Simulating the radio emission with NuRadioMC

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Emmy Noether-Programm
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DESY.

Simulations for RNO and Gen2

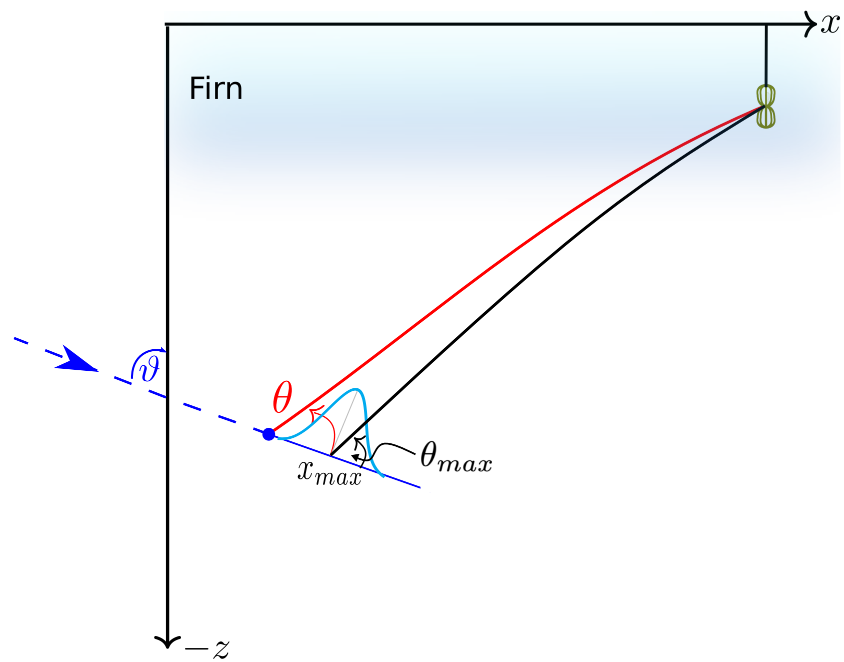
Emphasis on the radio component

- Effective areas of radio detectors are very sensitive to
  - Detector layout (depth, antenna types)
  - Emission models (LPM effect, phase content of radio pulse)
  - Trigger details (phased array, system response)
- Following ARA and ARIANNA: total revamp of Monte Carlos (see also talk from Ben later, PyRex and NuRadioMC)
  - Extensive community-wide discussion and implementation (“InIceMC working group”)
  - Most plots here from NuRadioMC paper (Glaser, Garcia, Nelles et al. in prep)
- Simulations for Gen2:
  - Handling of optical and radio simulations independently in first iteration
  - Prediction of potential coincidences in second iteration

What do simulations entail?

Building on the knowledge from air showers

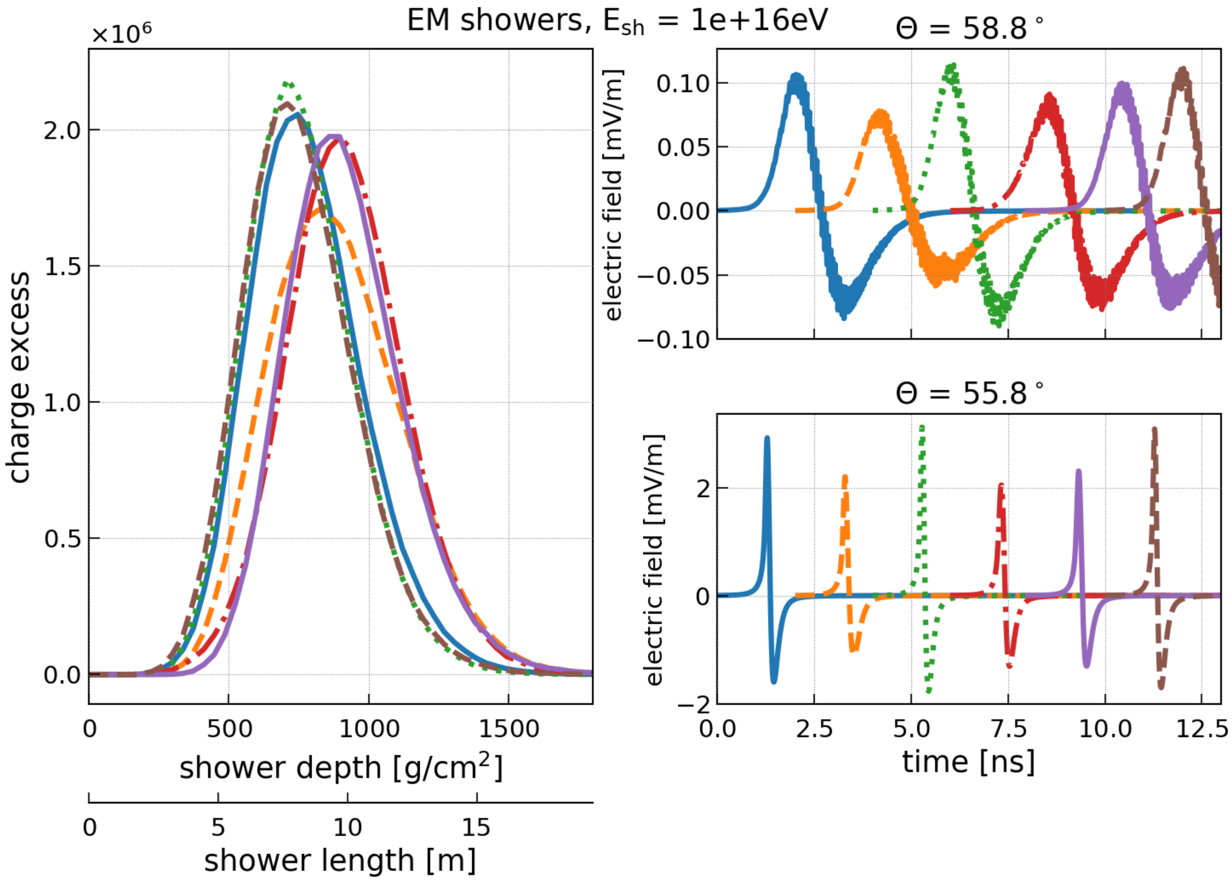
- Cosmic ray radio simulations (CoREAS, ZHAireS) have been confirmed to < 5% accuracy
- See Auger, LOFAR, Tunka, SLAC, …
- Radio emission of neutrinos same emission mechanisms, but (old) simulation codes not as sophisticated
- Additional complexities for neutrinos:
  - Signal propagation
  - LPM effect
  - Tau neutrinos (double cascade)
  - Tools need to be flexible enough to optimize a detector design



shower is always viewed from a distance

What do simulations entail?

Simulation of neutrino signals



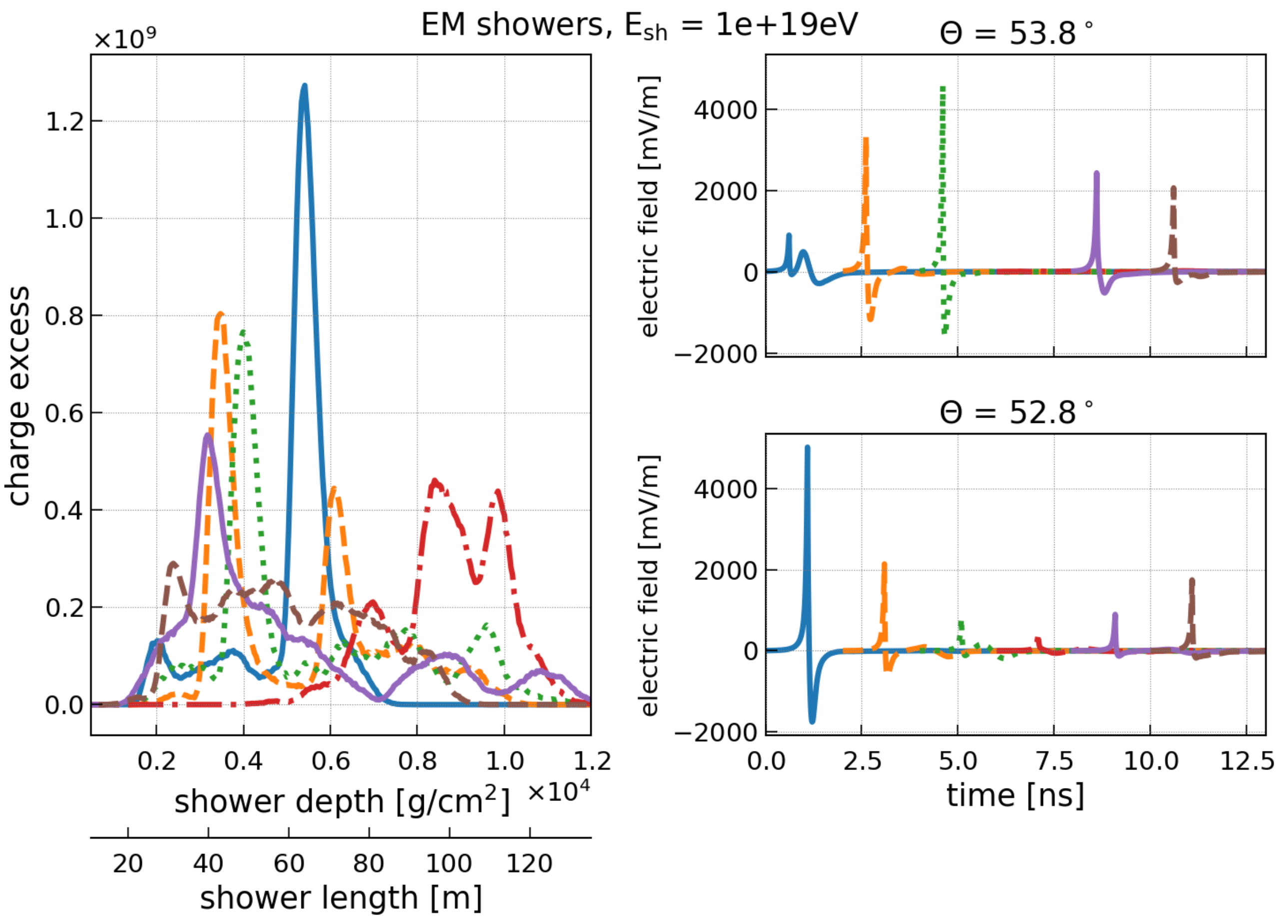
lower frequencies != Cherenkov cone

Signal on Cherenkov cone

- Simple and scalable emission of EM showers
- Amplitude scales with energy

What do simulations entail?

Simulation of neutrino signals



lower frequencies != Cherenkov cone

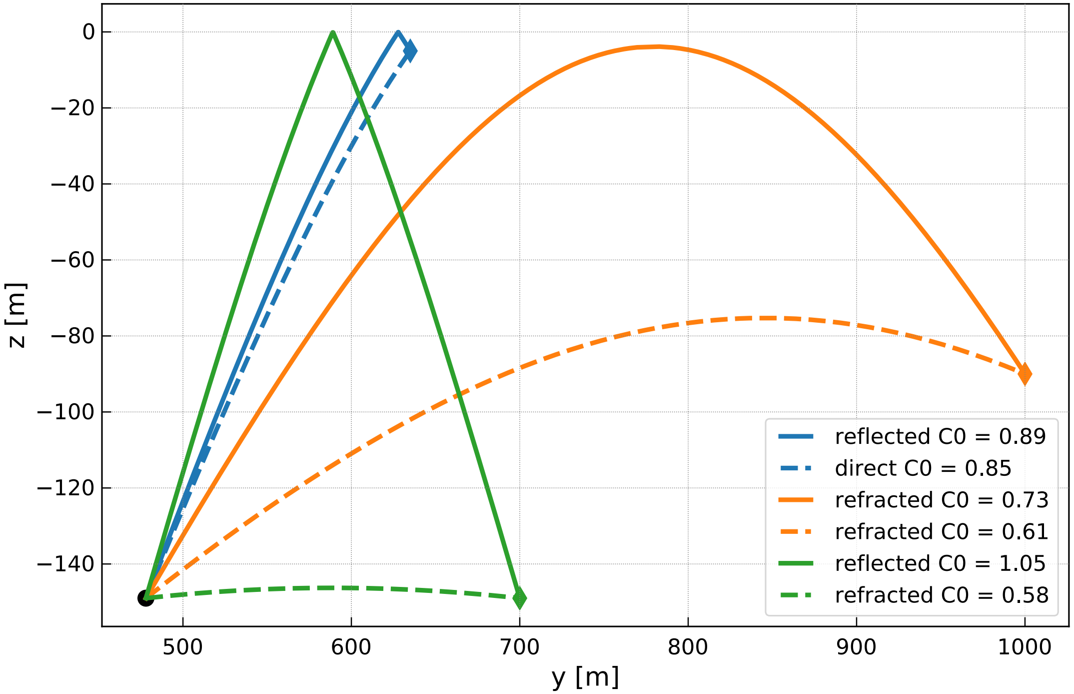
Signal on Cherenkov cone

- LPM effect leads to irregular showers
- Monte Carlo needed

What do simulations entail?

Signal propagation

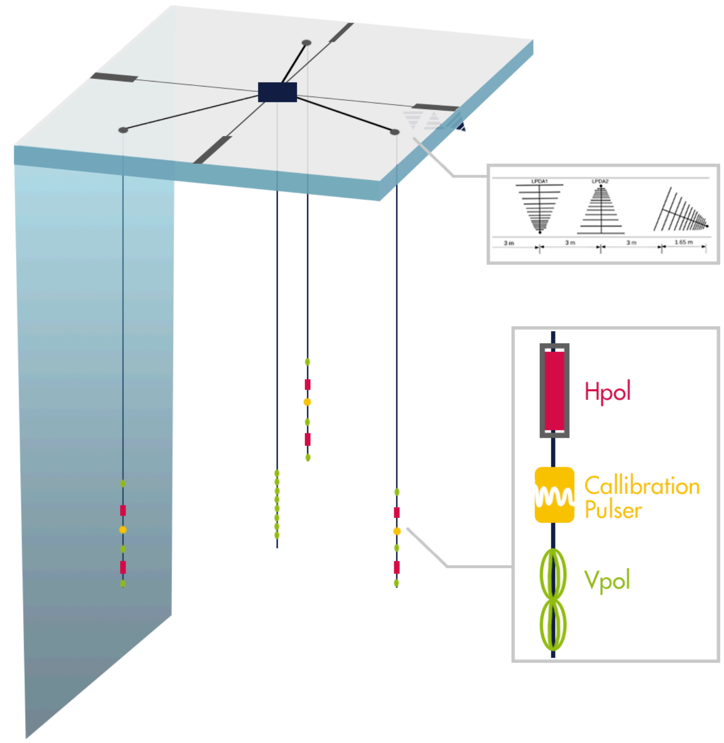
- Ice has a changing index of refraction (firn)
- Ray-tracing in smooth profiles
- “Solved” problem, “only” computational challenge
- Discontinuities and irregular behavior like birefringence not accounted for yet
- NuRadioMC has links to more complex codes (RadioPropa) that can deal with these



What do simulations entail?

Signal detection

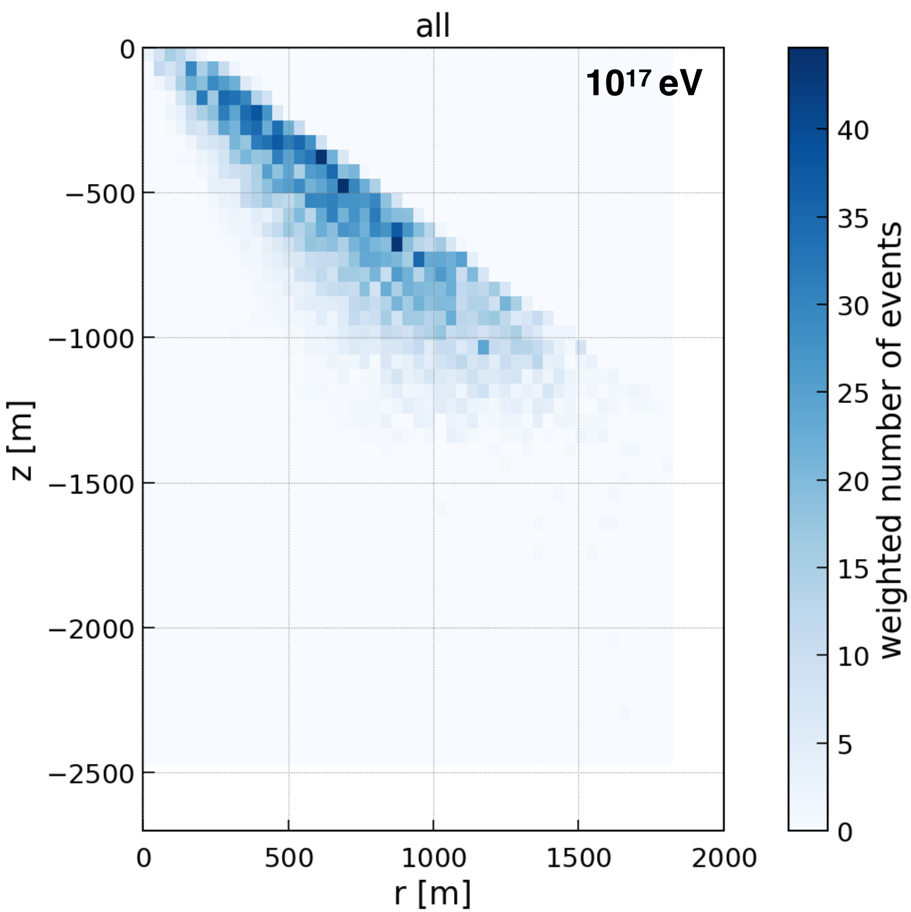
RNO design



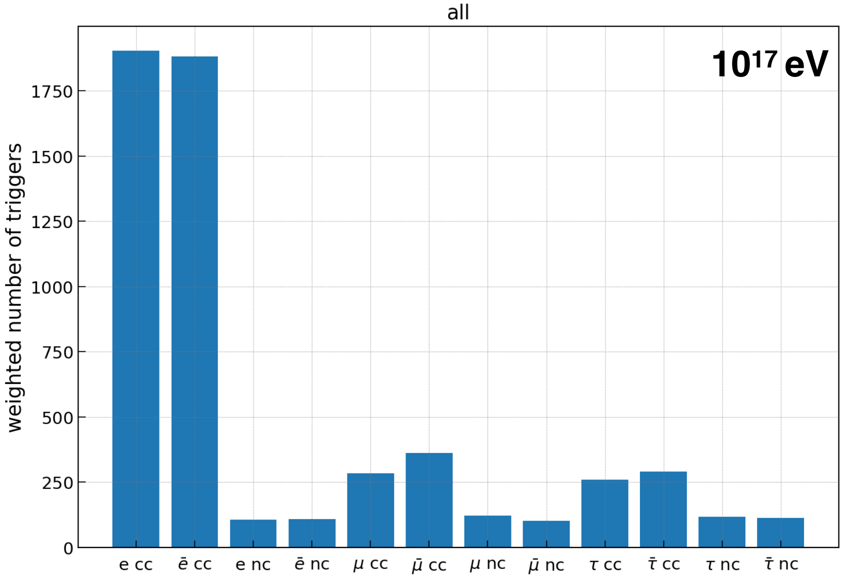
- Radio stations even in idealized form very complex
- Detector quantities (amplitude and phase) as function of frequency, arrival direction and signal polarization
- Simulations need to be flexible for layout optimization and fast in using all these quantities for a large detector
- Database built-in
(builds heavily on experiences with radio air shower experiments and known challenges)

What do simulations provide?

Some results from NuRadioMC



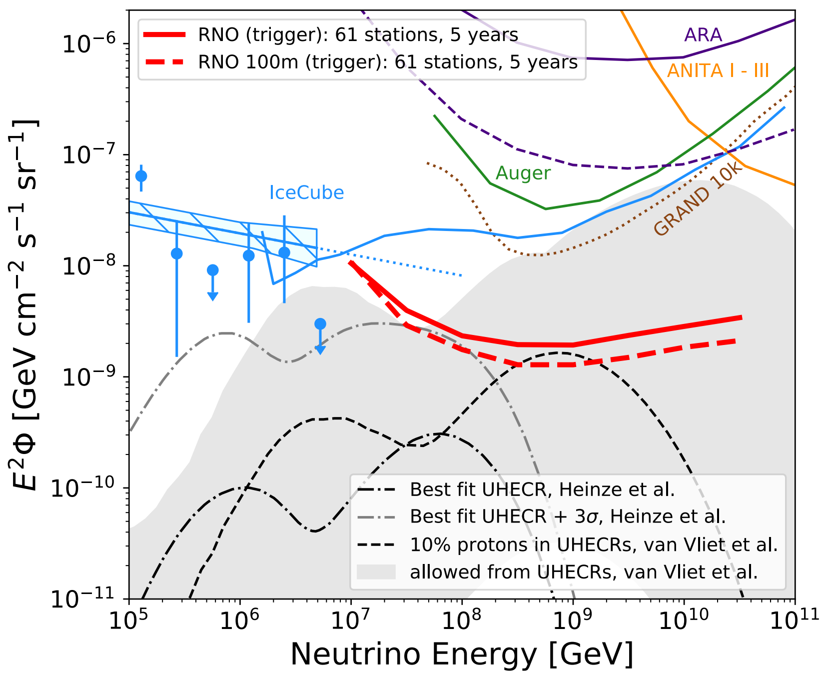
Vertices: Radio is viewing from afar

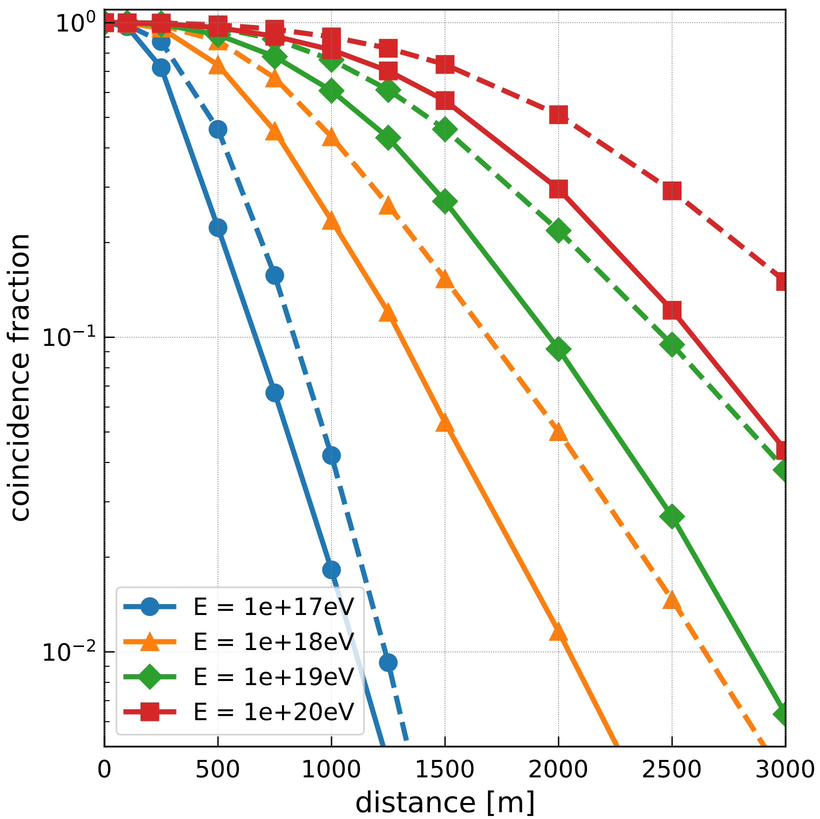


Flavor distribution: sensitive to showers

What do simulations provide?

Detector figures





RNO sensitivity (UL 90%)

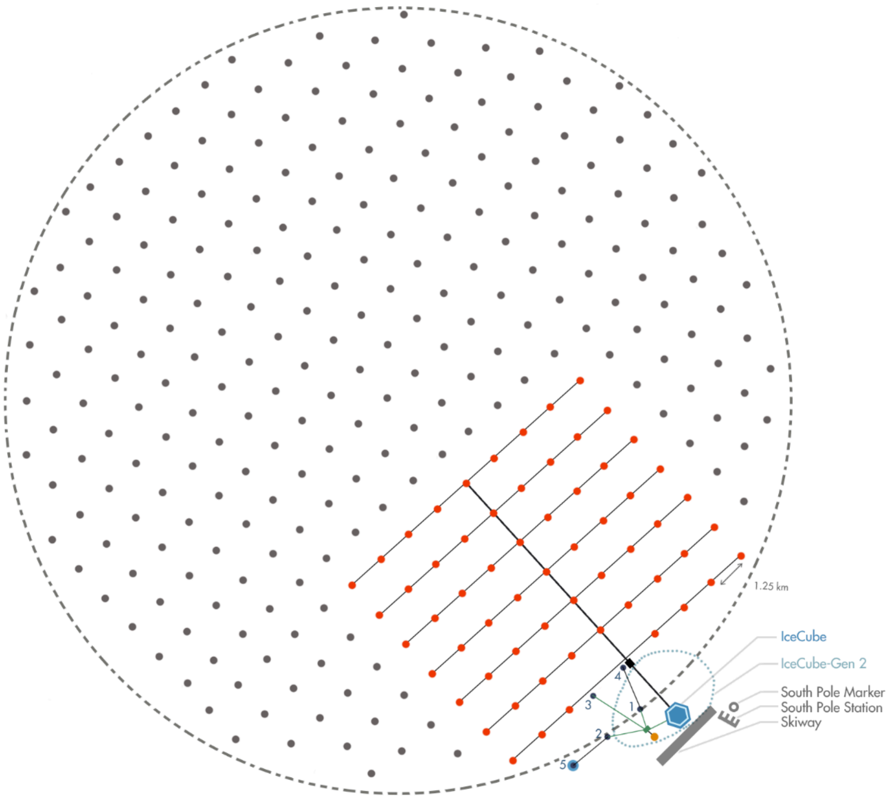
For full V_{eff} potential: spacing > 1km

What have we simulated for Gen2Radio?

Using RNOx5 as proxy

- RNO has been proposed end of last year, currently best guess for station design for a first generation array
- Assumption for Gen2Radio: RNO sensitivity x5
- This may be achieved via different routes (deeper stations, more lightweight, more aggressive triggering, …), but we need additional experimental evidence to justify an adaptation of the detector design
- For now: simple scaling of RNO design as is

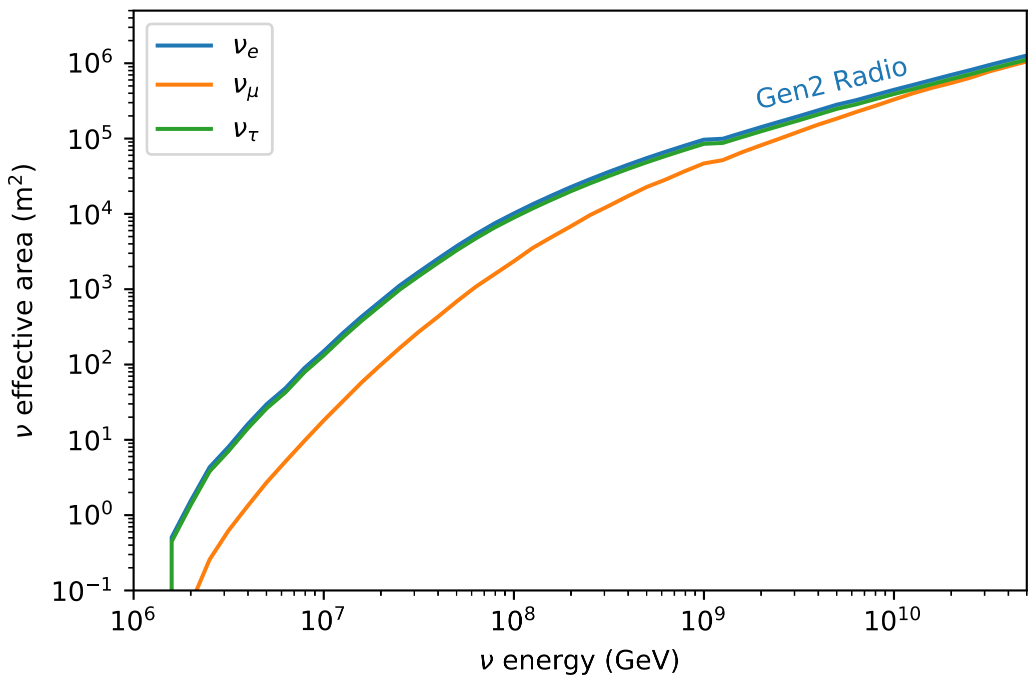
Real Gen2 probably won't look like this



Results for effective areas

Radio only, different flavors

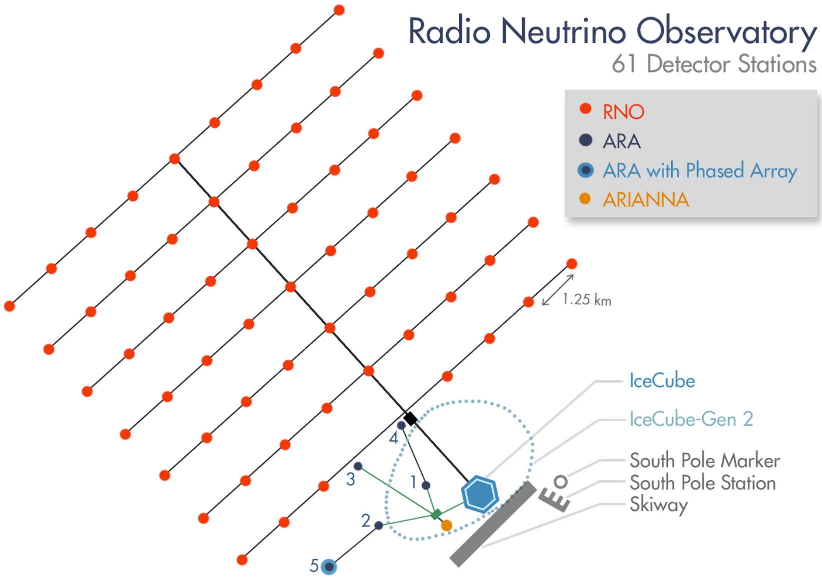
- Radio contribution as shown in talk earlier



Approach towards optical and radio coincidences

Focussing on radio

- Use optical Gen2 as volume only
- Assumption: every muon E > 10TeV reaching the optical sensors, will trigger and can be found using the time stamp from radio
- Use the radio simulation (including lepton propagation in PROPOSAL) to find interesting candidates
- Then simulate events with IceCube tools
- Radio simulations are fast and continuously developing
- IceCube simulations are much slower at these energies



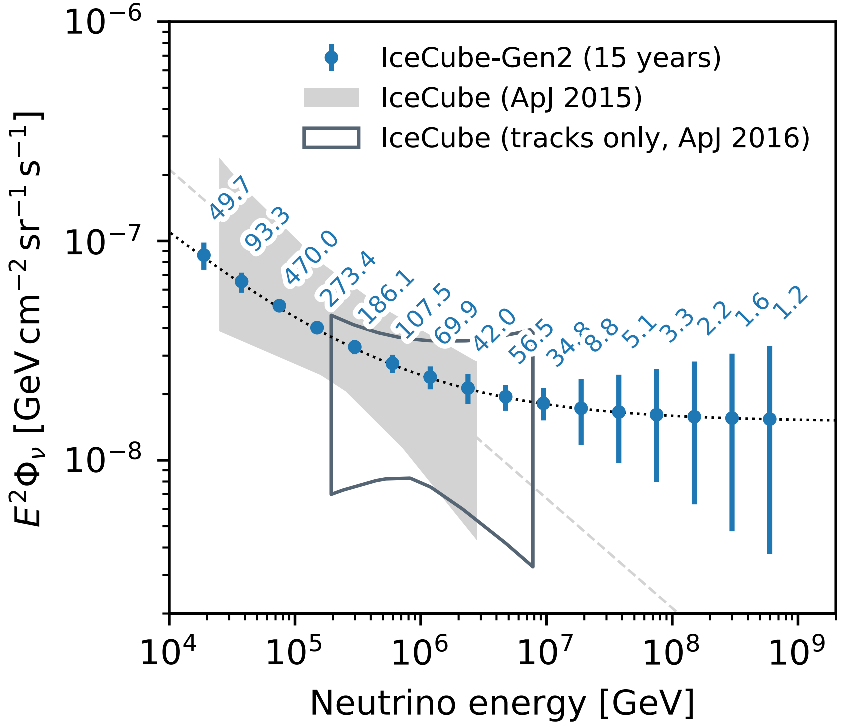
InIceMC simulation effort

Thanks for a great community effort

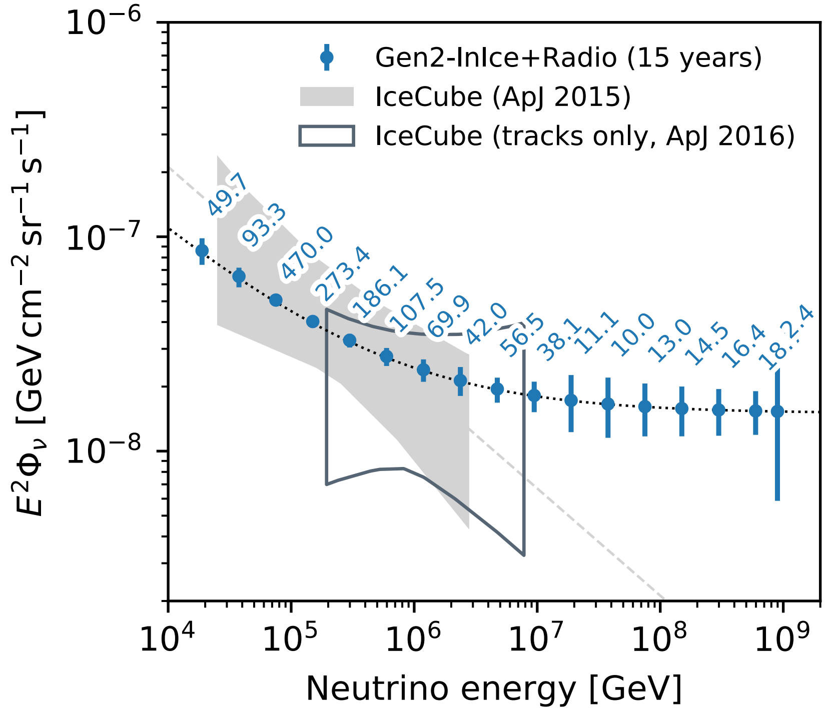
- Group at DESY: Daniel Garcia-Fernandez (post-doc), Ilse Plaisier, Christoph Welling (PhD students), Anna Nelles (group leader)
- NuRadioMC (co-)lead developer: Christian Glaser (UCI)
- Contributions from: Jaime Alvarez-Muniz, Brian A. Clark, Cosmin Deaconu, Ben Hokanson-Fasig, Uzair Latif, Jordan C. Hanson, Robert Lahmann, Christopher Persichilli, Yue Pan, Carl Pfendner, David Seckel, Jorge Torres Espinoza
- Software is open source and publicly available, please contact us, if you want to join the development: anna.nelles@desy.de
- https://github.com/nu-radio/NuRadioMC

Back-Up

Additional slides

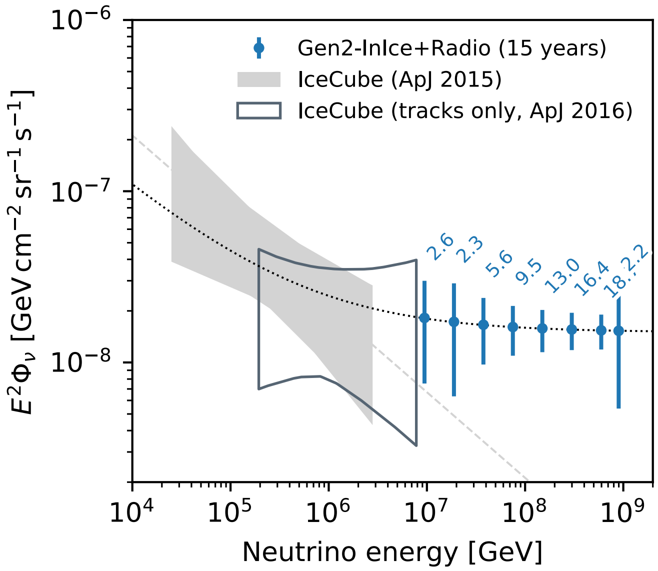


Optical only



Optical and radio

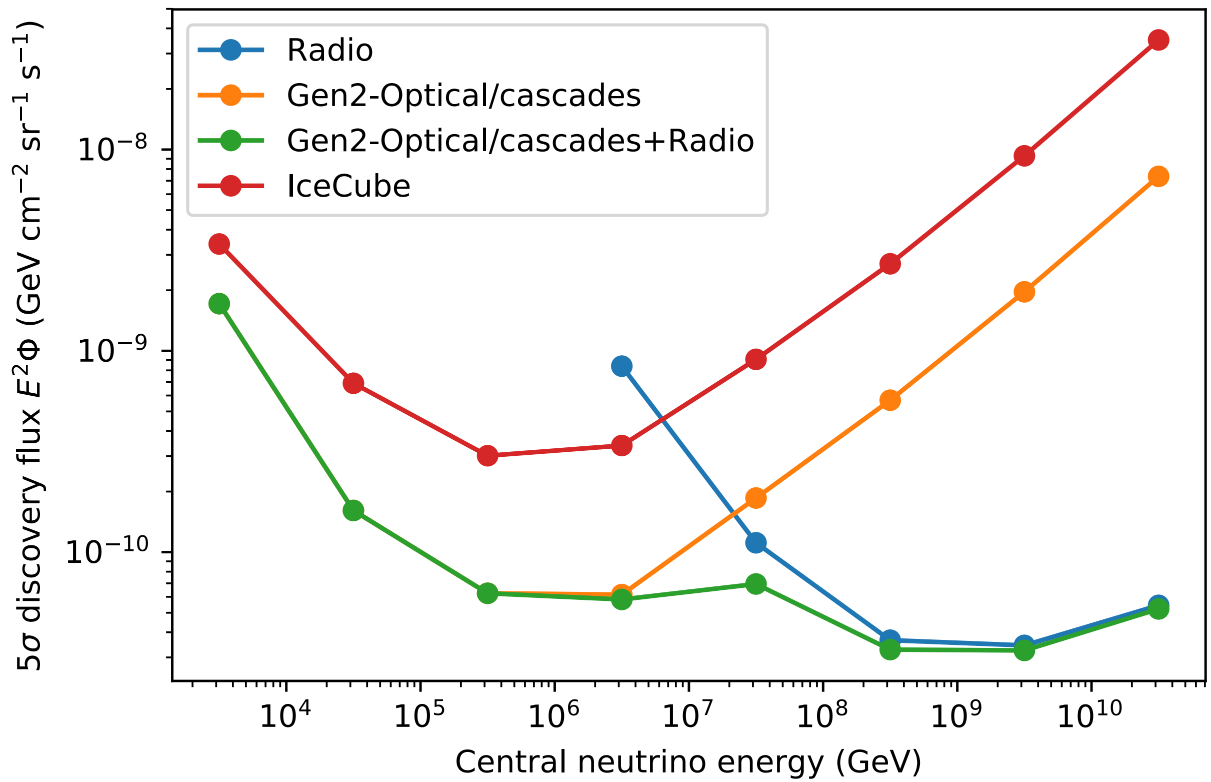
Additionla slides



Radio only

Sensitivity curves

- 5 sigma discovery potentials without astrophysical background (all-flavour)



Point source sensitivity curves

- 5 sigma discovery potentials for 100 seconds flares
- Solid lines: with radio. Dashed: only optical