Evolving Antennas for Ultra-High Energy Neutrino Detection

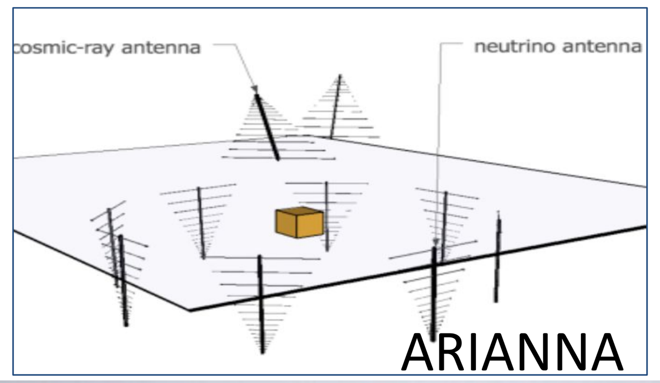
Julie Rolla and the GENETIS Collaboration

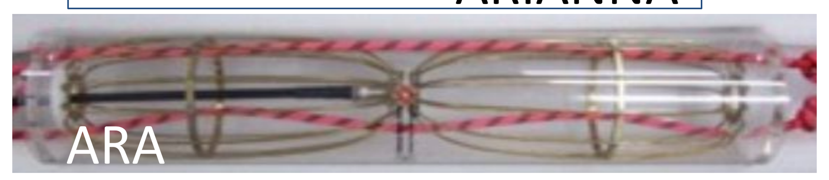
Ohio Supercomputer Center
An OH·TECH Consortium Member

CCAPP CENTER FOR COSMOLOGY AND ASTROPARTICLE PHYSICS

INTRODUCTION

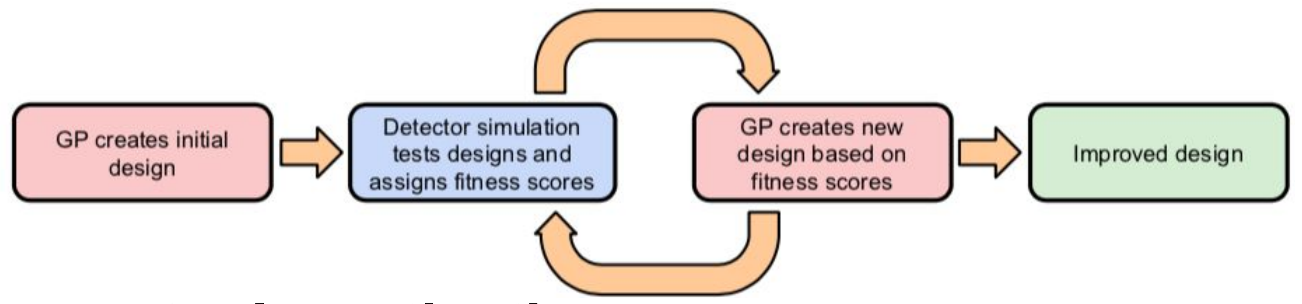
A number of experiments, including ANITA, ARA, ARIANNA, and RNO-G are attempting to detect Ultra-High Energy (UHE) neutrinos through the **Askaryan radio waves produced when a UHE neutrino strikes a dielectric target, such as the Antarctic ice** [1,2]. These experiments use different antennas with **complex design constraints**.





Genetic Algorithms (GA) are a form a machine learning that **mimics biological evolution to optimize parameters** over generations [3]:

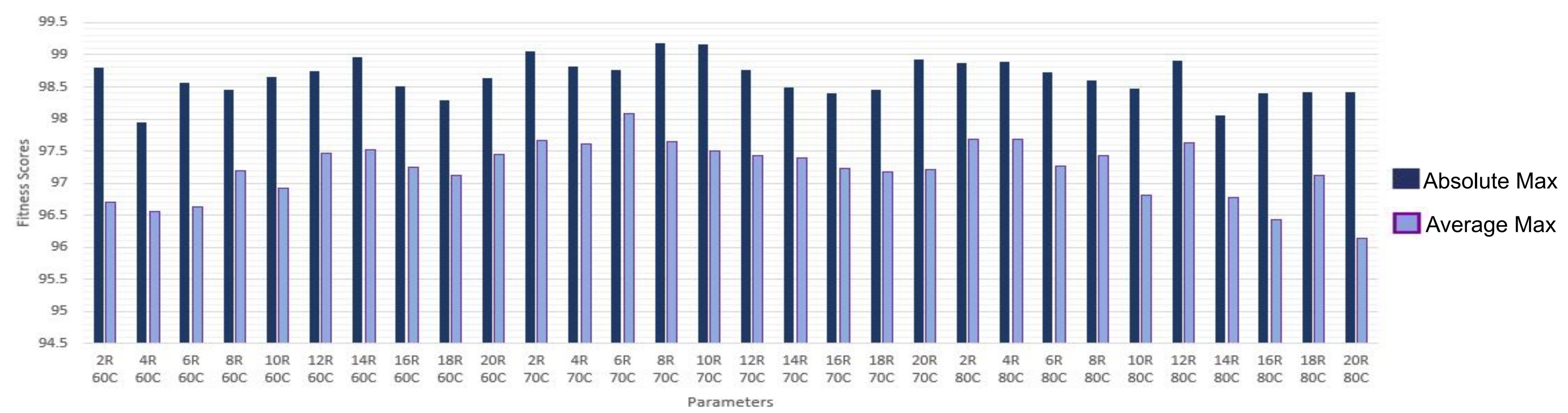
- Populations are initialized with a range of different parameter values
- Each individual is assigned a **fitness score based on a test**
- A new population is then generated based on the fitness scores
- This **cycle is iterated until optimized solutions are achieved**



1. GA Parameter Investigation

There are a number of parameters that affect the outcome and efficiency of a GA.

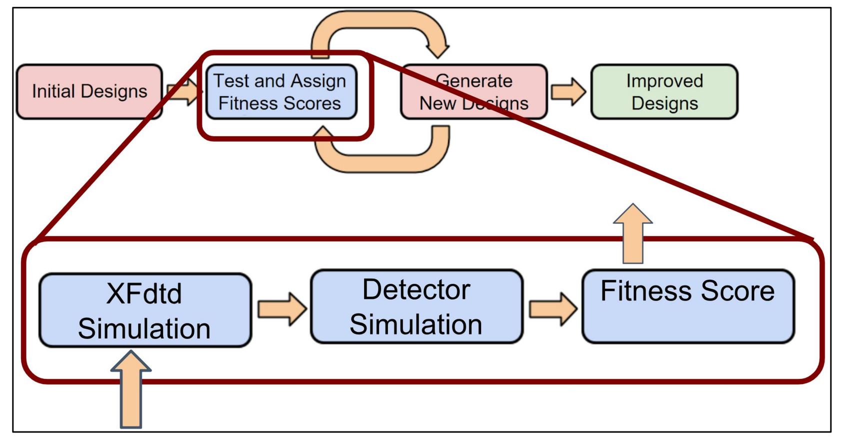
- Selection methods are the techniques used to decide which individuals are used to create the next generation and include roulette and tournament selection
- Operators are the techniques used to create the following generation and include crossover, mutation, and reproduction.
- **A wide range of parameters were tested in a simplified GA** with the following optimal result:
  - 80% Roulette - 20% Tournament
  - 70% Crossover - 24% Mutation - 6% Reproduction



2. Physical Antenna Evolution Algorithm (PAEA)

PAEA aims to **evolve antenna geometries to optimize sensitivity to neutrinos** [4].

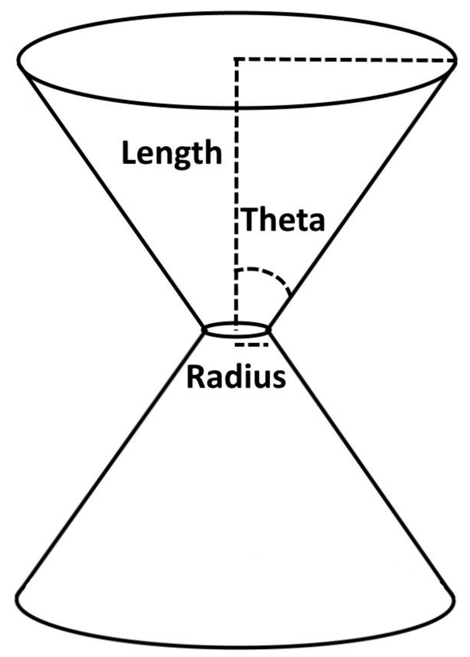
- Electrodynamics simulation software, XFdtd, is used to **simulate antenna beam patterns from the individual's geometric parameters**
- AraSim detector simulation software then simulates **the effectiveness at detecting neutrinos** [5]
- This determines the fitness scores used for generating new populations

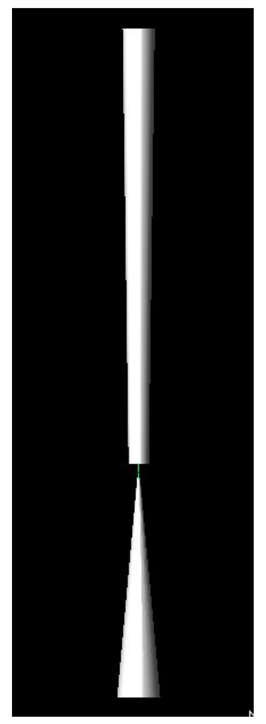


Algorithm has continued to improve and is able to evolve bicone parameters

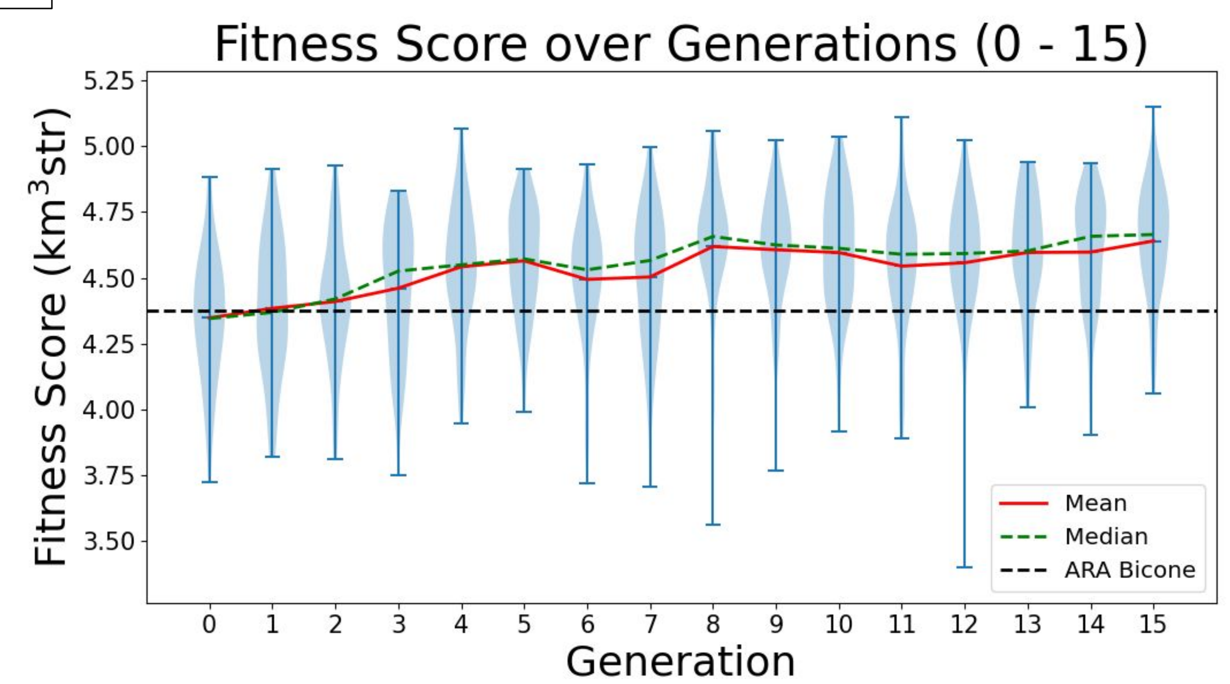
- Evolved 50 individual designs over 15 generations
- Parameters of length, radius and angle
- Allow top and bottom cones to have different shapes for additional complexity
- Results compared to the ARA bicone in ice

Bicone parameters





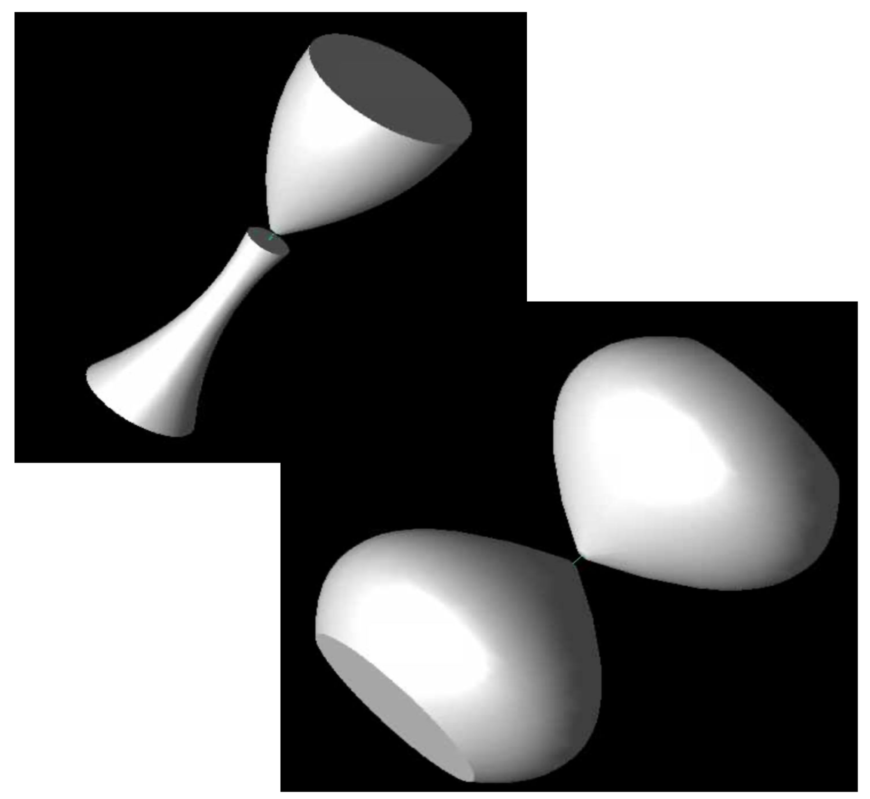
Best individual evolved so far.



3. Nonlinear Antenna Sides

Changing the shape of the bicone cross sections is the next step in adding complexity

- **Nonlinear sides will allow more diverse shapes to be evolved**
- Instead of evolving the opening angle, we evolve the coefficients of a polynomial
  - The polynomial describes the shape of the surface of the bicone
    - Thus, sides can look curved instead of straight
  - This method will still evolve the radius and length parameters
  - Each half of the bicone may evolve differently, adding even more diversity
- **Nearly fully developed and ready to be implemented into PAEA**

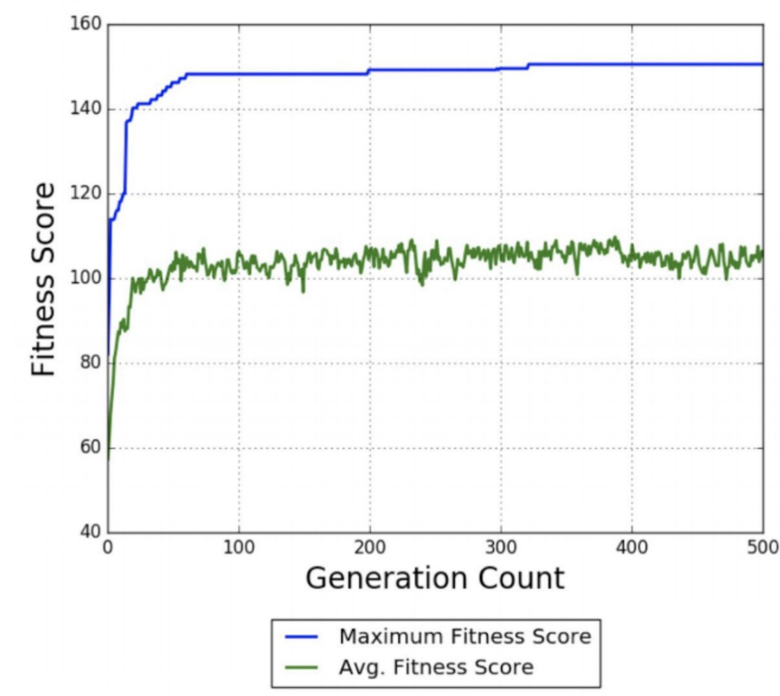


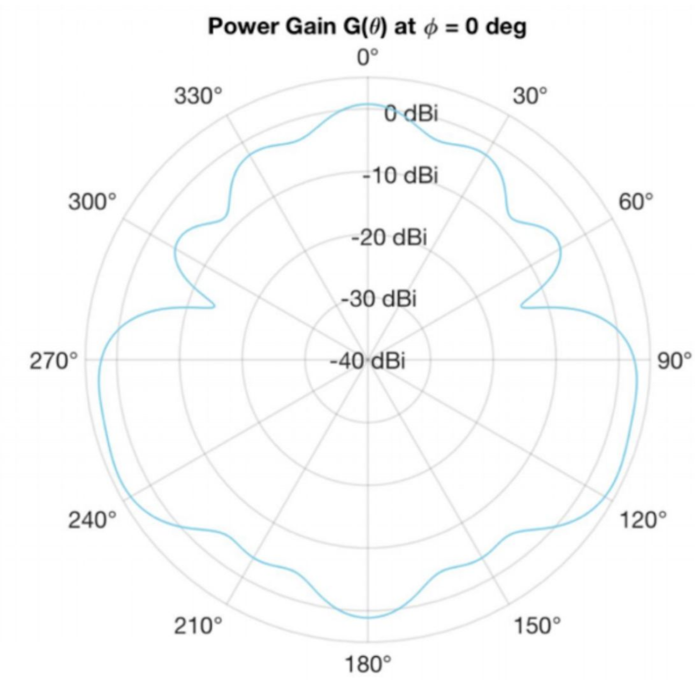
Two examples of bicones with non-linear sides

4. Antenna Response Evolution Algorithm (AREA)

AREA aims **to evolve antenna beam patterns to achieve specific responses for the best neutrino sensitivity**. This will allow us to determine how much room for improvement in the design there is.

- It can be **difficult to design an optimal beam pattern by hand** because of the complexity of the detector and the design constraints
- Uses a sum of 13 azimuthally symmetric spherical harmonic functions to model the antenna response
- Fitness score is based on AraSim simulated effective ice volume, the volume of ice that the detector is sensitive to.





CONCLUSIONS

Topic	Summary	Next Steps
1. GA Parameter Optimization	• We should use 6% reproduction, 70% crossover, and 24% mutation	• Investigate different fitness selection criteria, such as using rank roulette selection
2. Physical Antenna Evolution Algorithm	• Initial runs successfully evolve bicone antenna	• Implement more complexity and improve computational efficiency
3. Nonlinear Antenna Sides	• Updates to the GA are currently in development to allow for nonlinear sides	• Complete development and add to PAEA
4. Antenna Response Evolution Algorithm	• Convergence with both directional and omnidirectional patterns	• Run the GA with full AraSim on a high-performance cluster • Incorporate optimized GA parameters

This summer, the best performing antenna will be constructed at the Ohio State University Center for Design and Manufacturing Excellence (CDME) and later installed in the ice for additional testing.

ACKNOWLEDGEMENTS

The GENETIS team is grateful for support from the Ohio State Department of Physics Summer Undergraduate Research program, support from the Center for Cosmology and Astroparticle Physics, and the Cal Poly Connect Grant. J. Rolla would like to thank the National Science Foundation for support under Grant 1404266 and the Alumni Grants for Graduate Research and Scholarship. We would also like to thank the Ohio Supercomputing Center.

The Ohio State University

[1] Aguilar, J. *et al.* The Next-Generation Radio Neutrino Observatory. Decadal Survey on Astronomy and Astrophysics (2020), *arXiv:1907.12526.*
[2] Connolly, A. & Vieregg, A. Radio Detection of High Energy Neutrinos. Neutrino Astronomy - Current Status, Future Prospects (2016), *arxiv:1607.08232.*
[3] Davis, L. Handbook of Genetic Algorithms. Van Nostrand Reinhold. (2016).
[4] Rolla, J. Evolving Antennas for Ultra-High Energy Neutrino Detection. ICRC Conference Proceedings, (2019), arXiv:2005.07772.
[5] Allison, P. First Constraints on the Ultra-High Energy Neutrino Flux from a Prototype Station of the Askaryan Radio Array, (2014), *arXiv:1404.5285*
[6] Harris, C. and Lewtin, L. and Trevithick, J. Optimization of Antennas in the Askaryan Radio Array Using Genetic Algorithms. Senior Thesis, California Polytechnic State University, Adviser: S. Wissel. 2018