Status of the Askaryan Radio Array

GRAND Workshop – LPNHE, Feb. 10 2015

Aongus Ó Murchadha

SOUTH POLE

ASKARYAN RADIO ARRAY

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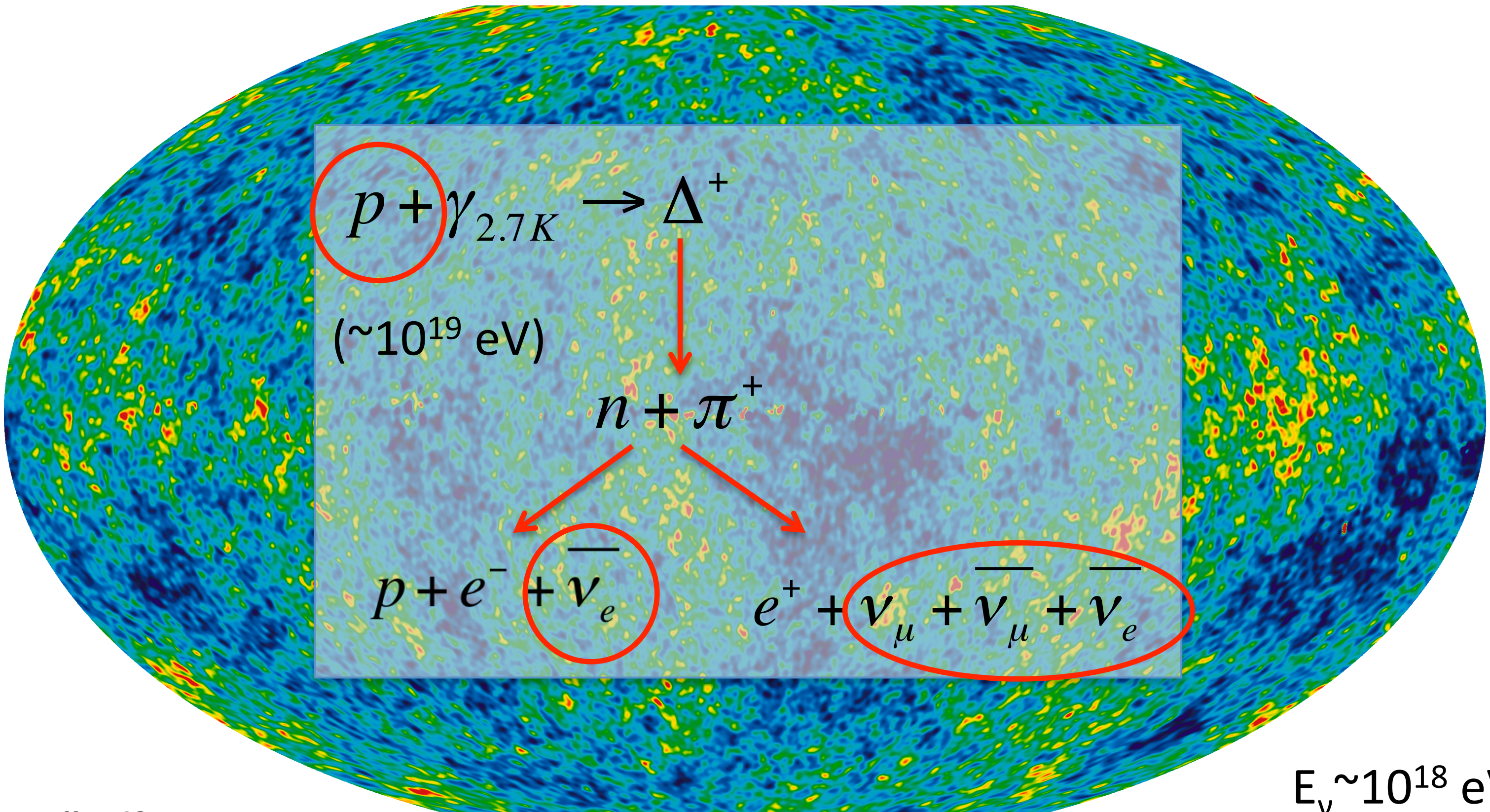
A guaranteed source of ultrahigh-energy neutrinos?

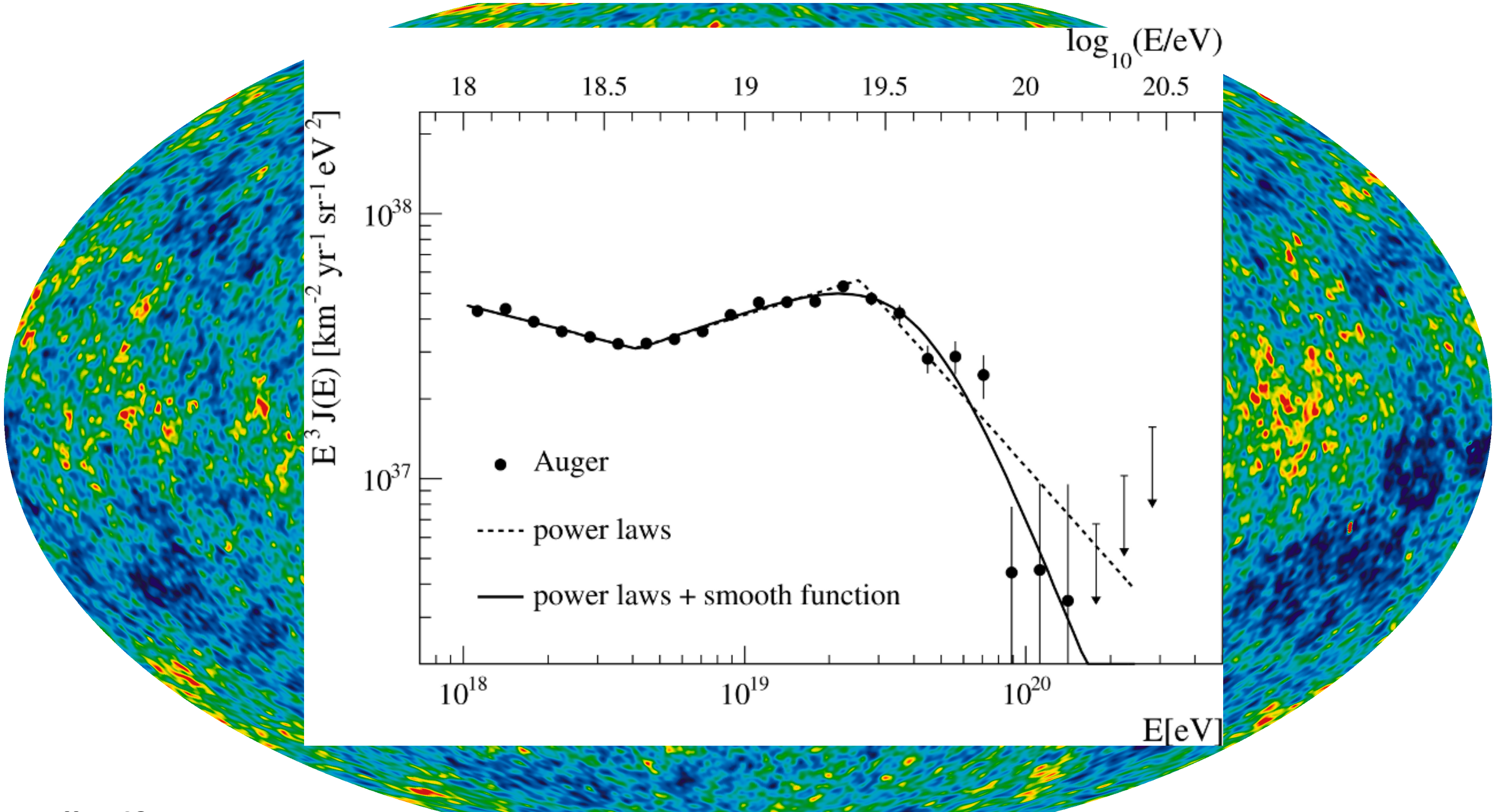


E_ν~10^{18} eV

"GZK" effect:

Greisen, Zatsepin, Kuzmin 1966: the universe is not transparent to cosmic rays!

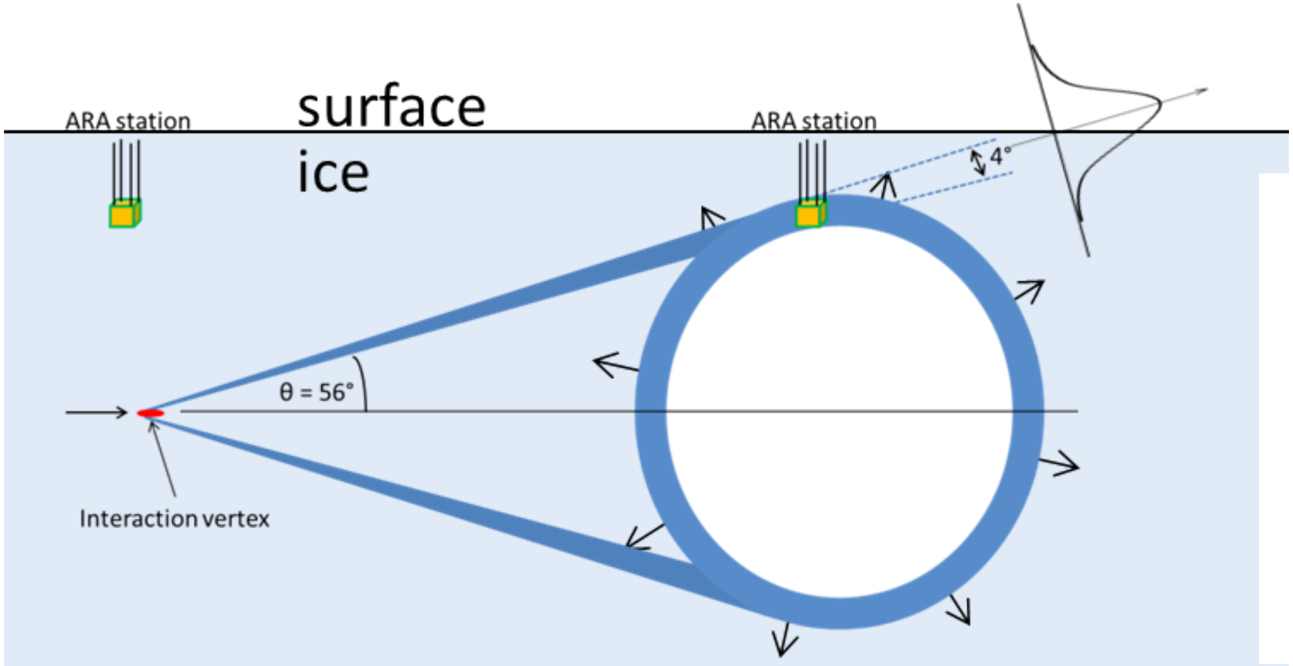
A guaranteed source of ultrahigh-energy neutrinos?

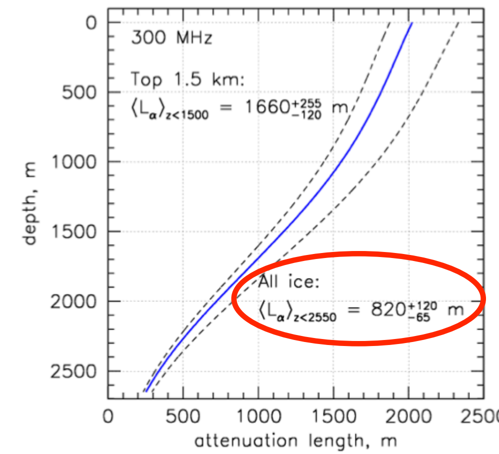


"GZK" effect:

Greisen, Zatsepin, Kuzmin 1966: the universe is not transparent to cosmic rays!

Detector concept





- Detect radio waves from neutrino-induced cascades – Askaryan effect
- Use South Pole ice as a medium – clear, environment (relatively) free of human-made noise
- O(100) km^2 area instrumented by radio antennas

the Askaryan effect

2 pieces of the effect:

- Showers in matter will have ~15% charge asymmetry due to

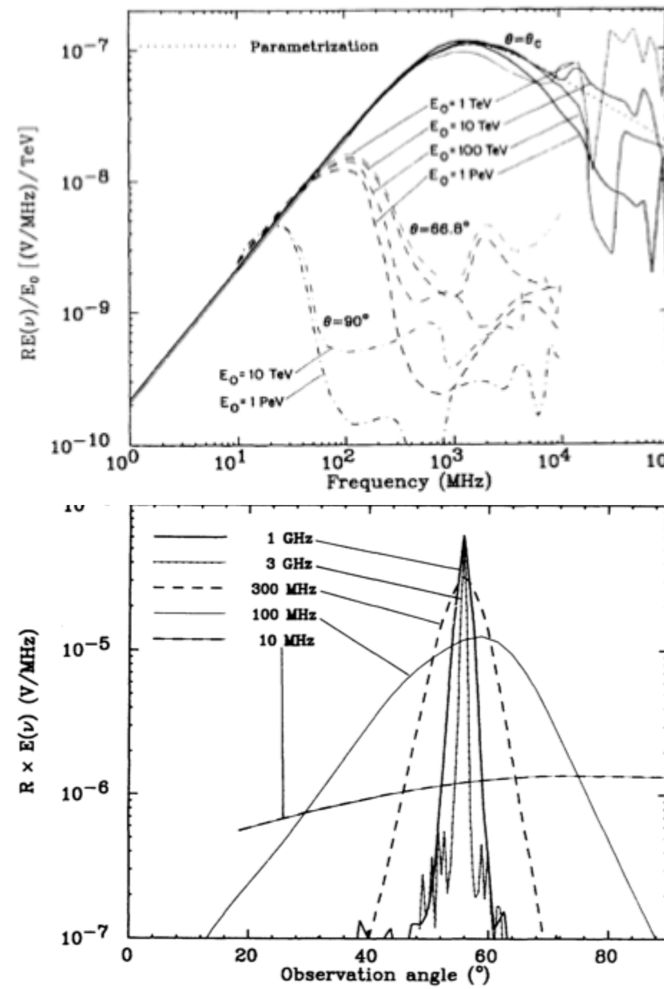
  Compton Scattering: $\gamma + e^-_{H_2O} \rightarrow e^-$

  Positron annihilation: $e^+ + e^-_{H_2O} \rightarrow \gamma$

- Small shower size: E-fields add coherently!

$$\lambda >> R_{moliere} \rightarrow P \propto N^2_{particles}$$

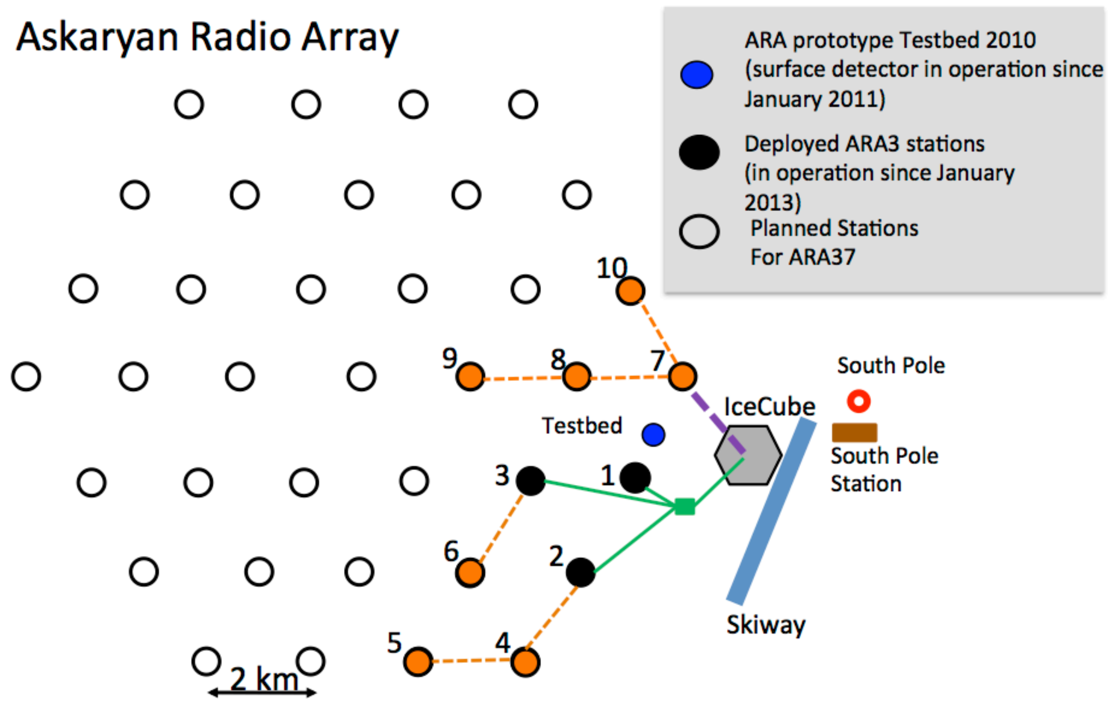
Ice: R~10 cm, ν_{peak}~1 GHz



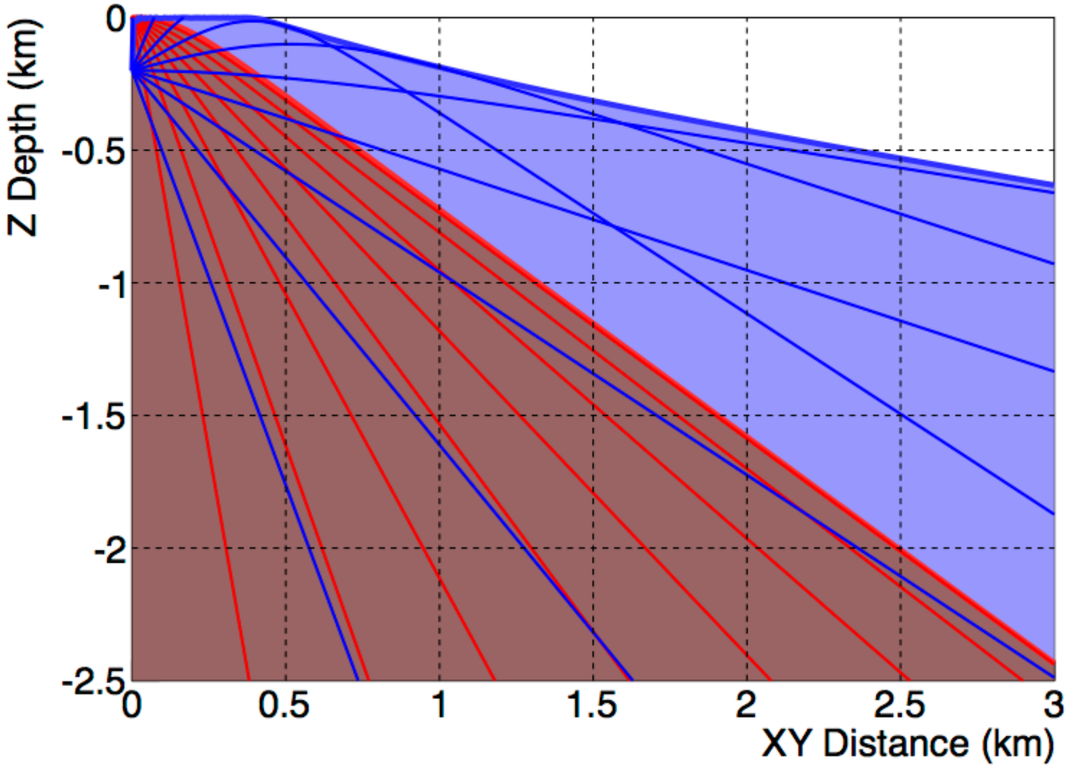
Zas, Halzen, Stanev (1992)

Towards 100 km^2

- Currently installed: 3 design stations + 1 shallow prototype Testbed:
  - Testbed installed 2010-2011 @ 30m depth
  - ARA1 installed 2011-2012 @ 100 m depth; ARA2/3 installed 2012-2013 @ 200 m depth
- Next installation phase: 7 more stations for ARA-10
  - Cable trenching 2015/2016, electronics installation 2016/2017?
- Total planned: 37 stations for ~ 100 km^2 surface area



Importance of deployment depth

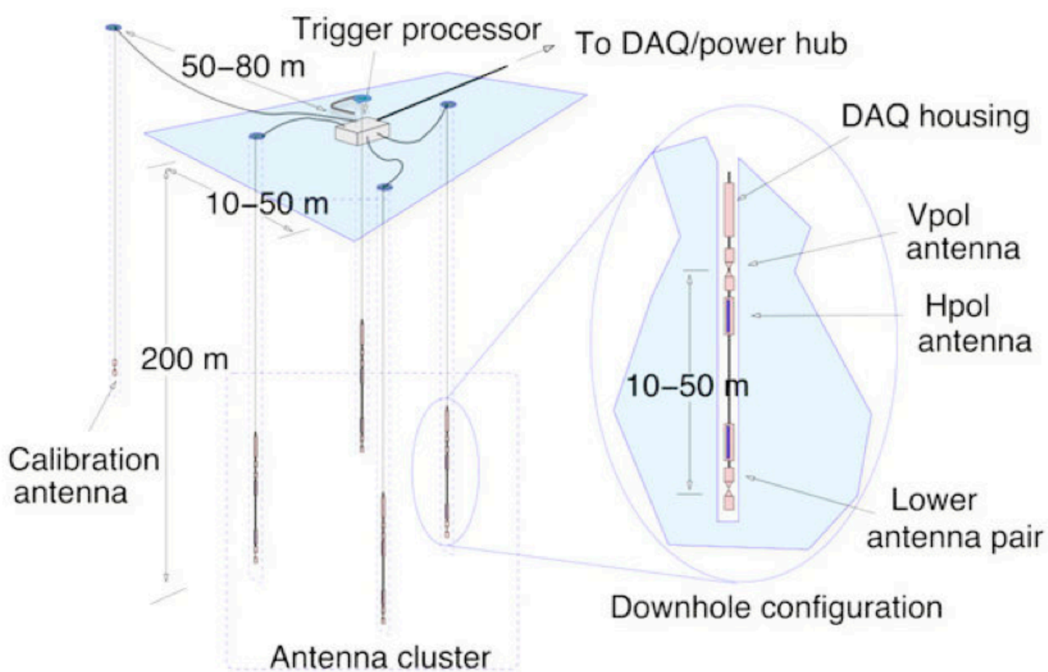


Red: antenna at 30 m

Blue: antenna at 200 m

- Index of refraction changes rapidly below surface ('firn' – compacted snow)
  - 1.35 at surface -> 1.78 below 150 m
  - Significant ray bending – limits observable volume
  - 200 m antennas vs. 30 m deep: factor 3.2 in effective volume

ARA station design



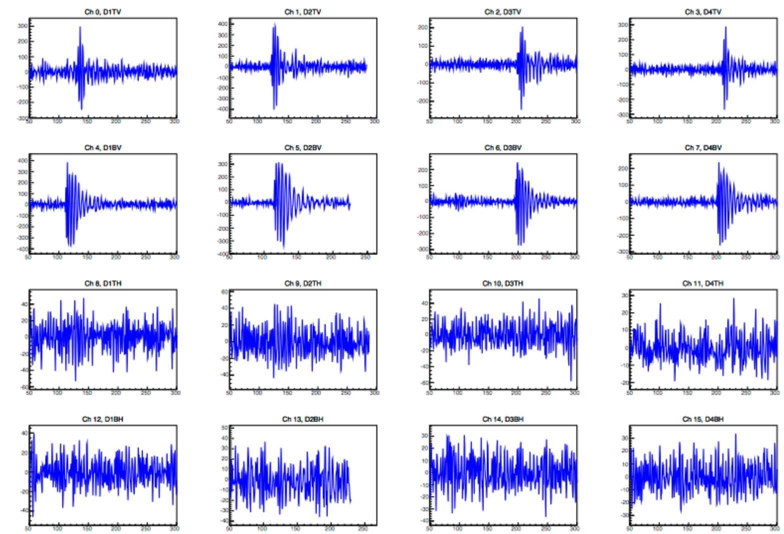
Hpol quad-slotted cylinder

Vpol bicone

- 4 strings with 4 antennas each:
  - 2 pairs (upper and lower) of 1 Hpol, 1 Vpol antenna
- 2 calibration pulsers at antenna depth
- 4 fat dipole antennas at surface for C.R. identification and background rejection
- 200 m deep: minimize effect of 'firn' layer

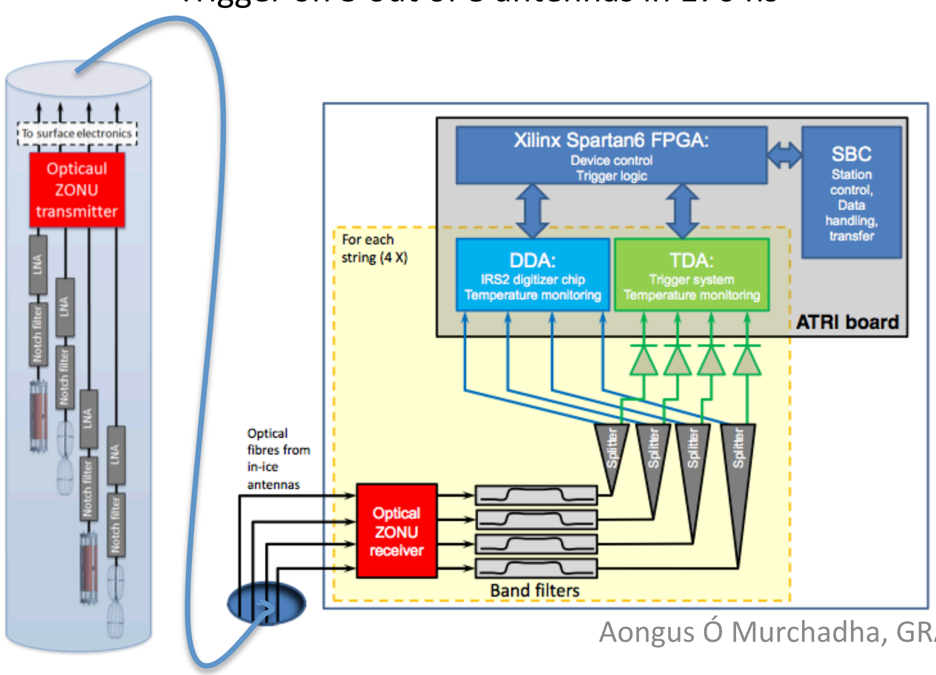
ARA DAQ

- In-ice:
  - Notch filter at 450 MHz (anthropogenic noise)
  - Low noise amplifiers
  - Optical Zonu RF over fiber
- Surface:
  - Band filters: 150-850 MHz
  - IRS2 digitizing chip: sampling up to 4 GHz, 10 µs buffer
  - Trigger on 3 out of 8 antennas in 170 ns



Vpol calibration pulser event in ARA03

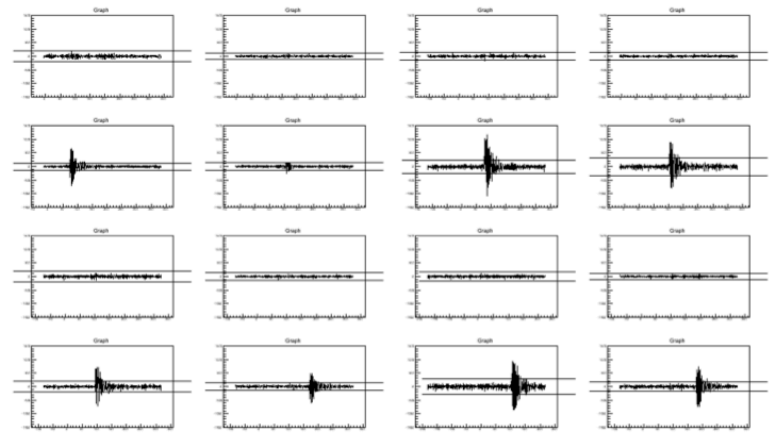
- Trigger rates:
  - ~ 5 Hz RF events
  - 1 Hz Calibration pulser
  - 0.5 Hz Forced software trigger

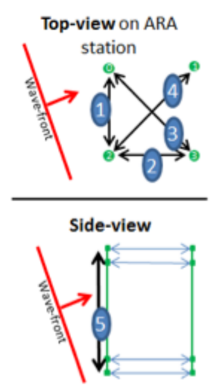


From the South to the North

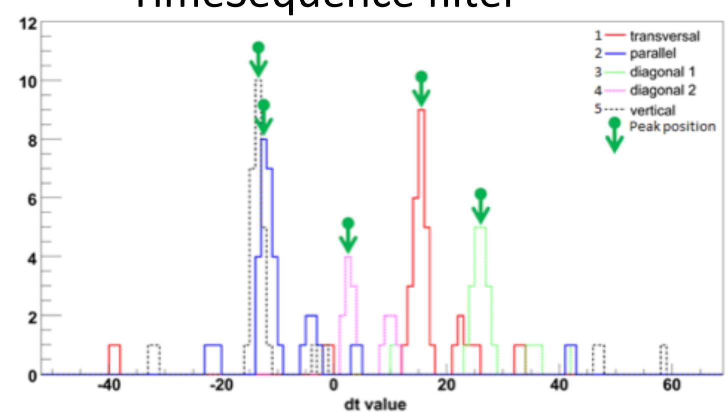
- Filtering at Pole to reduce data volume
- ~80 GB/day/station -> 250 MB over satellite
- Remainder is picked up by hand once a year
- Currently 3 filters:
  - Nchannel filter: calculate threshold from recorded waveforms, allow events that exceed threshold
  - TimeSequence: calculate compatibility of hit timing with plane wave
  - Minbias: random selection of 1 event per 200

Nchannel filter



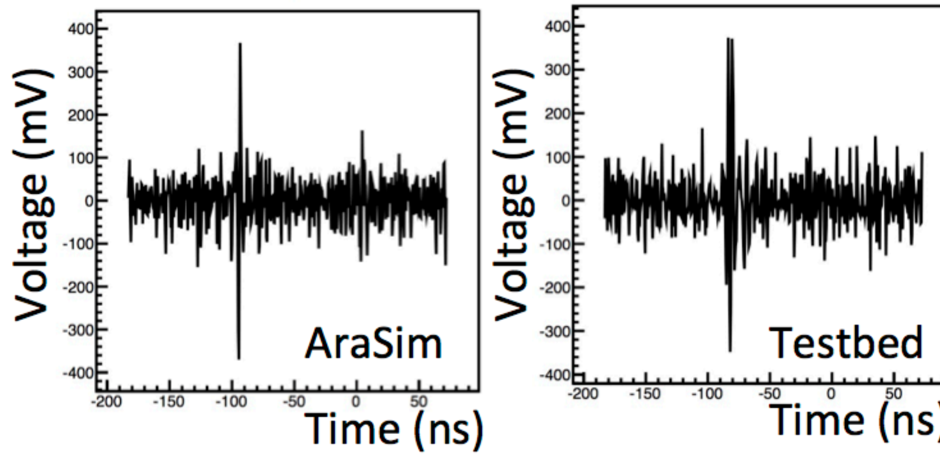


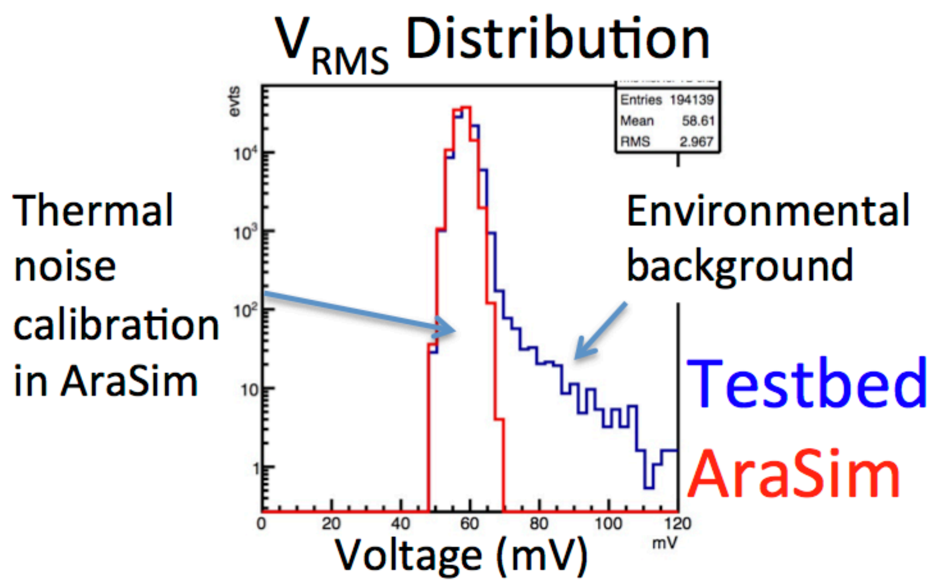
TimeSequence filter



Simulation: AraSim

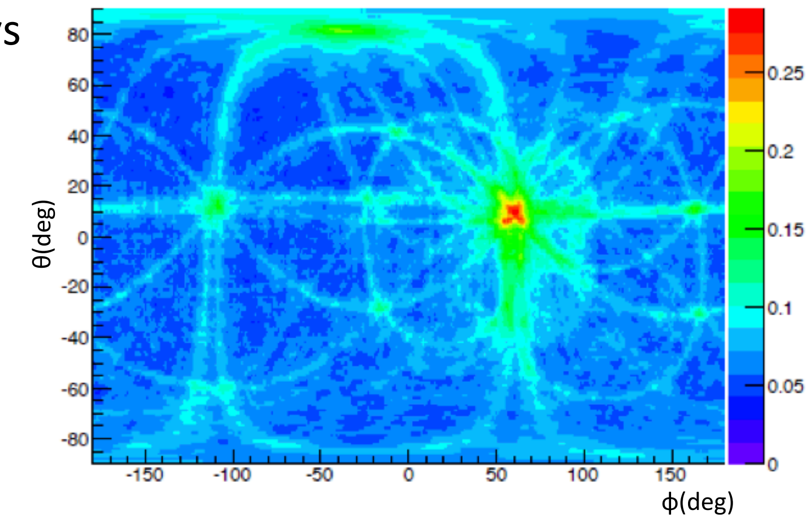
- Official collaboration Monte Carlo simulation package for assessing sensitivity and general use
- Simulated events written in data format for direct comparison
- Simulates full trigger and signal chain for neutrino events detected by ARA stations
- Takes into account:
  - Index of refraction model
  - Calibrated noise simulation
  - Antenna and electronics responses
  - Trigger model



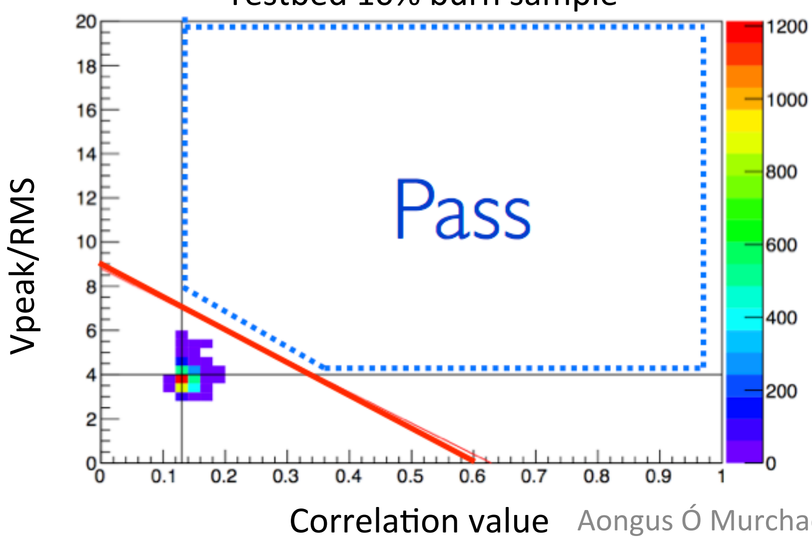


First analyses: Testbed

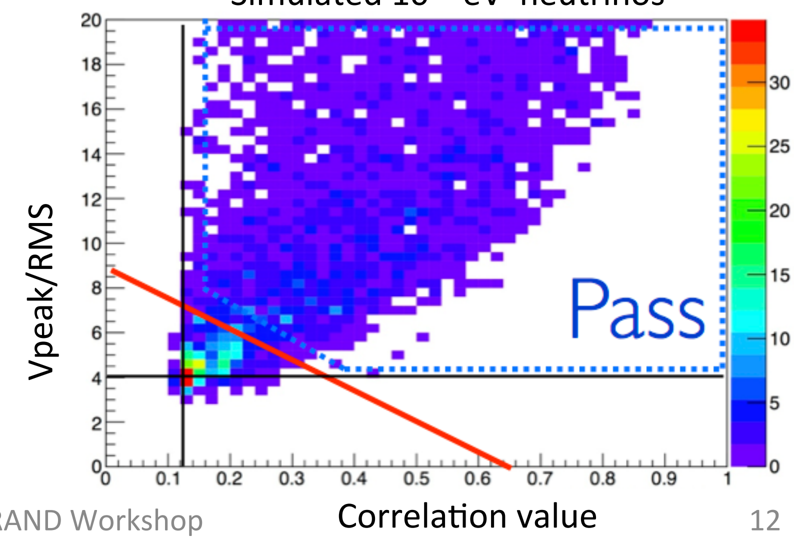
- arXiv:1404.5285, subm. to Astropart. Phys
- Event reconstruction: cross-correlation map based on event timing
- Includes varying index of refraction
- Cuts:
  - Reconstruction quality
  - Continuous wave
  - Vpeak/RMS versus correlation value
- No neutrino candidates, set upper limit



Testbed 10% burn sample



Simulated 10^{18} eV neutrinos



First Analyses: ARA 2/3 I

- Matrix based event reconstruction (Bancroft's Method)
  - System of equations based on arrival time differences from correlation
  - Causality for 1 antenna:

    $$c^2\left(t_v - t_i\right)^2 = \left(x_v - x_i\right)^2 + \left(y_v - y_i\right)^2 + \left(z_v - z_i\right)^2$$

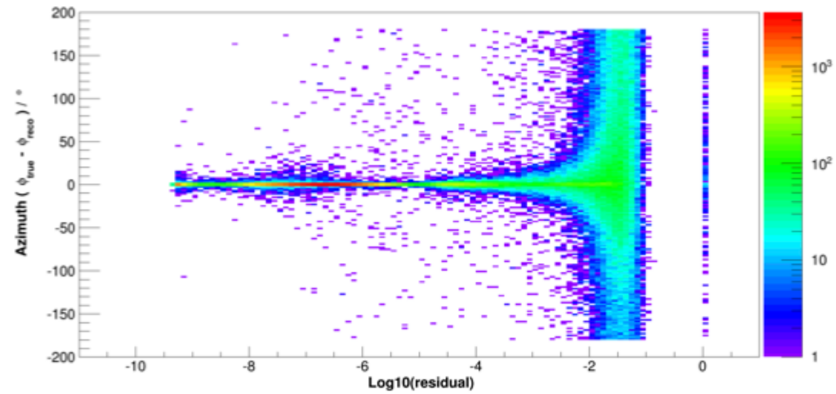
  - Difference for 2 antennas:

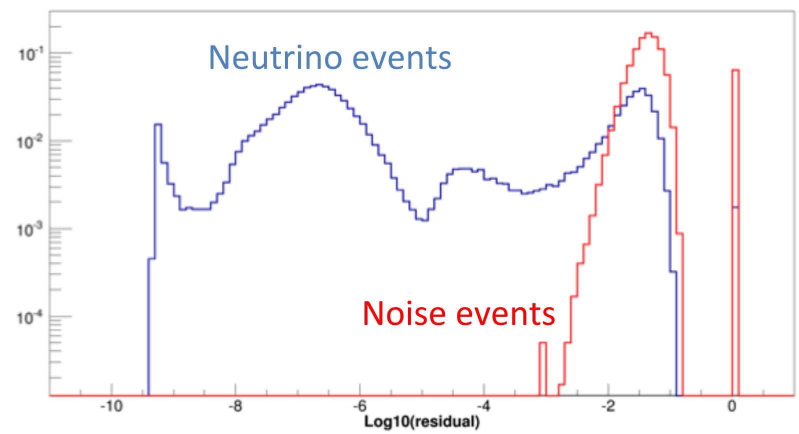
    $$x_v \cdot 2dx_{ij} + y_v \cdot 2dy_{ij} + z_v \cdot 2dz_{ij} - t_v \cdot 2c^2 dt_{ij} = r_i^2 - r_j^2 - c^2\left(dt_{i,ref}^2 - dt_{j,ref}^2\right)$$

  - Write as vectors: A*v = b, v = (x_v,y_v, z_v, t_v)
  - Linear algebra: scan over t_v, minimize residual

    $$\left\| \frac{b}{|b|} - \frac{A*v}{|A*v|} \right\|^2$$

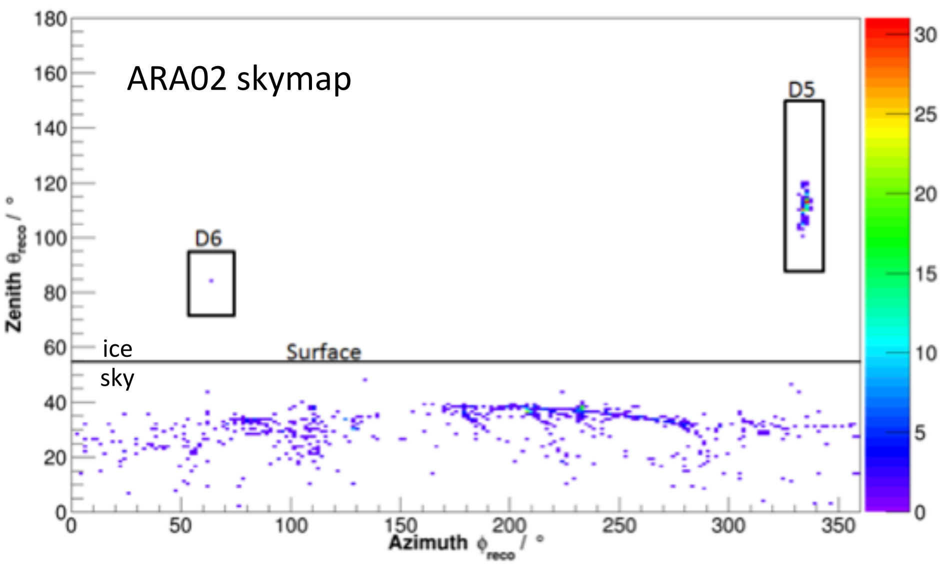
Azimuth error vs residual

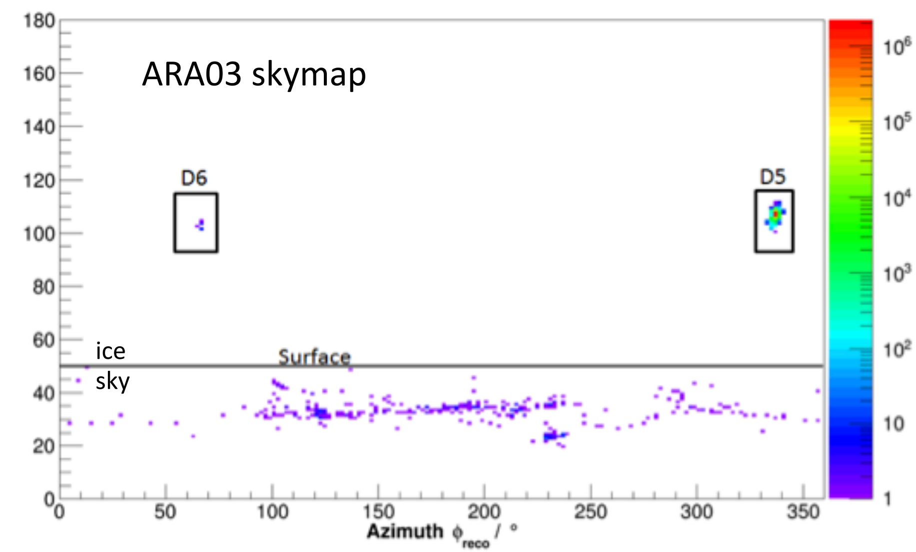




First Analyses: ARA 2/3 II

- 2 stations, 10 months of data
- Cut on:
  - Reconstruction quality (residual)
  - TimeSequence algorithm
- No neutrino candidates, set upper limit with systematic errors

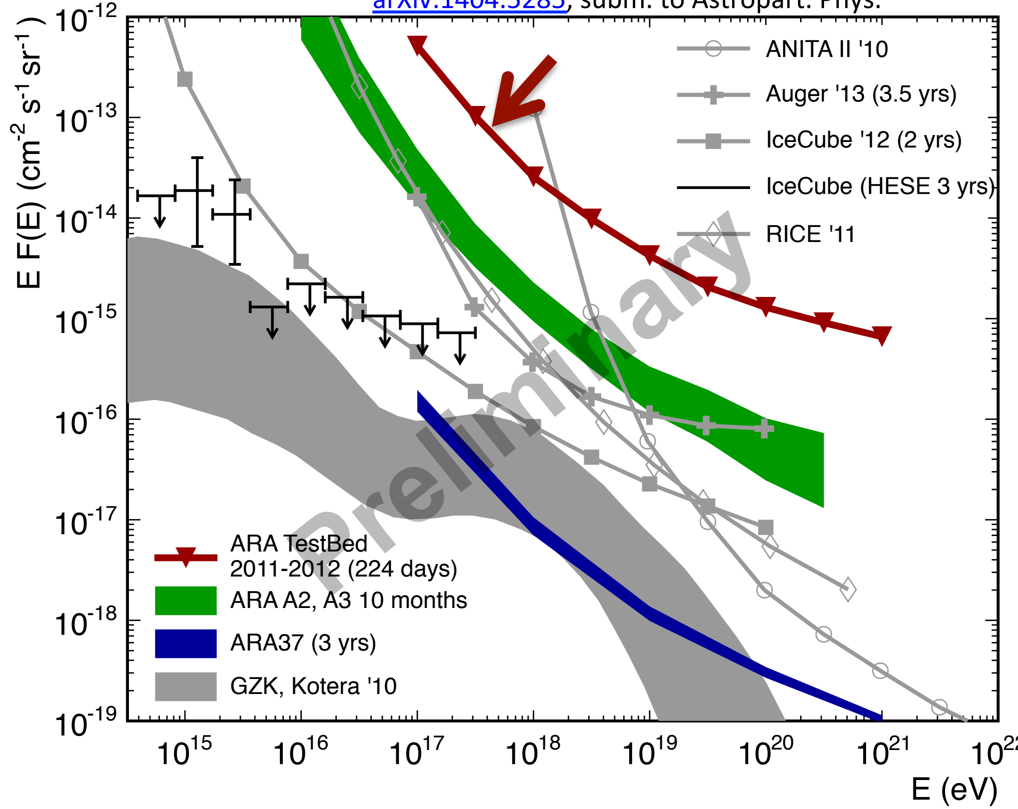




First results & summary

- Upper limits obtained from testbed (red)
- First analysis of 2 stations (green)
 - Demonstration of analysis chain

arXiv:1404.5285, subm. to Astropart. Phys.



•Good sensitivity above 10^{17} eV

•Relatively low energy threshold

•Determine cosmic neutrino flux at $E>10^{17}$

•Neutrino physics at highest energies

•Direct connection to cosmic ray flux and composition at $E>10^{19}$

the ARA collaboration