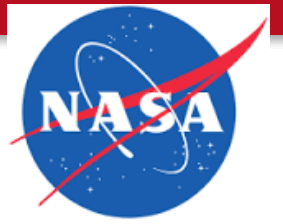
THE OHIO STATE UNIVERSITY

The GENETIS Project: optimizing detector designs for science outcomes

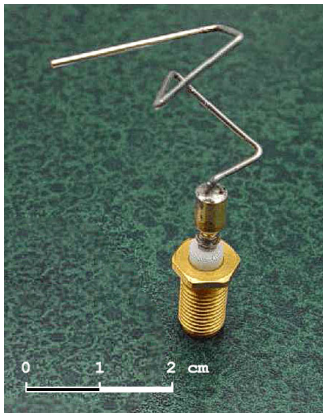
Amy Connolly for the GENETIS Collaboration

July 25, 2023



GENETIS (Genetically Evolving NEuTrIno teleScopes

- Goal: optimize detector designs with science outcomes as measure of fitness
- Started 2017 based at OSU, student-driven
- Started with improving antenna designs for neutrino telescopes using genetic algorithms (GAs), not limited to antennas, neutrinos, or GAs
- Inspired by *previous* NASA GA-designed antenna:

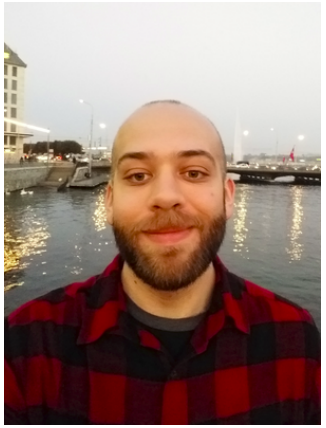


Antenna designed in 2006 for NASA ST5 spacecraft using evolutionary algorithms

Student-driven

Julie Rolla
JPL Scientist

Alex Machtay
grad student



Bryan Reynolds
OSU PhD

Dennis Calderon-Madera
Bridge student

Ben Sipe
gap

Jacob Weiler
undergrad

Dylan Wells
undergrad

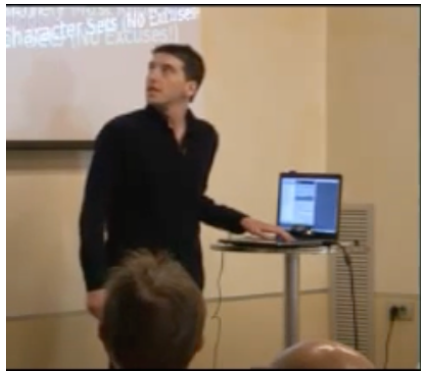
Ryan Debolt
gap

Jack Tillman,
undergrad

Lydon Bindall
undergrad

Senior Collaborators

Ezio Melotti
Software Engineer



Prof. Amy Connolly
Neutrino astrophysics
PI and GENETIS co-founder

Kai Staats
Univ. of Arizona
Biosphere 2
(GENETIS co-founder)

Prof. Wolfgang Banzhaf, Endowed Chair in Genetic Programming at Michigan State University

Prof. Chi-Chih Chen
Electrical and Computer Engineering
ElectroScience Lab

Remcom, OSU's Center for Design and Manufacturing Excellence (CDME) enthusiastic partners

Christian Miki
Scientific Instrument
Physicist/Engineer
University of Hawaii

Why Genetic Algorithms (GAs)

- Genetic algorithms part of evolutionary computation, use strategies inspired by biological evolution
- Choice inspired by NASA antenna design
- Behavior is transparent
- Optimizer has many parameters to explore
- Biological connection: intuitive, and fun
- Other algorithms, e.g., swarm, neural networks, explored in the future

Parameters of the GA

- Parent selection
  - Roulette
  - Tournament
- Genetic operators
  - Mutation
  - Crossover
  - Reproduction
  - Injection

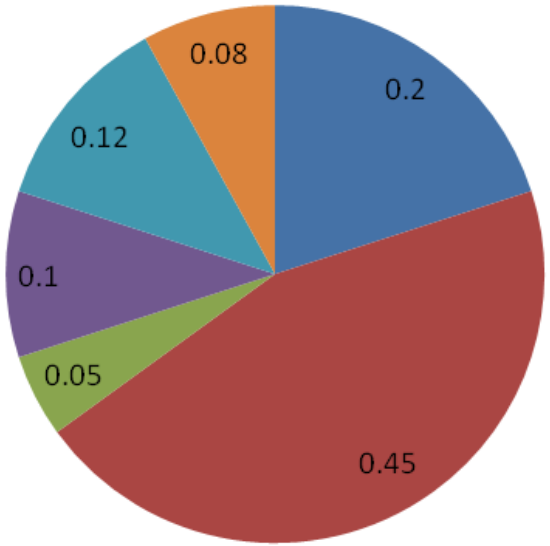
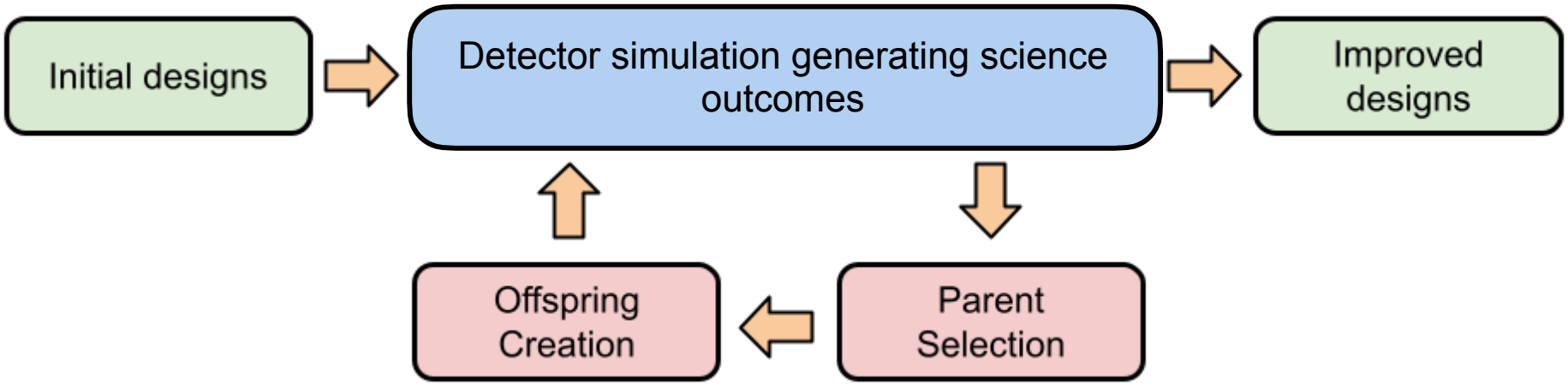


Illustration of roulette selection
towardsdatascience.com

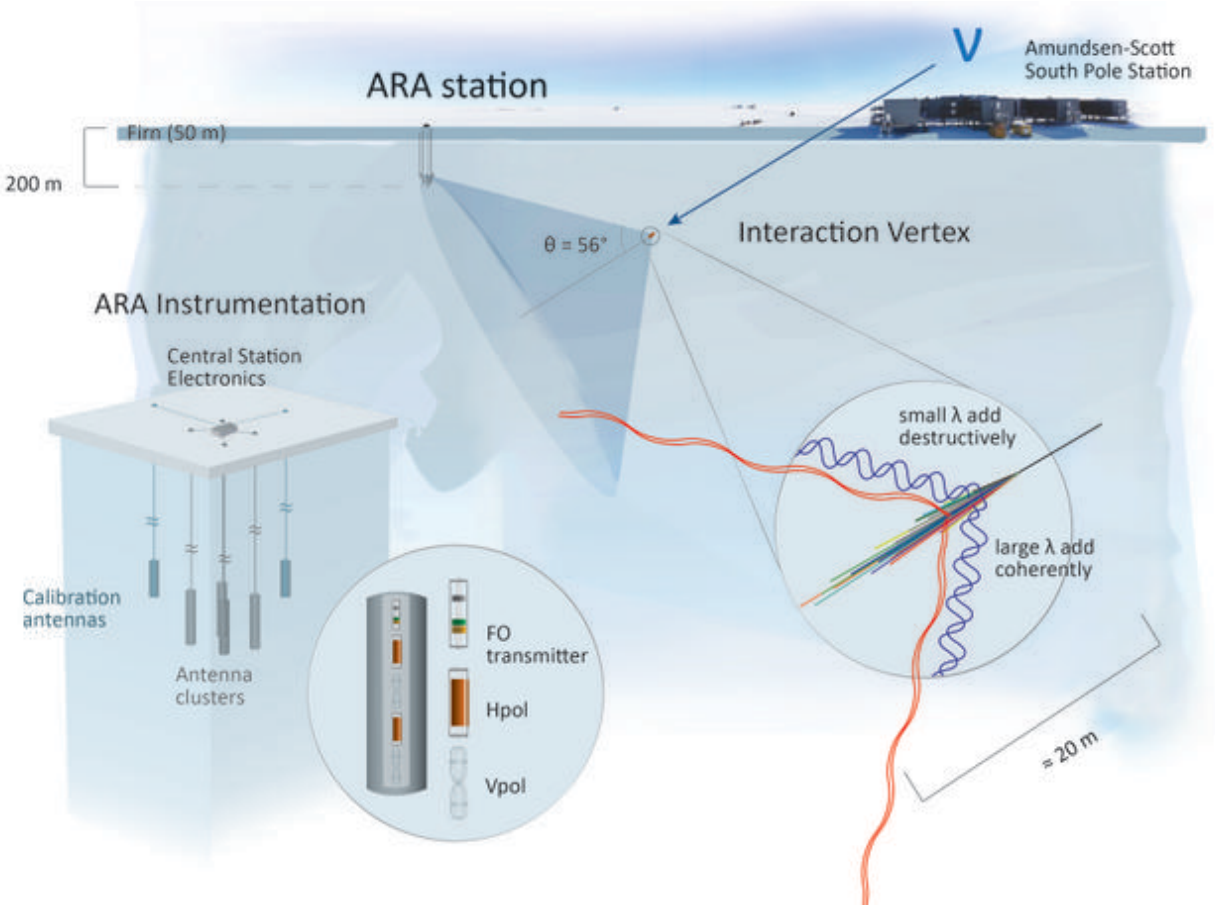
GENETIS main loop (any project)

The Loop:



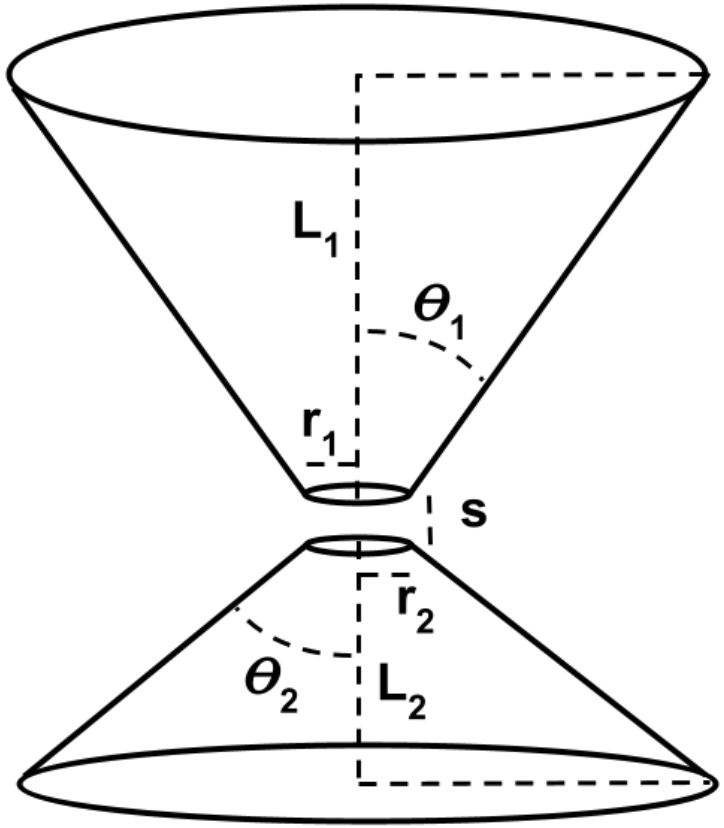
First major sub-project

- Antennas for ultra-high energy (>10^{18} eV) neutrino detection in ice
- Test case: Askaryan Radio Array (ARA) at South Pole



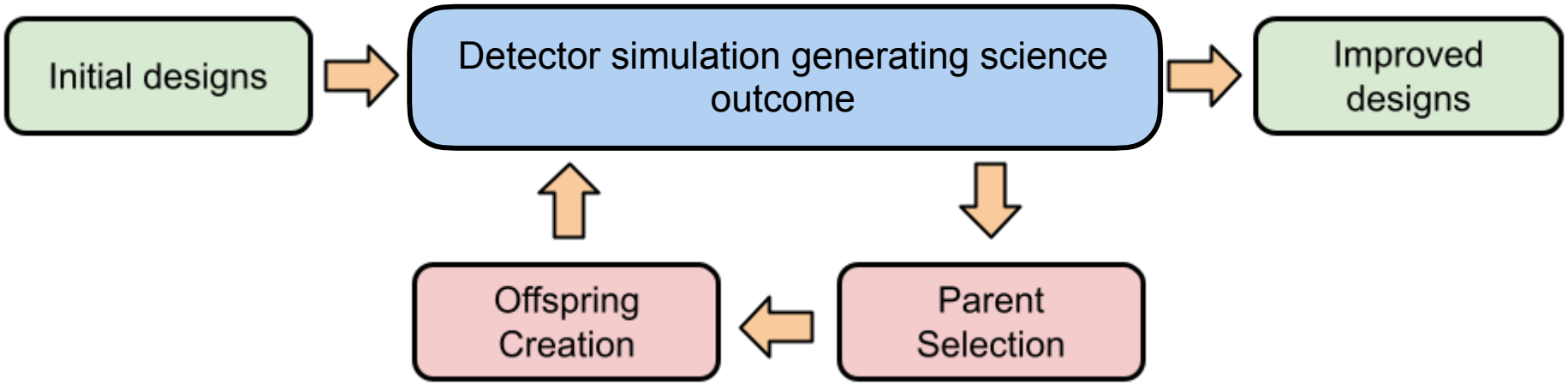
First major sub-project

- Begin with a bicone-like design
- Fitness score: neutrinos detected by ARA using the evolved "individual"
- "genes" - lengths, inner radii, opening angles



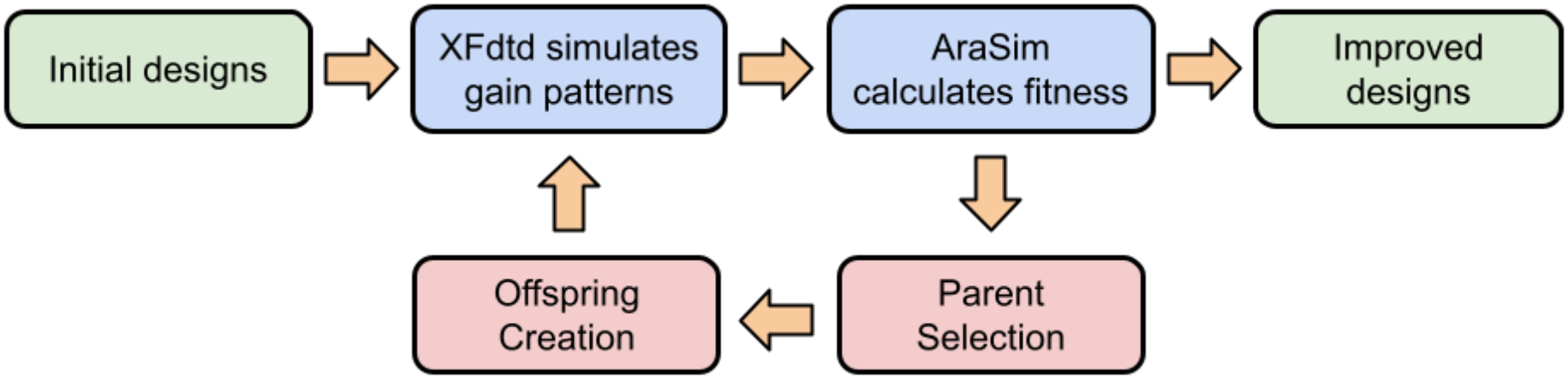
GENETIS main loop (any project)

The Loop:

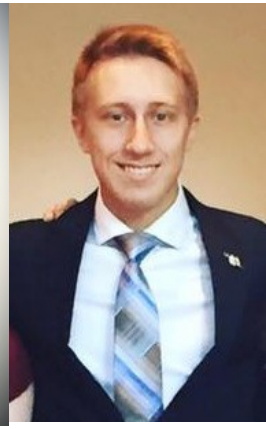


GENETIS main loop: radio ν project

- Automated - no human intervention in the loop itself



- Interfaces stages running many different types of code including GUIs

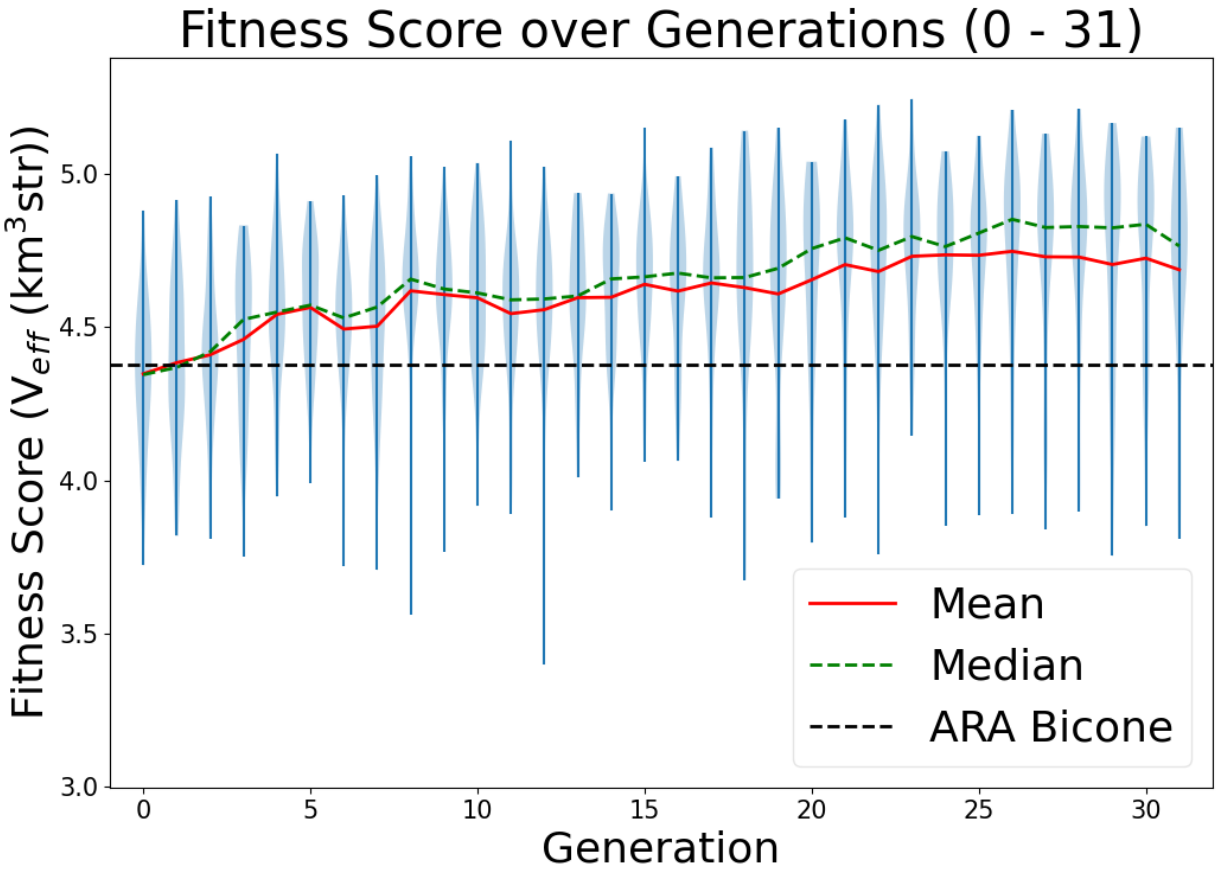


Julie Rolla Alex Machtay

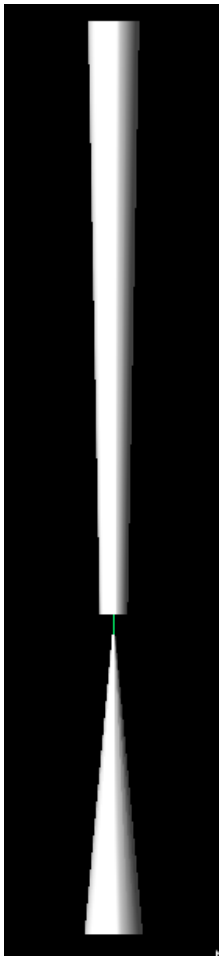
Antenna optimization

- First results: 10% improvement over ARA bicones

Neutrinos at 10^{18} eV



GENETIS antenna optimization



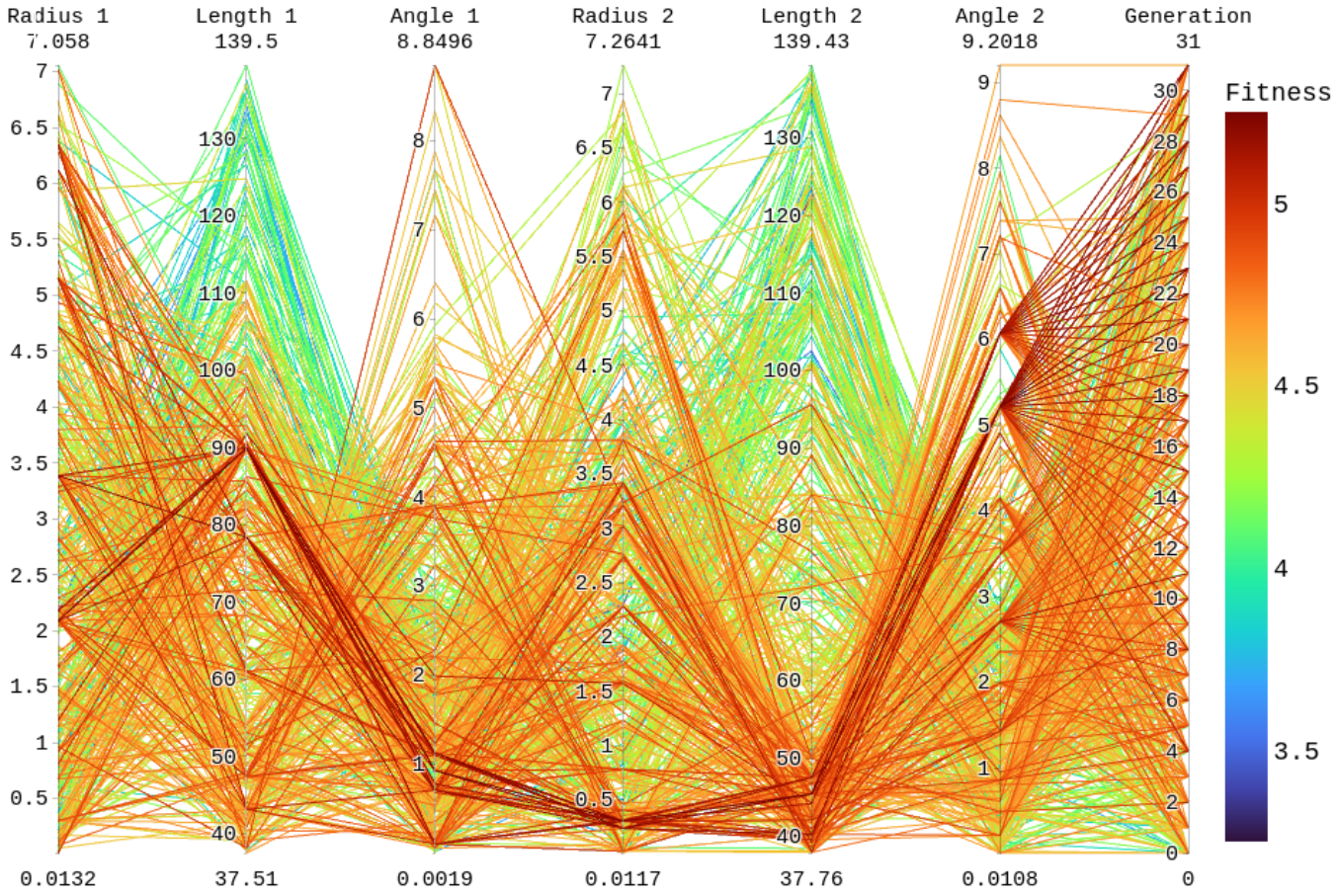
Most fit antenna, first run

arXiv:2112.03246
Submitted to PRD, final stages of review

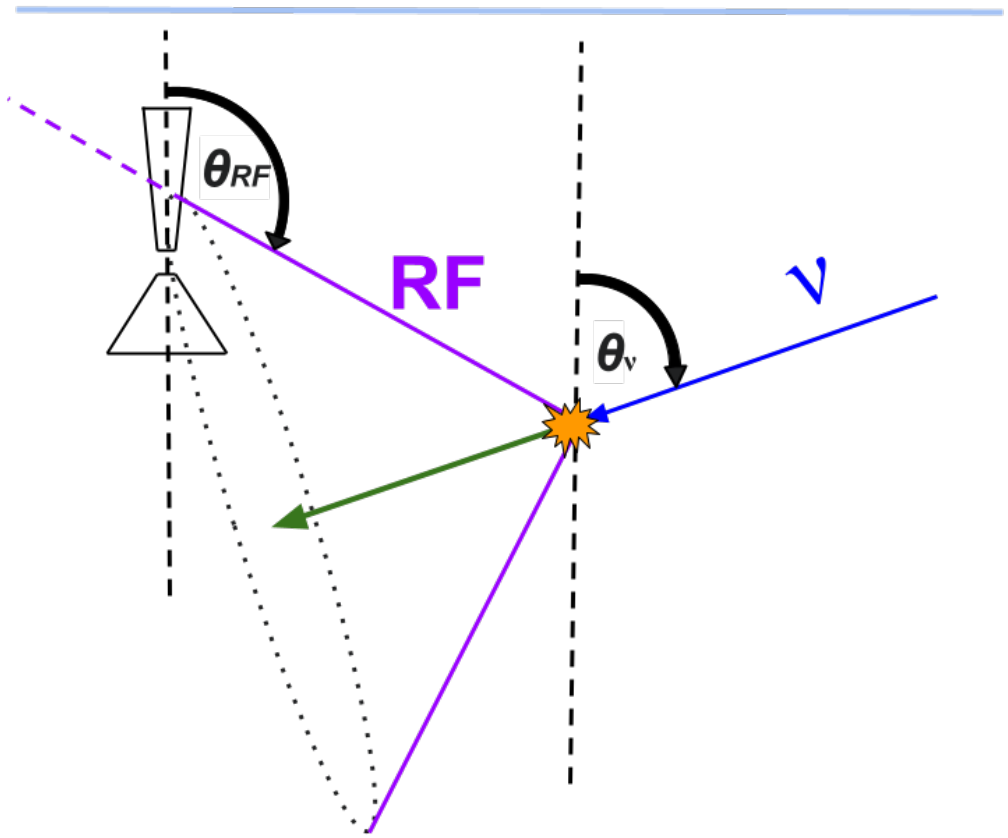
Ben Sipe

Rainbow plot

- Fittest have common design parameters

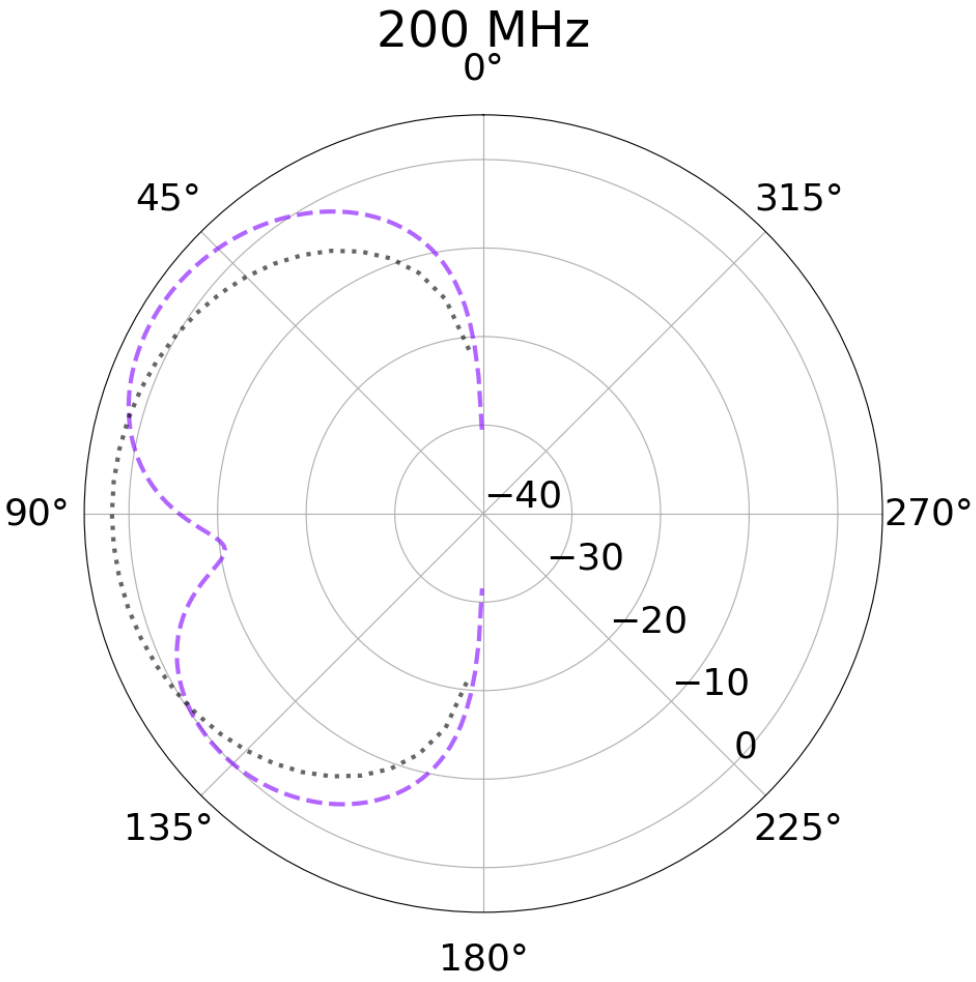


How they detect more neutrinos



Dennis Calderon-Madera

How they detect more neutrinos



Dennis Calderon-Madera

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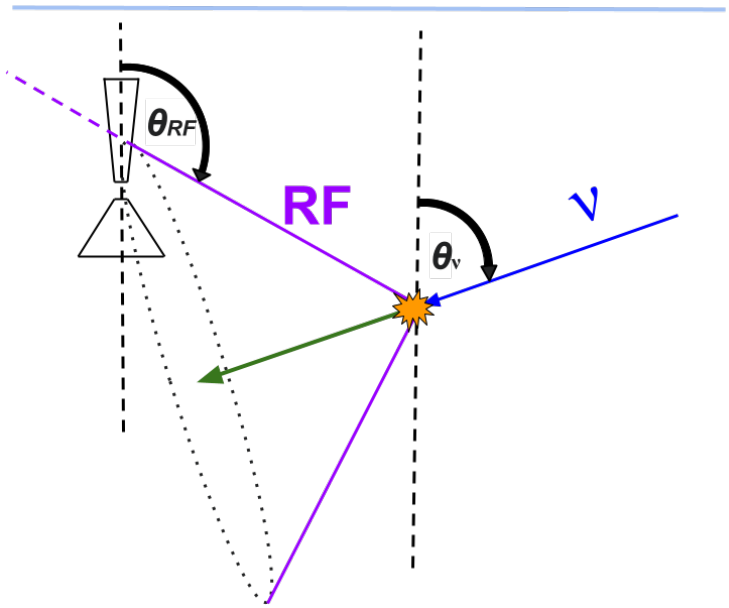
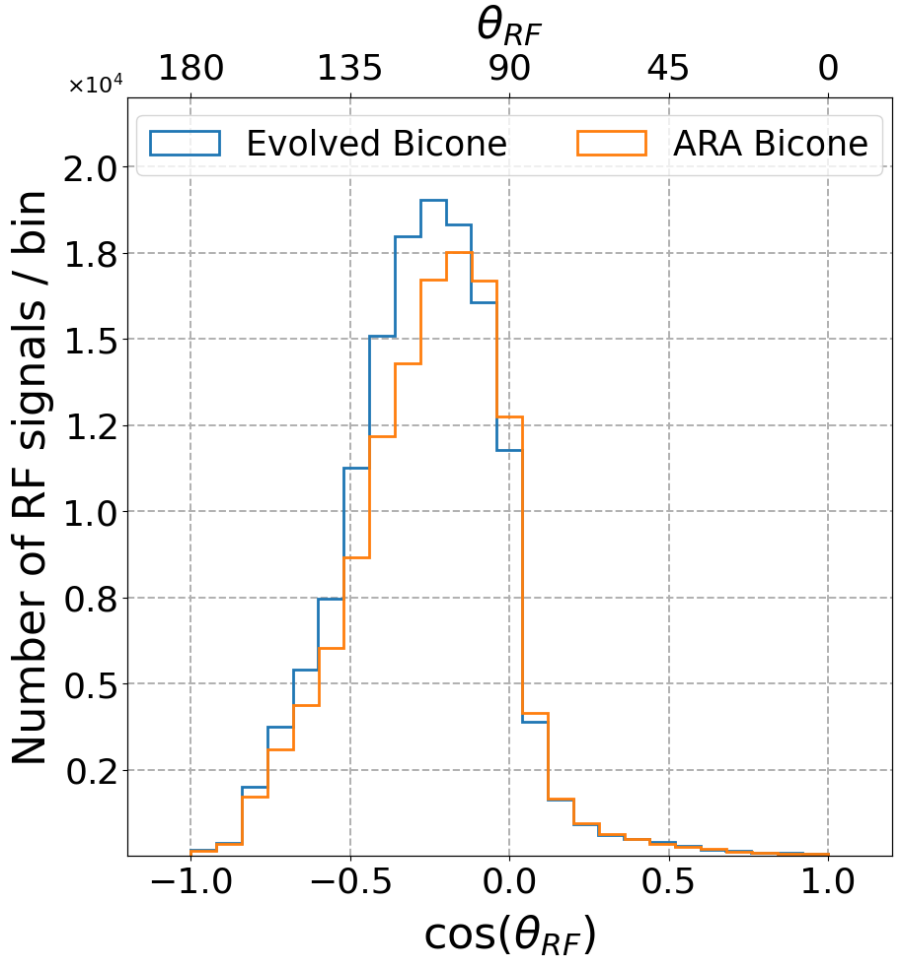
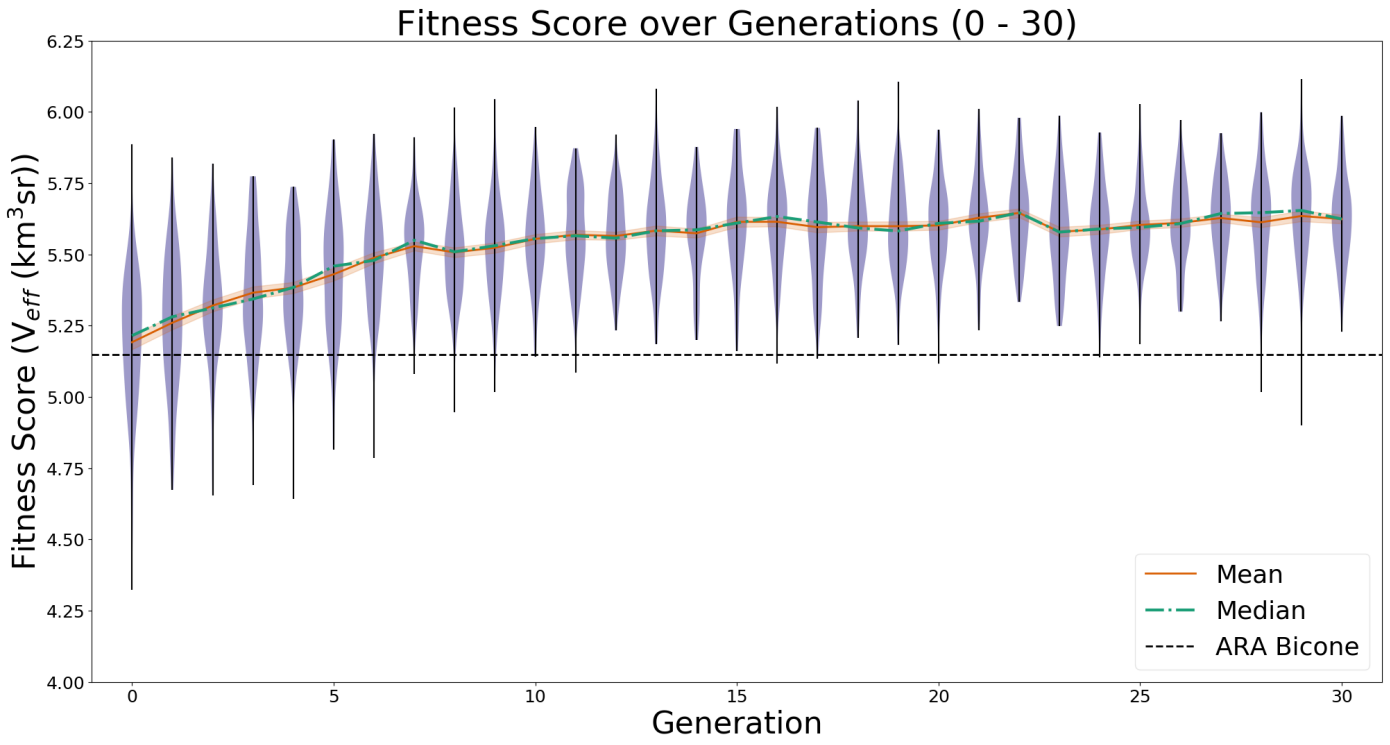


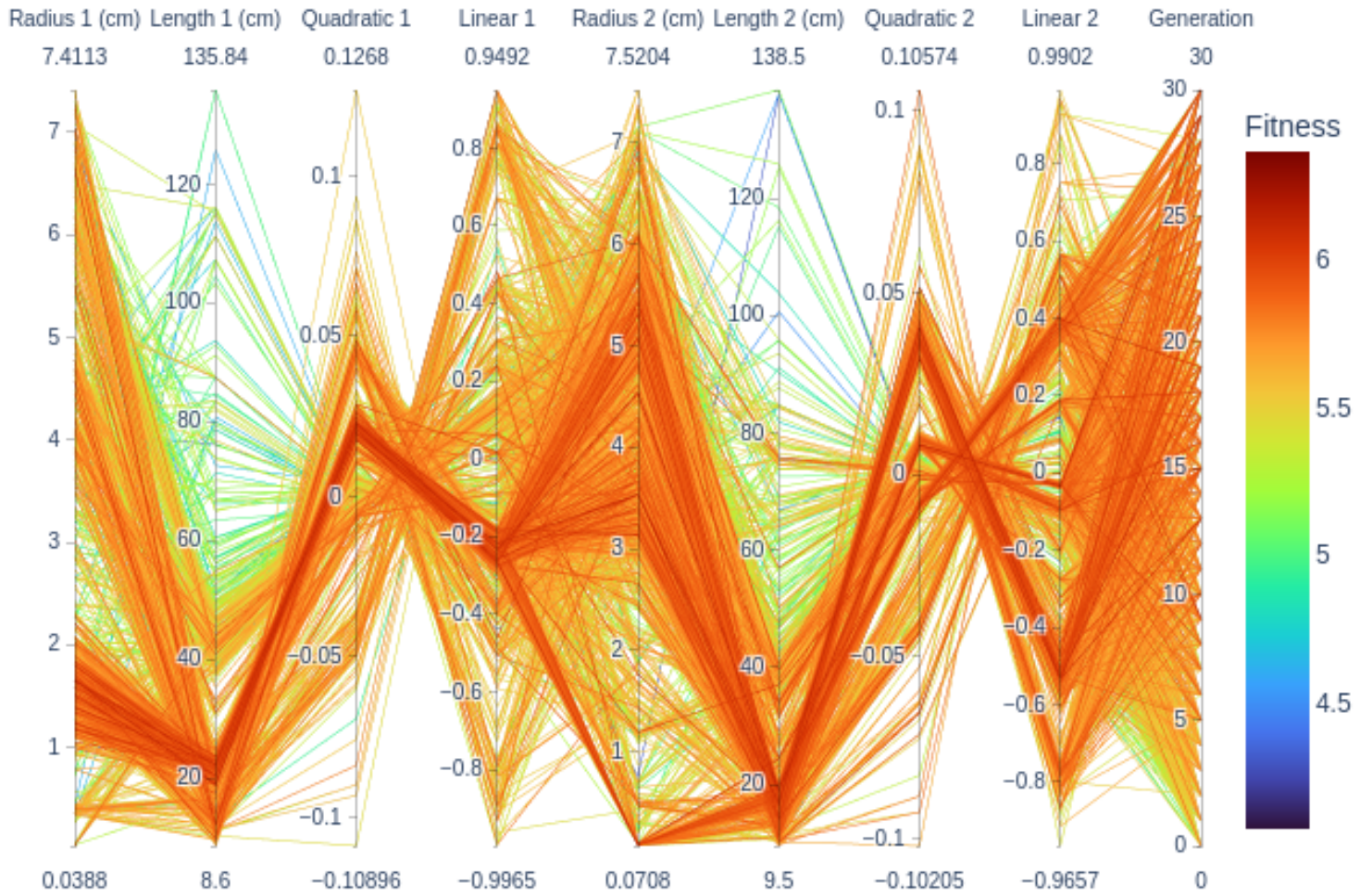


Bicone evolution - “crazy” sides

- Sides curved - linear and quadratic terms



Bicone evolution - “crazy” sides

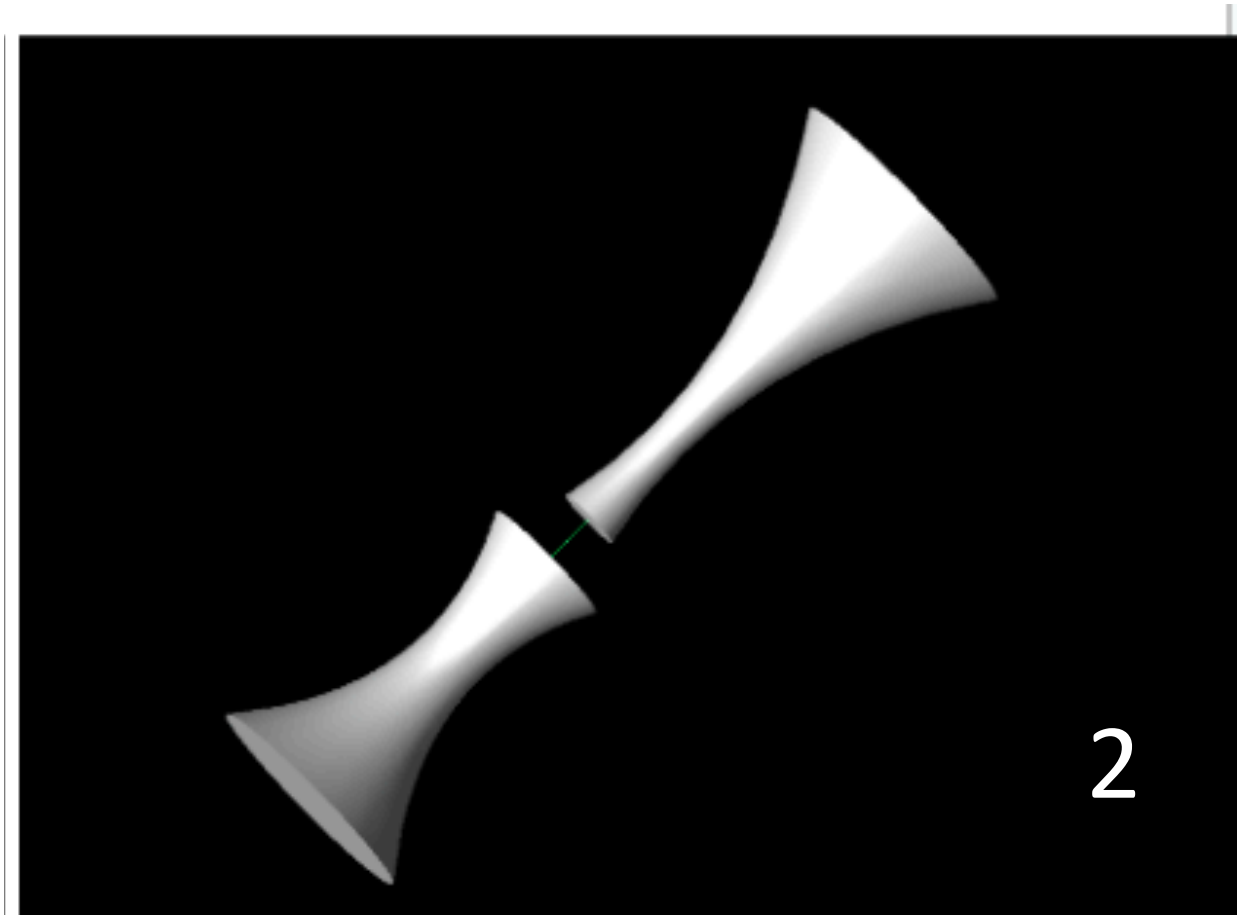


Bicone evolution - “crazy” sides

Longer side ~19 cm

Building best antenna (Gen 29, Ind 87) with OSU’s CDME

Bicone evolution - “crazy” sides



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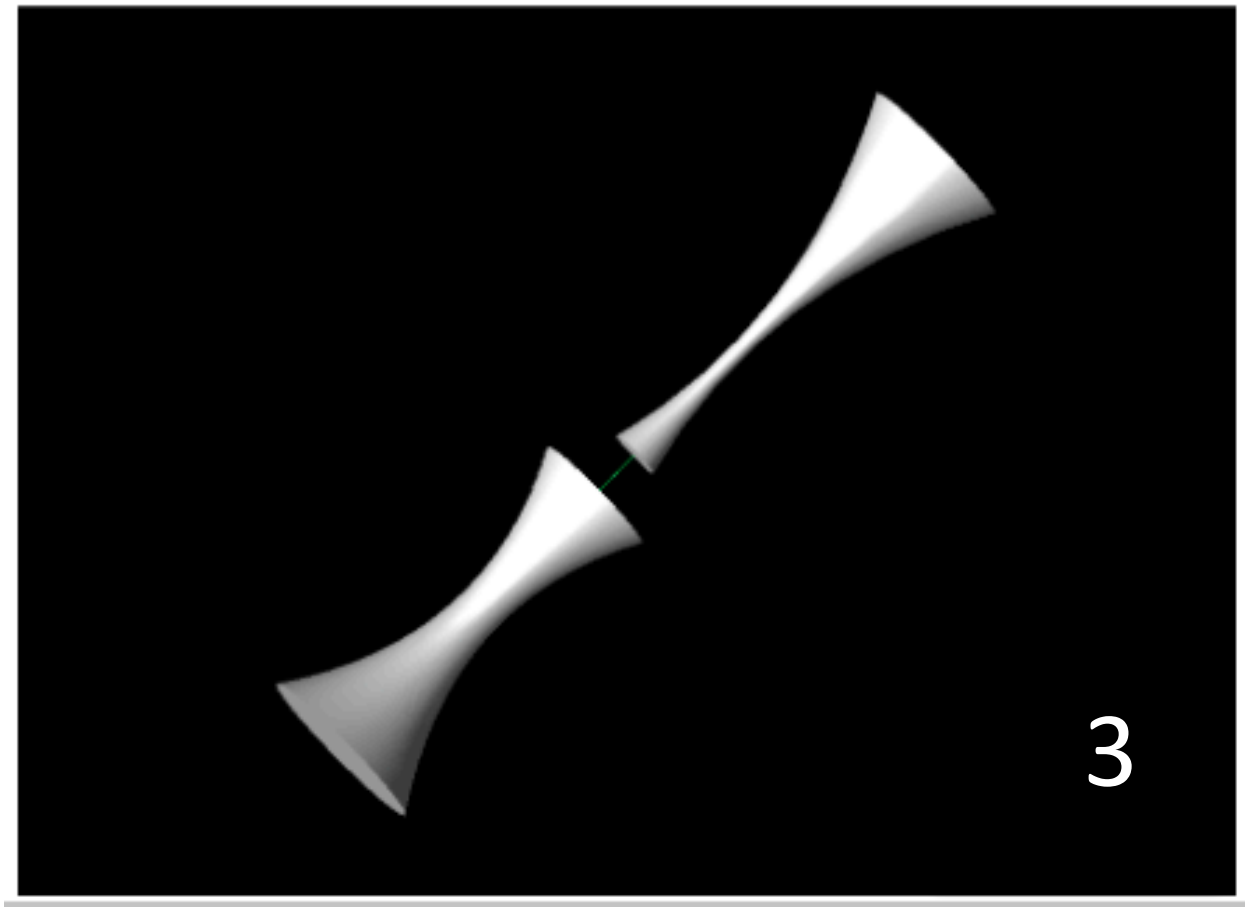

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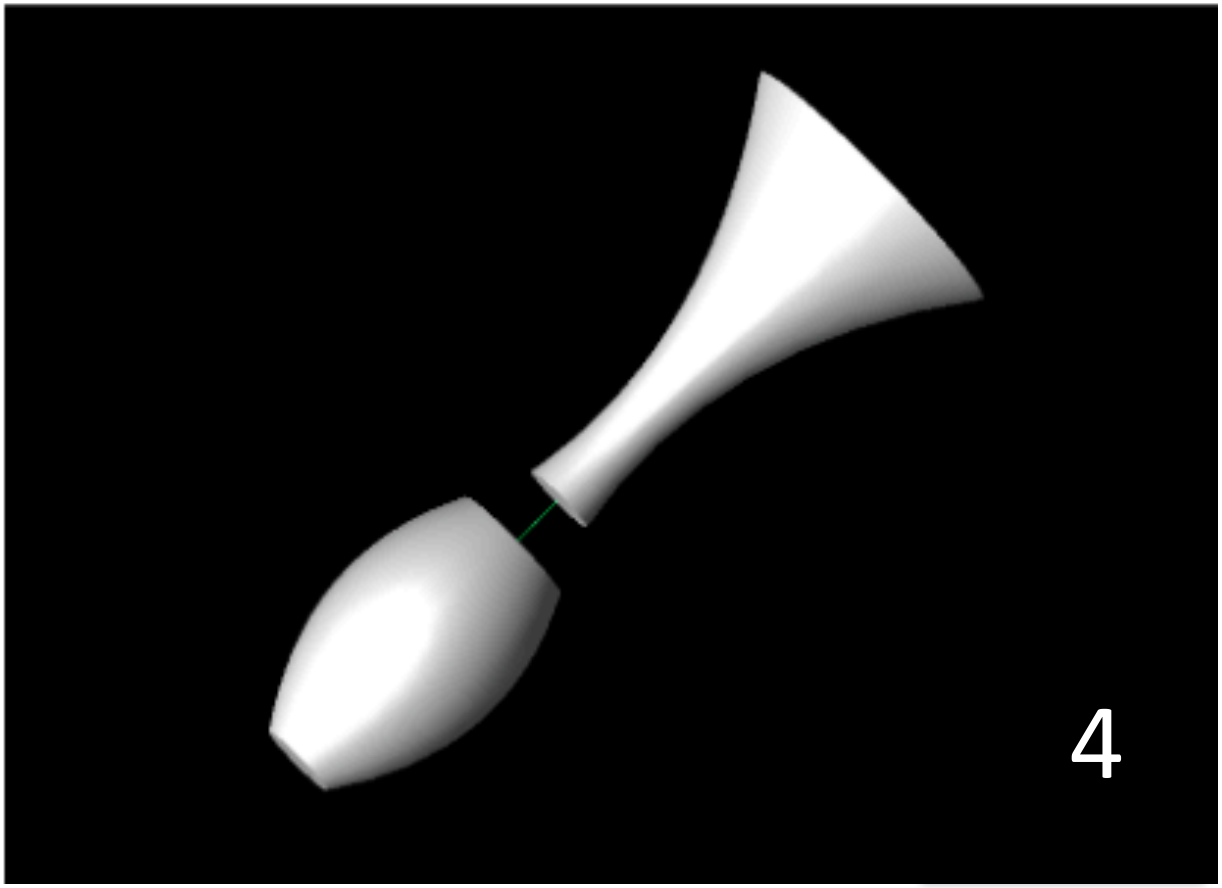

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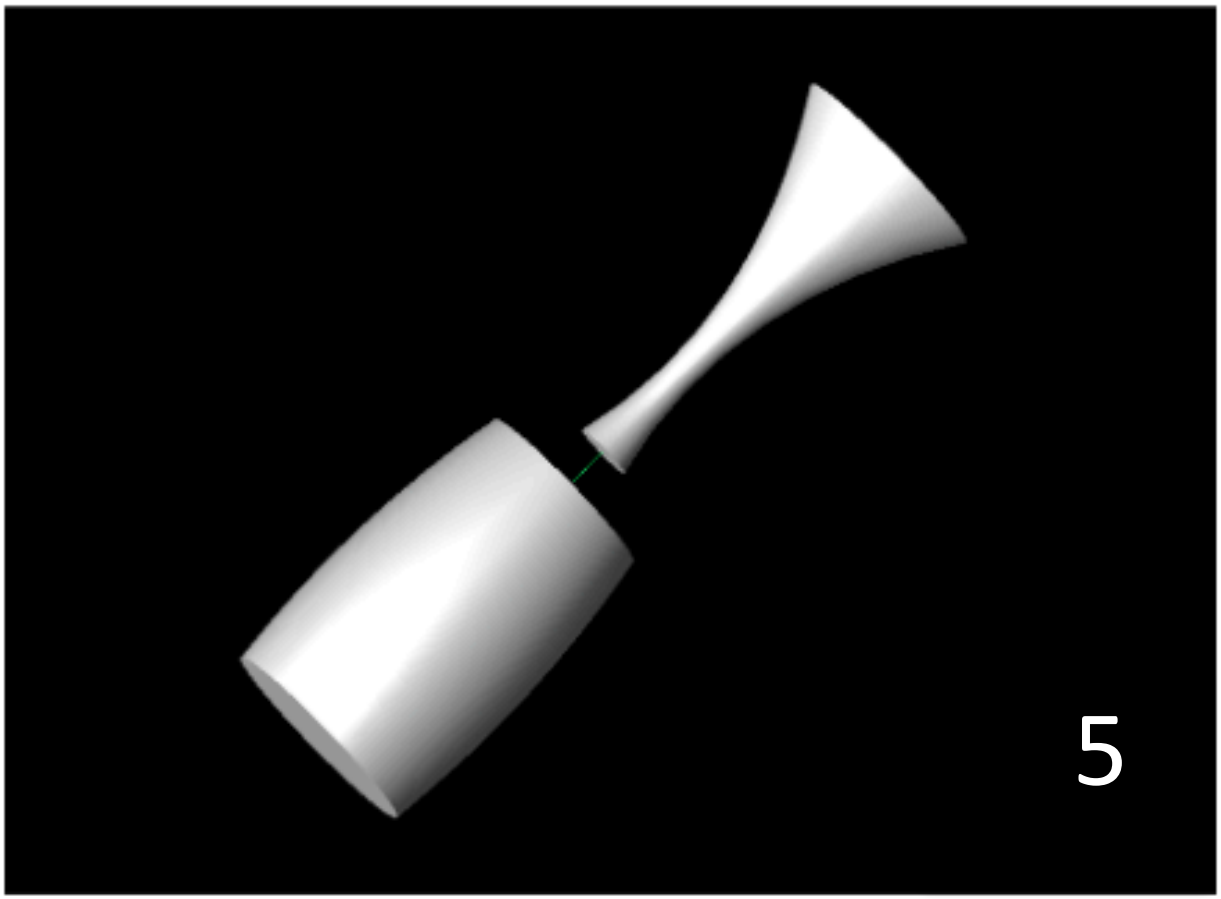
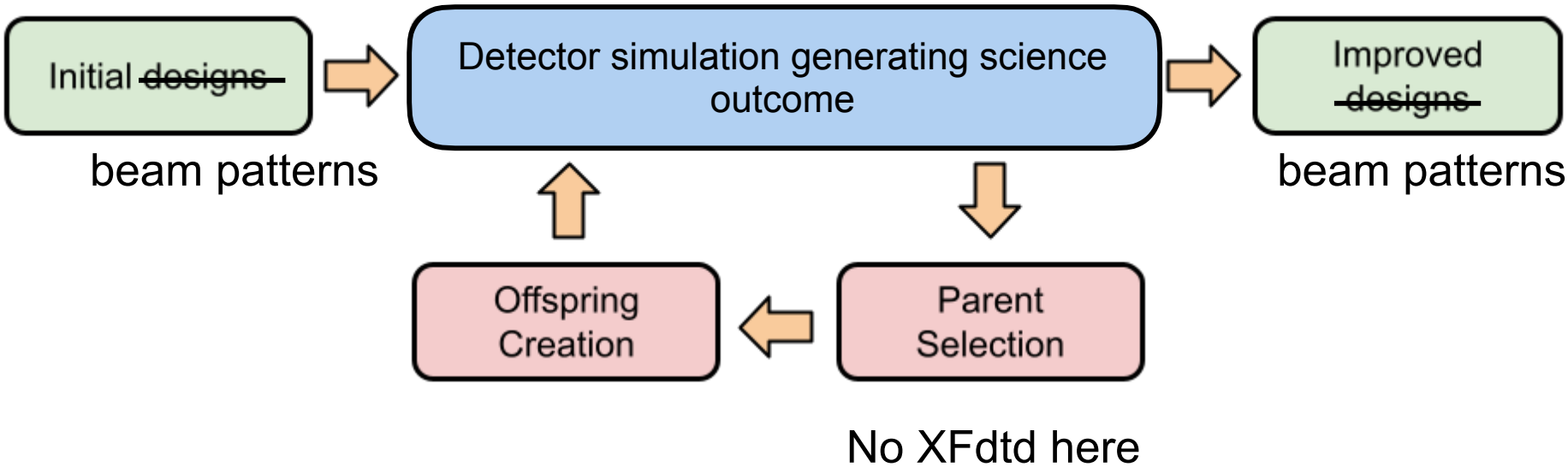


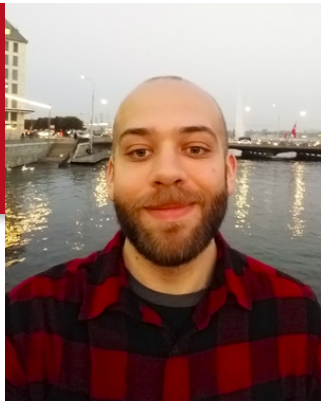
Next steps for in-ice

- Evolve HPol antennas too
- Evolve antenna parameters, array geometries together
- Important because ice birefringence causes signal polarizations to rotate
  - Phys.Rev.D 105 (2022) 12, 123012
  - NSF funding for this (Connolly PI)

Evolving beam patterns

- Evolve antenna beam pattern (gains vs. direction)
  - nevermind how we'd build the antenna

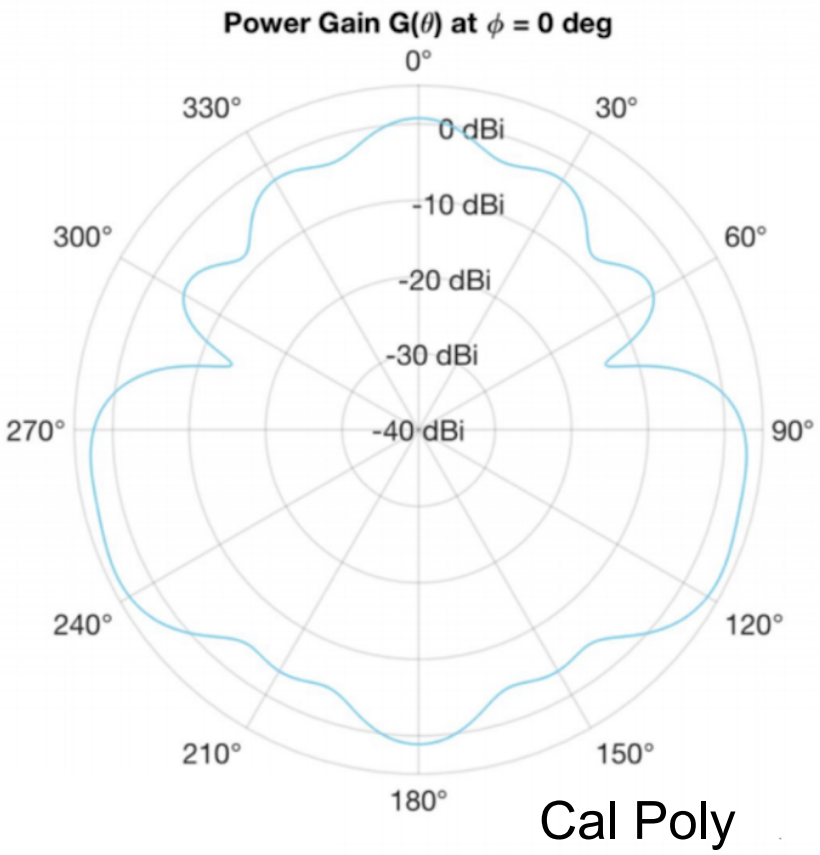




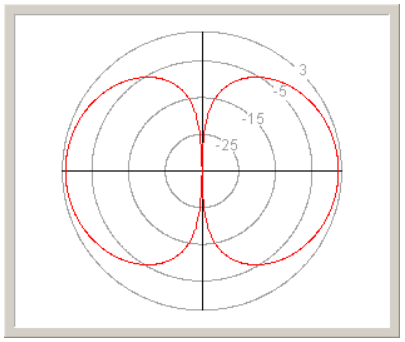
Bryan Reynolds

Evolving beam patterns

- Assess room for improvement



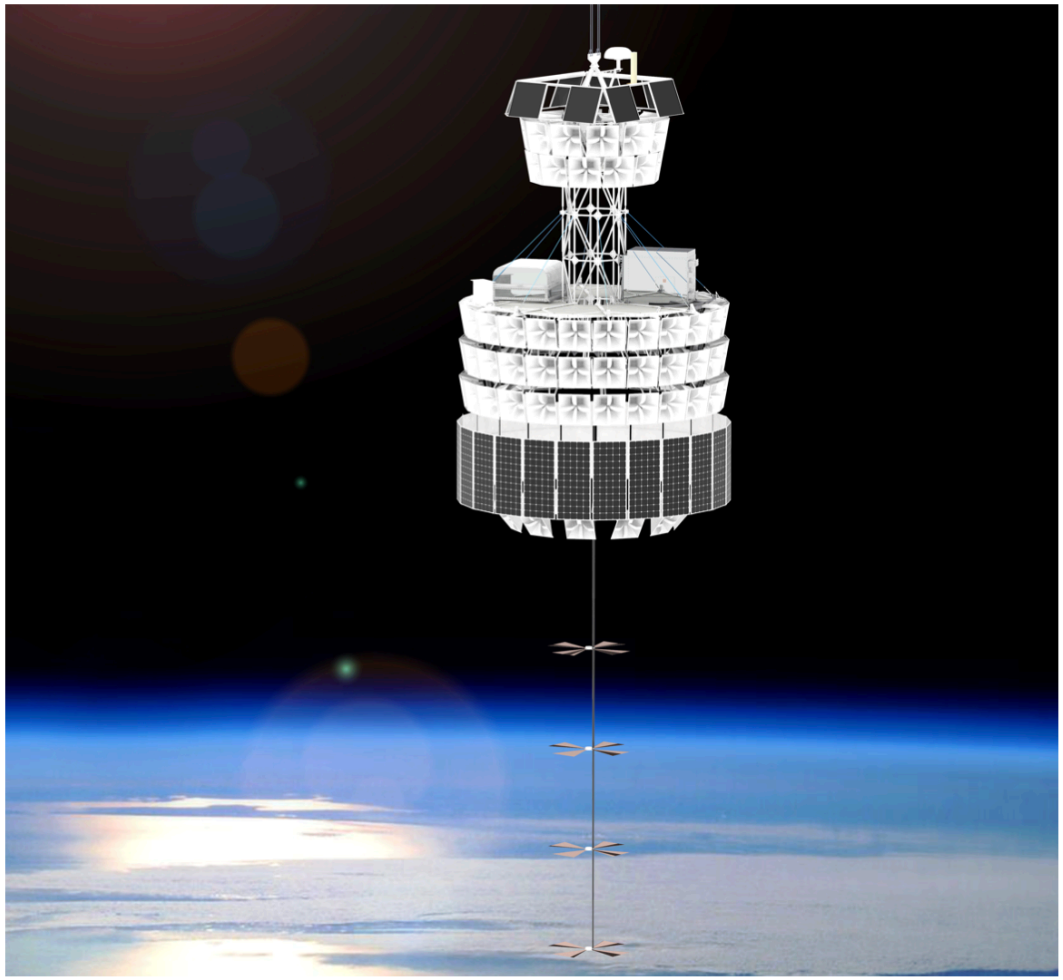
Cal Poly



Typical bicone pattern (up-down symmetric)

- Could assess ideal response for any detector

PUEO



PUEO
JINST 16 (2021) 08, 08

GENETIS PUEO loop

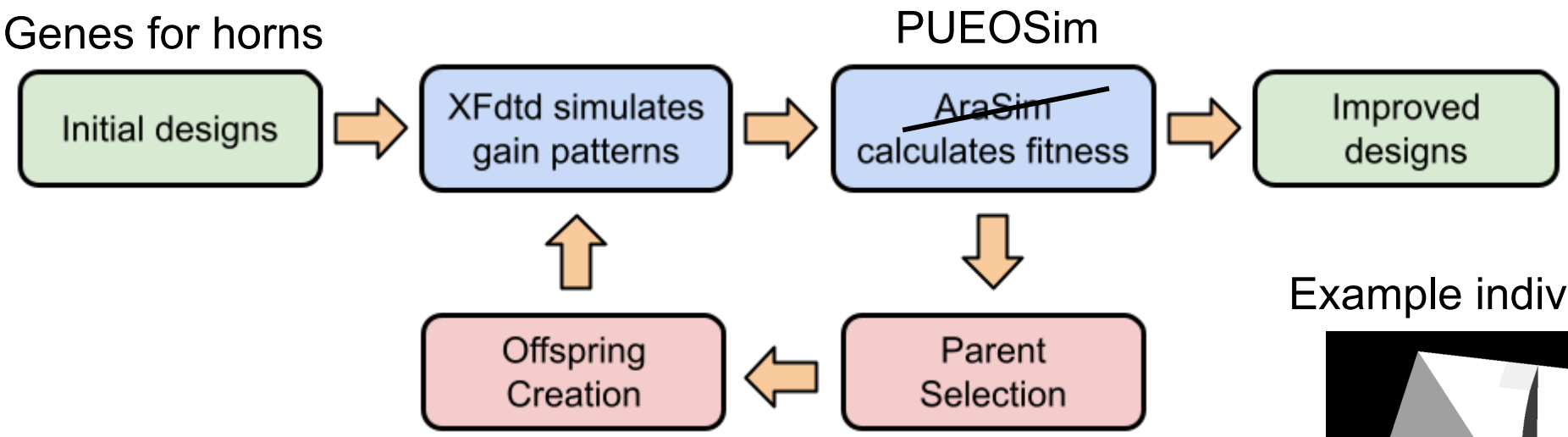

Julie Rolla


Alex Machtay

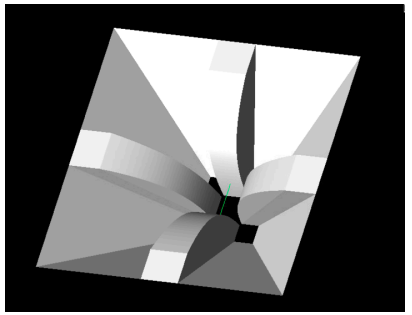

Dylan Wells


Ryan Debolt

The Loop:



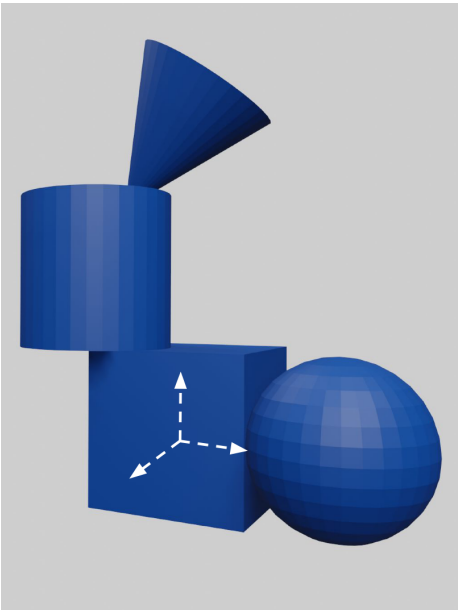
Example individual



Julie Rolla
JPL Scientist

Nebulous sub-project

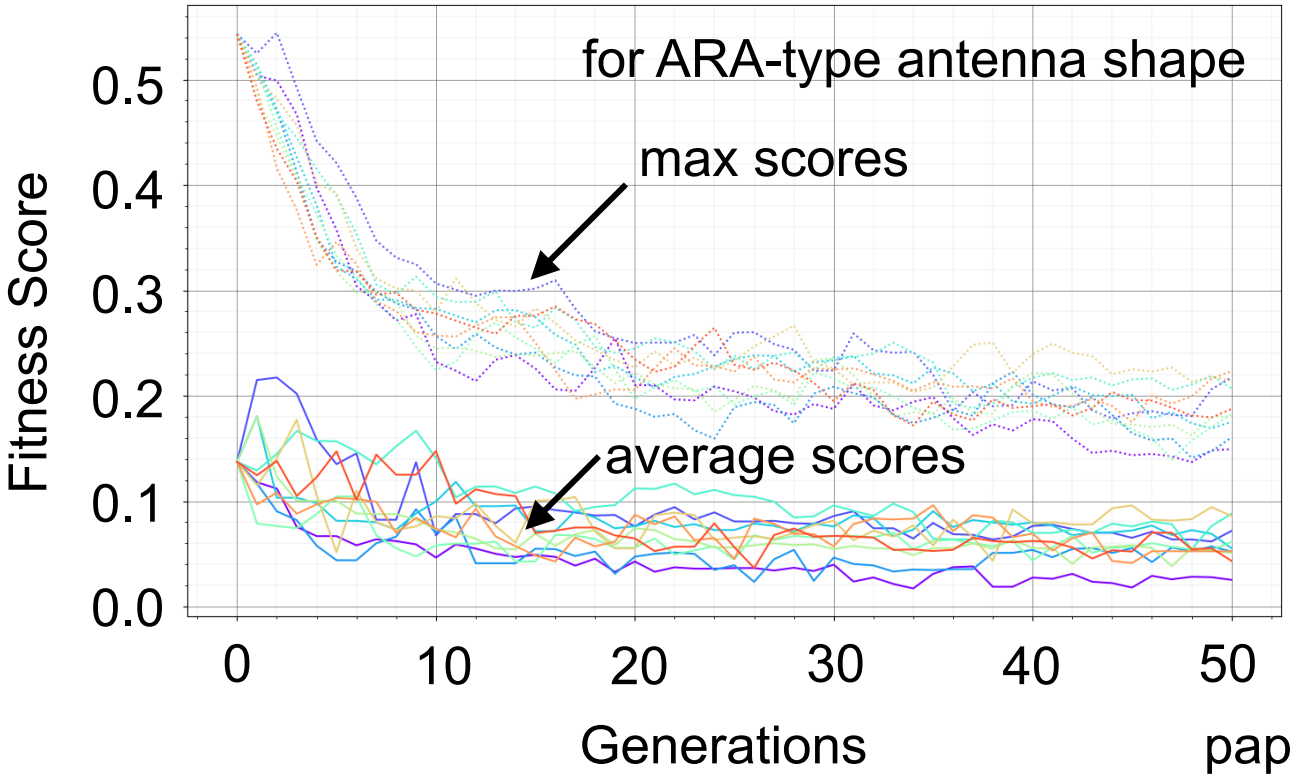
- trl0 funding from JPL (comms, tracking, radar)
- No preconceived idea (bicone, horn)
- Start from scratch, build from LEGOs (genetic algorithm → genetic program)
- First step: evolve to a target shape
- Initial results to be published in JPL's Interplanetary Network (IPN)



Example individual with four primitive shapes

Optimizing the parameters of GA itself

- Use toy program that is faster than main loop
  - Fitness: likeness to predetermined shape
  - Test frequency of use of selection methods



Ryan Debolt

paper in progress

Summary

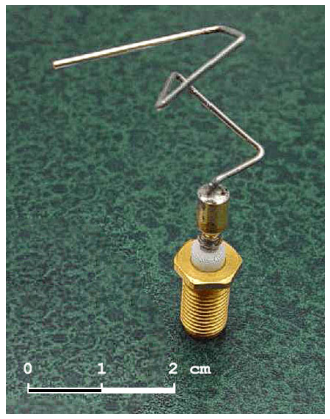
- Developed first genetic algorithm designing antennas for science outcome
- Generalizable beyond antennas
- Generalizing to different projects
- Training ground, launching pad for students: problem solving, working in groups
- Welcome new collaborators - send a student to our zoom working meetings!

Backup slides

GENETIS (Genetically Evolving NEuTrIno teleScopes)

- GENETIS project started 2017 after OSU genetic algorithms (GAs) workshop
  - Inspired by *previous* NASA GA-designed antenna:

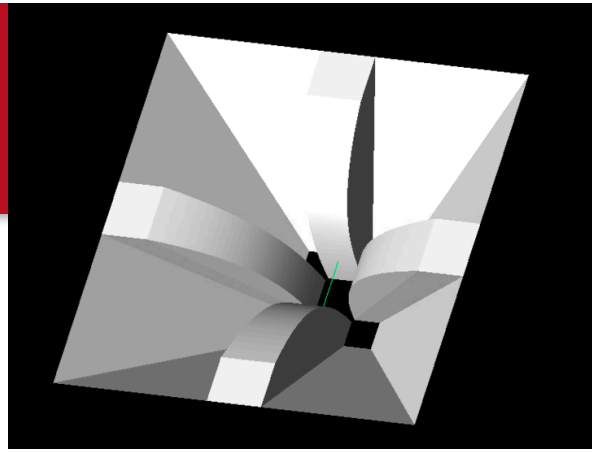
Antenna designed in 2006 for NASA ST5 spacecraft using evolutionary algorithms



GENETIS Mini-Collaboration Meeting April APS 2018

GENETIS:

- Student (largely undergraduate) -driven
- Fitness measure: *science outcome*



GENETIS PUEO loop genes

- **Antenna Walls**
  - S: half side length of bottom of wall
    m: slope of outer wall
    H: max height of the outer wall
- Current Constraints:
  - S < 50cm
    H < 50cm
    m = 1

- **Antenna Ridges**
  - x_0, y_0, z_0: initial points of inner part of the ridge
    x_f, y_f, z_f: final points of inner part of the ridge
    β: curvature of the ridge

Binary gene for walls or not