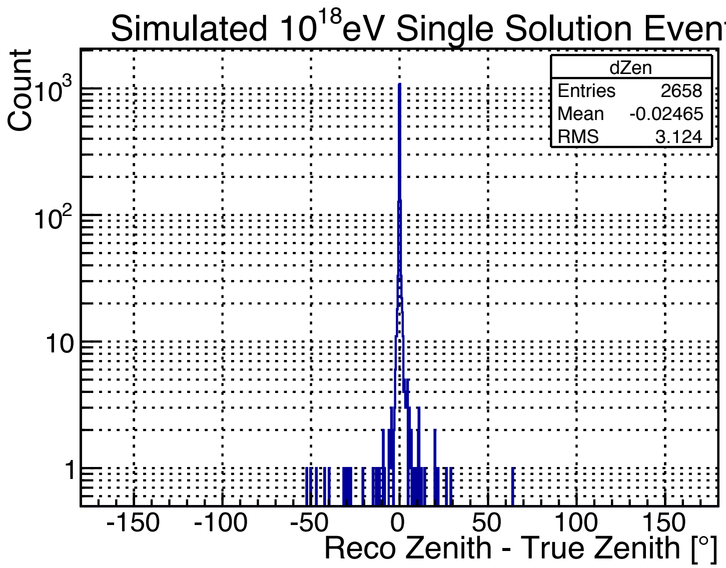
- Dataset: 10^{18}eV neutrinos vertices randomly distributed up to 5km horizontal distance from station
- Trigger: default 3/8 multiplicity trigger
- Only allow single (1st) raytrace solution in simulation – no reflection!
- As starting point, place stringent event selection criteria
  - Nchnl(V_{peak}>5σ_{noise}) >=4
  - Exclude saturated channels
- Assume simulation-true vertex distances in reconstruction

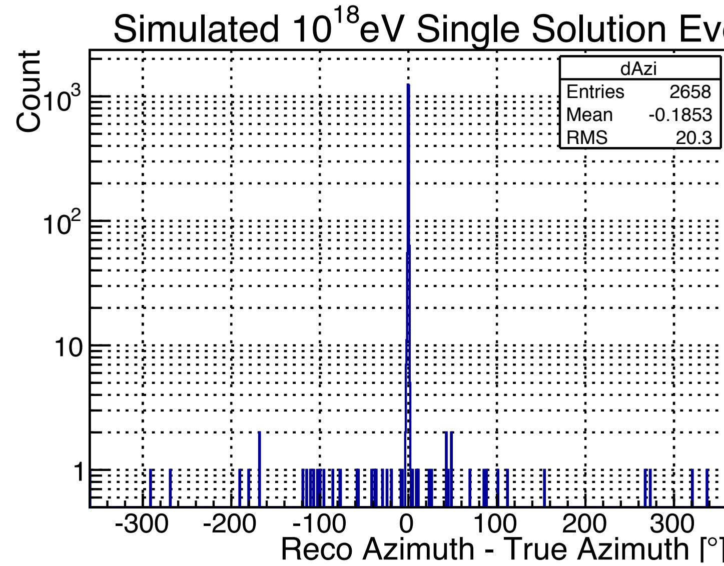
Example event

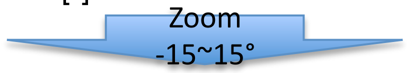


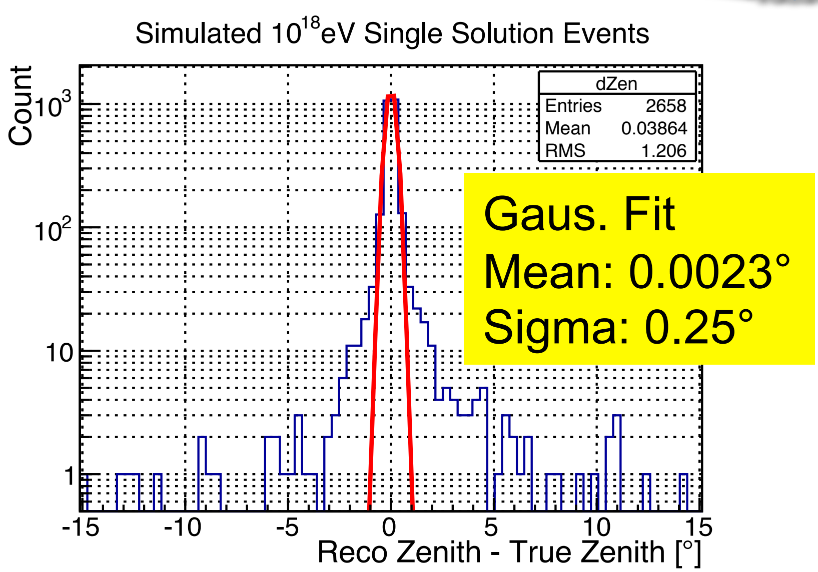
True Vertex Distance: 2581m			
	True	Reco	Diff.
Zenith	102.74°	102.94°	0.2°
Azimuth	222.69°	222.89°	0.2°

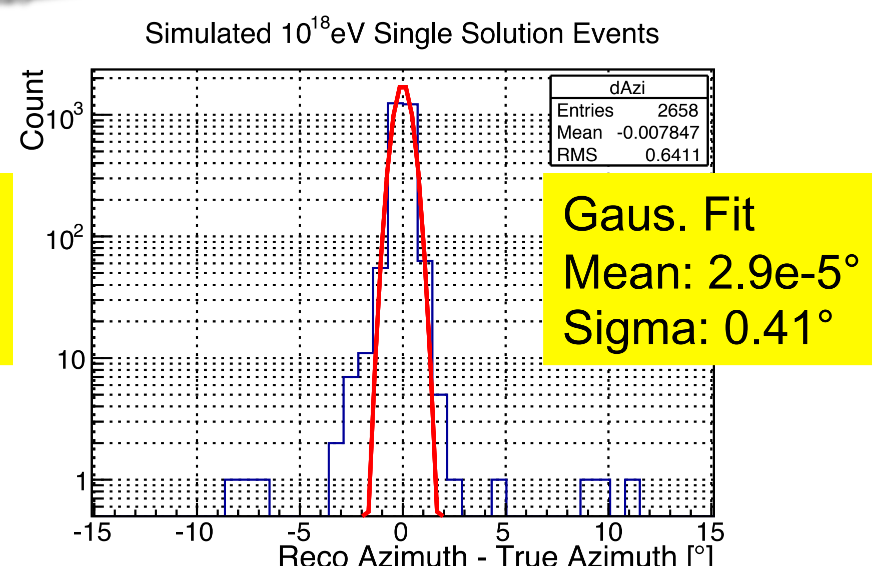
Angular reconstruction



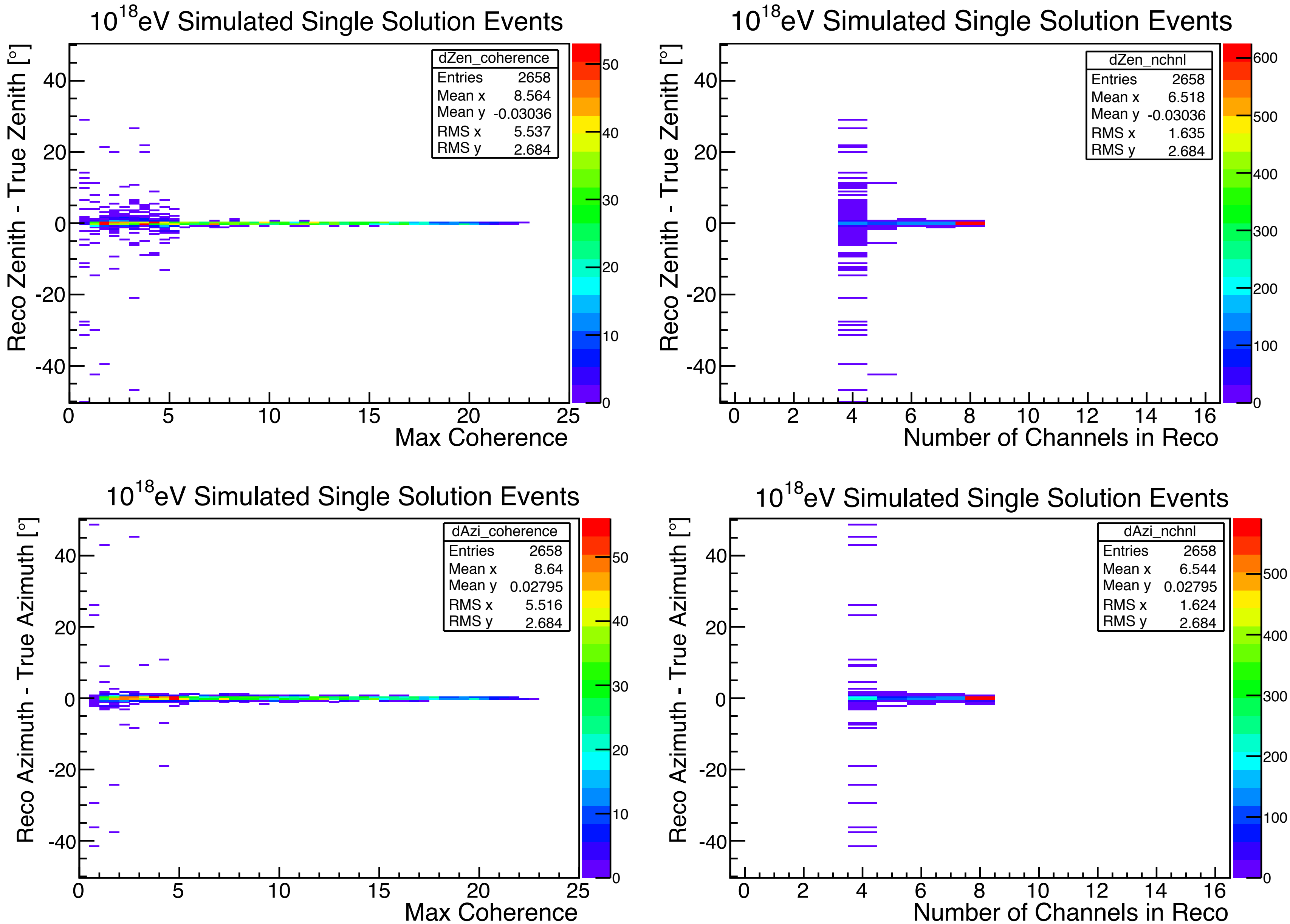






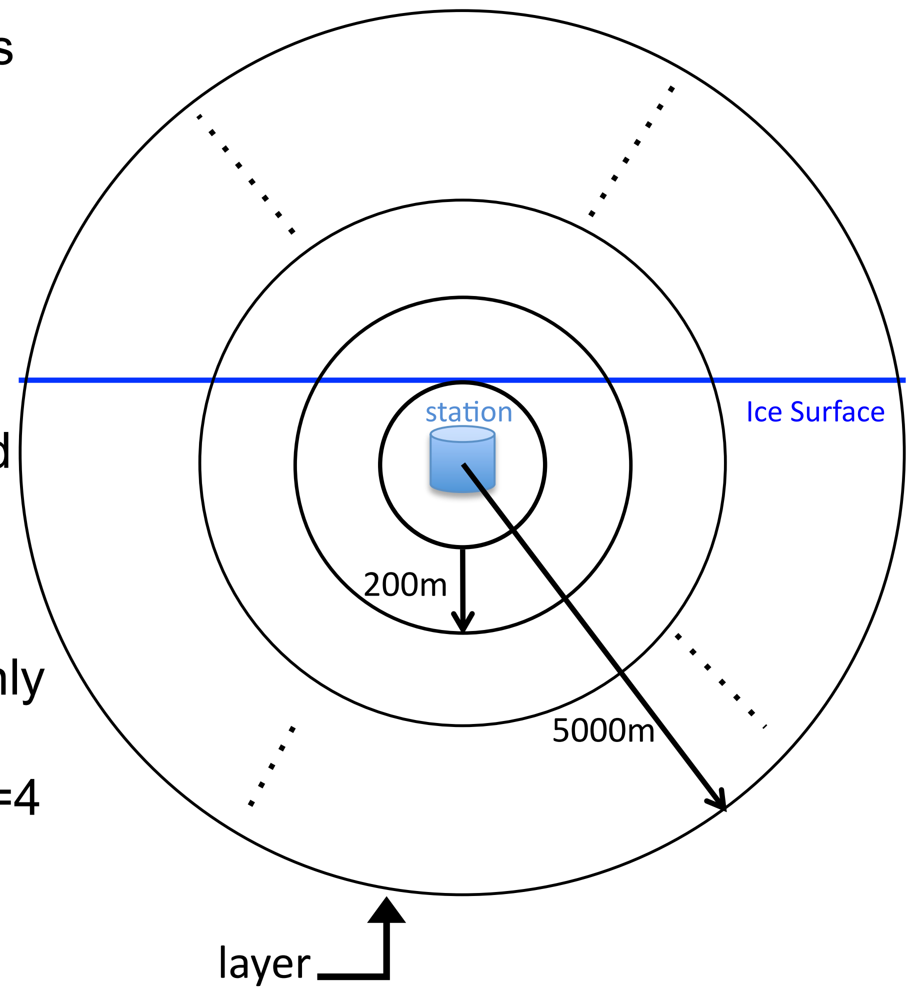


Angular reconstruction

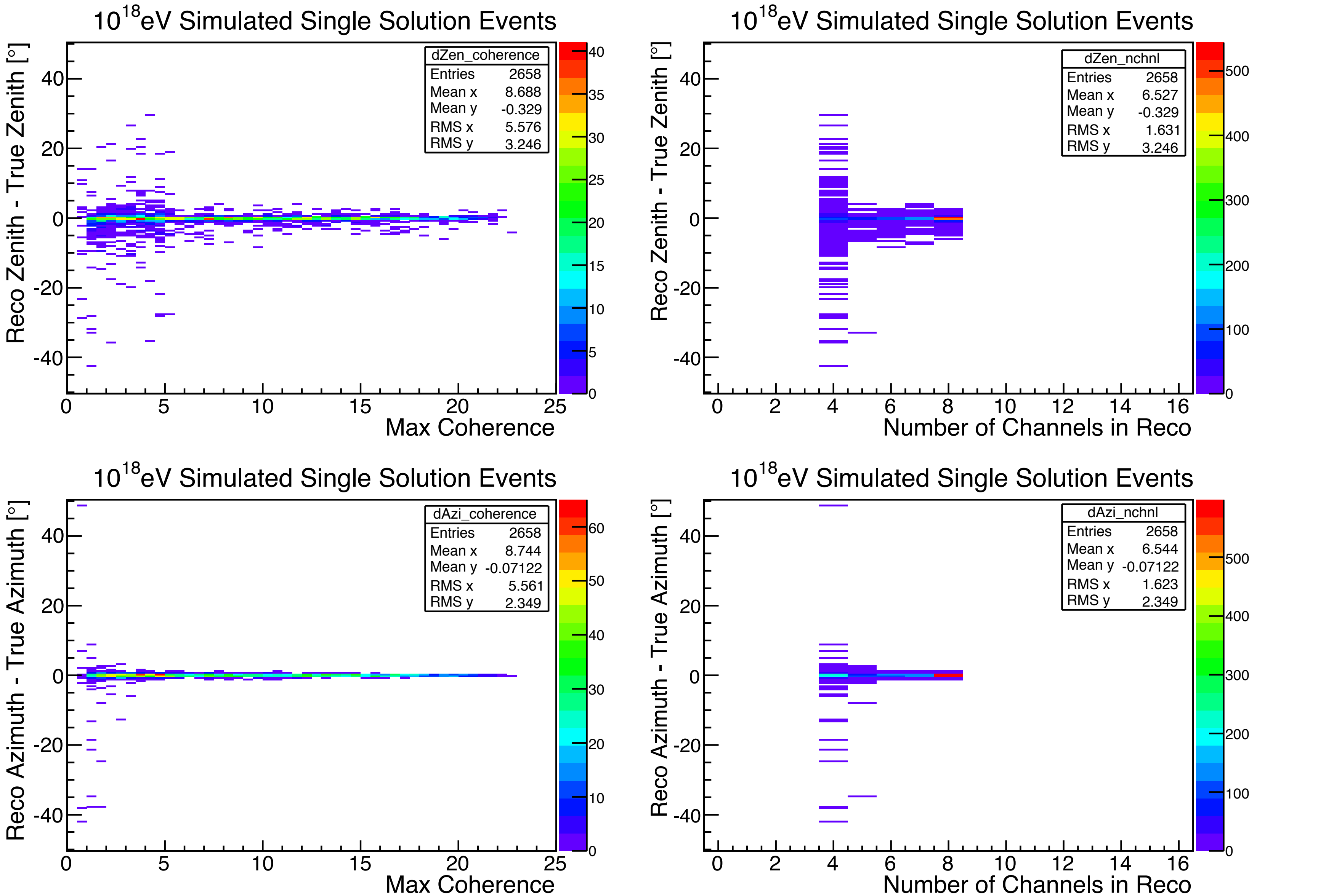


Vertex Position (angular+distance) Reconstruction Framework

- Time delays computed for all pixels on a set of Healpix skymaps at different "radii".
- Radii range from 200-5000m, constant interval 200m
- For each event, all $N_{layer} * N_{direction}$ pixels are looked at. The pixel with the max coherence value is treated as giving reconstructed distance/ direction
- Simulation: 10^{18}eV neutrinos on conventional multiplicity trigger. Only single raytrace solution is allowed.
- Event selection: Nchnl(V_{peak}>5σ)>=4 for clean/strong events. Saturation cut applied



Angular and Vertex Distance Reconstruction



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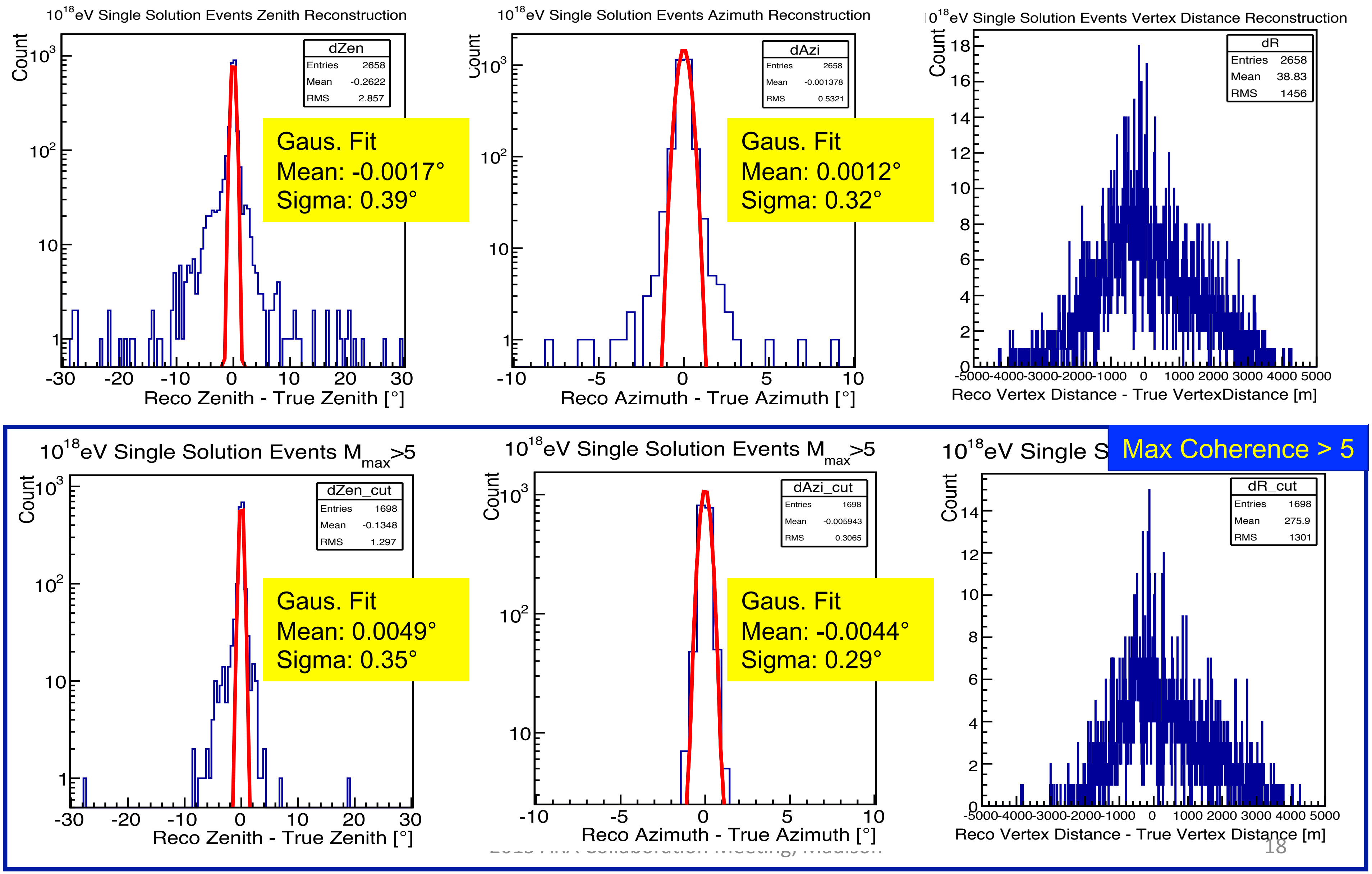
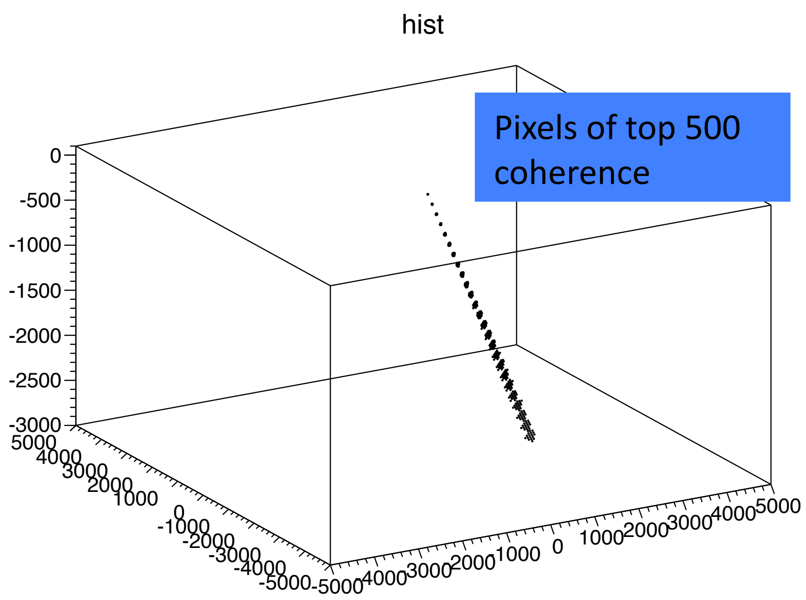
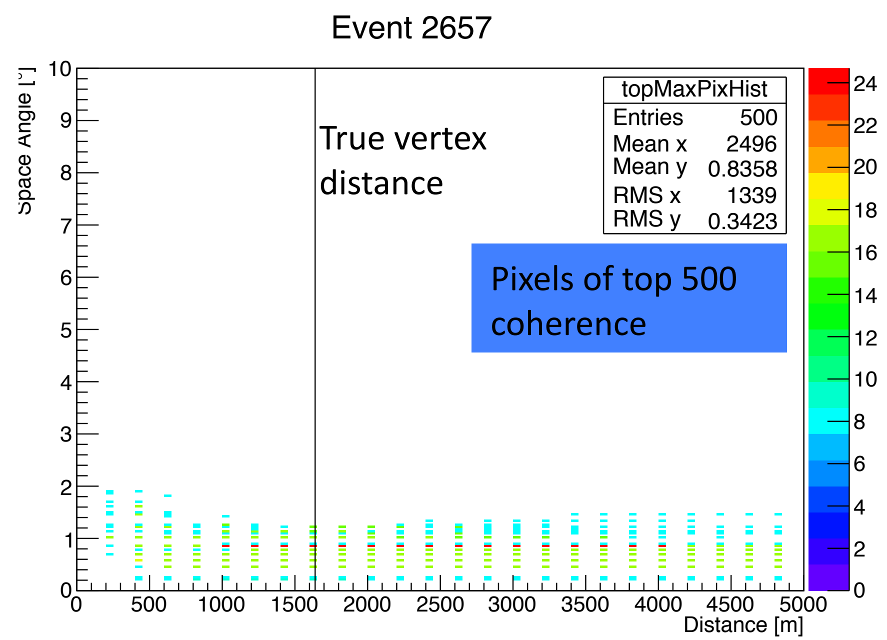
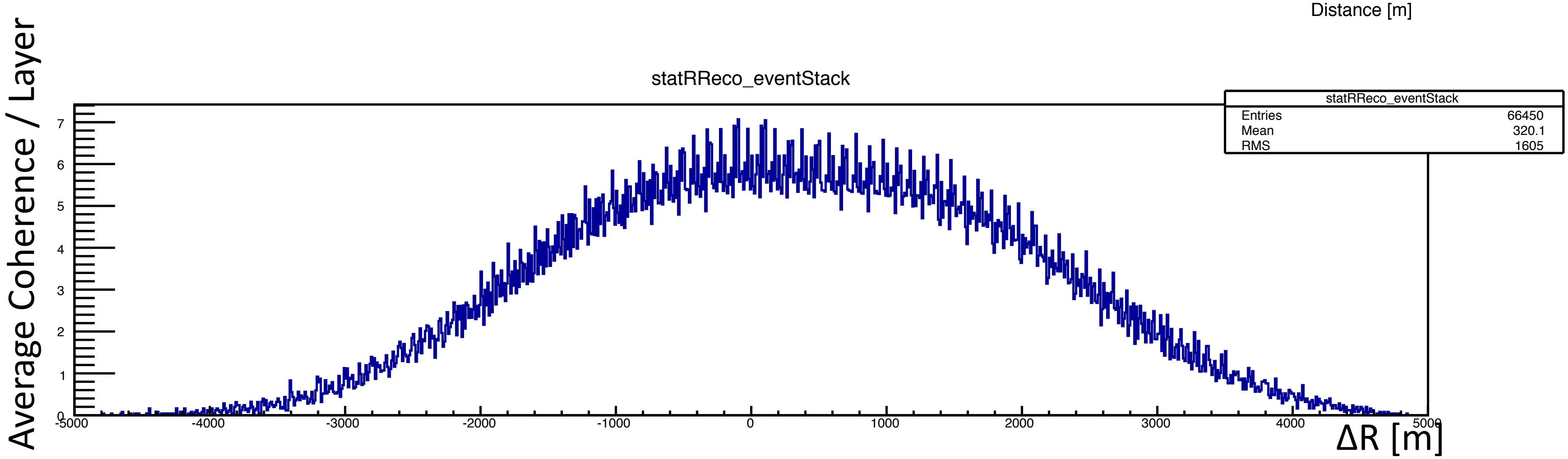


Vertex Distance Reconstruction







Stacked ΔR distribution for averaged coherence value on each layer

Summary & Future Works

- An interferometric reconstruction framework with raytrace timing table was built. Vpol reconstruction of calpulsers successful.
- Framework tested with simulation. Distance as free parameter:
  Coherence cut ✖: σ_θ:2.9° σ_ϕ:0.53°
  Coherence cut ✔: σ_θ:1.3° σ_ϕ:0.31°
- Vertex distance resolution is poor, possibly limited by our time resolution

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- Simulation with larger baseline could verify the above hypothesis, and point to future designs
- Develop thermal / CW rejection methods

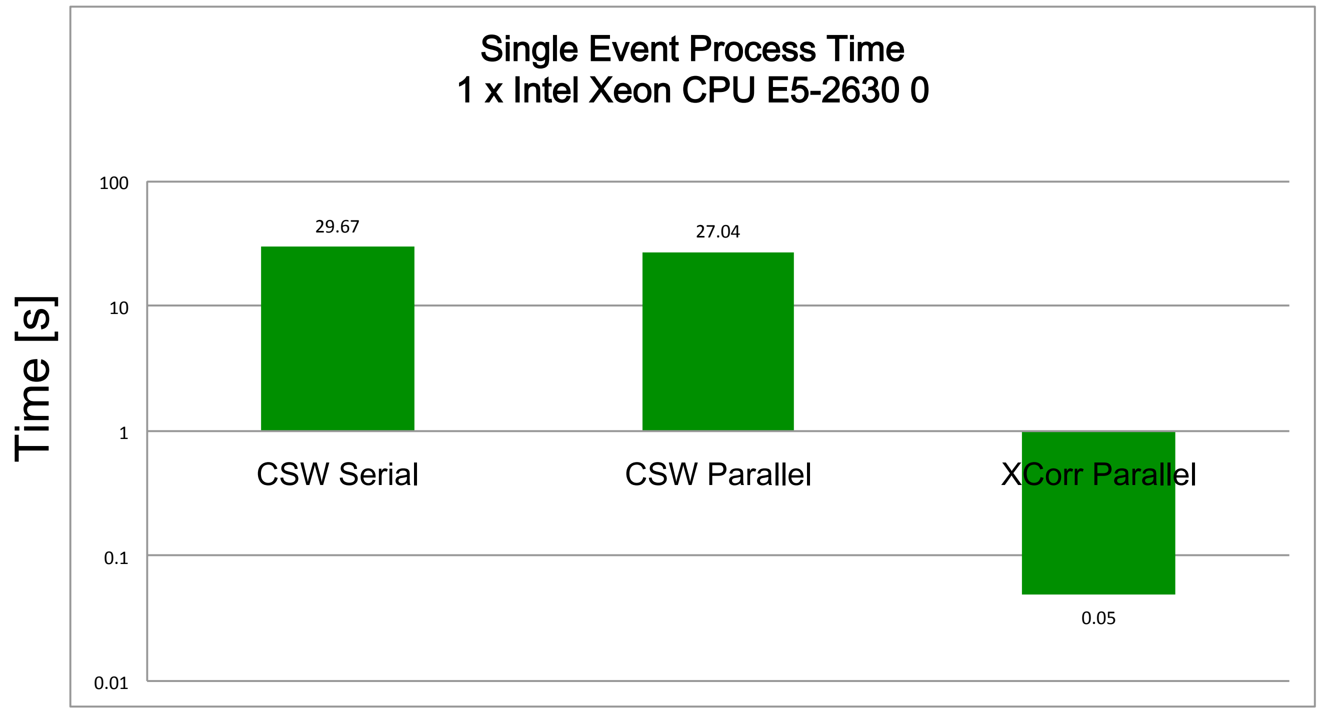
Backup

Event Vertex Reconstruction

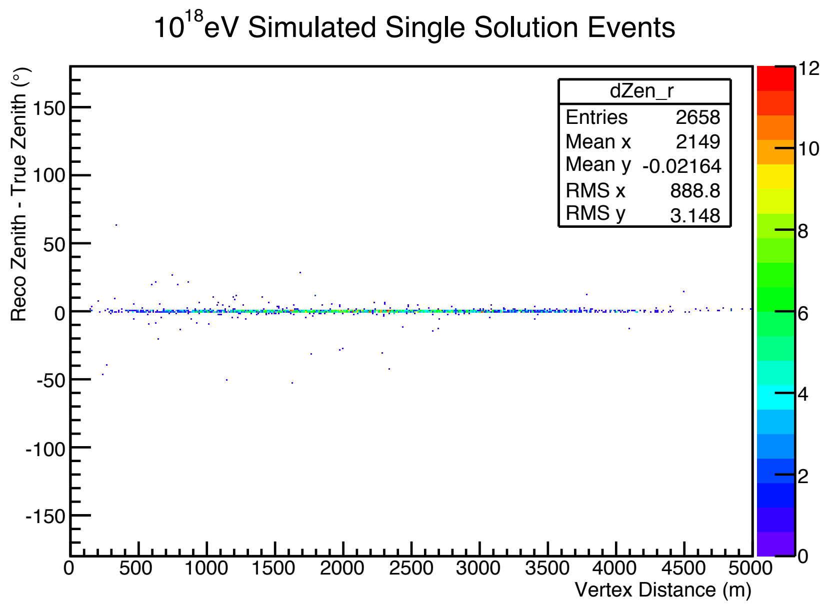
- Direction reconstruction – Identify backgrounds/anthropogenic sources
- Distance reconstruction – Neutrino energy
- Polarization measurement – Neutrino direction

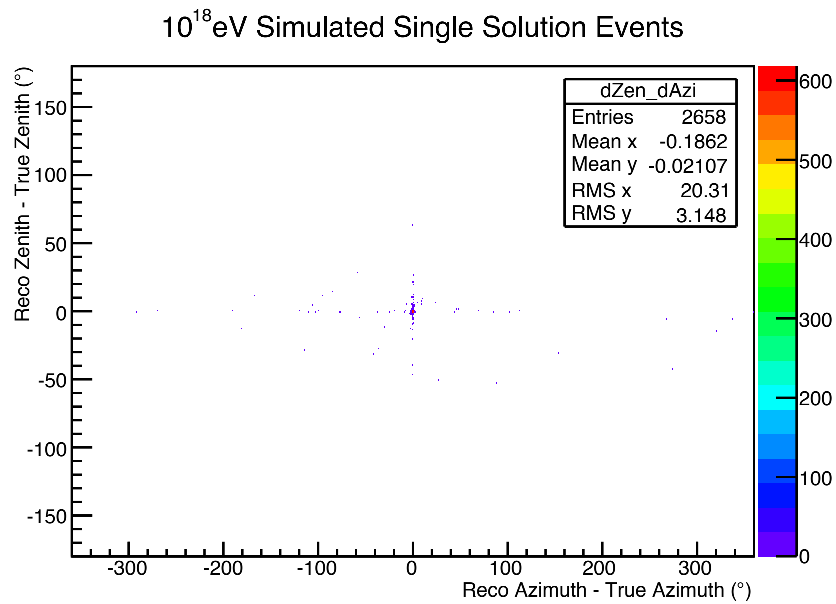
Parallel Implementation

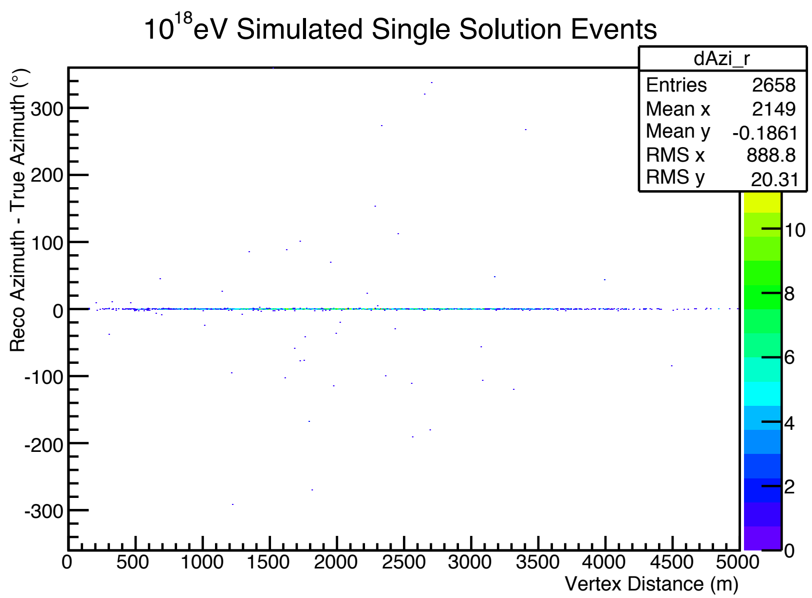
- OpenCL parallelism facilitates fast implementation of reconstruction – waveform-shifting, FFT, cross-correlating, waveform-summing
- Multiple GPU/CPU can be combined to maximize speed boost



2D Angular Reconstruction







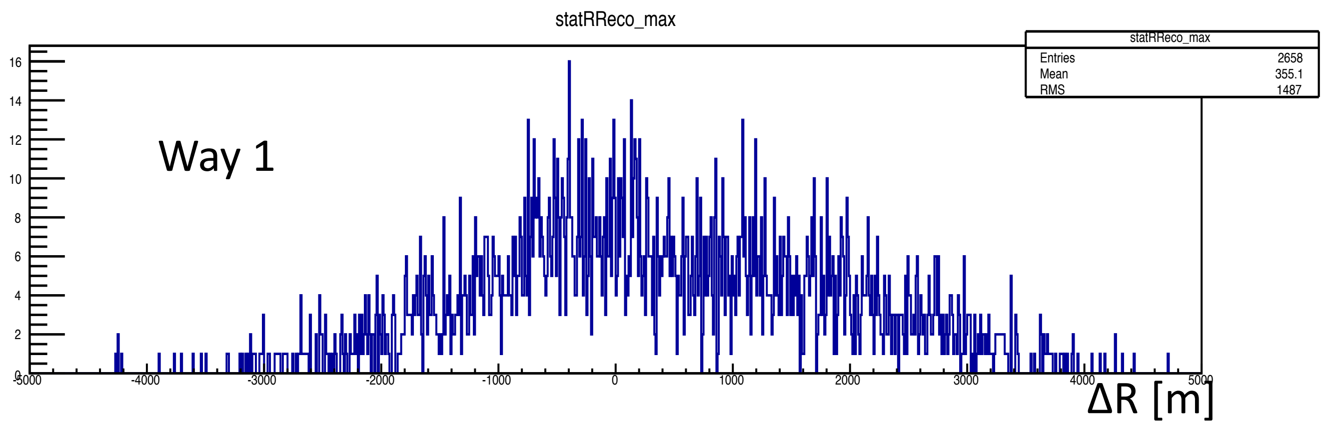
Vertex Distance Reconstruction

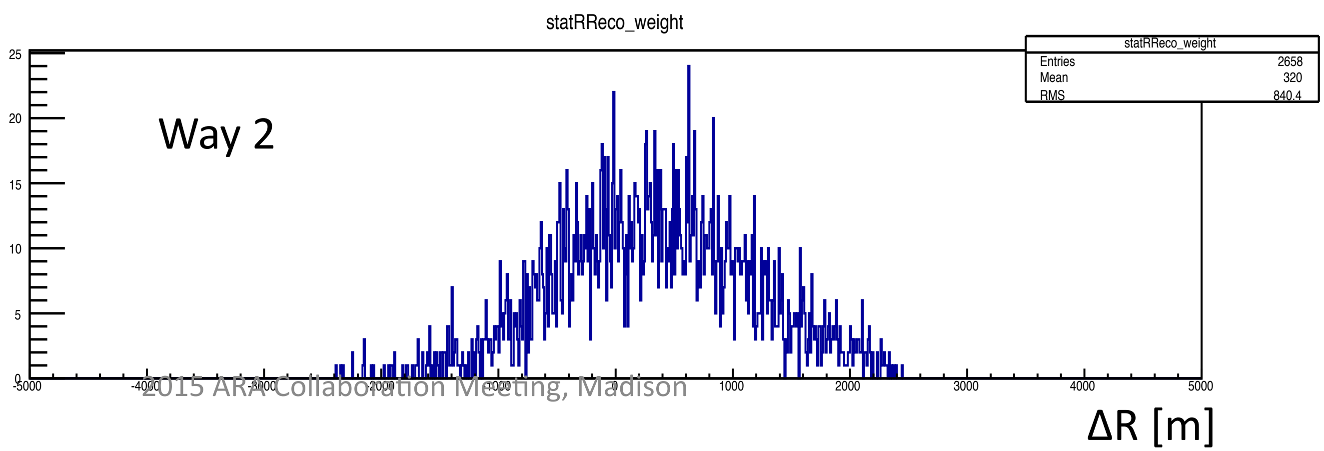
Question: with the ~flat distribution of coherence values around true vertex distance, can we use the distribution to get closer to the true distance?

Simple way 1: treat the layer with the maximum averaged coherence as giving reconstructed distance

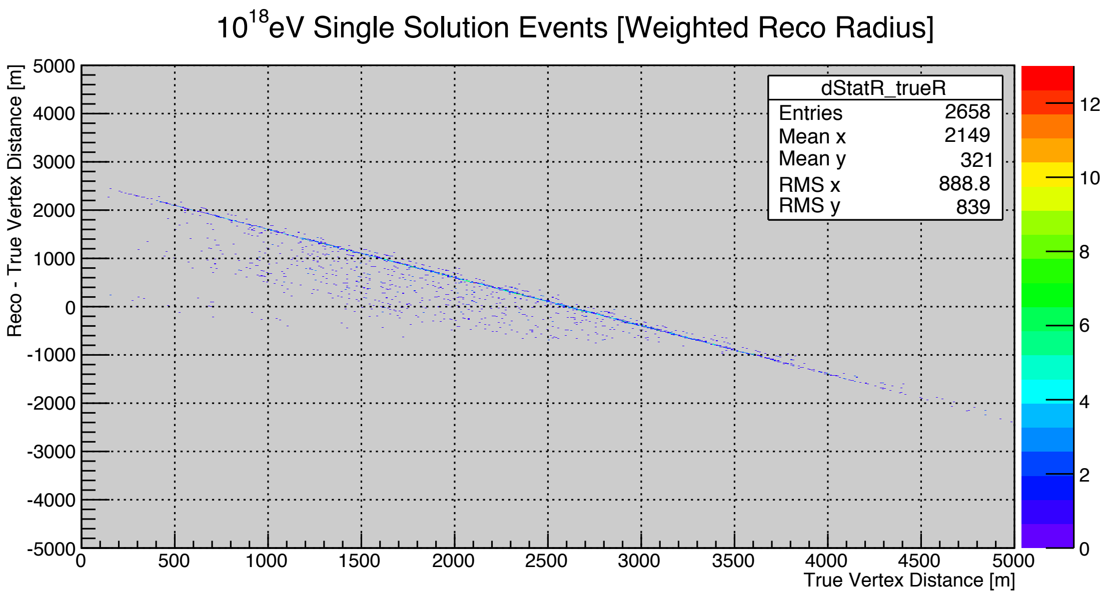
Simple way 2: use averaged coherence value on all layers to compute a weighted reconstructed distance

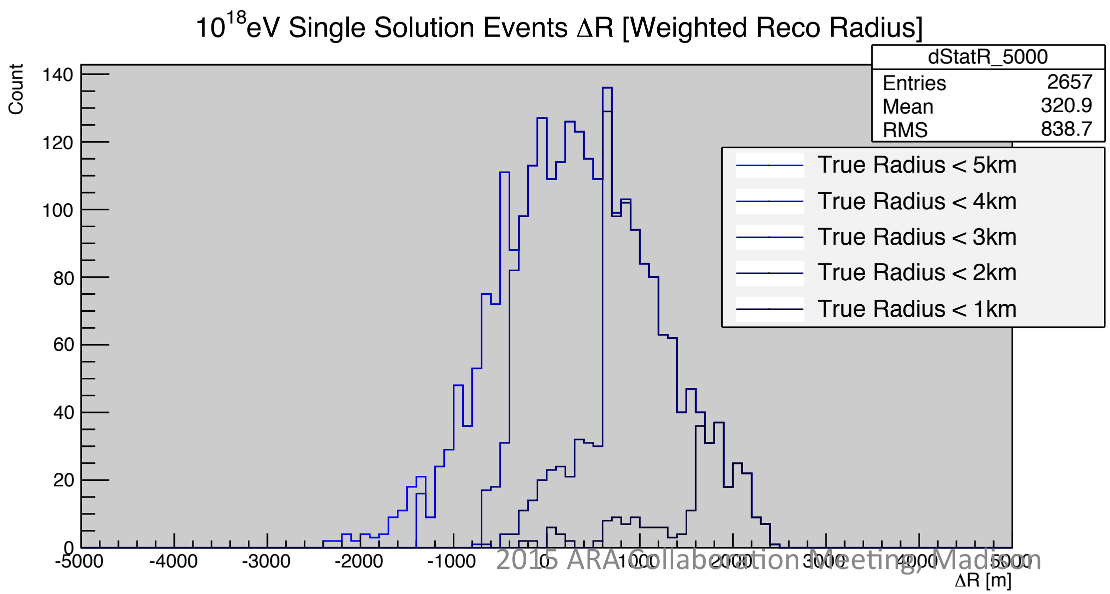
$$\bar{r} = \frac{\sum_{i=1}^{N_{layer}} r_i M_i}{\sum_{i=1}^{N_{layer}} M_i}$$





Weighted Distance





Reconstruction tends to give result at the center of the distance phase space [20-5000] ->2600