

Observation of deep, distant impulsive RF transmitters by the Askaryan Radio Array

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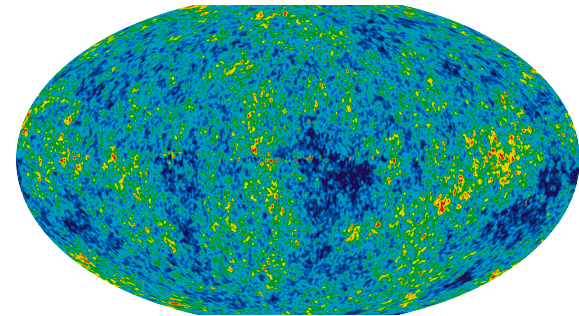
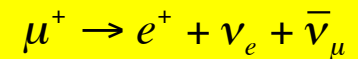
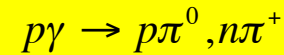
for the ARA Collaboration

July 14, 2017, 35th ICRC, Busan, Korea

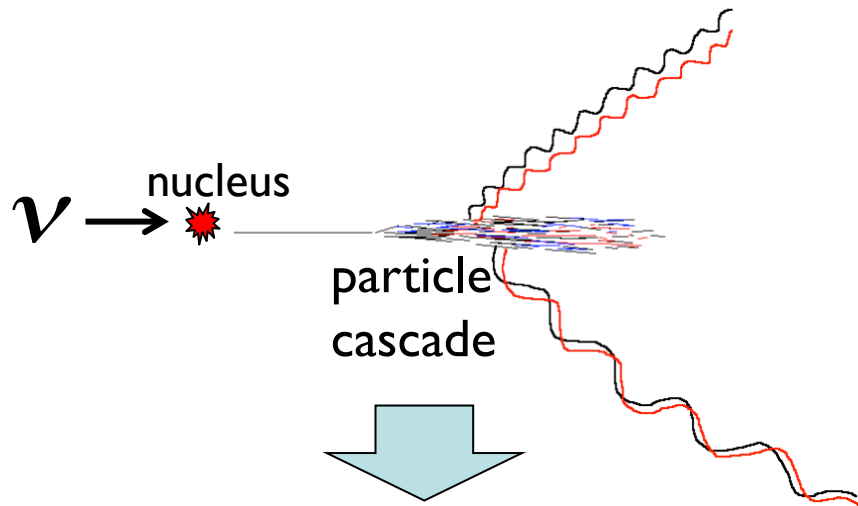
*speaker

Neutrino / Cosmic Ray Connections

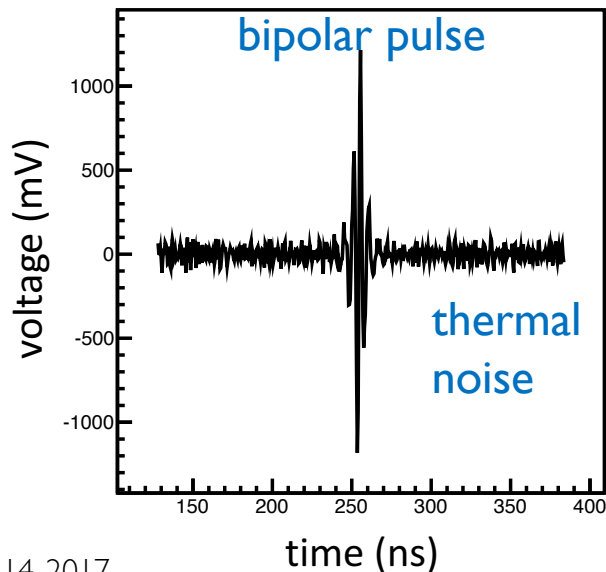
- Can neutrinos reveal origins of ultra-high-energy cosmic rays?
- Cosmogenic neutrino flux on CMB ($E_\nu \sim 10^{18}$ eV)
- Neutrinos generated in accelerator region on photon background or in hadronic interactions ($E_\nu \sim 10^{15}$ eV)



Radio Detection of Neutrinos

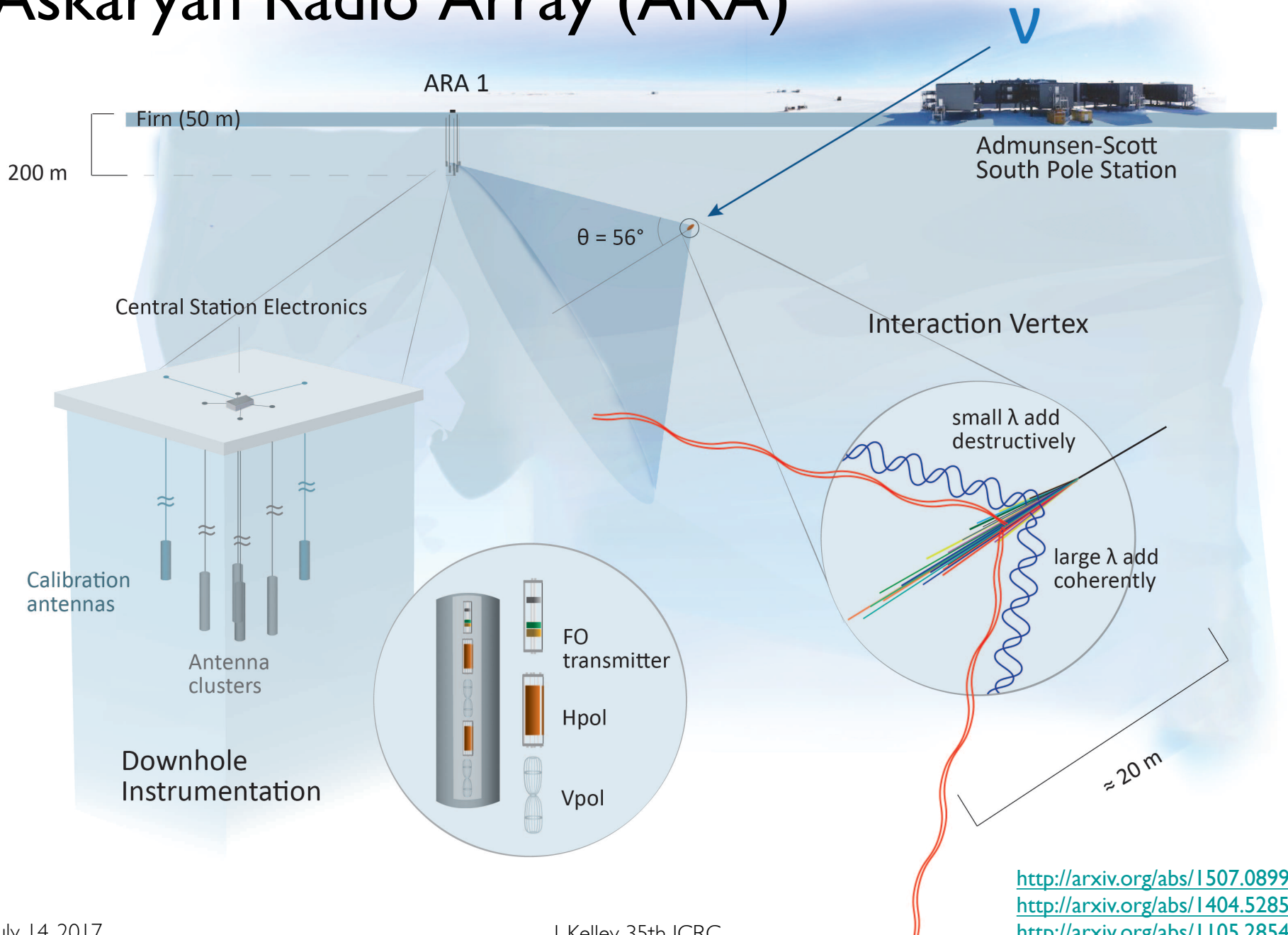


simulated 10^{18} eV neutrino event



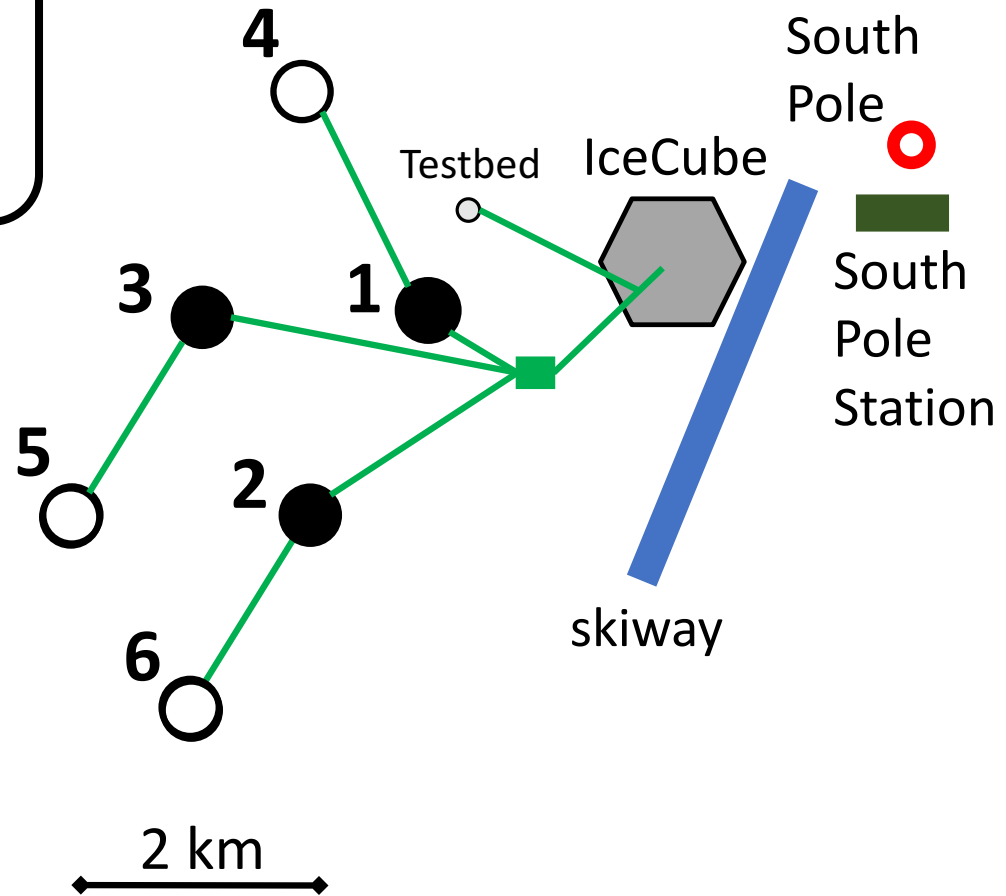
- Many km^2 target needed for ultra-high-energy neutrino detection
- Neutrino-induced showers in dense media produce broadband radio pulses (Askaryan effect)
 - detectable by radio antennas
- Ice is RF-transparent and plentiful in Antarctica
 - $\text{O}(\text{km})$ attenuation lengths
 - ANITA (balloon), ARIANNA (Ross ice shelf), ARA (South Pole)

Askaryan Radio Array (ARA)



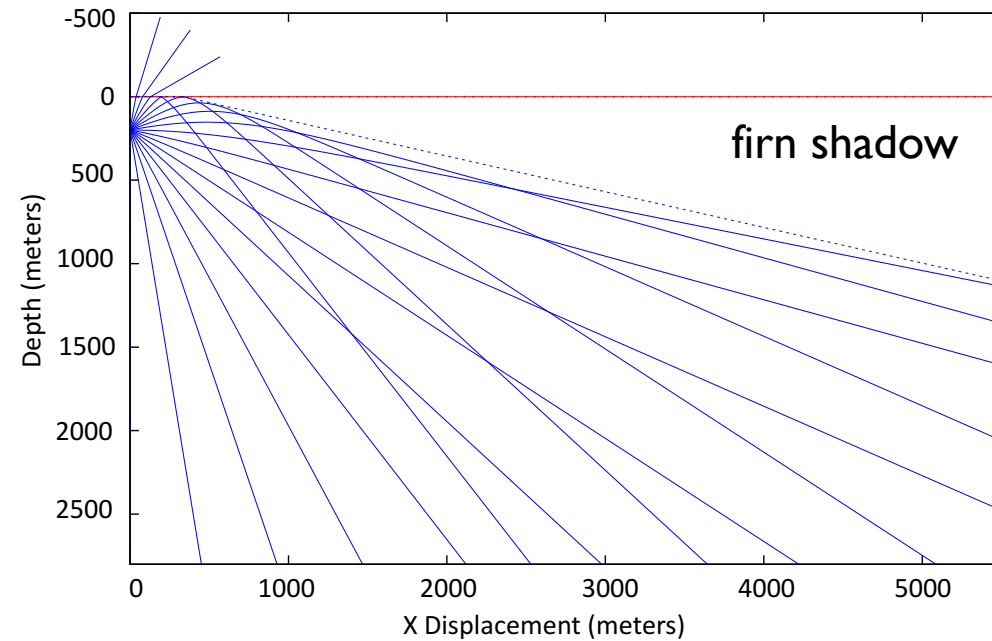
ARA Station Layout

- currently deployed
- 2017–18 deployment



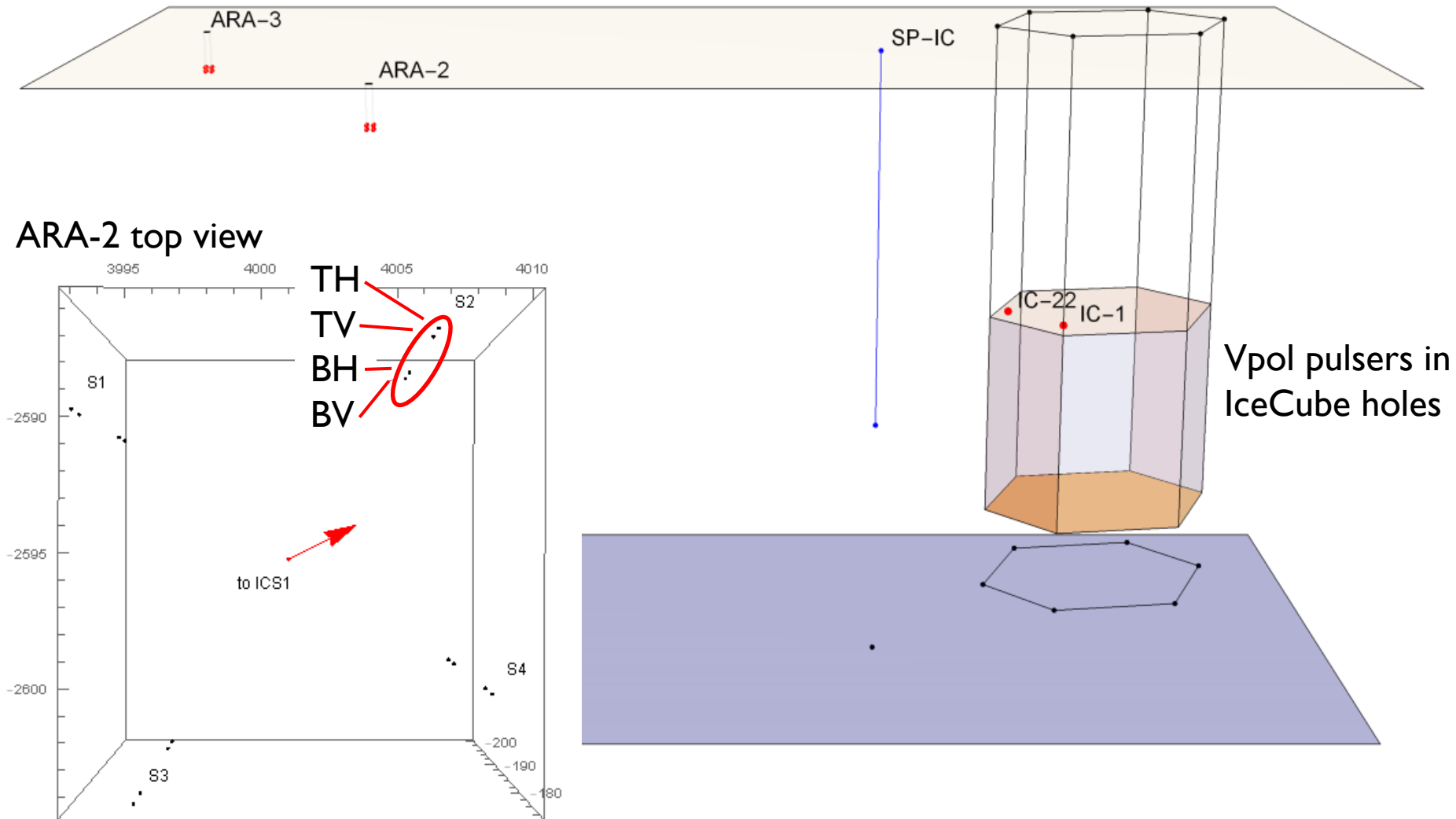
Optics in South Pole Ice

Raytrace paths (antenna at 200m depth)

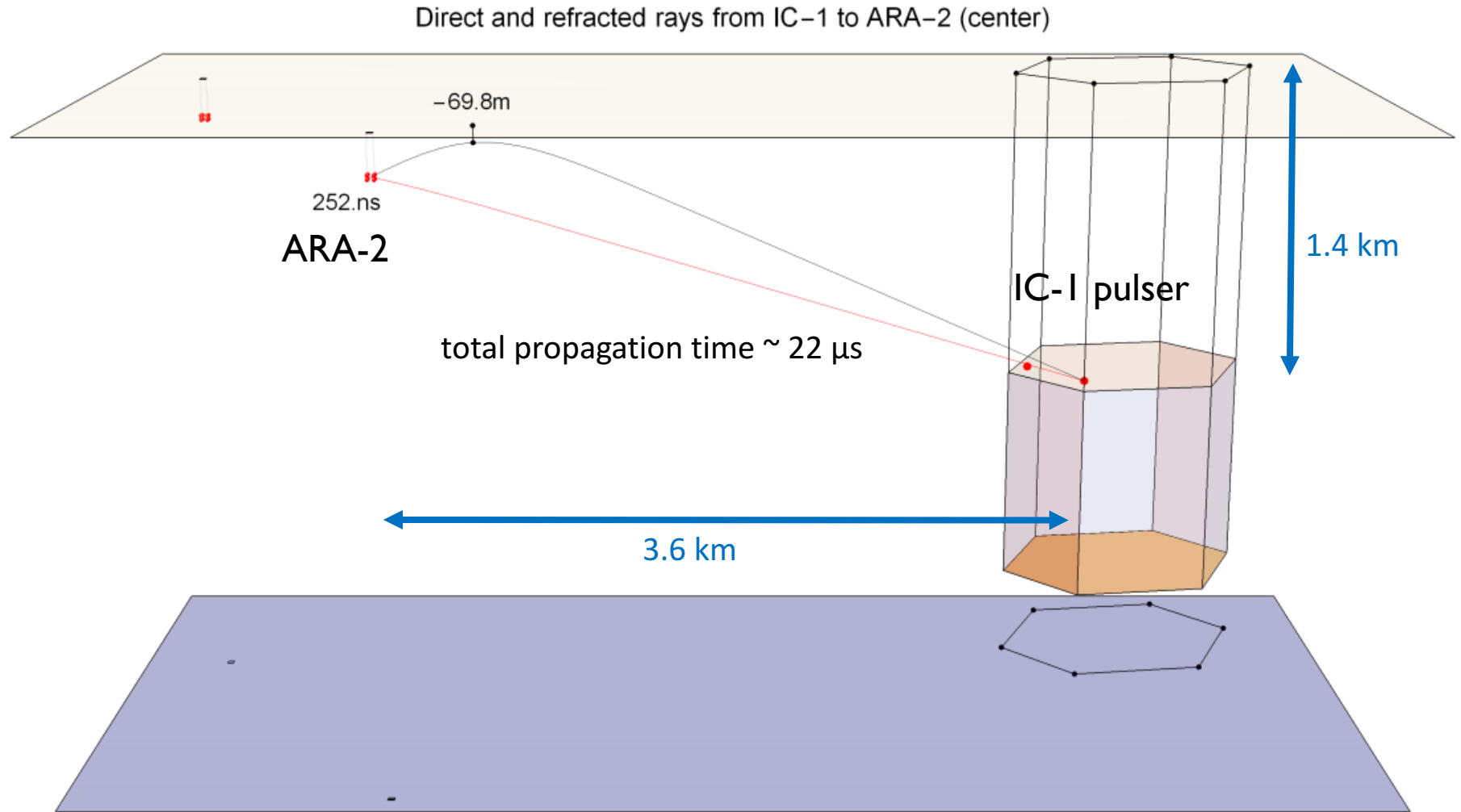


- Index of refraction a function of depth (firn layer)
- Radio waves bend away from surface
- Multiple paths possible
 - quasi-direct (QD)
 - quasi-reflected (QR)

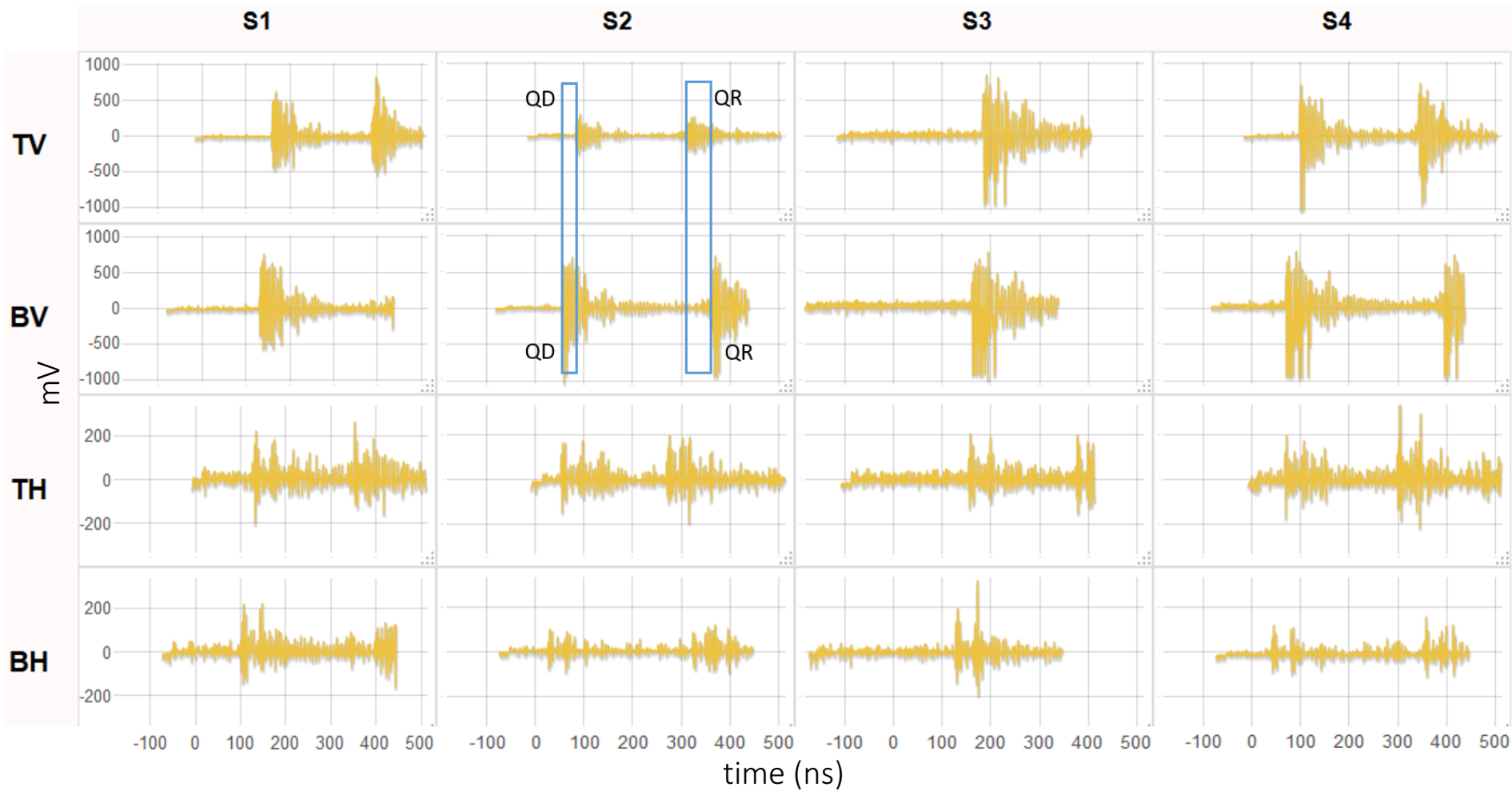
Deep Calibration Pulsars



Raytraced Radio Paths



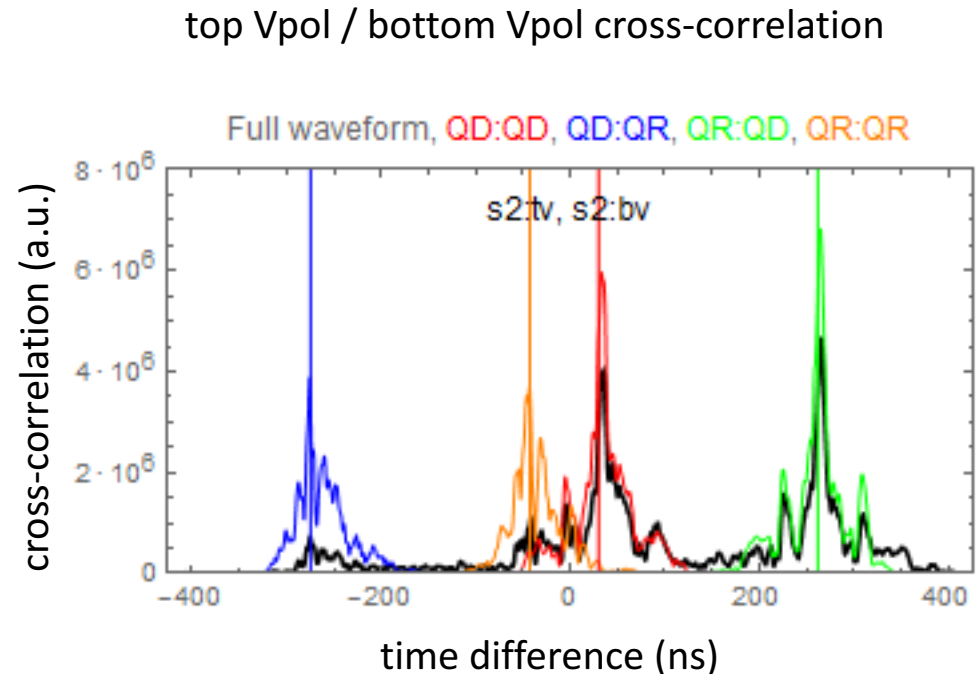
Deep Pulsar Event (IC-1 to ARA-2)



both pulses observed: QD (upgoing) and QR (downgoing)

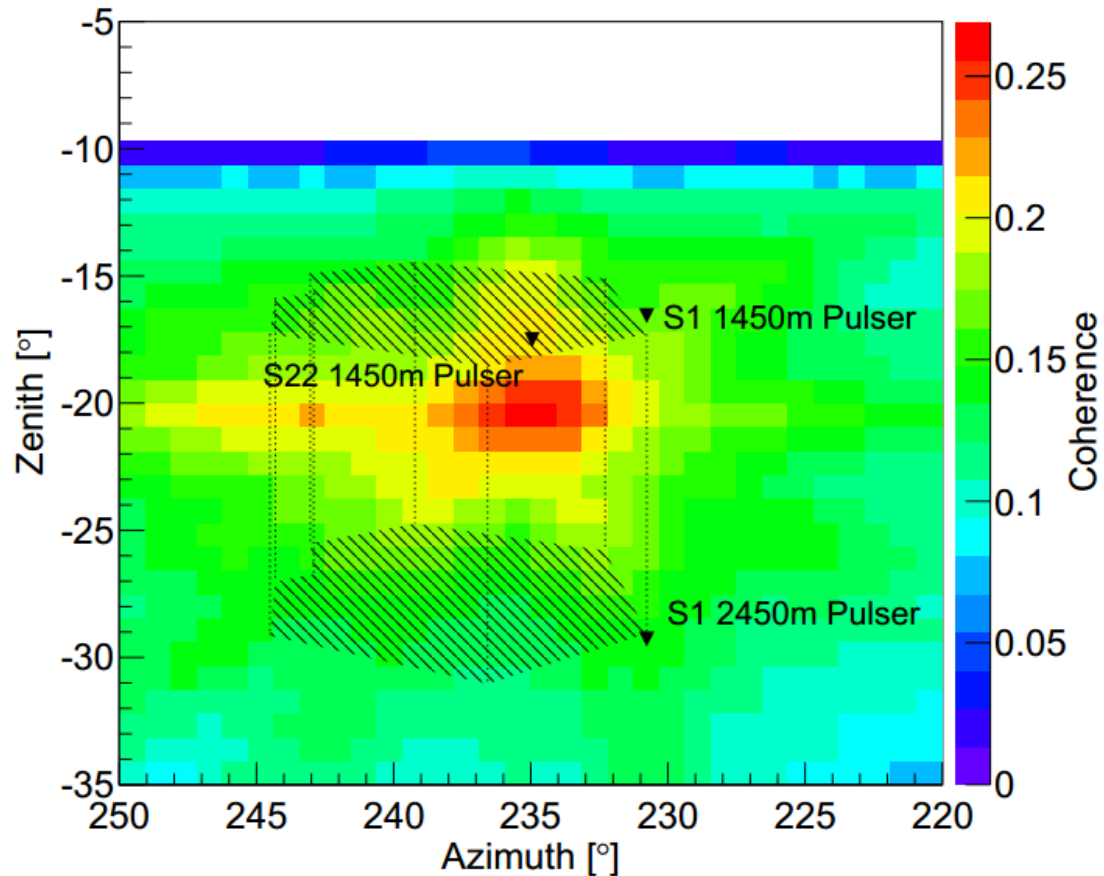
Timing Analysis via Cross-correlation

- Time-difference analysis via cross-correlation of antenna signals
 - four QD/QR pairs
 - peaks of Hilbert envelope
- Observations consistent with ice model raytracing



Directional Reconstruction (QD only)

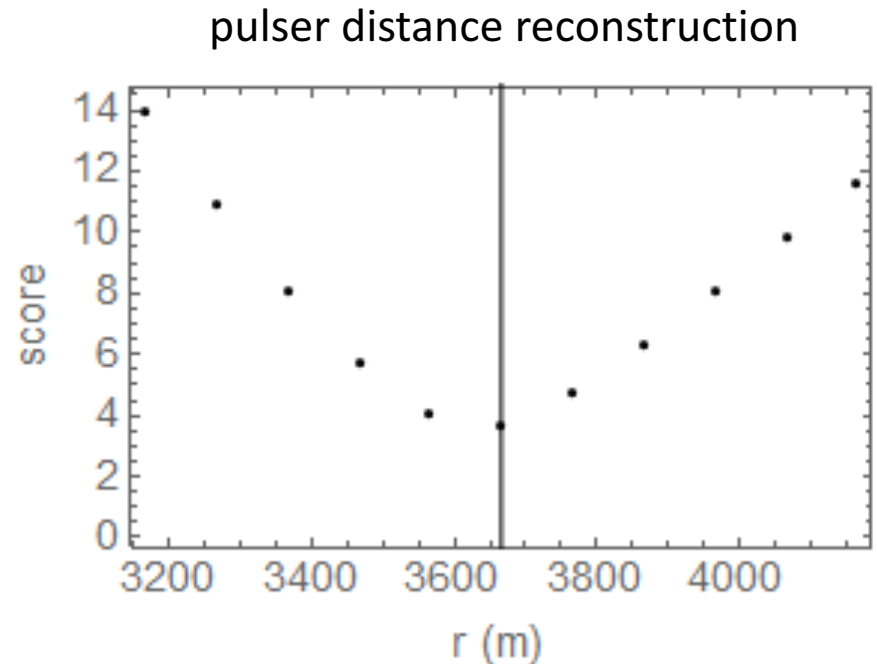
ARA3 run8311 evt12472



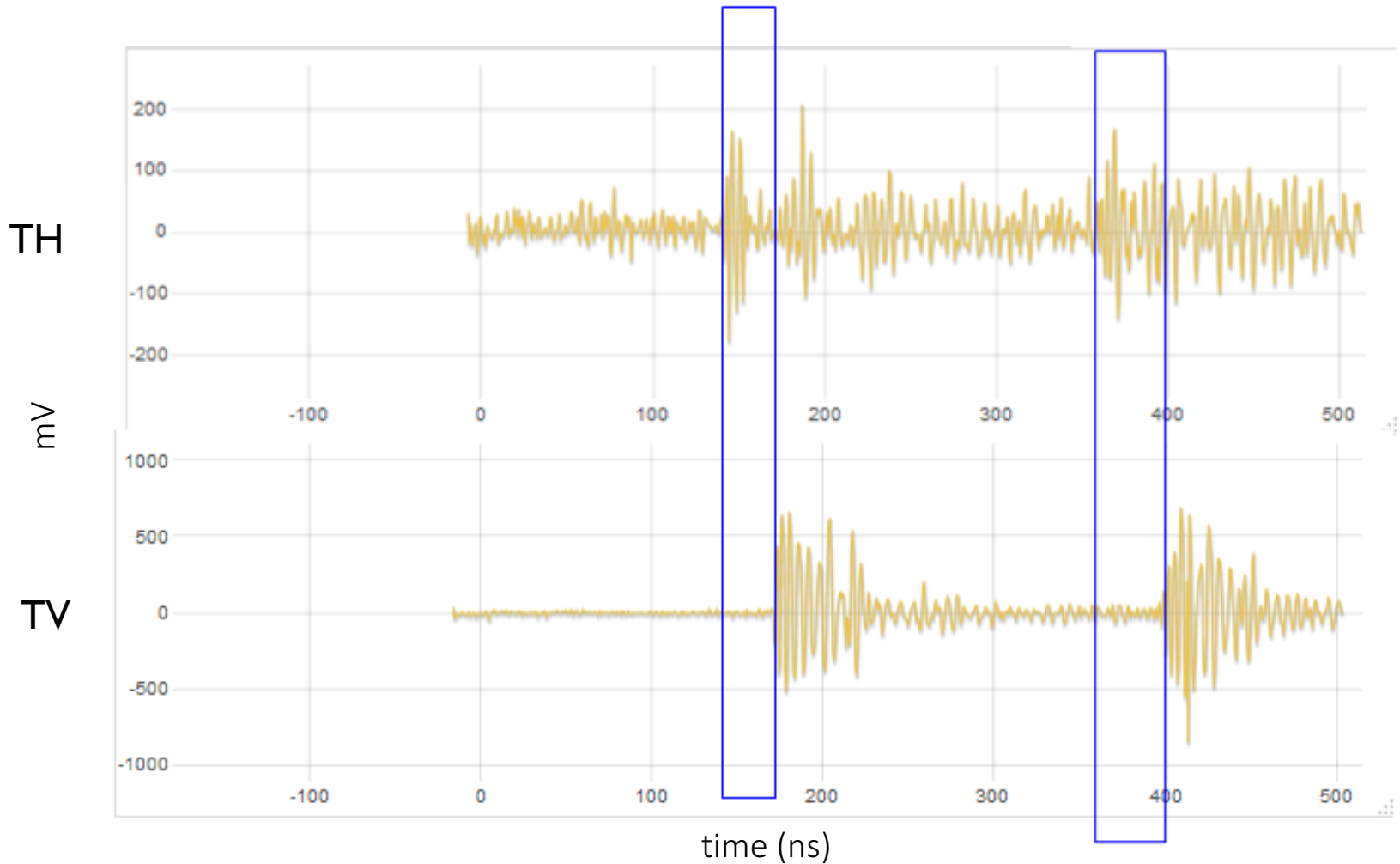
- cross-correlation reconstruction of QD pulses
 - sum of CC pairs for all directions in sky
 - see also M.-Y. Lu NU080, JK poster
- $O(\text{degree})$ directional resolution
 - distance reconstruction very difficult due to near-plane-wave timing

Distance Reconstruction with Both Pulses

- QD+QR: stereoscopic view of event allows vertex reconstruction
- Distance resolution of $O(100)$ m
- Next step — event-by-event reconstruction
 - improvement in angular resolution also expected

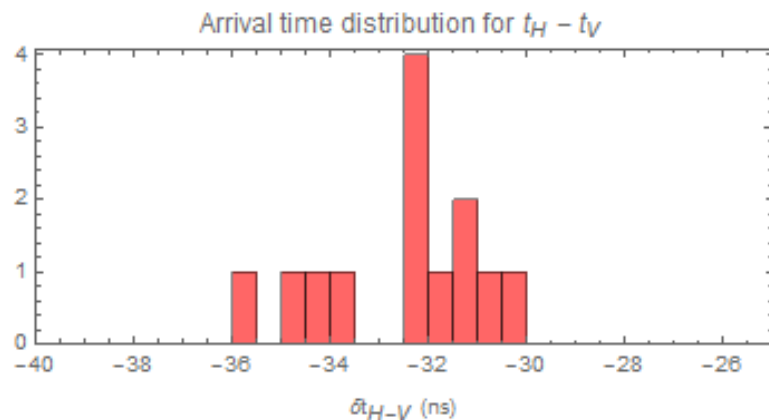
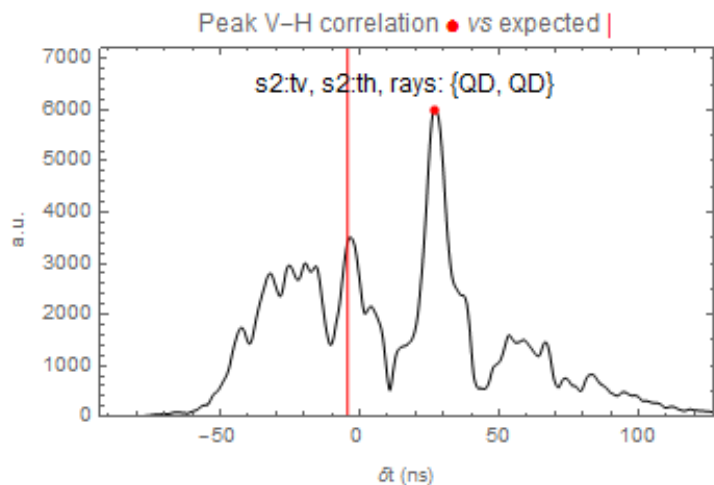


Hpol vs. Vpol Signals



fraction of Hpol arrives ~ 30 ns early (also on-time cross-polarization)

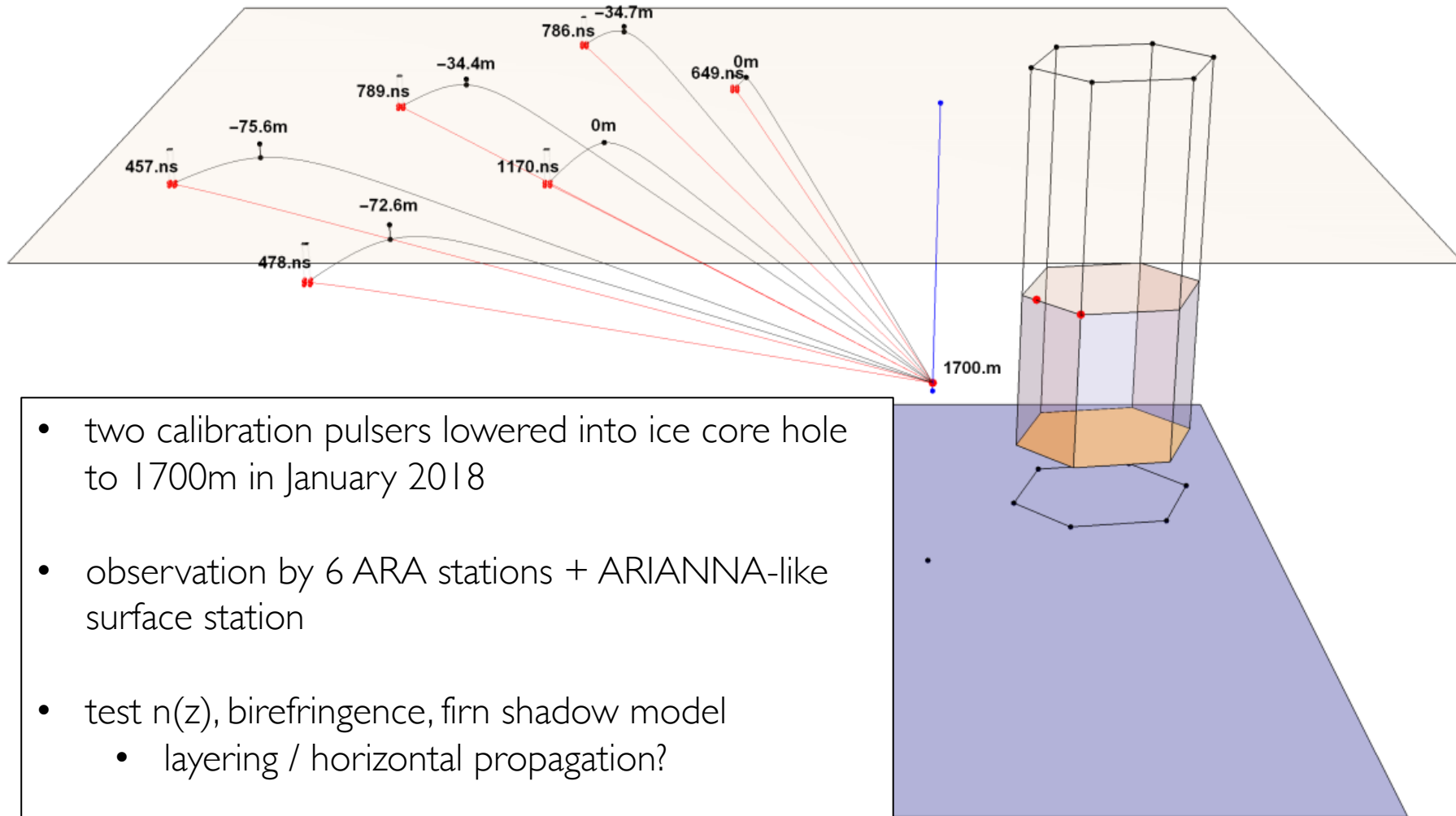
Birefringence



- consistent time delay across events, antenna pairs
- evidence of birefringence
 - previously observed with near-vertical pulses in deep ice[§]
 - order-of-magnitude of effect reasonable ($\sim 10^{-3}$)
- next steps: fully understand and model this effect

[§]Kravchenko et al., Astropart. Phys. 34, 10 (2011)

SPICE Hole Logging (2018)



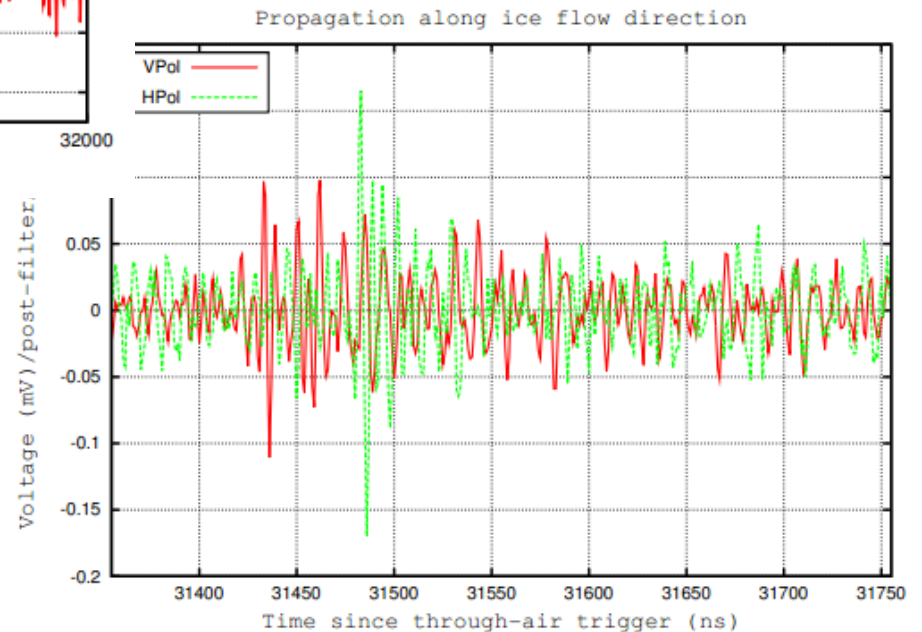
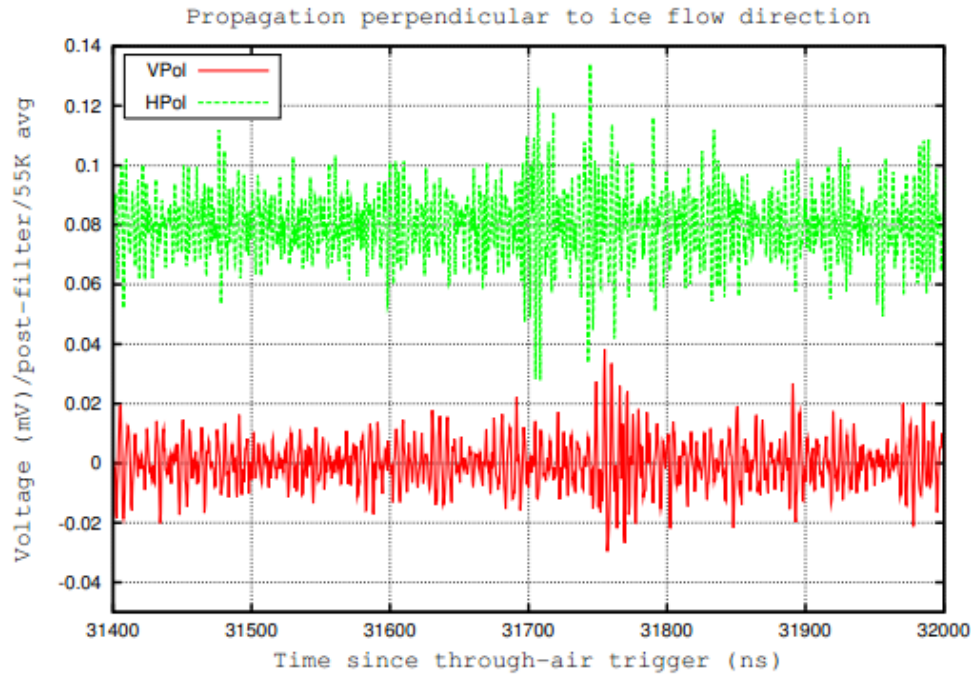
- two calibration pulsers lowered into ice core hole to 1700m in January 2018
- observation by 6 ARA stations + ARIANNA-like surface station
- test $n(z)$, birefringence, firn shadow model
 - layering / horizontal propagation?

Conclusions

- Observation of deep calibration pulser events in ARA
 - validates ice model, geometric optics paradigm
- Reflected pulses allow distance reconstruction of distant event
 - close events via direct ray timing (wavefront curvature)
- Evidence of birefringence from Hpol signals
 - potentially another handle on vertex distance
- SPICE hole logging planned for this pole season
 - refine model of index of refraction vs. depth
 - birefringence vs. depth, ice flow

Backup

Previous Measurements



Hpol/Vpol Cross-Correlations

