The quest for validated simulations

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Radio Workshop @ 

Limitations: no data..yet

- Neutrino flux ($E > 10^{17}$ eV) is very small: $< 1\,\mathrm{km}^{-2}\mathrm{y}^{-1}$
- Limited also by ignorance of UHE world: neutrino-nucleon cross section, for example.
- Field is young. Other areas have a plethora of MC softwares.

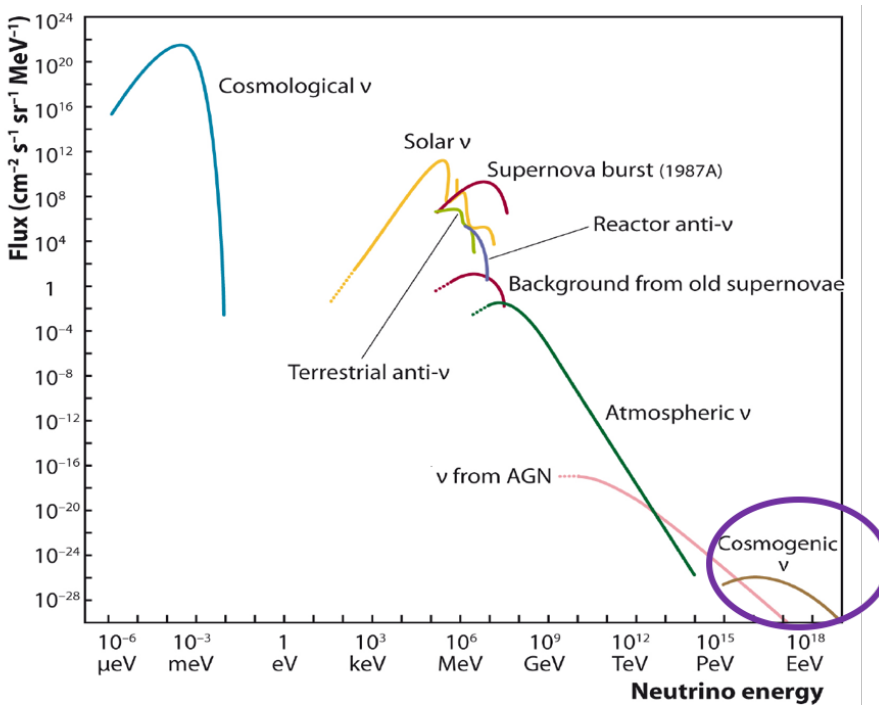

Figure: Katz *et al., 2011*

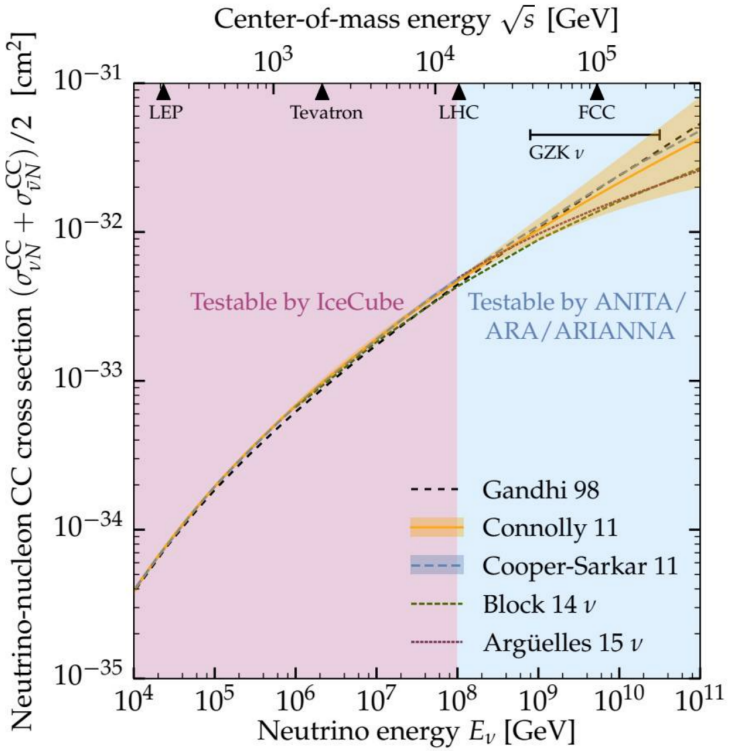

Figure: Bustamante & Connolly, 2017

Can we really validate our simulations?

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???

While we wait to detect a real neutrino...

Non-physics (technical validation)

- The canonical debugging.
  - Correct filenames, outputs
  - precision
- State-of-the-art packages: numpy, astropy, etc.
- Conventions

Physics

- Make sure that we're using validated data/physics:
  - Cross section values
  - Ice models
  - Askaryan models
- Check against new/legacy code
- Add features to make simulation more realistic.

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Structure of the MC simulations

- Event generation:
  - Neutrino flux→birth ($E, \vec{p}$, flavor)
  - propagation
  - interaction
  - shower development
- Signal generation: Askaryan emission
- Signal propagation:
  - attenuation length
  - optical effects: diffraction, birefringence, etc.
- Detector simulation
  - Antenna effective height
  - Electric chain

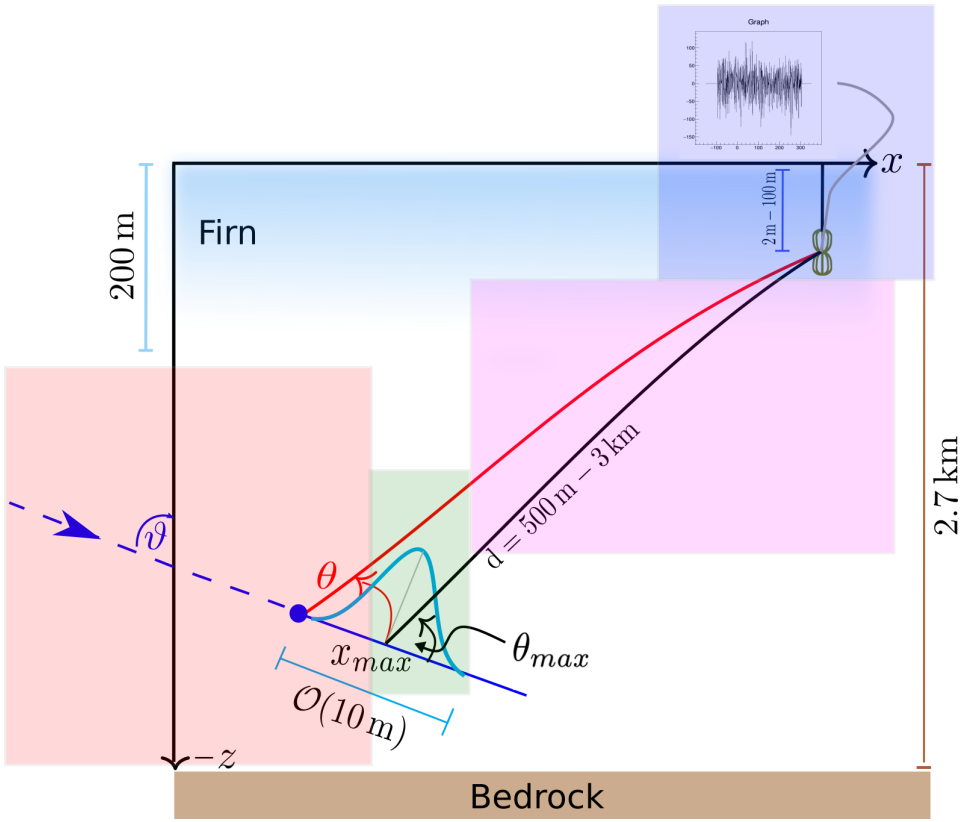


Figure: Modified from NuRadioMC paper.

Exercise in autumn, 2018: comparison

- Comparison of AraSim, PyREx and NuRadioMC:
- Simulated same geometry, configuration, parameters.
  - 4 surface LPDAs
  - 4 surface vpol bicones
  - 12 in-ice vpol bicones

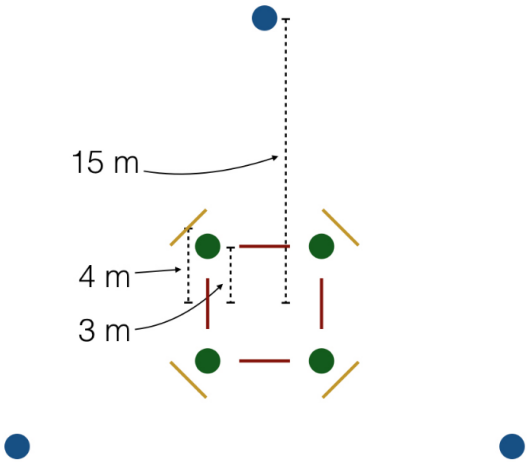


Figure: Top view

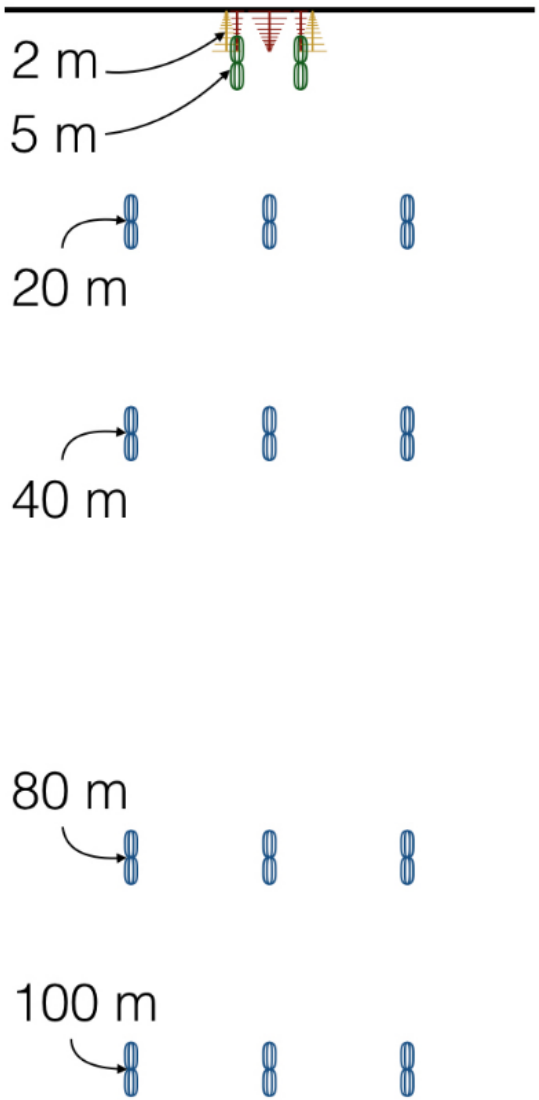


Figure: Side view

Comparison of antenna models

- Models from different simulation softwares: XFDTD and WIPL-D.
- Systematics were there, but tried to minimize discrepancies
- Realized that we were using different quantities for h_{eff} (gain vs. realized gain) and fixed it.

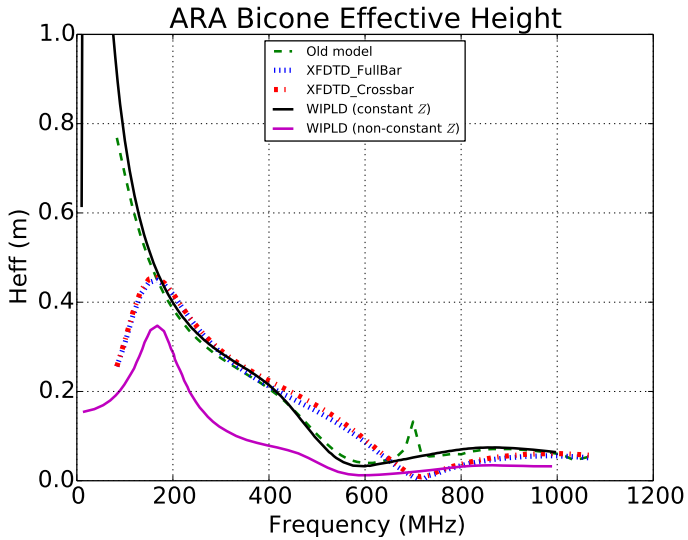
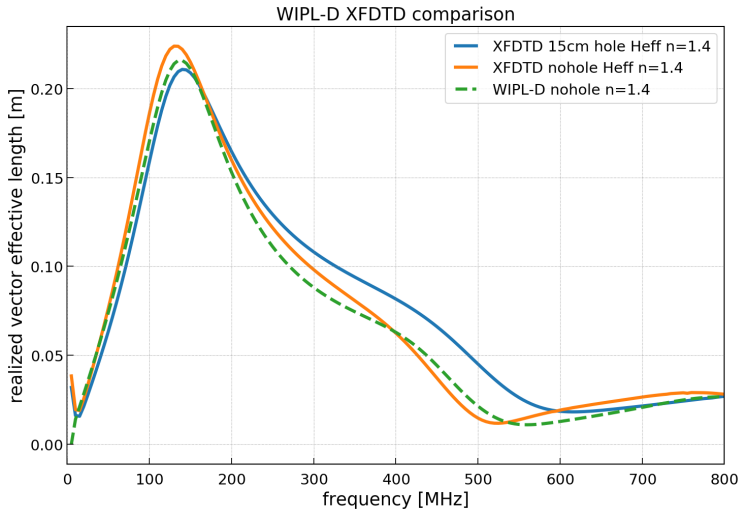


Figure: Before



Comparison of signal properties and propagation

- Simulated identical simple configuration under same condition/parameters.
- Event by event comparison of same triggered events:
  - signal amplitude at different locations.
  - launch and receiving angle
  - signal polarization
- Results:
  - All 3 sims agree on ray tracing and signal polarization.
  - NuRadioMC and Pyrex agree on signal time traces and spectra up to a factor of 2 if using same Askaryan models.

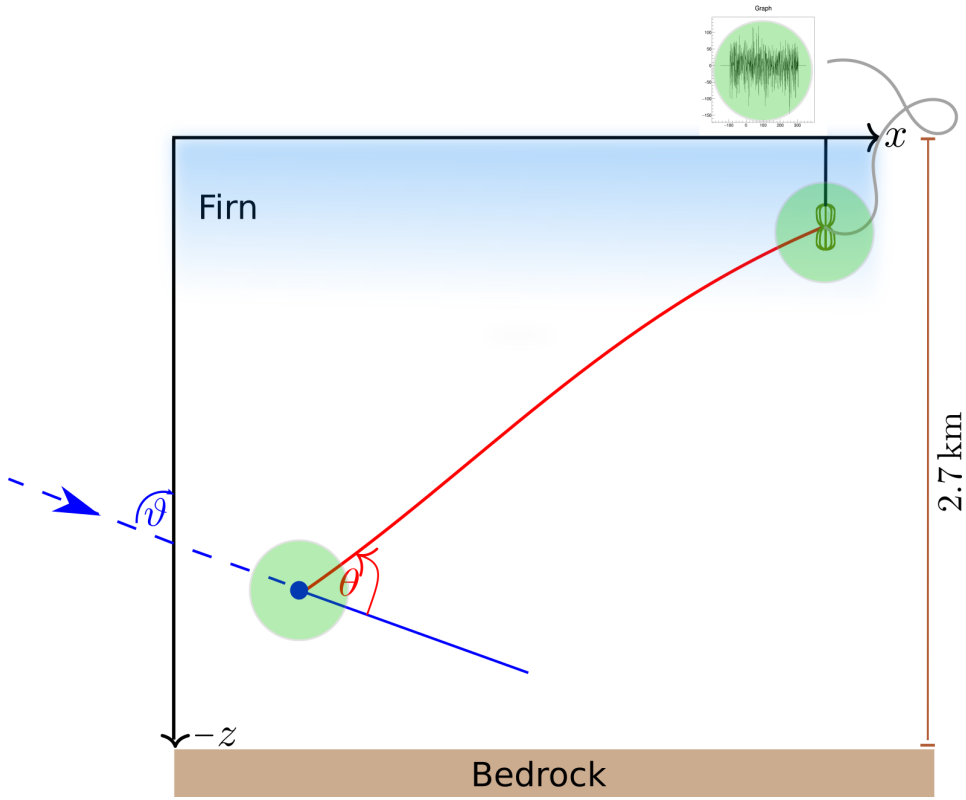
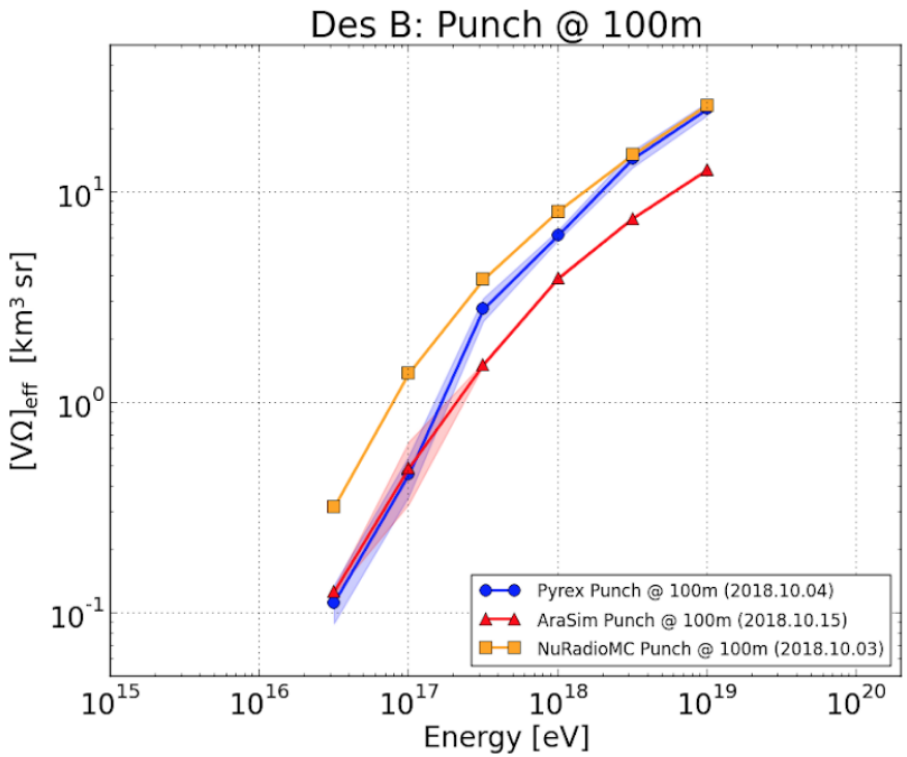


Figure: In green: locations where the signal amplitude was checked

Comparison of effective volumes

- The final step was a comparison of effective volumes for the same configuration.
- Disagreement of simulations. PyREx discrepancy is energy dependent.
- Differences are maybe caused by Askaryan modules.



What can we add to make simulations more realistic?

Noise profile

- Thermal noise samples were taken from ARA data.
- Noise was characterized by fitting Rayleigh distributions to spectrum profiles for different frequencies.
- Next step: include real thresholds from stations.

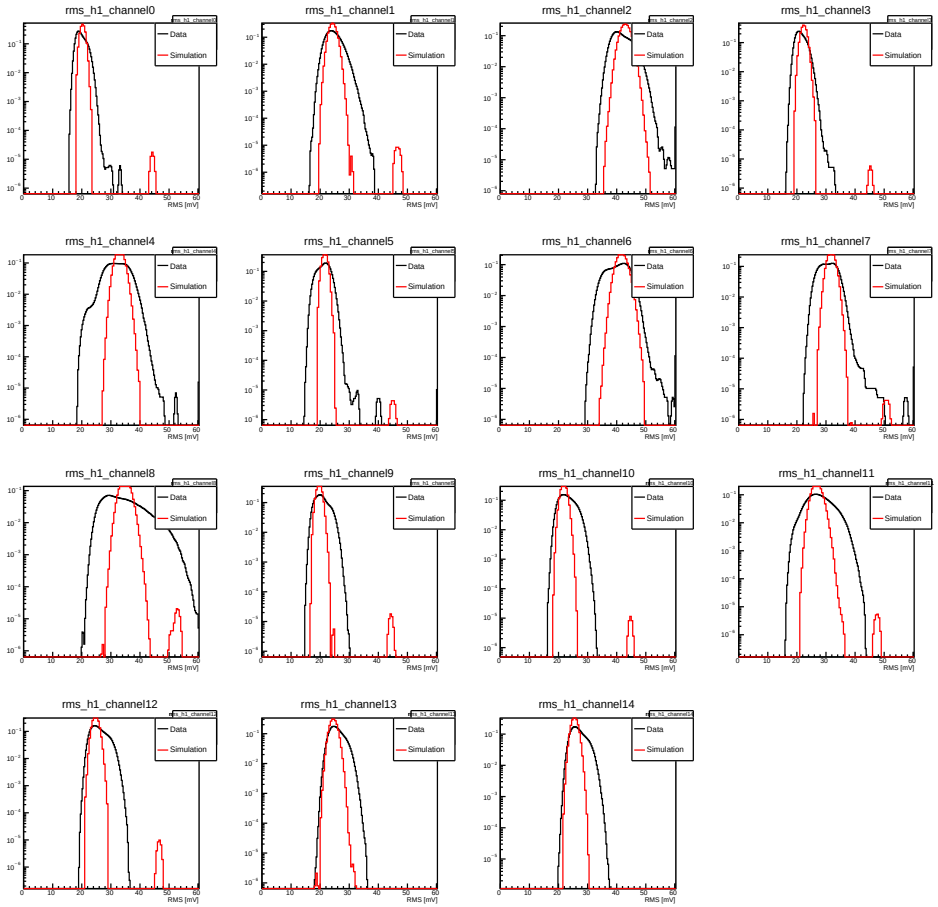


Figure: Comparison of RMS of data and simulation. Differences are due to anthropogenic noise and CW signals.

What else?

- Add calibration pulsers to the simulation?
- Tau regeneration integration?
- Your contriubution...

Conclusions & discussion (and Jorge's naive questions)

- Validation of simulations is an interesting problem.
- Let's talk about having standard/default models and quantities for the detectors:
  - Ice models
  - Antenna models
  - Askaryan models
- Would be a great exercise to estimate systematic errors from different models.
- Making simulations more realistic, e.g., to include features such as real noise, LPM effect, etc. helps with accuracy.
- Comparing simulations, either old or new, between them is important.
- Need modular simulations so the comparison is easier.
- We can benefit of synergy between simulators.

Backup Slides

Detailed simulation paremeters for comparison

- Antenna front-ends consist of a 2nd-order high-pass filter at 80 MHz and 10th-order low-pass filter at 500 MHz
- Simulate without noise, but for triggers assume a 300 K noise temperature (9.3 mV noise sigma)
- High/low triggers on Vpols and LPDAs with a window of 5 ns.
- Phased array simulated by a proxy antenna at the center with a 2σ absolute voltage threshold