ARA ANALYSIS - STATUS QUO & LESSONS LEARNED

GEN2 UPGRADE MEETING - WORKSHOP ON RADIO NEUTRINO DETECTION AT THE SOUTH POLE

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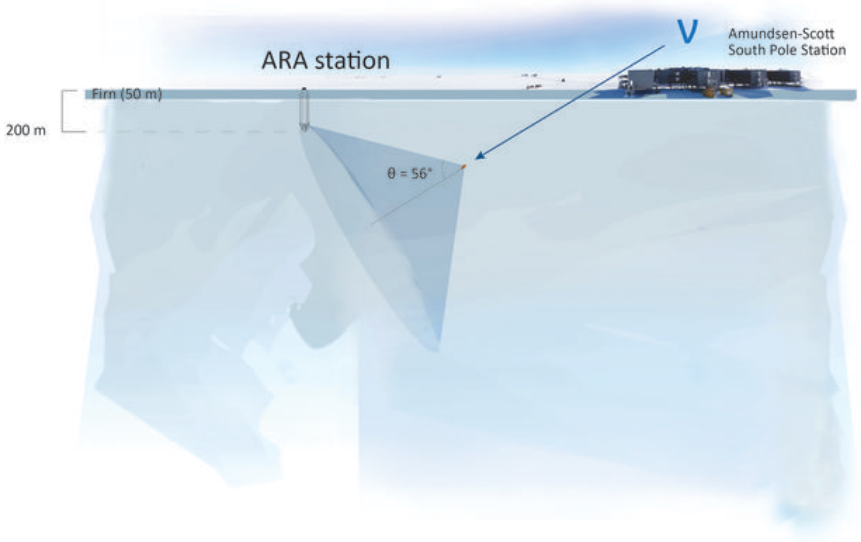
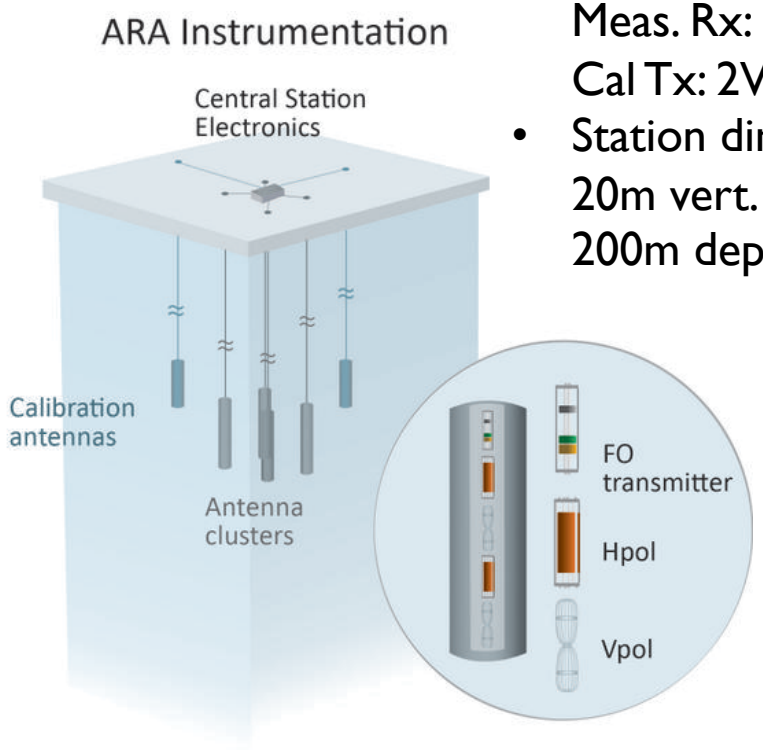
04.28.19 – MADISON, WI

OUTLINE

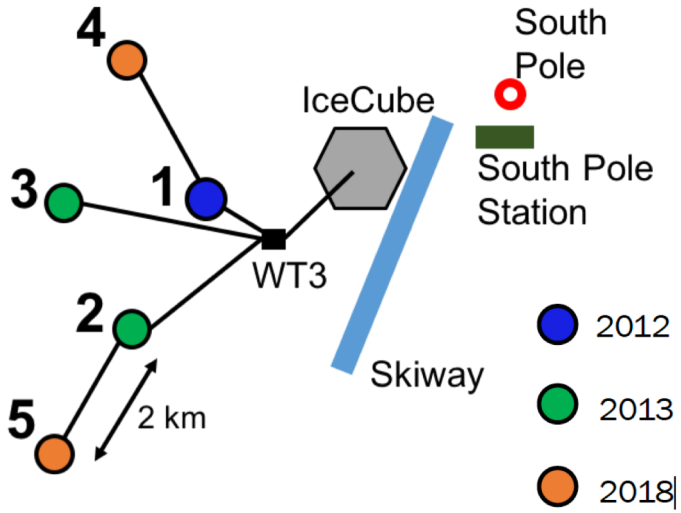
- Askaryan Radio Array
- Diffuse Neutrino Search with ARA
- Calibration
- Data Cleaning & Event Selection
- Event Reconstruction
- Cuts & Efficiency
- Projected Upper Limits
- Side Topic 1 – IceCube Deep Pulser Range Reconstruction
- Side Topic 2 - SpiceCore Test
- Looking Forward – What Have We Learned?

ASKARYAN RADIO ARRAY





- Each station:
  Meas. Rx: 8 Vpols + 8 Hpols
  Cal Tx: 2Vpol + 2Hpol (1PPS)
- Station dimensions:
  20m vert. * 20m diagonal
  200m depth

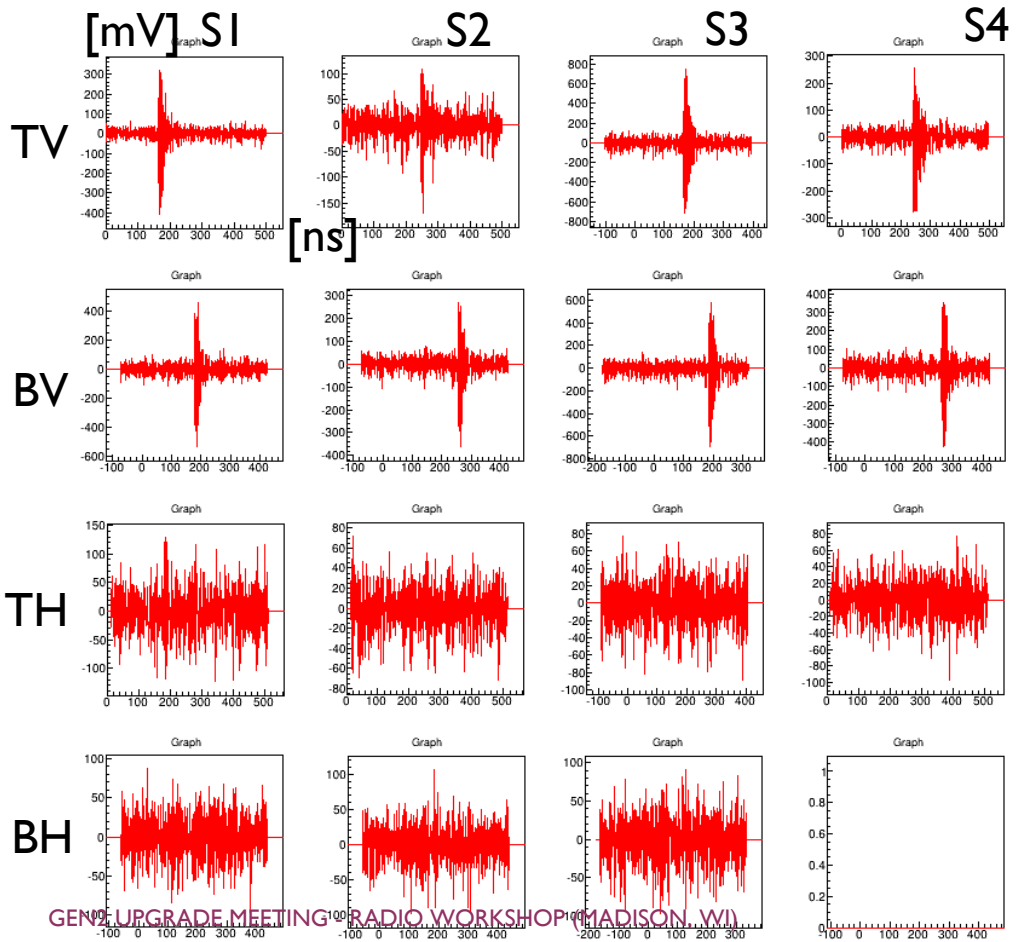


DIFFUSE NEUTRINO SEARCH WITH ARA

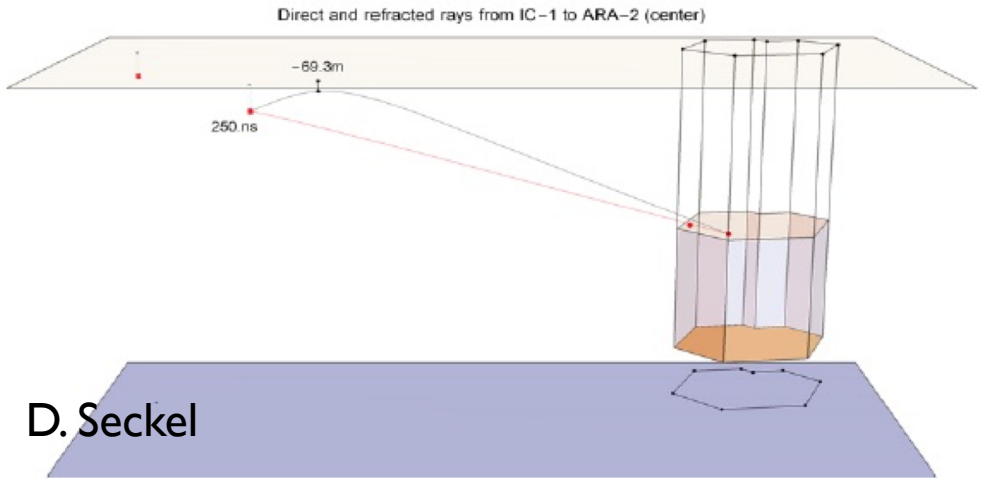
- ARA was built with discovering & measuring cosmogenic neutrinos > 10PeV in mind
- Analysis goal: diffuse neutrino search with two ARA stations from 2013 to 2016 (2x4 station*year compared to previously published 2*1). Two parallel analyses on-going.
- In the case of null-detection, place meaningful upper limits to the cosmogenic neutrino flux
- ”Blinded” analysis approach: random10% sample of all data is unblinded to develop cuts and understand backgrounds. Then we ”open the box” based on pre-defined set of cuts
- Will focus on ARA station 2 (A2) in this presentation

CALIBRATION

A2 Calpulser event run5505 ev1185



- No physics background – artificial signals for calibration
  - Local calibration pulsers
  - Radio transmitters on IceCube string 1 & 22 (deep pulser)
  - Rooftop pulser from IC Lab
  - Mobile surface pulser
- Calibration at the chip level & signal chain level made with a comb. of lab and field measurements
- Station geometry calibrated with local calpulser
- Calibration so far are "manual" - weeks to months / person / station

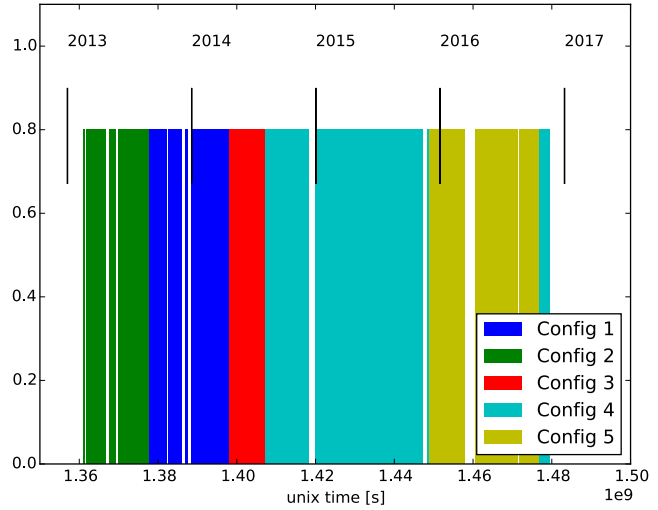


D. Seckel

DATA CLEANING & EVENT SELECTION

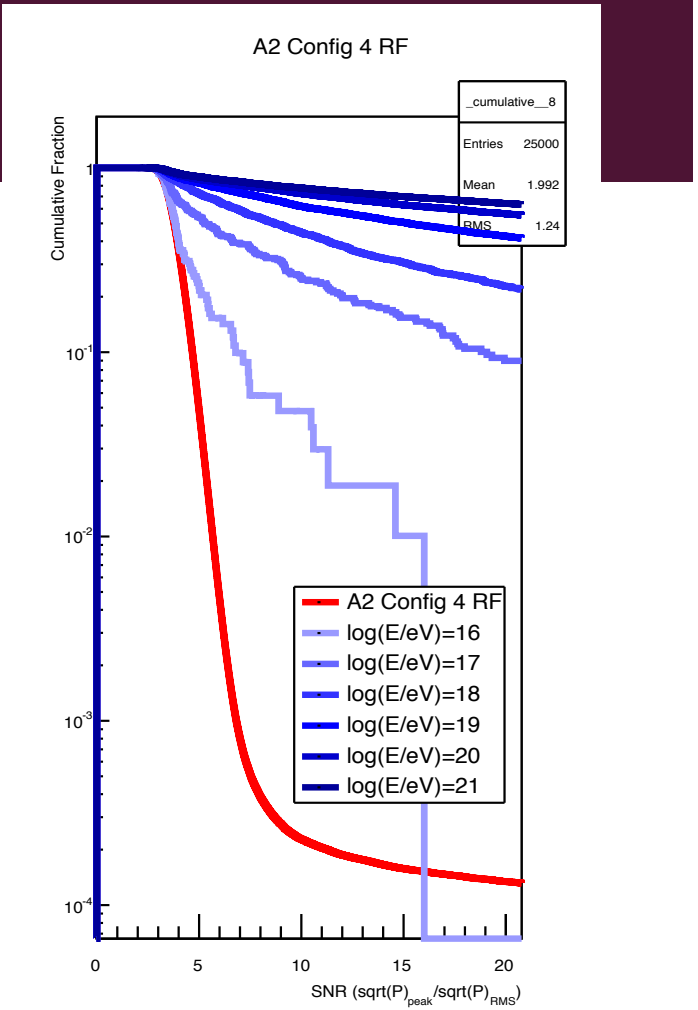
- 2013 to 2016 RF triggered events
- A number of DAQ config changes were applied.
- Related to trigger/analysis efficiency are:

ARA02 Config	L1 trigger masking	Readout win. [ns]	Trigger win. [ns]	Trigger delays	Livetime [day]
1	none	400	110	yes	179.07
2	none	400	110	no	142.55
3	D4BH	400	110	yes	94.54
4	D4BH	520	170	yes	439.02
5	D4BH	520	170	no	287.28



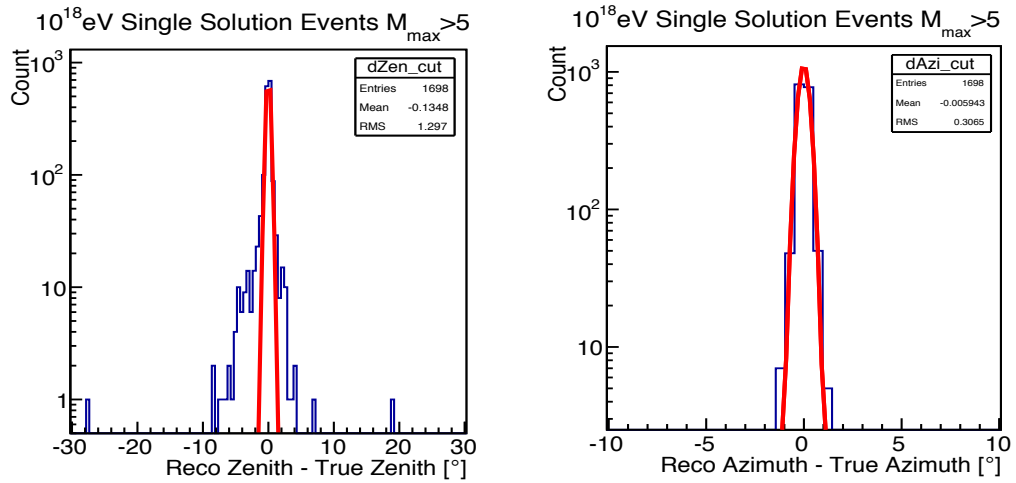
DATA CLEANING & EVENT SELECTION

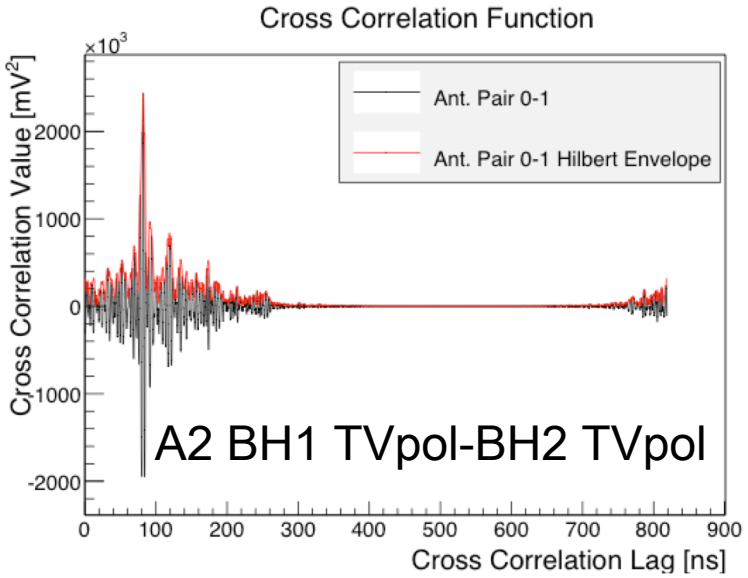
- Run exclusion – calibration runs, known faulty electronics or configuration runs - total livetime : ARA02 1142.46days
- Exclude various types of event corruption found from initial round of quality check:
  - Digitization error (repetitive sample time)
  - "First 3 event" corruption
  - "Offset-block"
  - "Block-gap"
  - Short waveform or mistagged software trigger (nSamp < 16 blocks)
  - Low frequency dominance (>=4 Vpol/Hpol with max power bin < 170MHz)
- Event filter
  - Station trigger rate 5Hz. Yearly data 10TB (1.6e8 evts). >99% thermal triggers
  - Filter only events with large SNR for reconstruction. Filter threshold set at 1% trigger rate



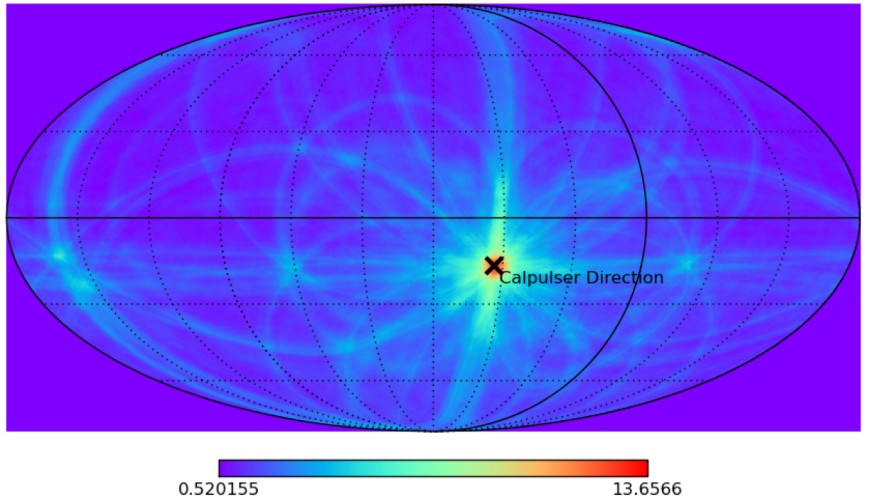
EVENT RECONSTRUCTION

- Standard radiospline interferometry (Hilbert enveloped cross-correlation function)
- Radii range from 40-5000m, constant intervals
- Pixel size ~0.45°
- Refracted (2nd ray) included
- All Vpol channels used in interferometry

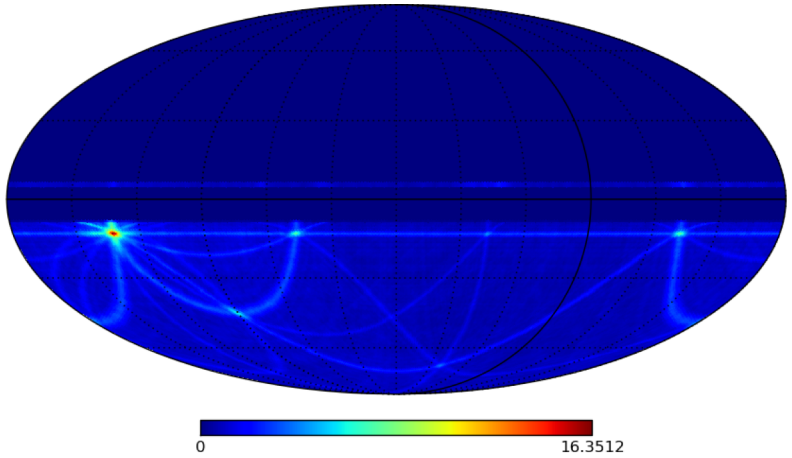




Calpulser event from A3

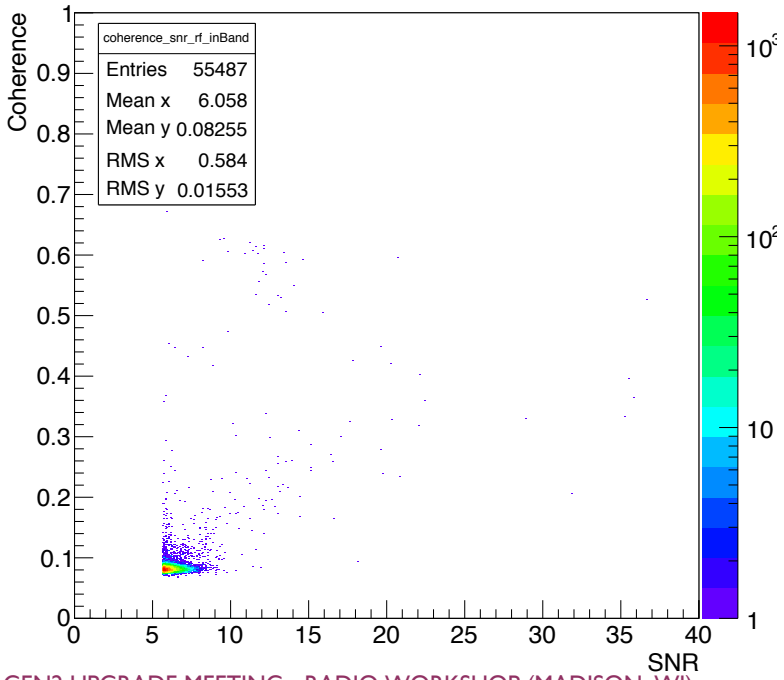


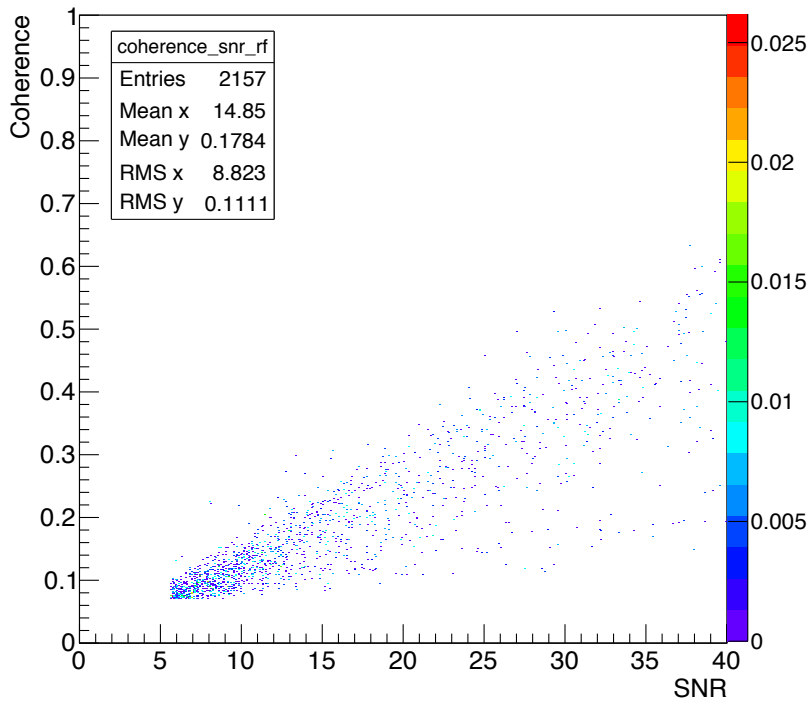
10^{18}eV MC event

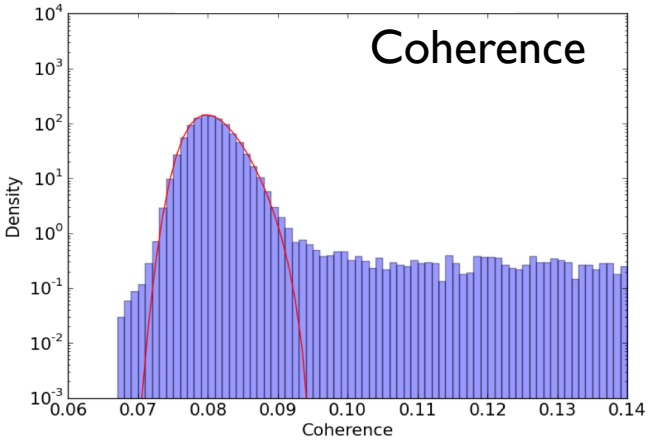


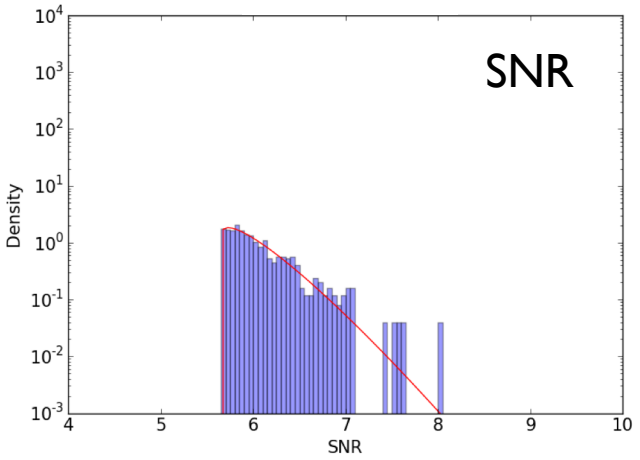
CUTS & EFFICIENCY

- Consider two features of from the reconstruction of each event
  1. best-fit pixel on the interferometric skymaps, use the cross-correlation value, called "coherence" value, as a cut parameter to reject thermal backgrounds
  2. SNR: 3rd largest Vpol SNR values

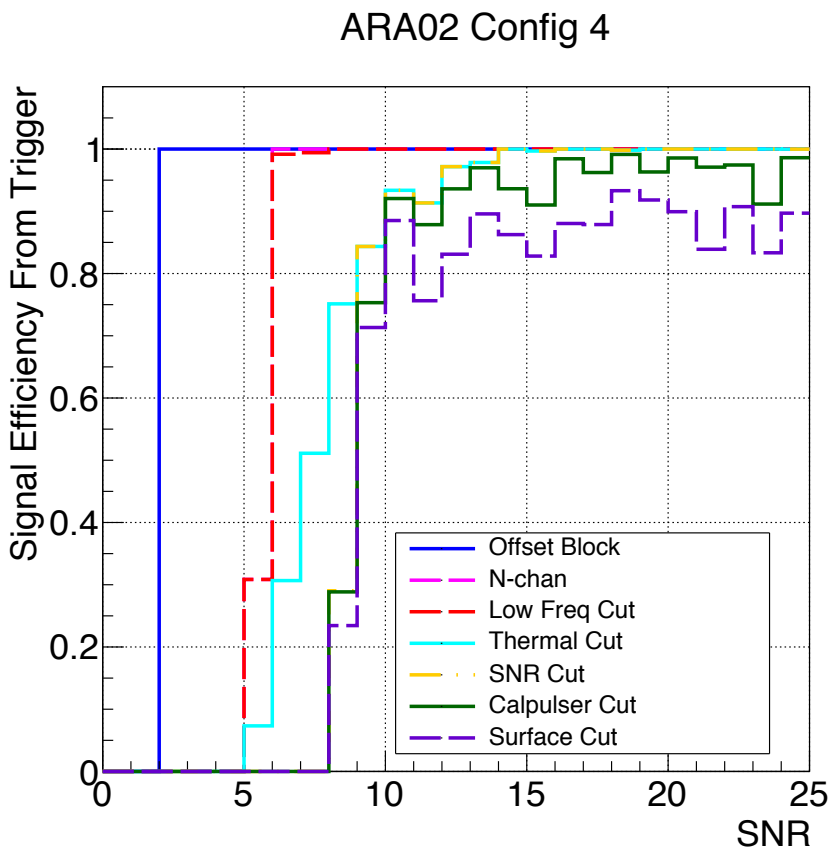








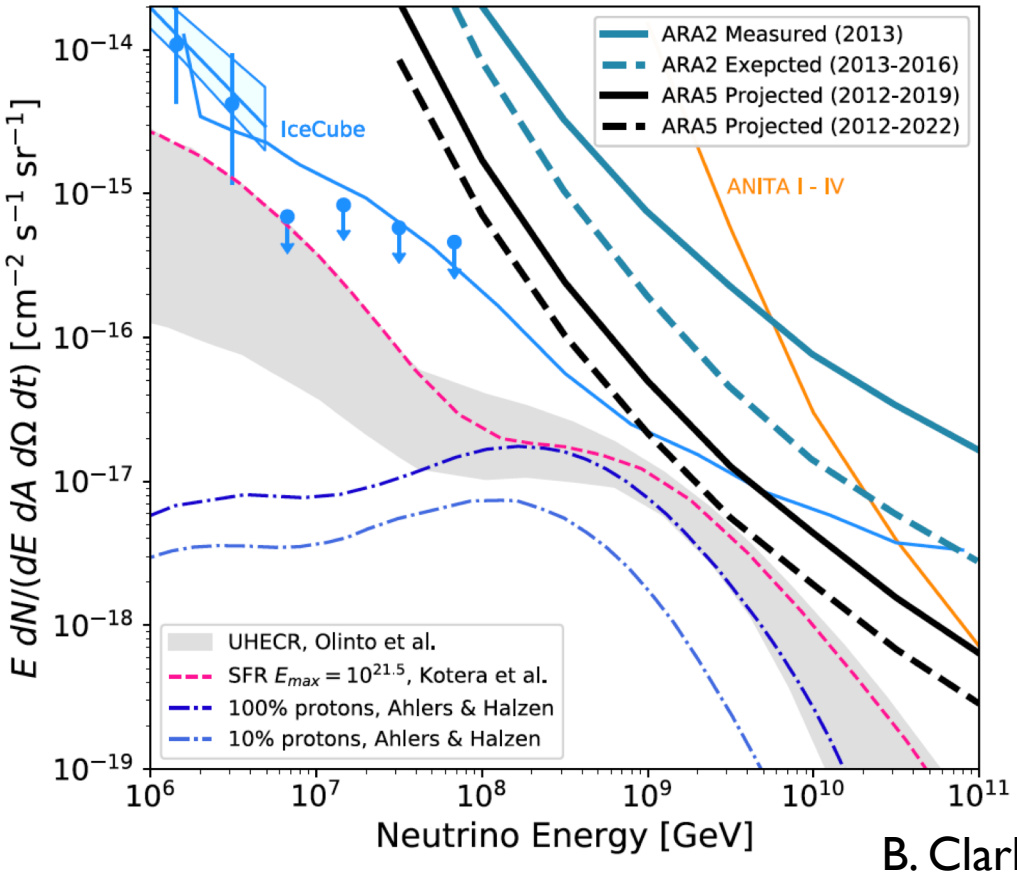
CUTS & EFFICIENCY



ARA02 Vpol Config	1	2	3	4	5
All	10651068	9942060	5180126	20598741	12321592
RF	7650584	7499337	3584869	13366155	8098326
Wf level selection	7648184	7474954	3584844	13362381	8097973
Nchan	76466	74743	35841	133582	80957
Low Freq	68593	71558	33268	120763	73897
Deep pulser	68593	71558	33268	114905	73897
Thermal	2187	171	95	1478	820
SNR	1392	37	10	373	126
Calpulser	1335	9	7	354	121
Surface cut	22	0	0	2	10
Surface noisy run	0	0	0	0	0

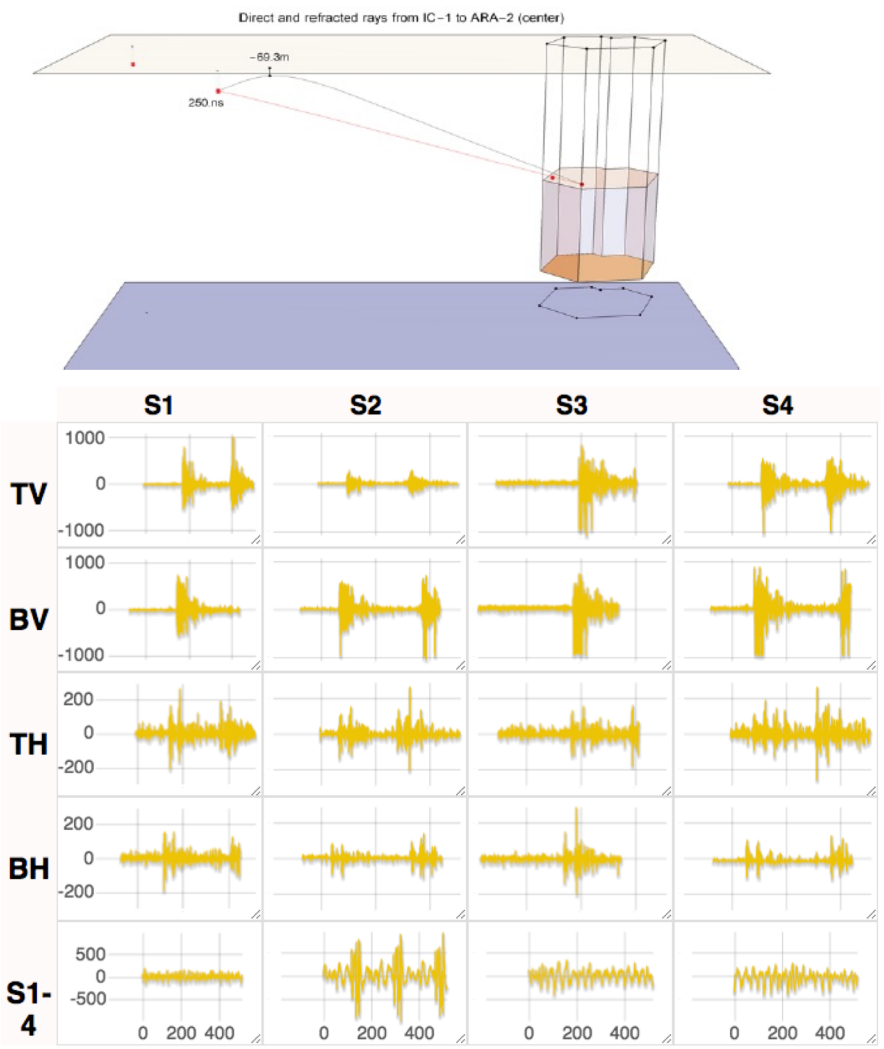
PROJECTED UPPER LIMITS

- Assumes no event is observed, & ~0 background
- With ARA5, at the end of 2019 we will be able to set best limit above ~1e19eV



B. Clark

SIDE TOPIC 1 – ICECUBE DEEP PULSER RANGE RECONSTRUCTION

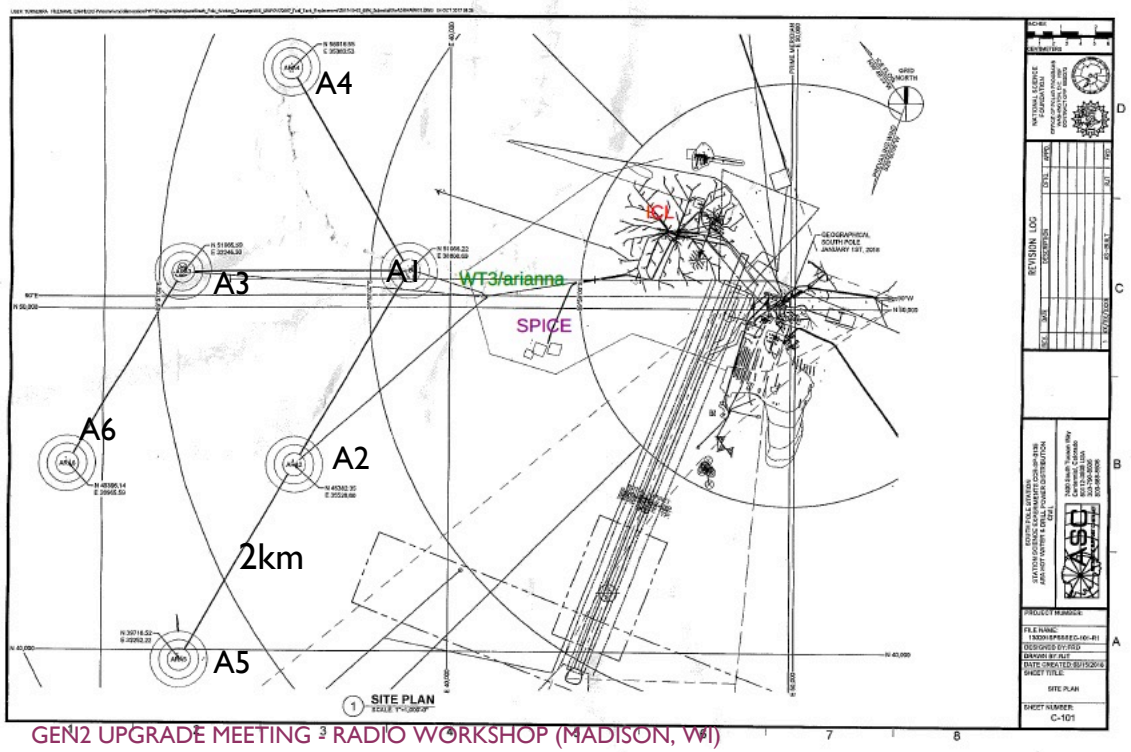


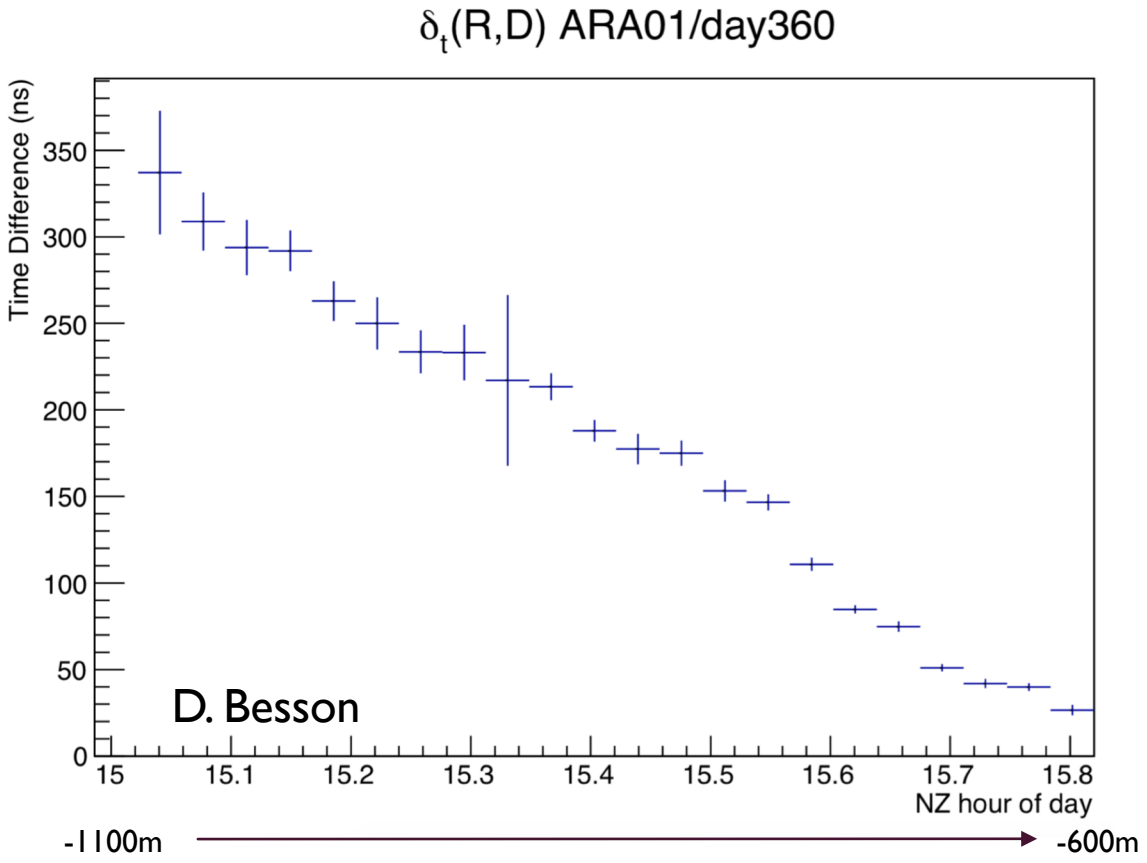
	Nominal			Reconstructed		
	θ [°]	ϕ [°]	r [m]	θ [°]	ϕ [°]	r [m]
A2 IC1S	-19.36	259.99	3666	-20.09	257.6	4215 (+15%)
A2 IC22S	-19.65	266.17	3609	-20.74	264.4	4896 (+36%)
A3 IC1S	-16.57	230.77	4269	-18.21	231.7	4711 (+10%)
A3 IC22S	-17.51	234.95	4040	-18.84	235	4298 (+6%)

- Double-pulse events valuable due to extra handle in range reconstruction (necessary to energy reco)
- Actively taken into account in RNO design (talk by B. Hokanson-Fasig)

SIDE TOPIC 2 - SPICECORE TEST

- In '18 & '19 Pole season, pulsers were lowered into the South Pole IceCore (SPiceCore) hole
- We can:
  - constrain n(z) profile from double pulse ΔT
  - measure attenuation from multi-station data
  - H/V birefringence





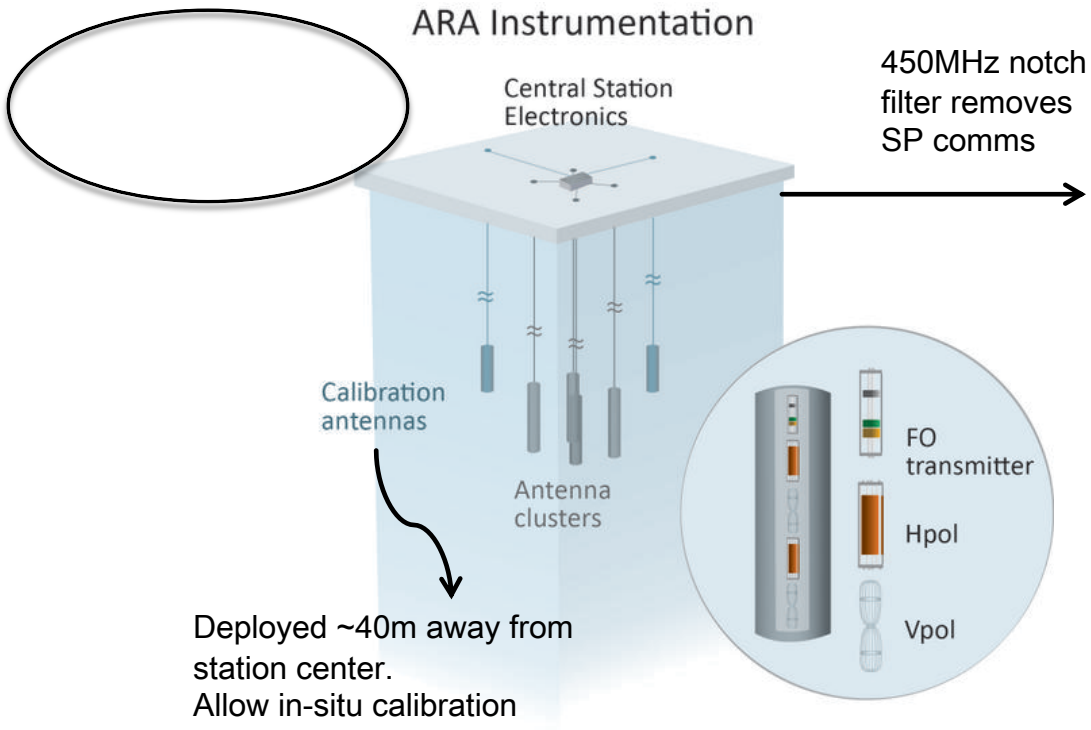
LOOKING FORWARD – WHAT HAVE WE LEARNED?

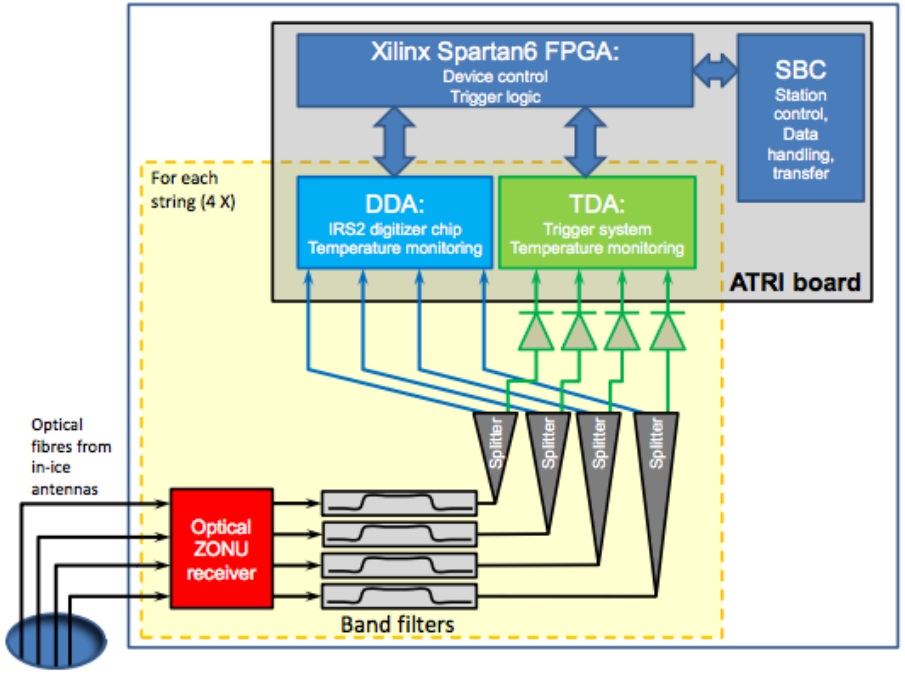
- ARA diffuse neutrino search with 4x exposure is near completion. Close to placing competitive upper limits in the near future
- Some lessons for future radio neutrino telescopes
  - Automated calibration for scalability
  - Waveform enveloping necessary so far. Points to future envelope detector/phasing (T. Meures talk)
  - Lower energy threshold needed to connect ~PeV IceCube astrophysical flux. Phased array approach key to achieving that
  - SpiceCore test results actively being studied. Detailed ice properties key to sensitivity and resolving neutrino properties

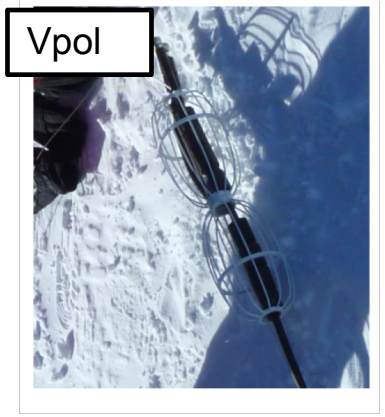
BACK-UP SLIDES

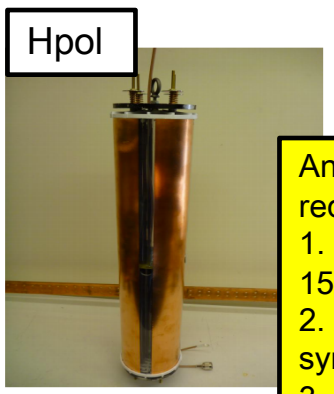
ARA DETECTOR

- Each station is an autonomous detector





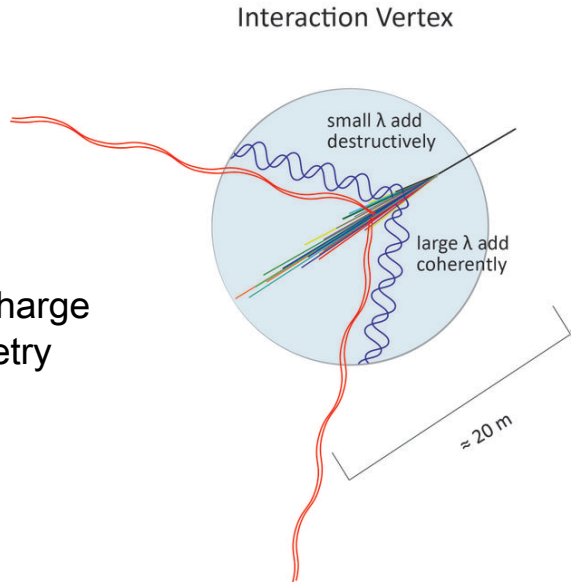




Antenna requirements:
1. Broadband 150~850MHz
2. Azimuthal symmetry
3. Fit in the hole

RADIO DETECTION

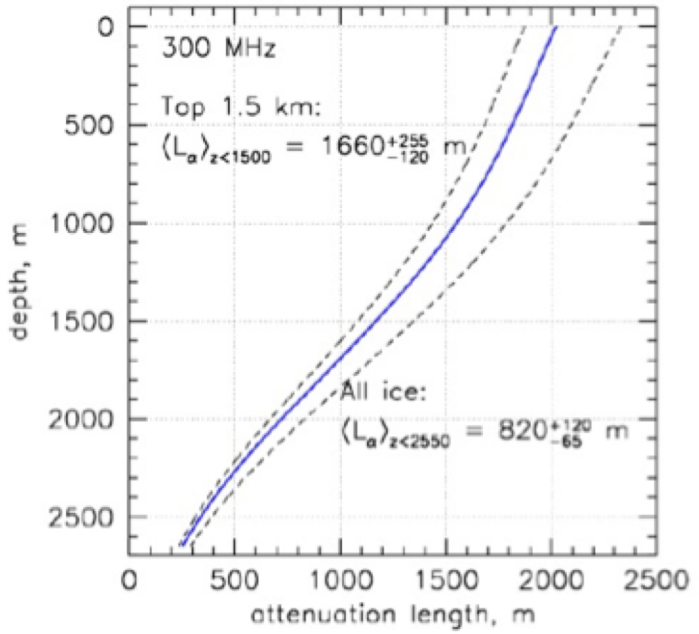
The Askaryan Effect



~20% charge asymmetry

Peak emission 0.1~1GHz
$P \sim N_e^2 \sim E^2$
Highly polarized broadband signal
Confirmed detection in ice, SLAC 2006 (Phys. Rev. Lett. 99:171101)

Radio transparency in ice



Kilometer-scale attenuation length for radio signal in South Pole ice

- Estimated cosmogenic neutrino event rate: ~< 1/km^3/yr
- Requires ~100km^2 of detector effective area

DAQ CONFIG A_{EFF}

- The 9 types of MC data generated (with TM signal chain calibration)
- ARA03 test delays: randomly assigned delays from 0 – 1500ns (in 100ns steps)

ARA2

String	Fiber Delay
A2D1	0ns
A2D2	0ns
A2D3	100ns
A2D4	0ns

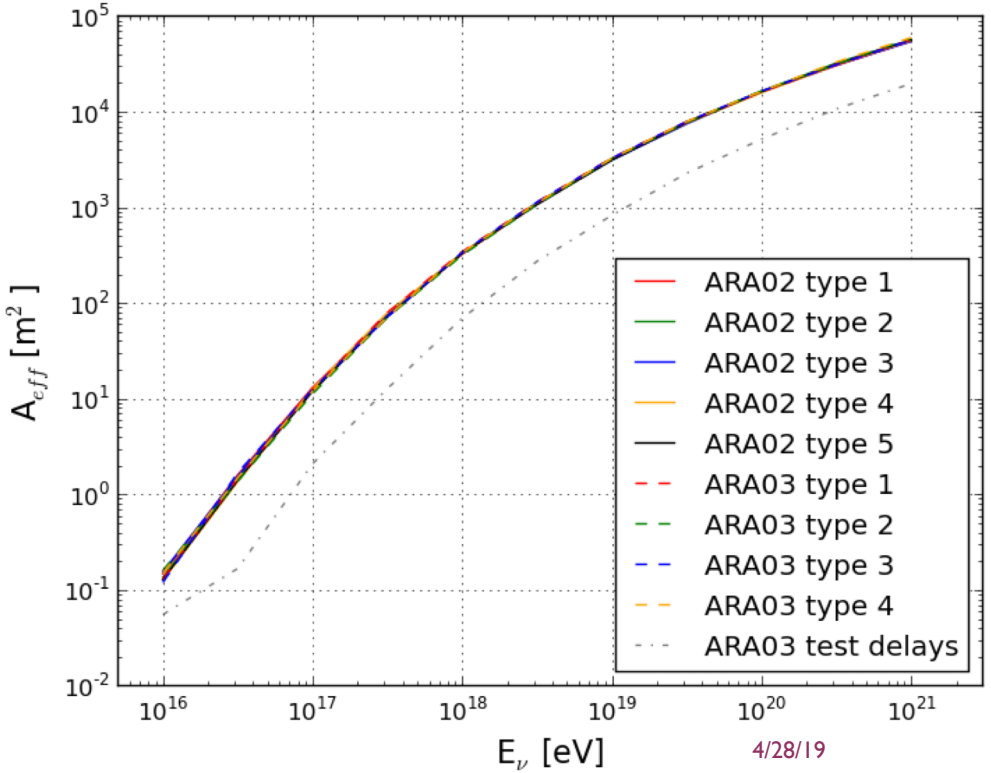
ARA3

String	Fiber Delay
A3D1	0ns
A3D2	100ns
A3D3	0ns
A3D4	0ns

Delay due to depth in the hole:

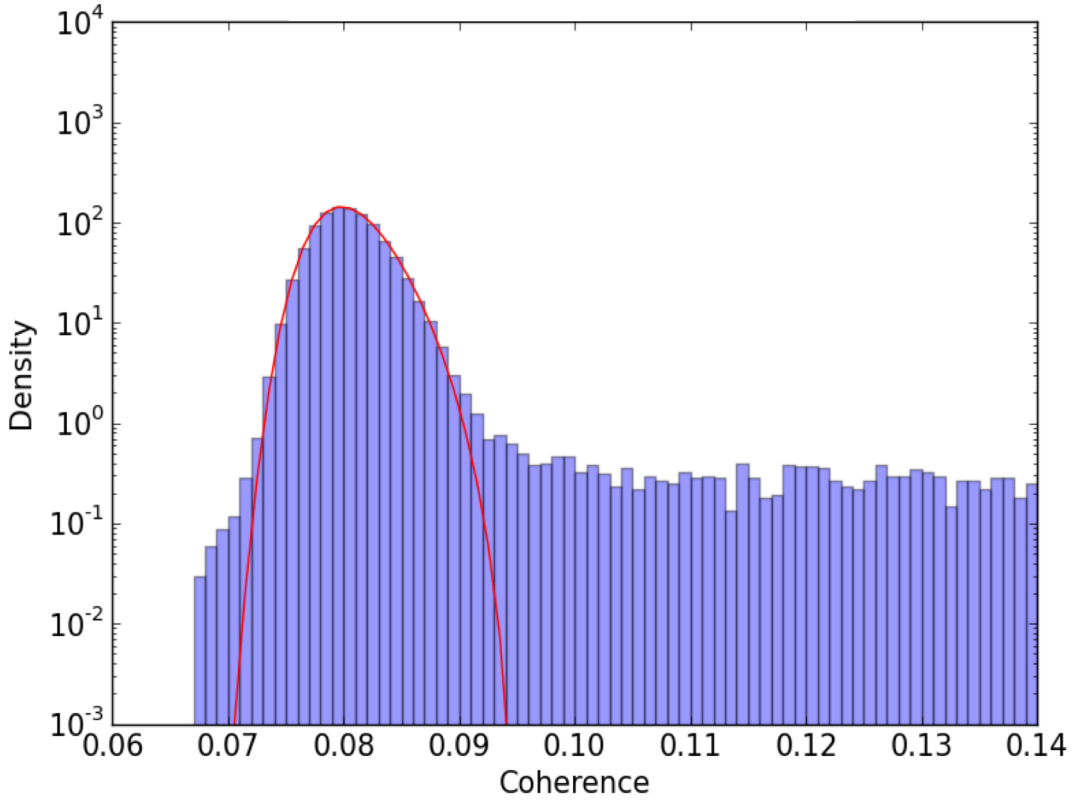
Antenna	Delay
BV	81.4ns
BH	73.2ns
TV	15.4ns
TH	7.2ns

- Delay diff show up in analysis level
- Each MC set matched with real data for cut-tuning



INITIAL CUT – THERMAL CUT

- Consider the best-fit pixel on the interferometric skymaps, use the cross-correlation value, called "coherence" value, as a cut parameter to reject thermal backgrounds
- Target rejection 10^{-8}

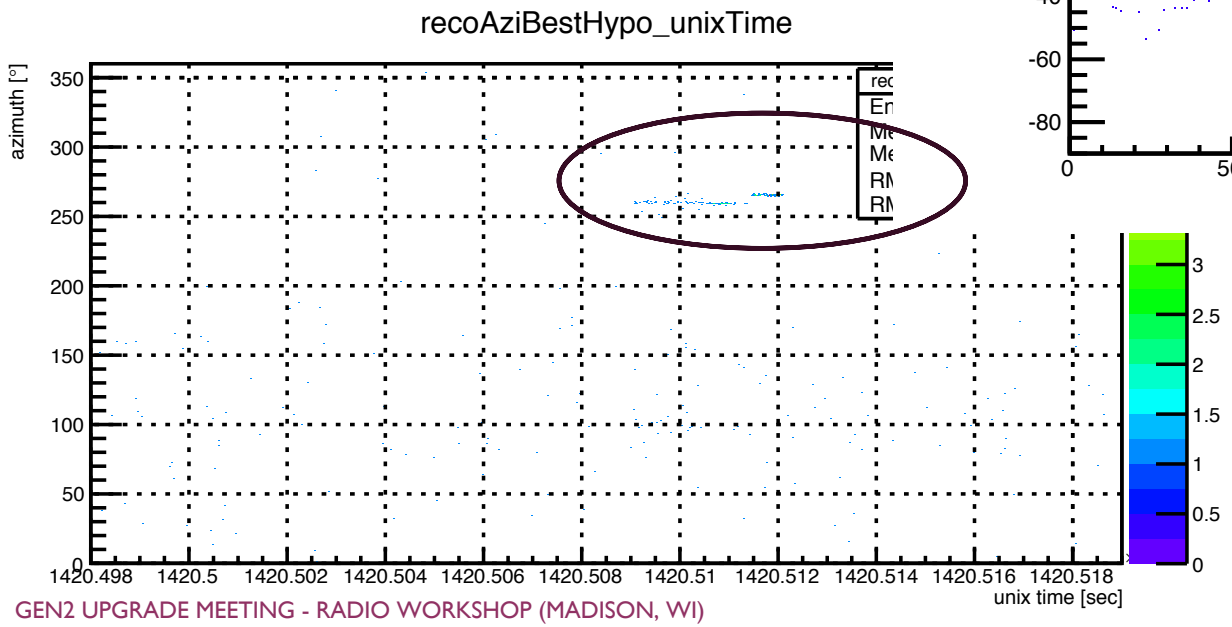


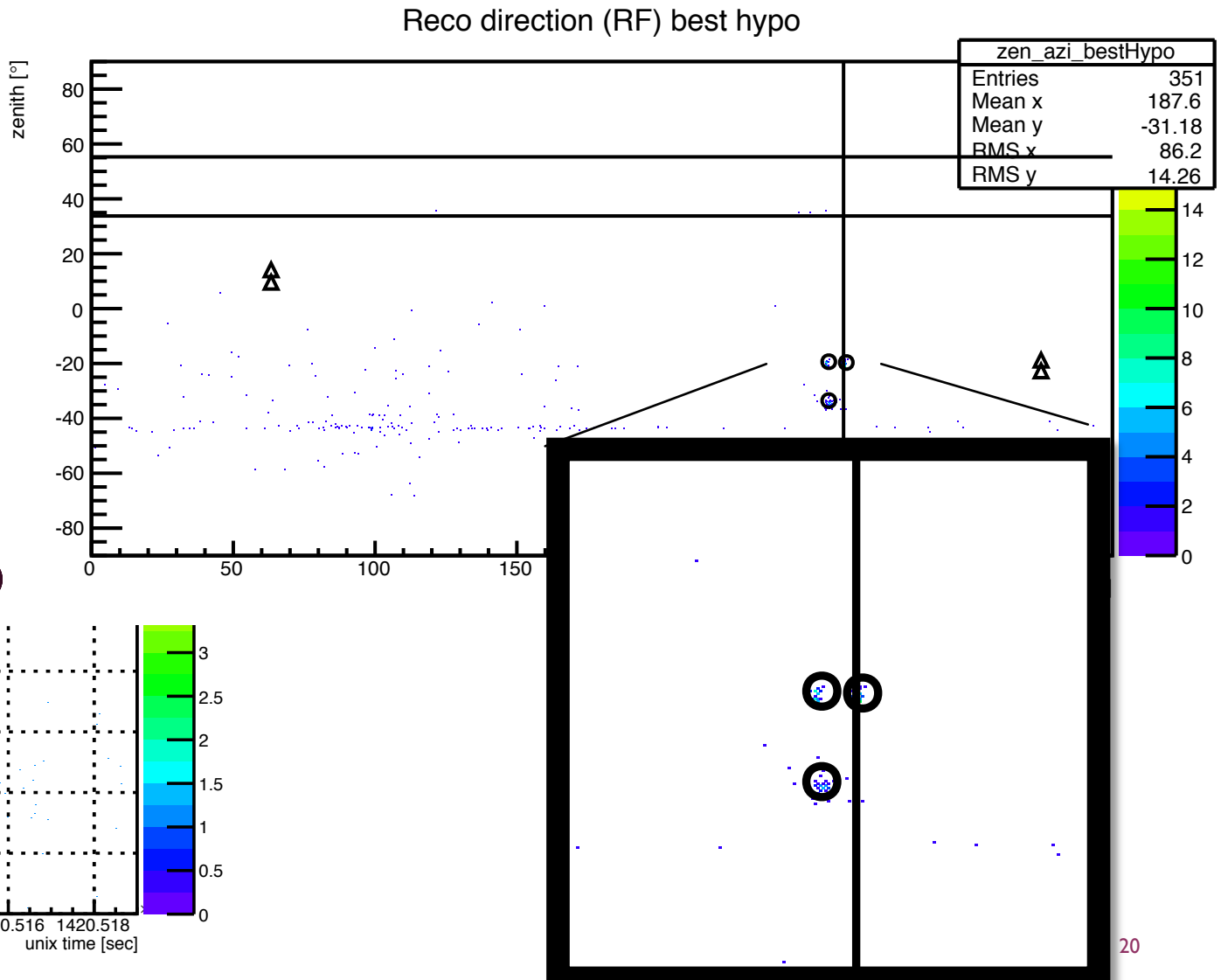
A generalized extreme value distribution (GEV) was used to model the coherence data and extrapolate to determine the cut value

Config 4 cut value: 0.1043

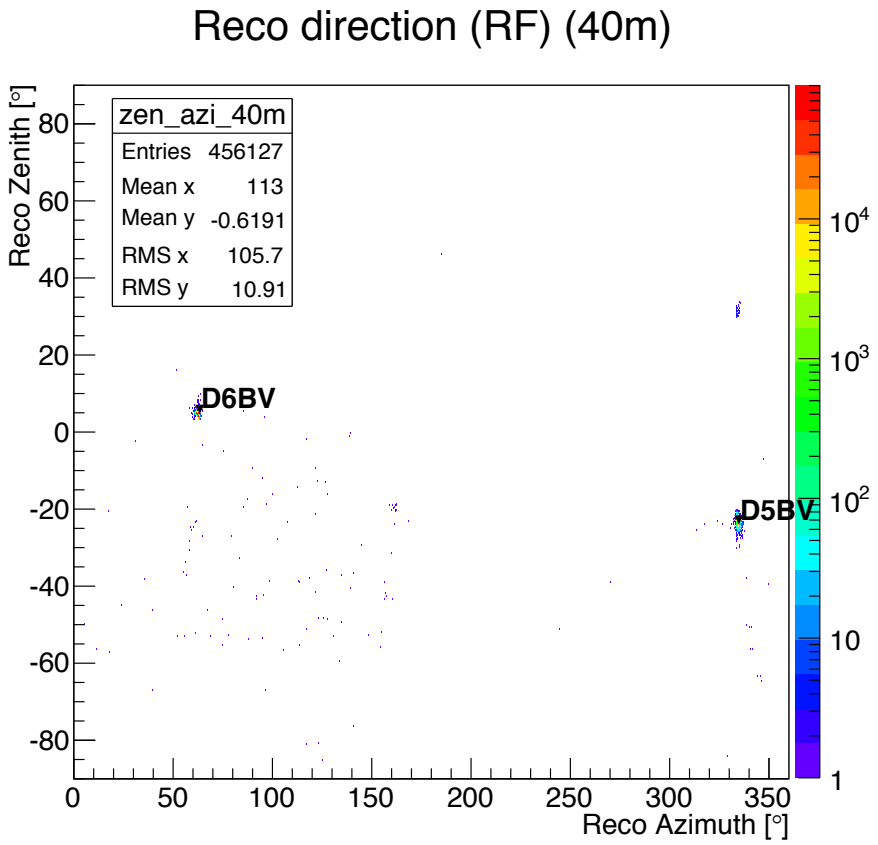
INITIAL CUT – DEEP PULSER TIME CUT

- Only one deep pulser operation in data period: early 2015
- ARA02 run 4785, 4787, 4795-4800
- Duration: ~1.58 days
- Simply exclude data from this period





INITIAL CUT – CALPULSER GEOMETRY CUT

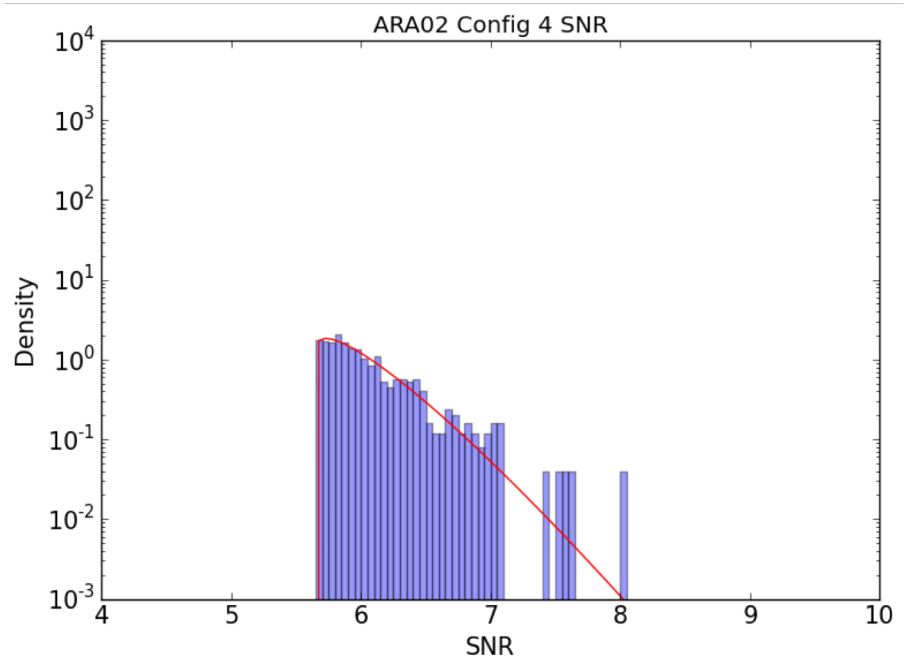


- Run 40m iterative reconstruction on the whole dataset
- First 100 calpulser events from each run were used to define the geometric cuts
- Calpulser ID criterion: at least one iteration points to one of the box regions

A2 cal box	theta min	theta max	phi min	phi max	note
D5BV	-32.45	-15.09	329.18	341.48	
D6BV	-0.50	11.20	55.32	67.23	
D5BV Mirror	26.68	36.75	330.64	340.74	Only config 5

INITIAL CUT – SNR CUT

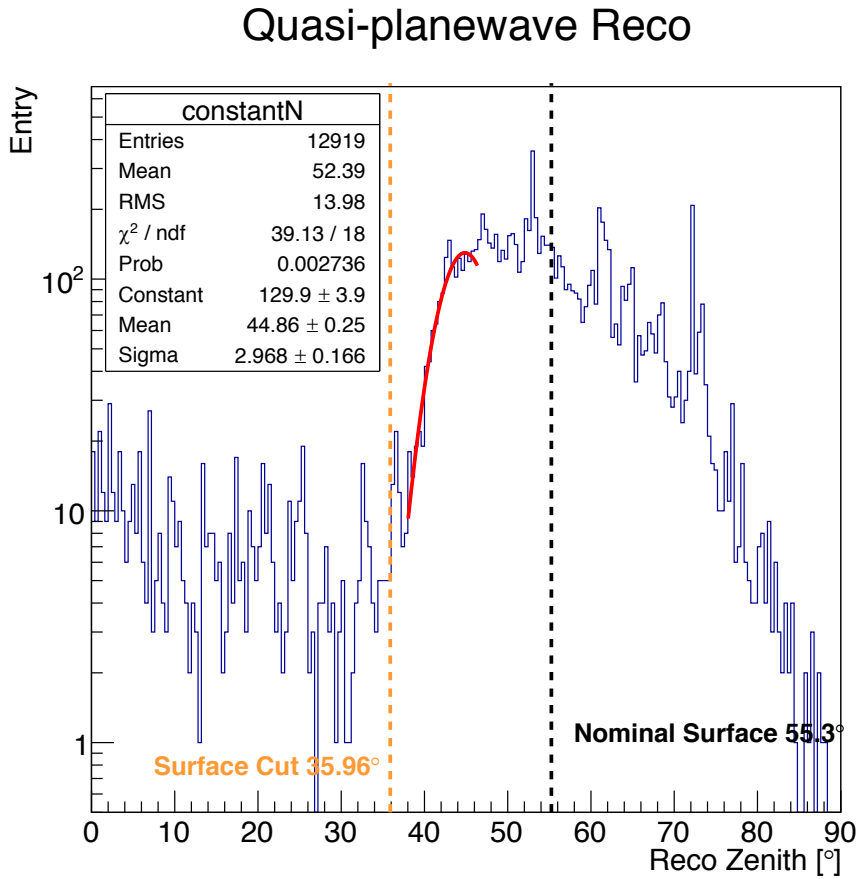
- Thermal cut: using coherence distribution alone, with the GEV fit, determine the 10^-8 backgrounds rejection cut value
- Apply all the rest of the cuts: low-freq, calpulser, deep pulser, surface (defined with preliminary round of analysis), noisy runs (defined with preliminary round of analysis)
- Fit Weibull distribution, extrapolate to background rate ~0.1/yr



Config 4 cut value: 8.57

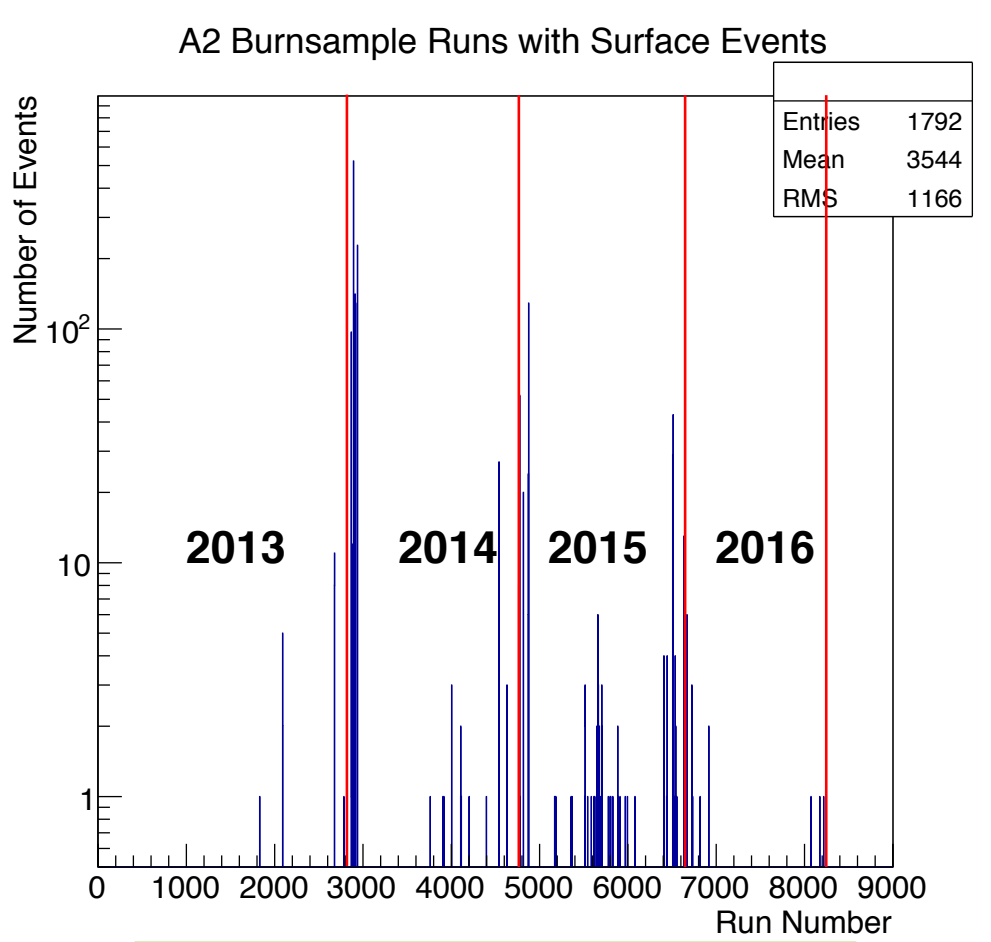
INITIAL CUT – SURFACE CUT

- Quasi-planewave reco: using bulk-ice model and 5km skymap radius to approximate plane wavefront. Proved to be most robust in reconstructing ICL rooftop pulser events
- Apply thermal, deep pulser, calpulser cuts on the n-chan filtered sample
- Model the zenith distribution with a Gaussian
- Extrapolate to 3-sigma as cut



INITIAL CUT – SURFACE NOISY RUN

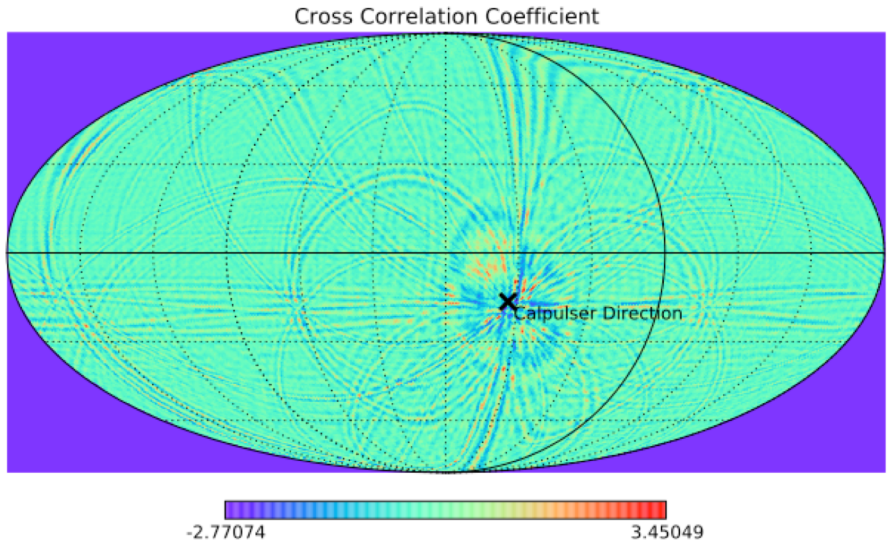
- Specific runs are heavily contaminated by anthropogenic signals and are not suitable for neutrino search
  Think: austral summer time cut in TestBed analysis
- If a run contains >=2 surface events, as defined by $\theta_{reco} > \theta_{surface\_cut}$, in the burnsample, the run is deemed noisy
- Noisy runs defined as such with the burnsample will be excluded from unblinding → essentially a livetime cut
- NB: no extension of the list of noisy run will happen after unblinding! The list is defined using the burnsample and remains fixed



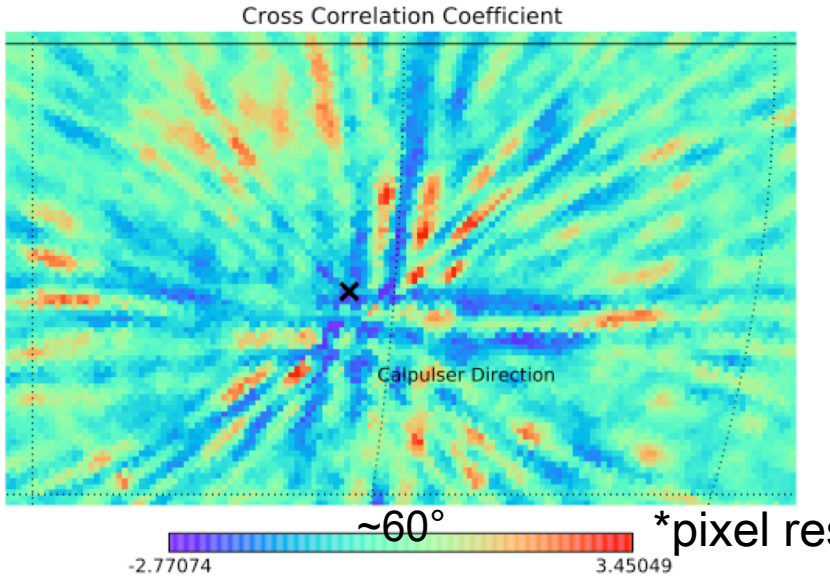
Number of (surface) noisy runs: 46

FULL-BAND CROSS-CORRELATION SKYMAP

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



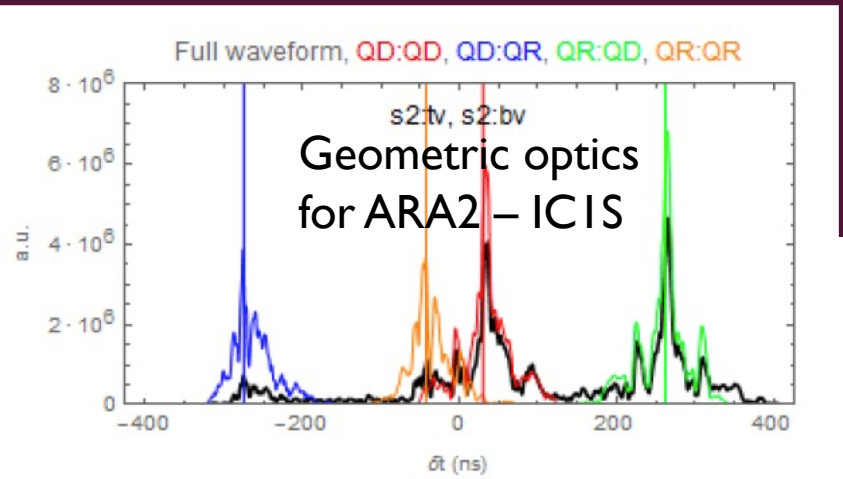
~30°

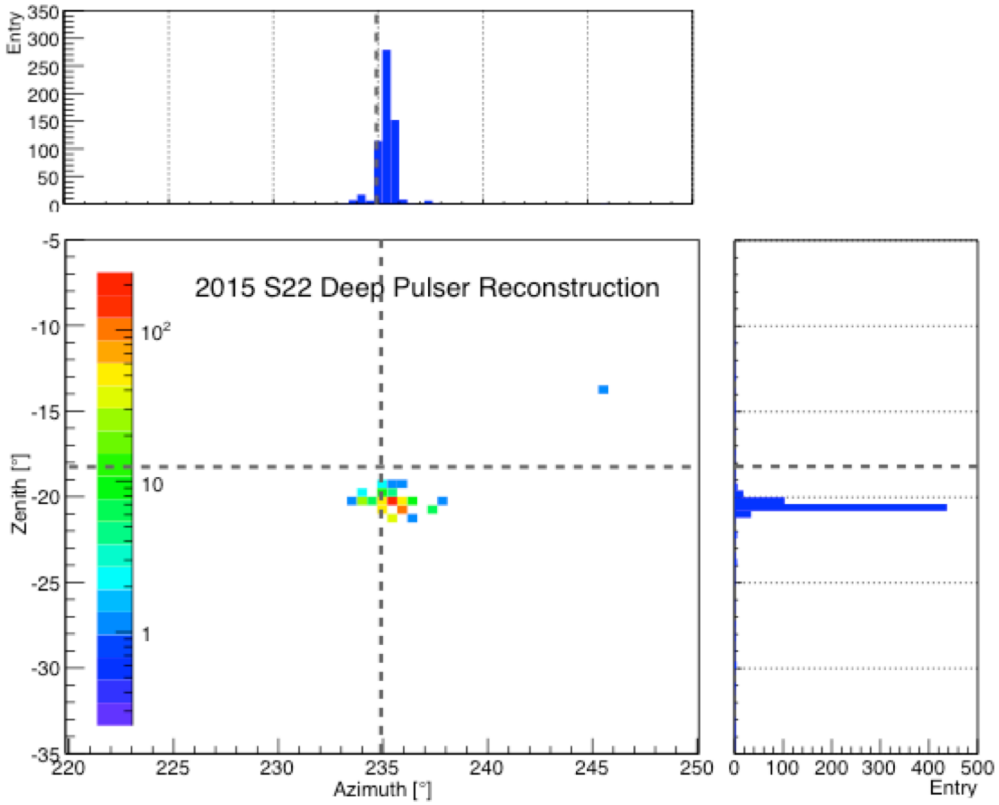


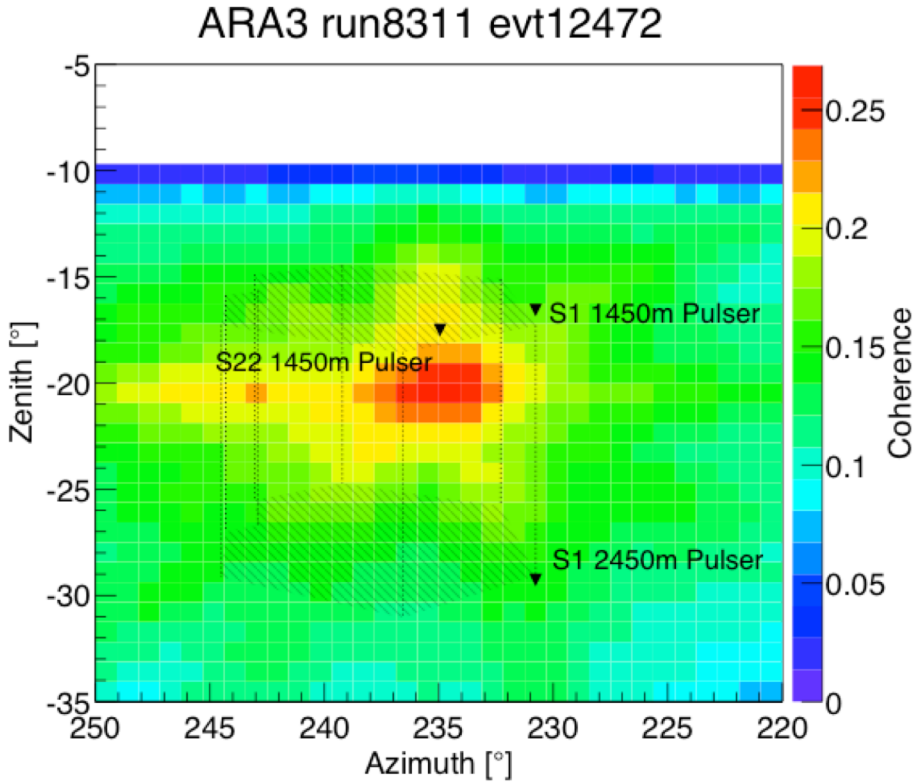
~60°

*pixel res.:0.46°

DEEP PULSER RECO - DIRECTION







PROJECTED UL