Prospects for a radio air-shower detector at South Pole

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Outline

Motivation

- IceCube / IceTop observatory
- first composition result

  ➔radio air-shower extension

Experimental results

- antenna design
- setups at ARA
- environmental conditions

  ➔ noise!

Performance estimate

- simulation chain
- reconstruction

  ➔first performance estimate

Outlook

Charged cosmic rays

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IceTop

- sample shower on the ground
- $e^{\pm} \gtrsim 10$ MeV

IceCube

- high-energy muon core
- $\mu^{\pm} \gtrsim 300$ GeV

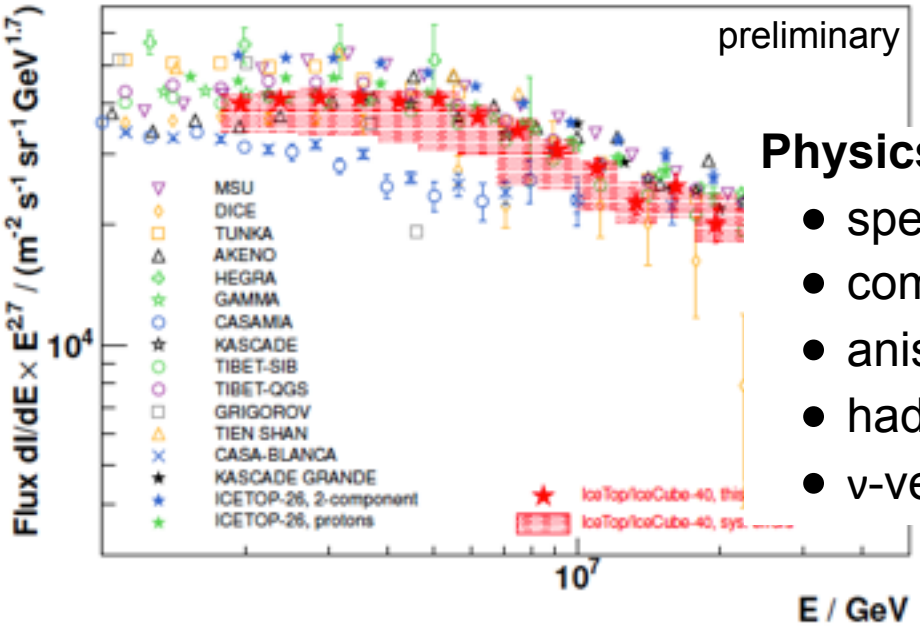
➔ 3D air-shower array

Combined

- $A_{eff} \cdot \Omega \approx 0.3$ km^2 sr
- $E_{prim} \gtrsim 300$ TeV

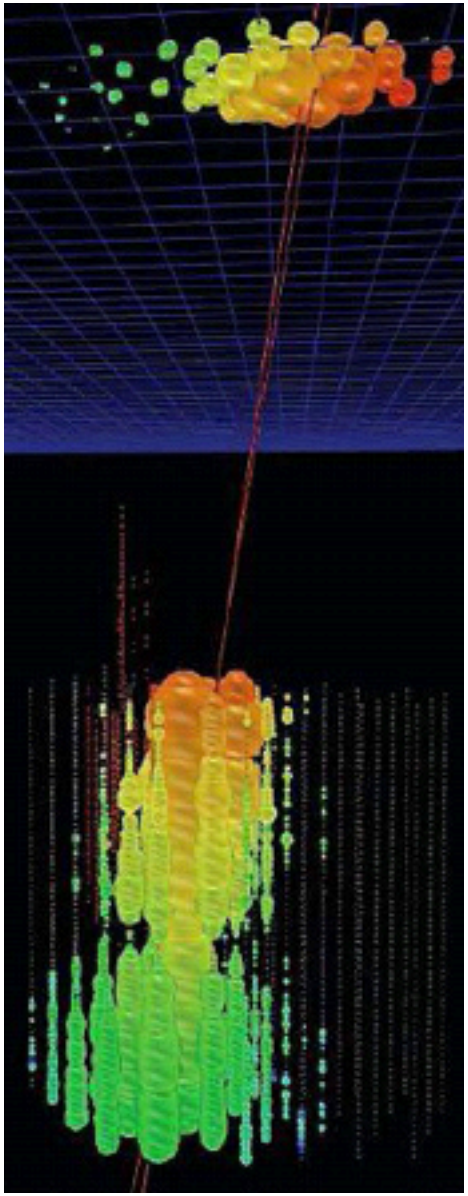
➔ 10^{10} showers per year

➔ 10^7 with InIce signal



Physics program

- spectrum
- composition
- anisotropies
- hadronic interactions
- ν-veto



Composition with IceCube/IceTop

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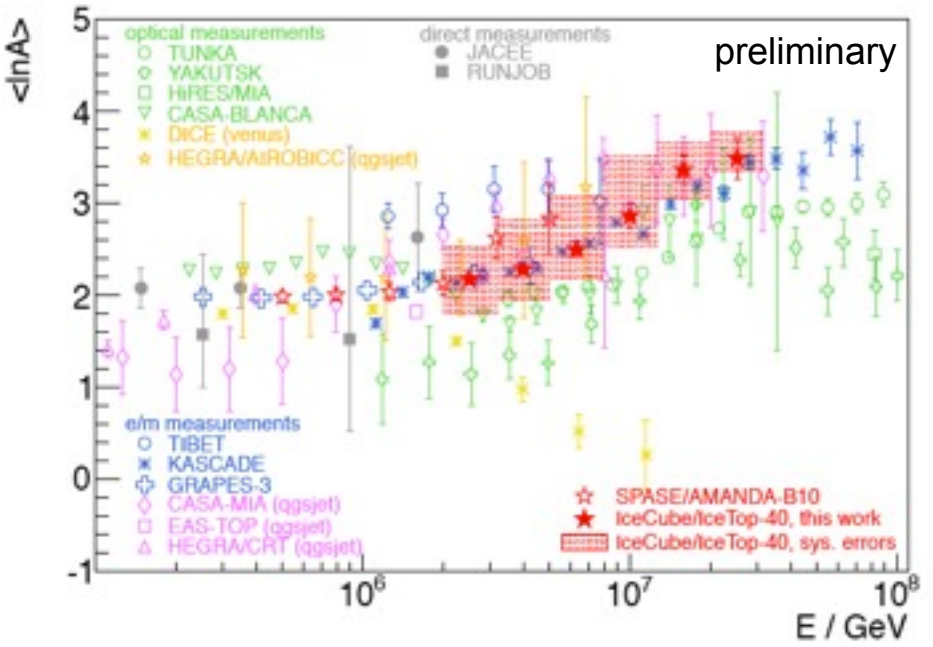
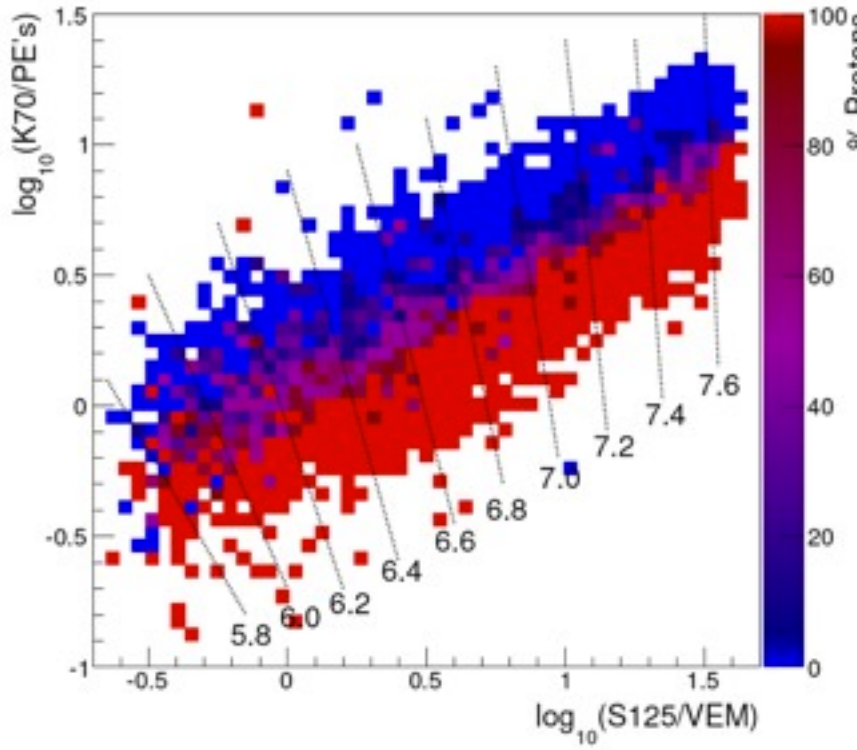
Measuring composition

- shower size on ground (S125)
  ➔e/m-component
- width of muon bundle in ice (K70)
  ➔μ-component
- extract energy and ln<A> from NN
  ➔ fit with template distritbution





Systematic uncertainties

- in-ice sensitivity
  (ice models, DOM efficiency)
- IceTop sensitivity
  (snow accumulation, environment)
- air-shower development
  (interaction models, atmosphere)

Motivation

Idea

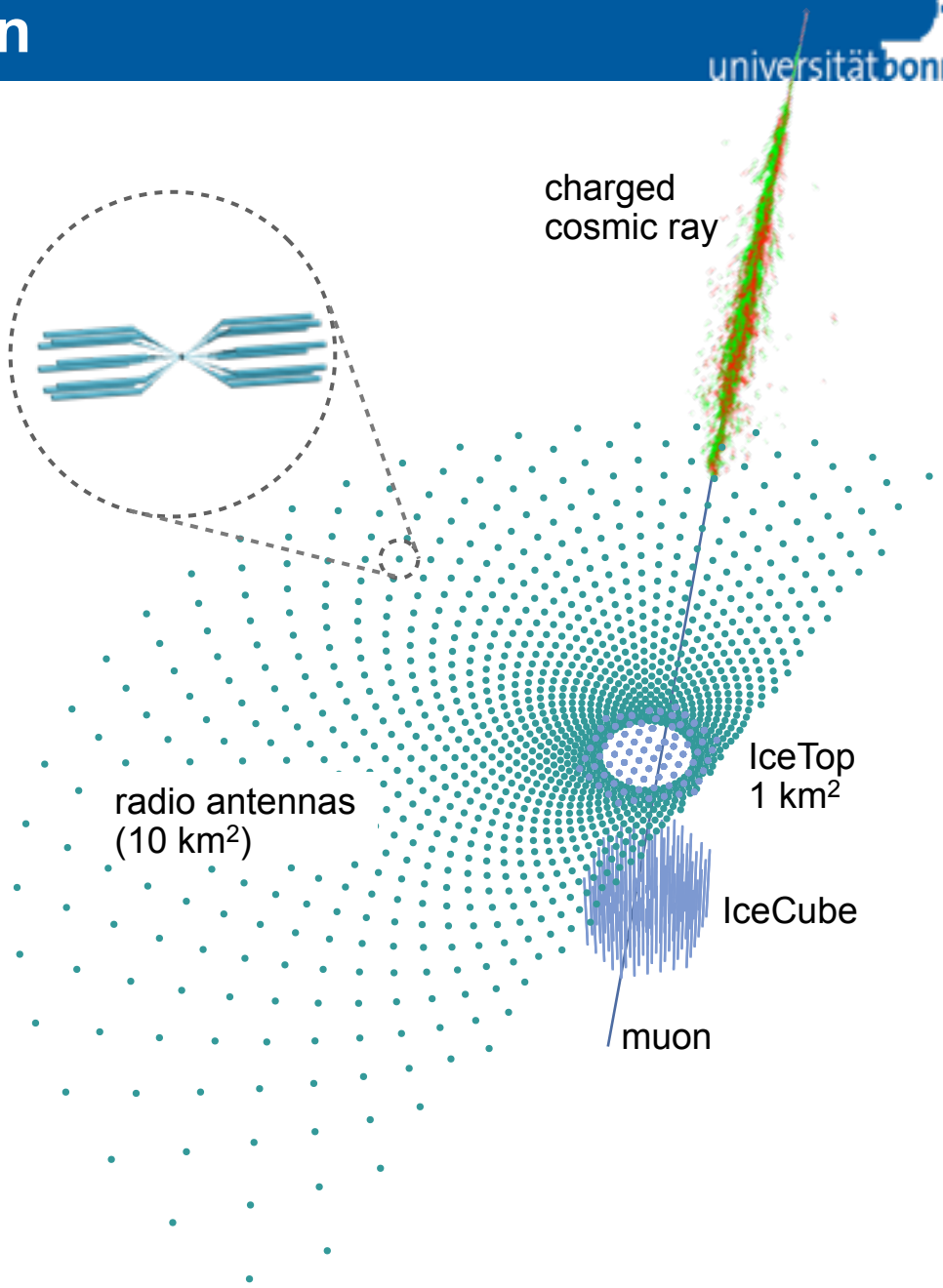
- add a radio air-shower detector

Overlapping IceTop

- add complementary method
  ➔reduce systematic uncertainties
  - energy resolution
  - directional resolution
- additional handle on X_{max}

Extending IceTop

- extend energy range
  ➔increase A_{eff} Ω
- air-shower veto
  ➔increase ν-sensitivity
- μ-veto
  ➔sensitivity to UHE-γ

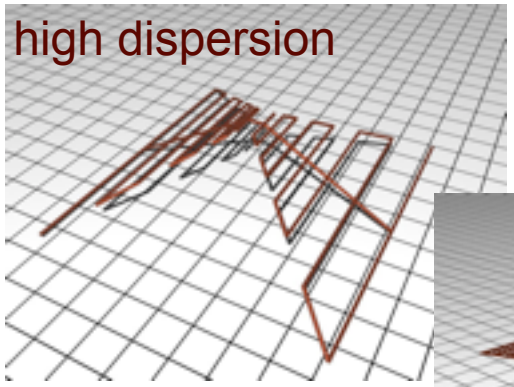


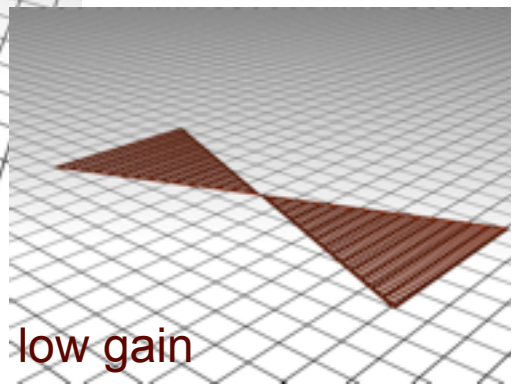
Antenna design

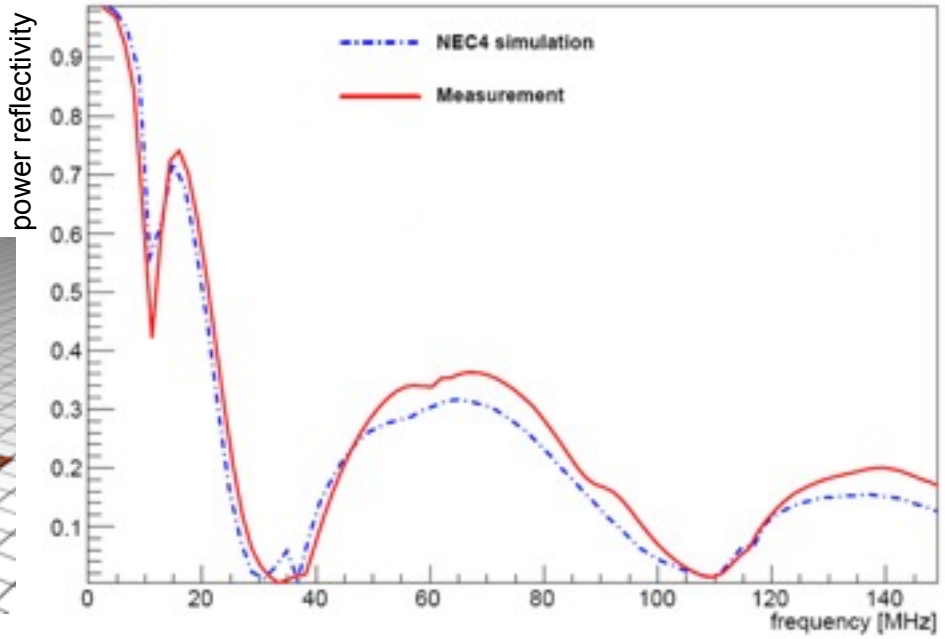
Requirements

- high bandwidth
  ➔optimize for 25-150MHz
- low dispersion
  ➔triggering
- robustness
  ➔buried in snow (size!)
  ➔temperature -55ºC

Fat Wire-Dipole (FWD) design wins







(Recent) exploratory setups

Season 2010/2011

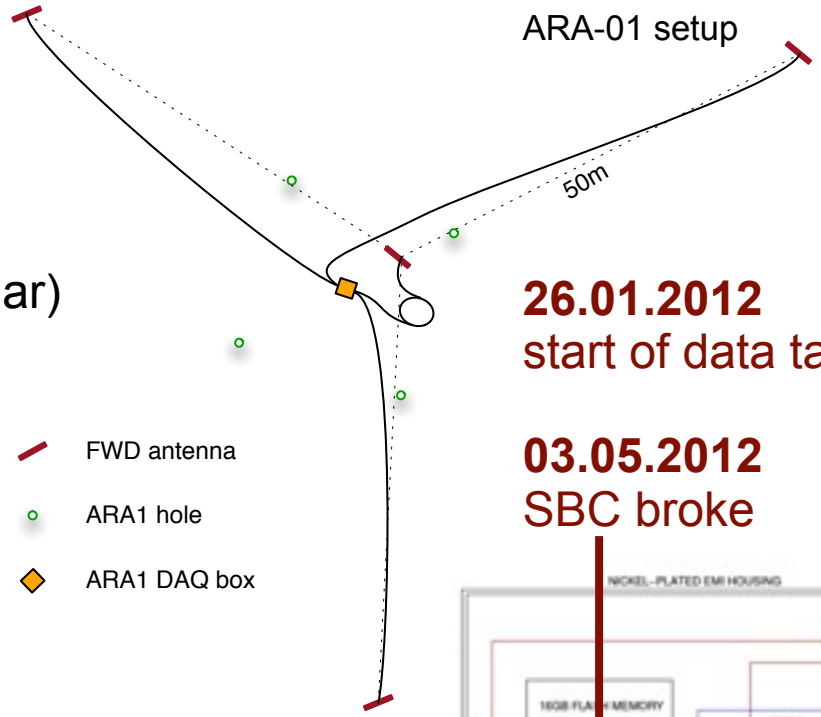
- ARA testbed
  - ➔2 FWD antennas
  - ➔30-300 MHz
  - ➔single notch (meteor radar)
  - ➔no dedicated trigger

Season 2011/2012

- ARA-01 station
  - ➔4 FWD antennas
  - ➔25-120MHz (diplexed)
  - ➔no notches
  - ➔dedicated trigger

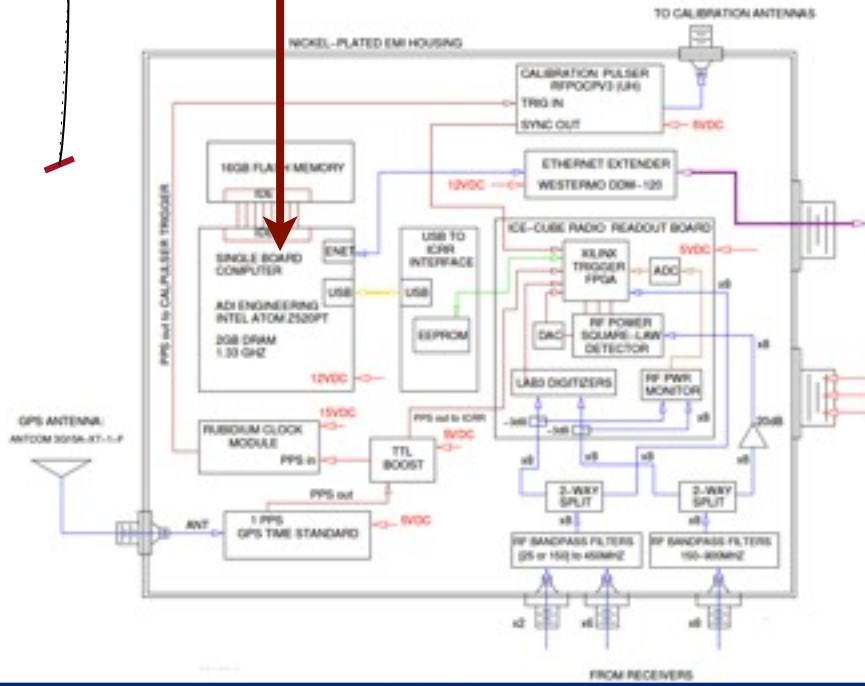
ICRR-DAQ system

- RF power detector
  - ➔trigger (ARA-01 only)
- Labrador-3 digitizer
  - ➔12bit, 2GS/s



26.01.2012
start of data taking

03.05.2012
SBC broke



Noise results

ARA testbed

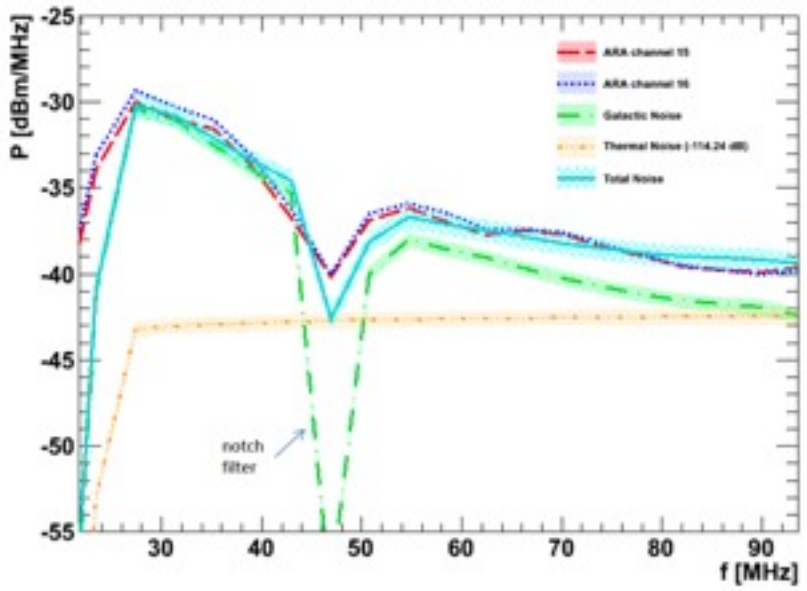
- full year of data
- minbias trigger

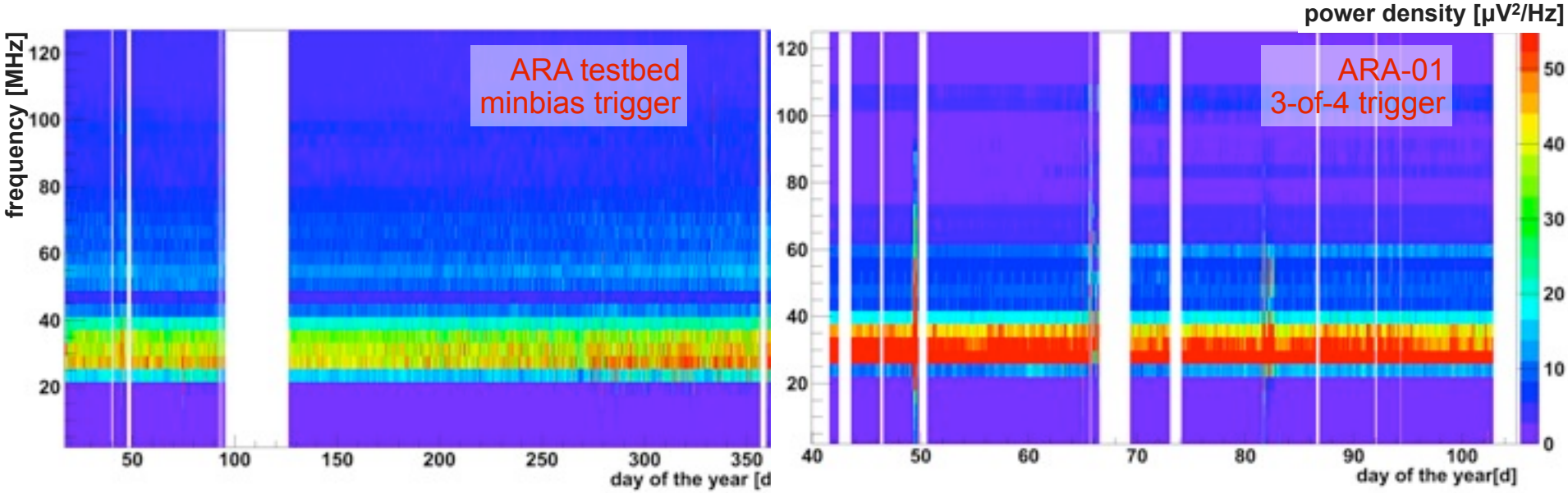
➔very stable throughout year

➔spectrum matches model

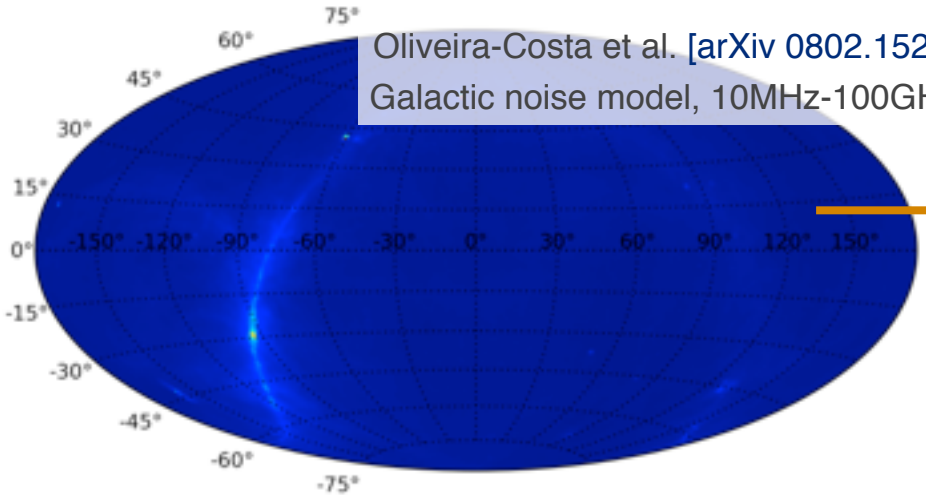
ARA-01 setup

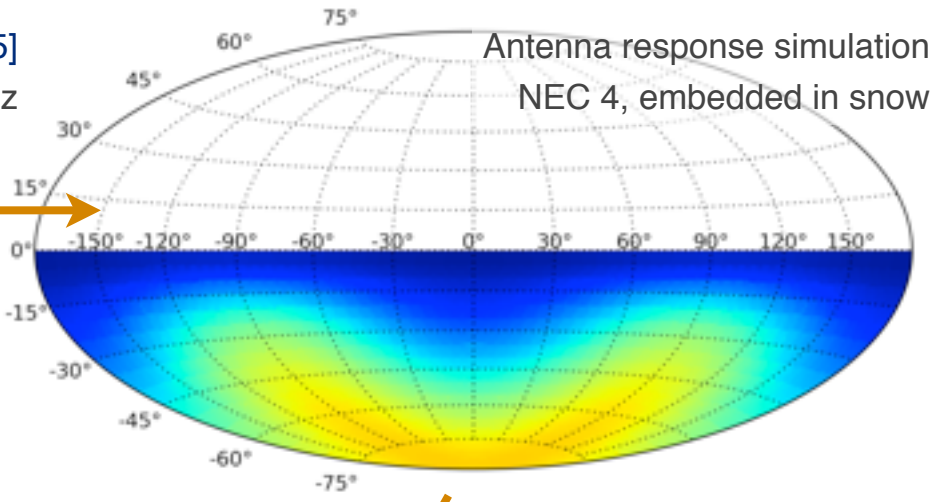
- 3-of-4 trigger
- dominated by thermal noise

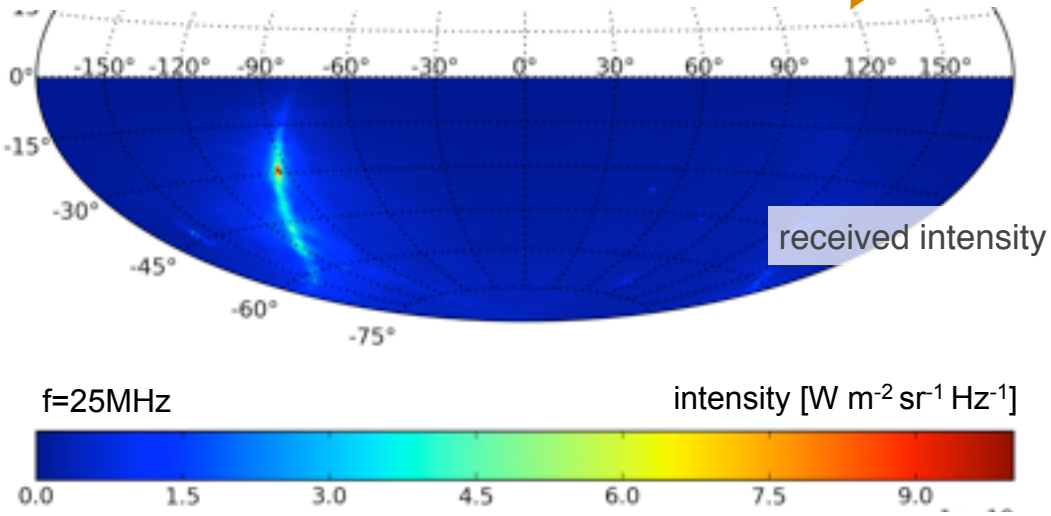




Galactic Noise







Noise studies and permitivity

Spectral analysis

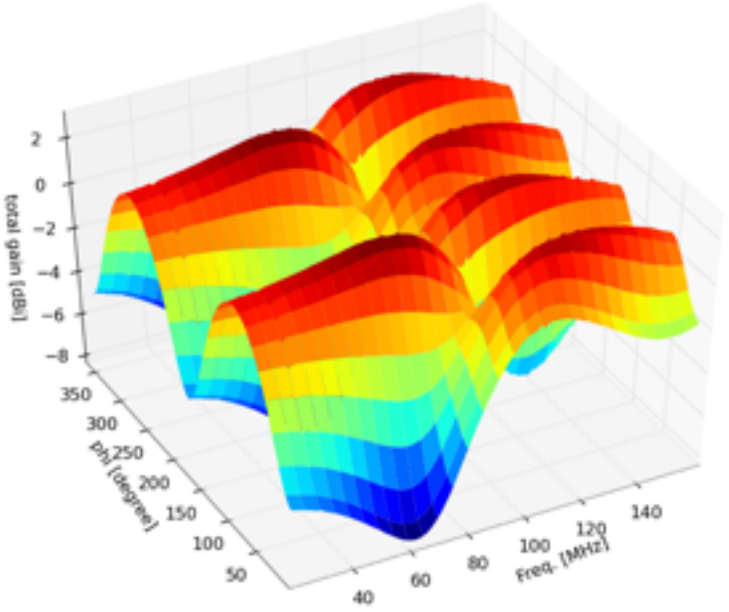
- falling galactic spectrum
  - ➔ decrease in modulation amplitude with frequency
- sensitivity inversion (H-pol vs. V-pol)
  - ➔ inversion of galactic noise phase

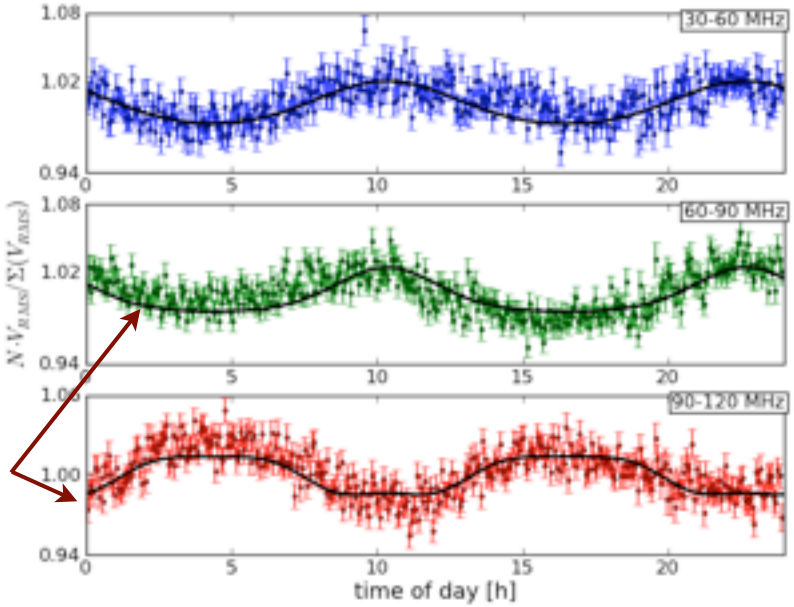
Very good agreement with data!

- from inversion point
  - ➔best fit permittivity: 1.3

$$\epsilon_{snow} = 1 + 2.15\frac{\rho_{snow}}{\rho_{ice}}$$

  - ➔eff. snow density: 0.2 g/cm^3
  - rough agreement with measurements





not a fit

Environmental conditions

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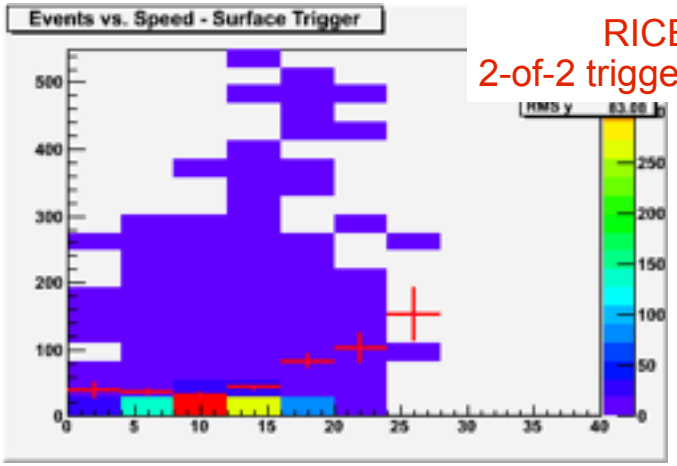
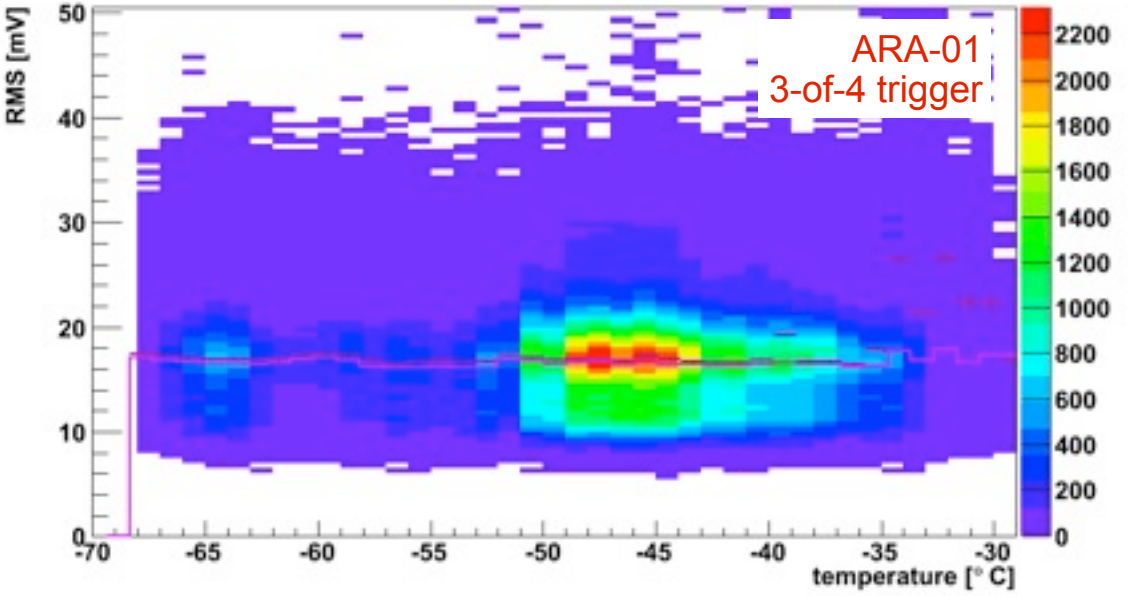
ARA-01 setup

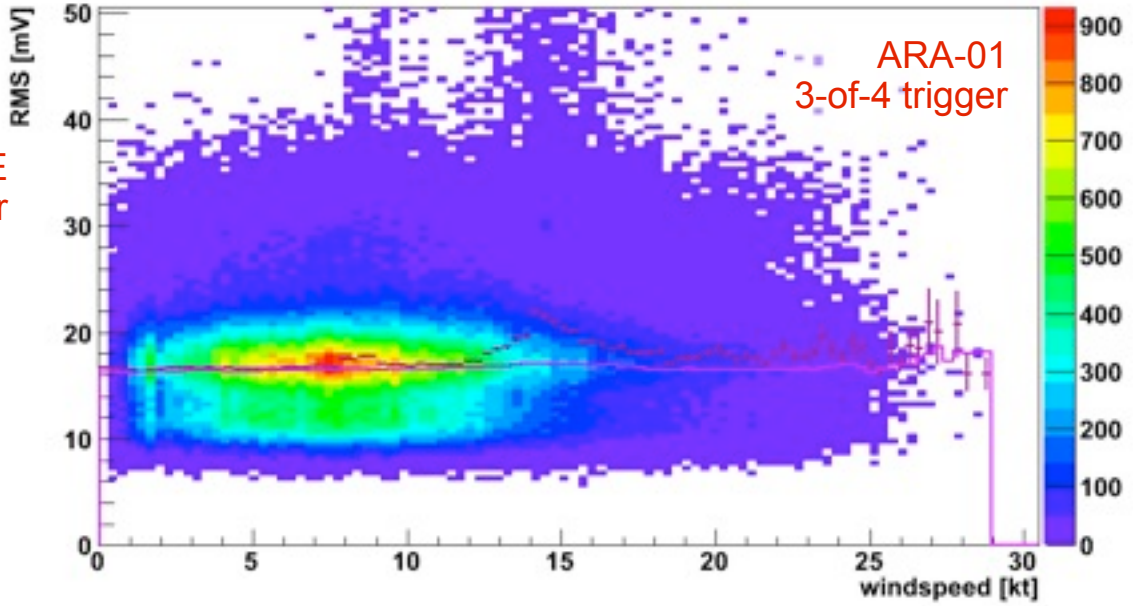
- signals not correlated with
  - ➔ wind
  - ➔ pressure
  - ➔ temperature
- environment under control

Previous RICE test setups

- surface triggers correlated with wind speed
  - ➔ hypothesis: discharge on structures (buildings, etc.)







Solar flare event

Feb 13th, 2011

- largest solar flare since 2006

Green banks radio observatory

290MHz - 390GHz

Light curves

16:00 18:00 20:00 22:00

Time (UT) 20110213

ARA surface antenna RMS

25MHz - 300MHz

4500 4000 3500 3000 2500 2000 1500 1000 500 0

12 14 16 18 20 22

Hour of Day

RASTA - Radio Air-Shower Test Array

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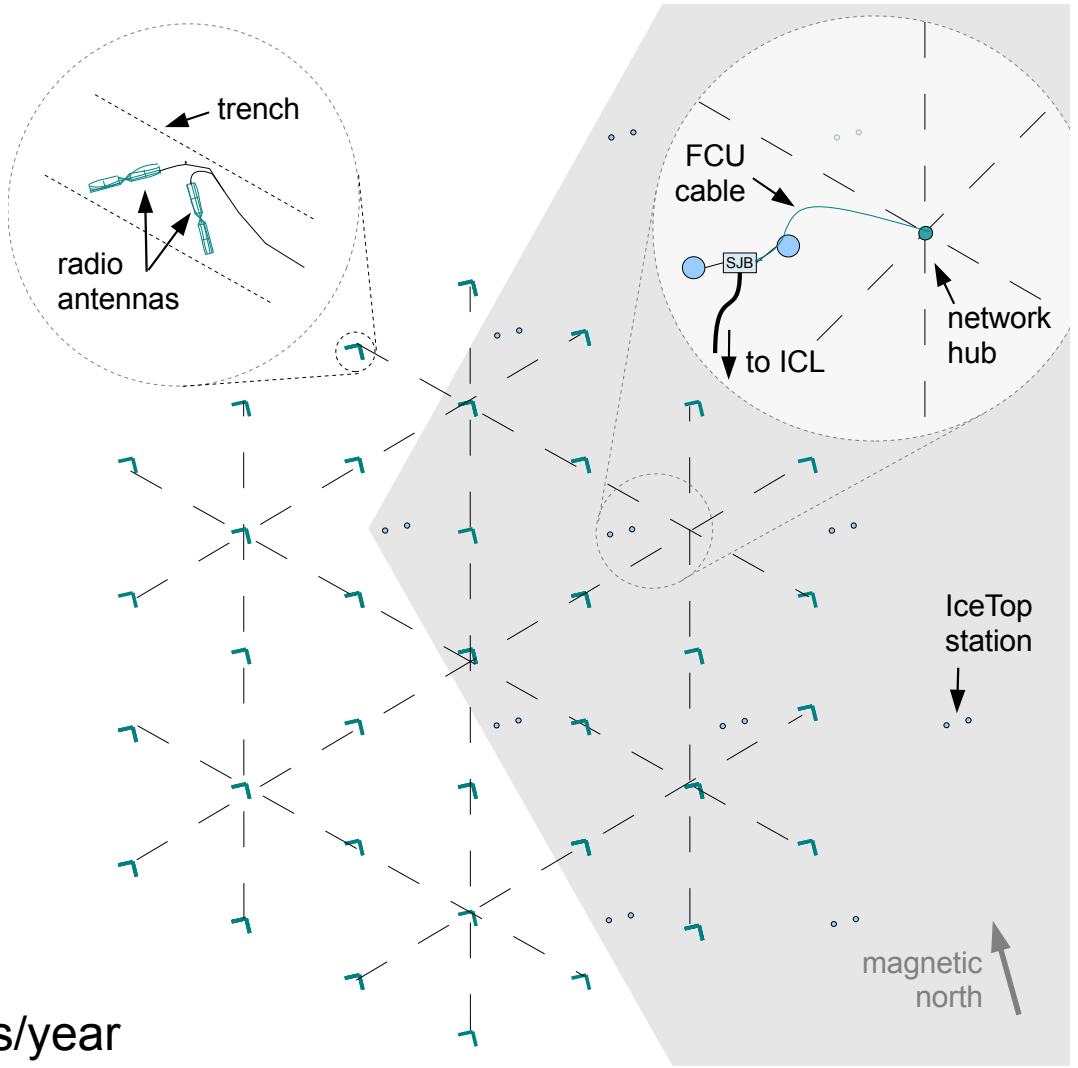
Proposed Setup

- 37 stations
- 2 antennas per station
- AERA-like DAQ
  - ➔interleaved sampling
    - 150MHz bandwidth

Goals

- develop technologies
  - ➔trigger (IceCube/IceTop)
  - ➔timing
  - ➔readout
- detect air-showers
  - ➔proof-of-principle
- start analysis
  - expected dataset (REAS3.0)
  - ➔50k radio triggers/year
  - ➔15k IceTop coincident triggers/year



Simulation chain I

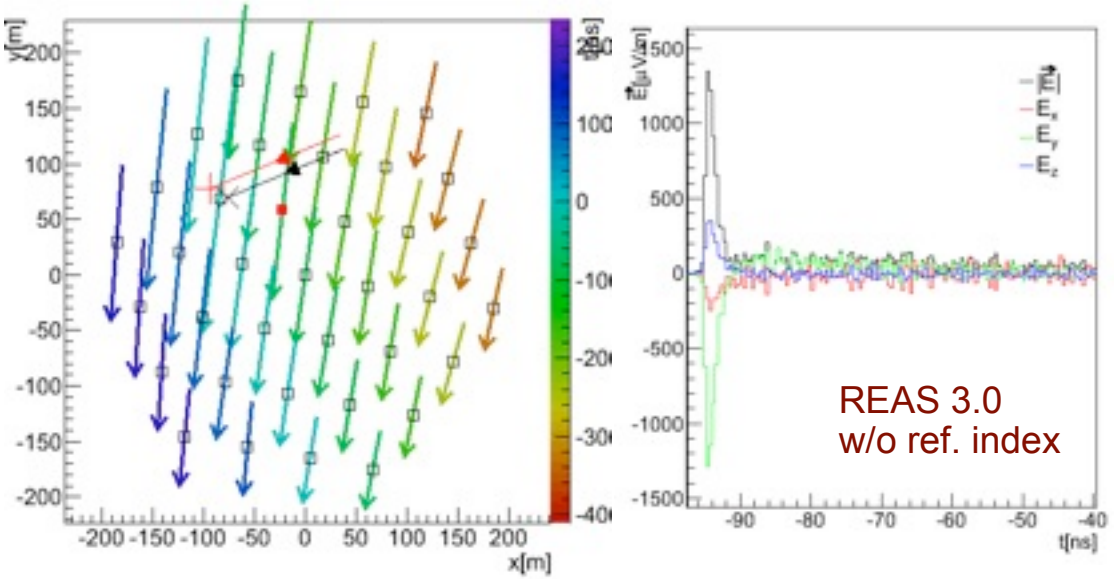
IceCube software system

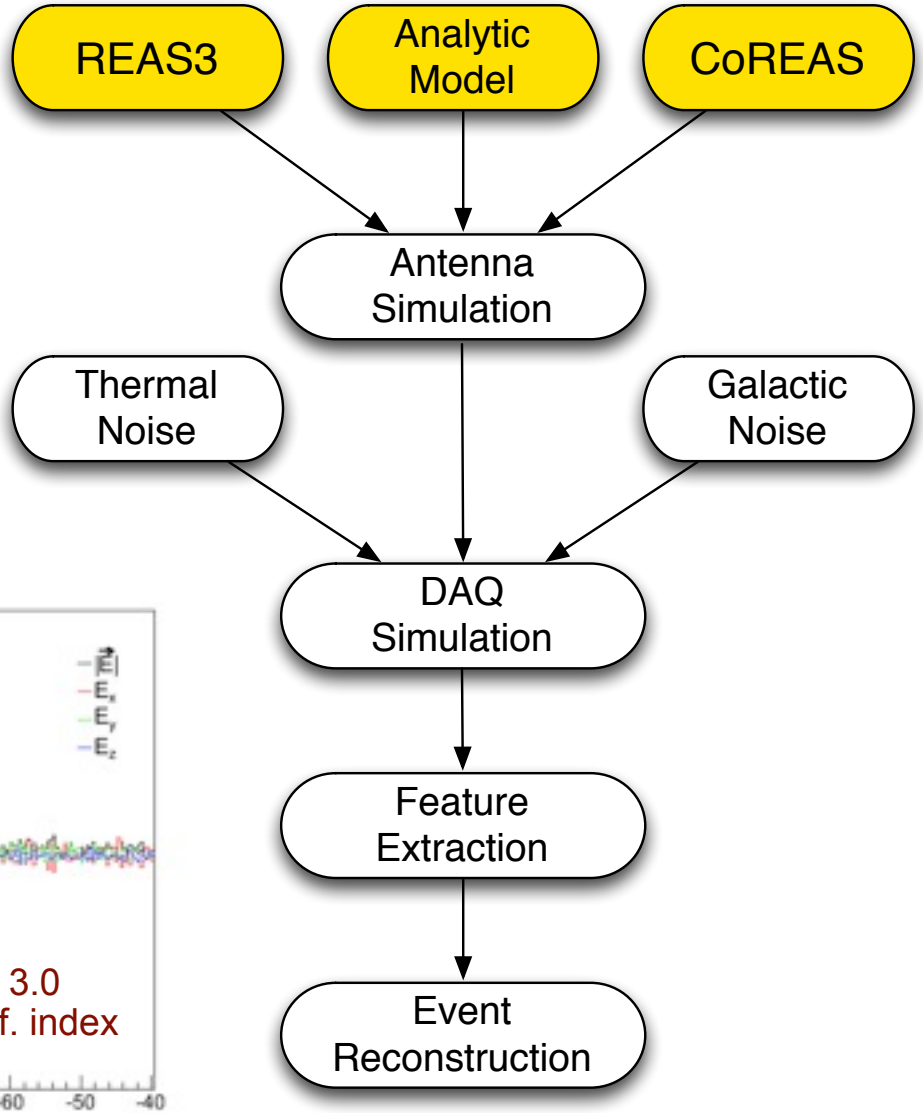
- modular design
- integrates w/ existing tools

  ➔combined RASTA/IceCube/ IceTop analysis

Radio event simulation

- REAS-3.0
- CoREAS (T. Huege)
- Semi-analytic model (Dave S.)





Simulation chain II

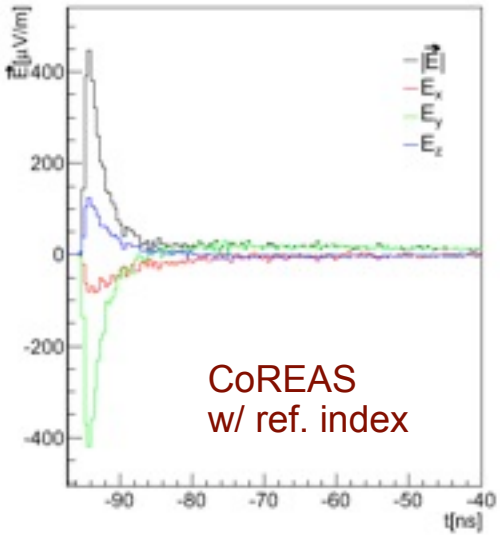
IceCube software system

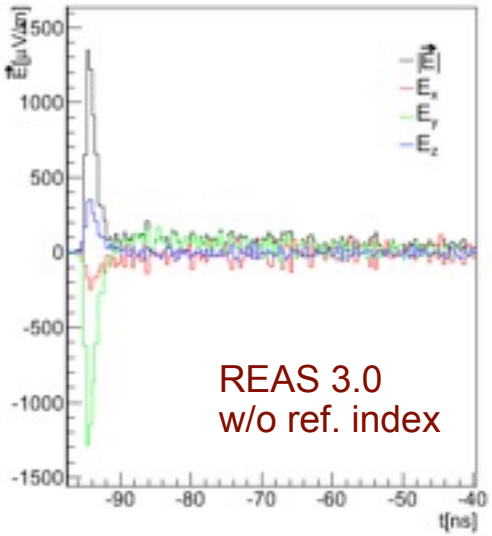
- modular design
- integrates w/ existing tools

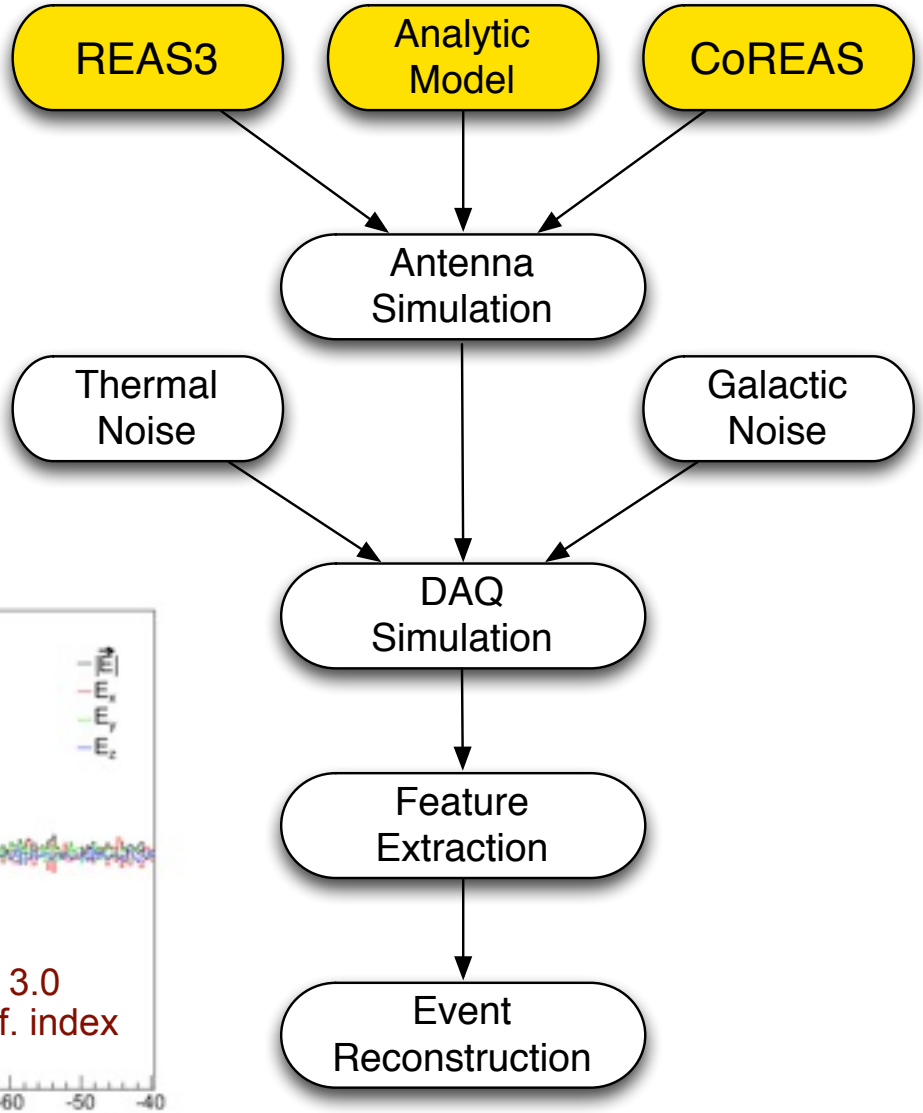
  ➔combined RASTA/IceCube/ IceTop analysis

Radio event simulation

- REAS-3.0
- CoREAS (T. Huege)
- Semi-analytic model (Dave S.)







Simulation chain III

Antenna simulation

- NEC4 model

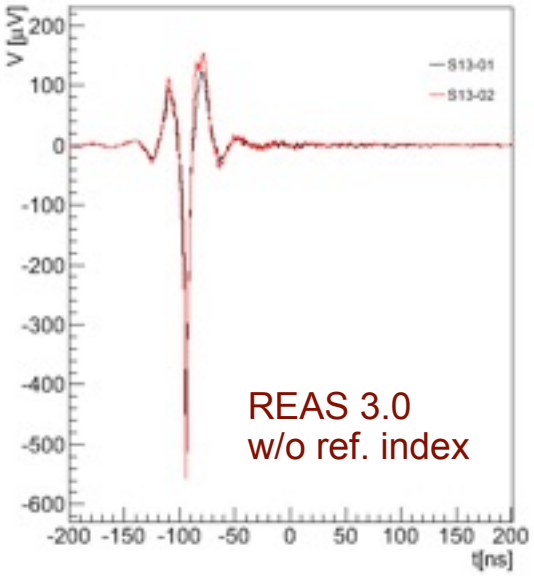
Noise simulation

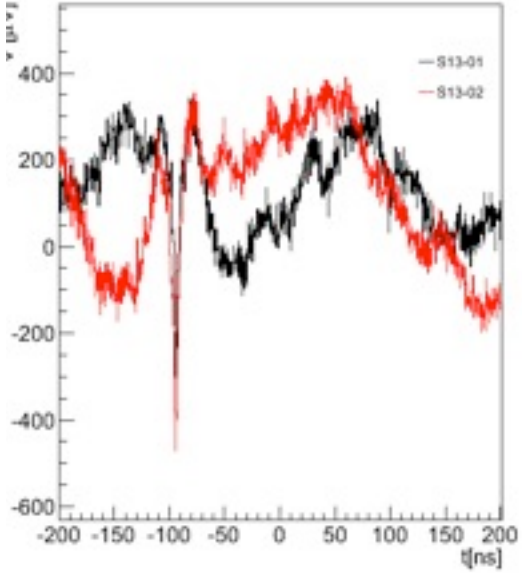
- thermal noise @ -55ºC
- galactic noise

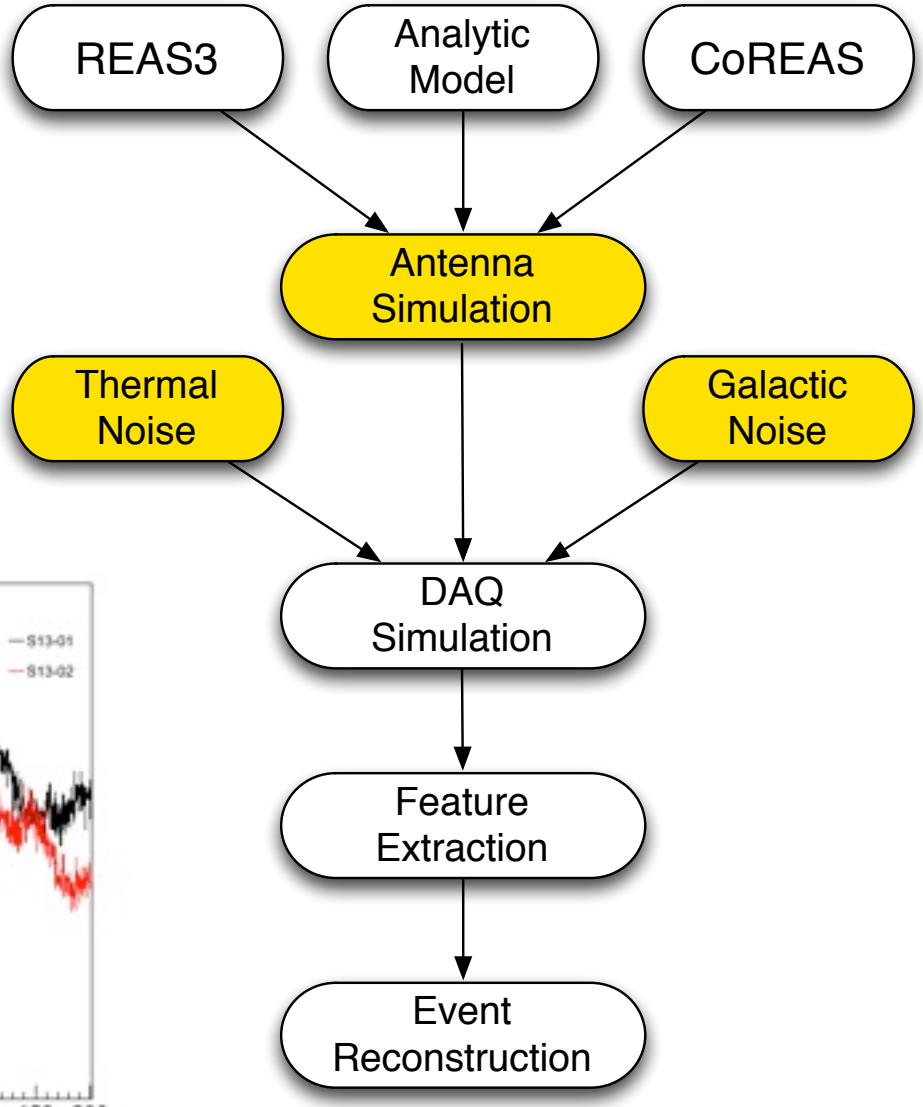
➔simplified model

$I = I_0 \cdot \exp(-\beta f)$

[Cane (MNR.astr.Soc, 1979 189, 465)]
[Dulk (A&A, 2001, 365 294]







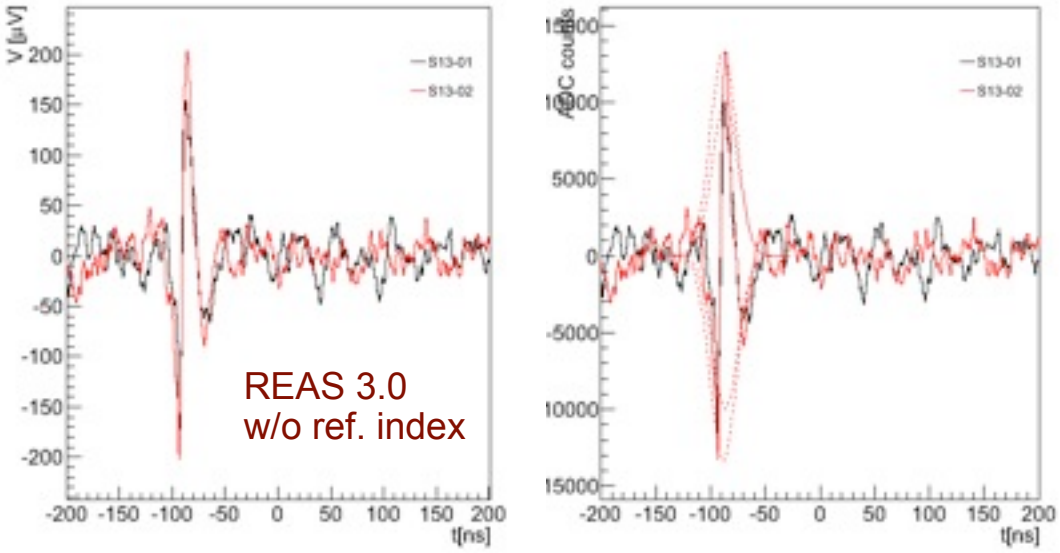
Simulation chain VI

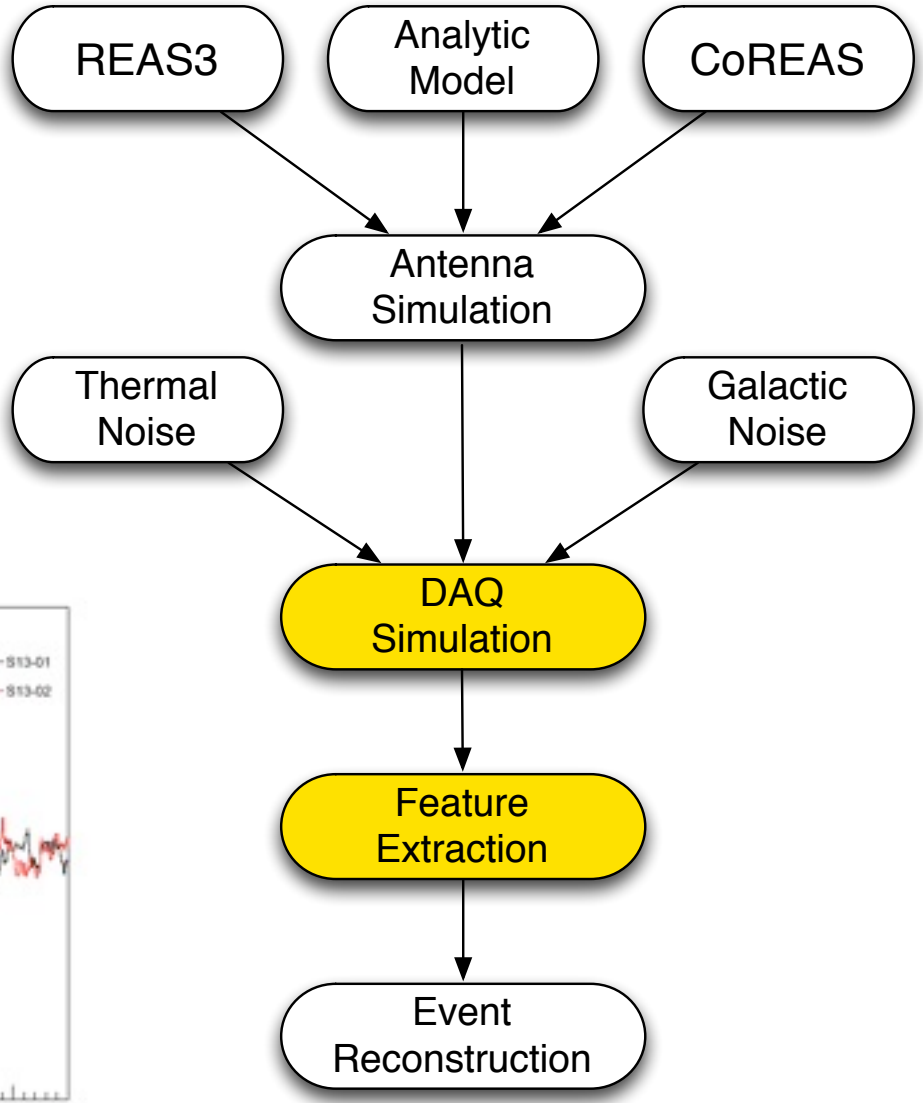
DAQ simulation

- simplified chain
  - ➔30dB amp,16bit ADC, 300MHz
  - ➔2nd order bandpass 25-300MHz
- full ARA-01 chain
  - ➔implemented from data sheets

Feature extraction

- fit gaussian to Hilbert transform
  - ➔cut at 5σ RMS





Reconstruction

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Plane-wave reconstruction

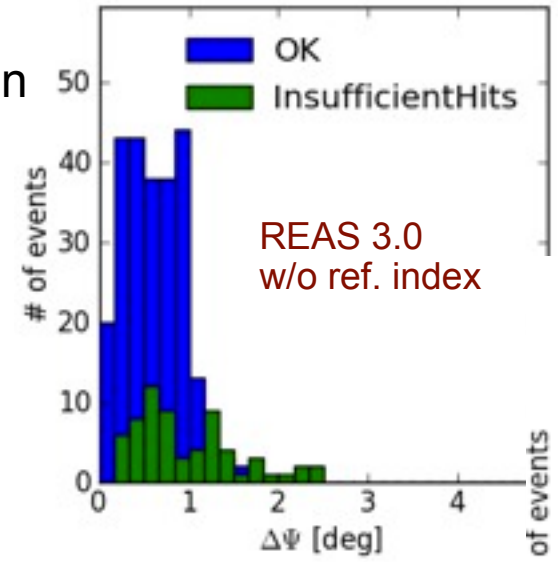
- use Single Value Decomposition
  ➔analytic solution
- iterative method
- while (NHits > 6)
  and ($\Delta\Psi < 0.005$)
  ➔refit w/ every hit excluded
  ➔calculate $\Delta\Psi$ to original fit
  ➔exclude hit w/
  largest $\Delta\Psi$ (pull)

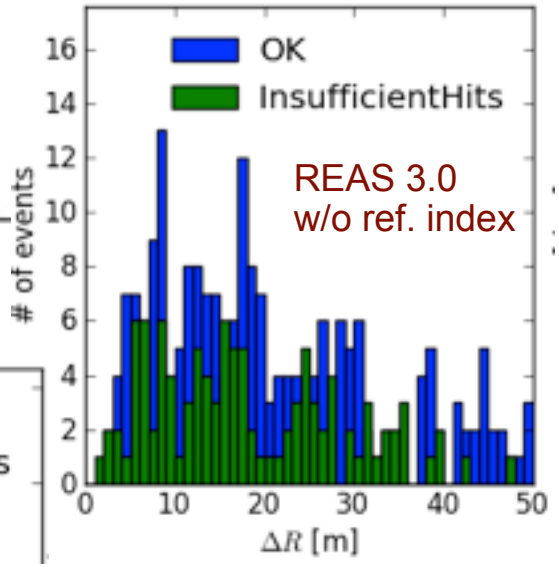
Core approximation

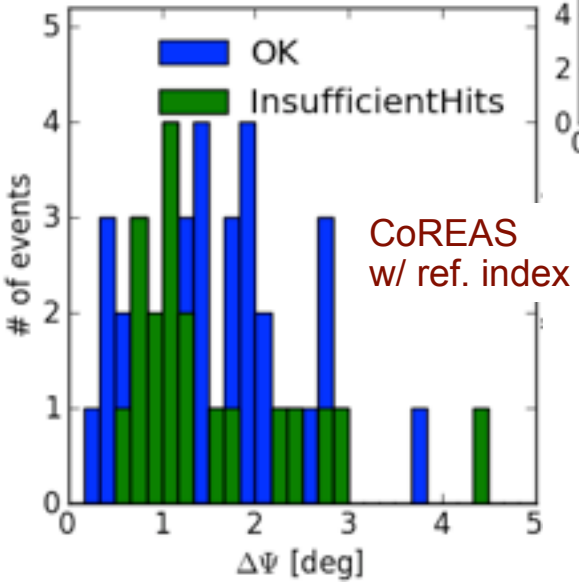
- simple weighted mean

Results

- densely spaced array
  ➔simple method provides
  $\sigma_\Psi \sim O(1°)$
  $\sigma_R \sim O(10m)$
  ➔comparable to IceTop







Performance estimate

Trigger setup

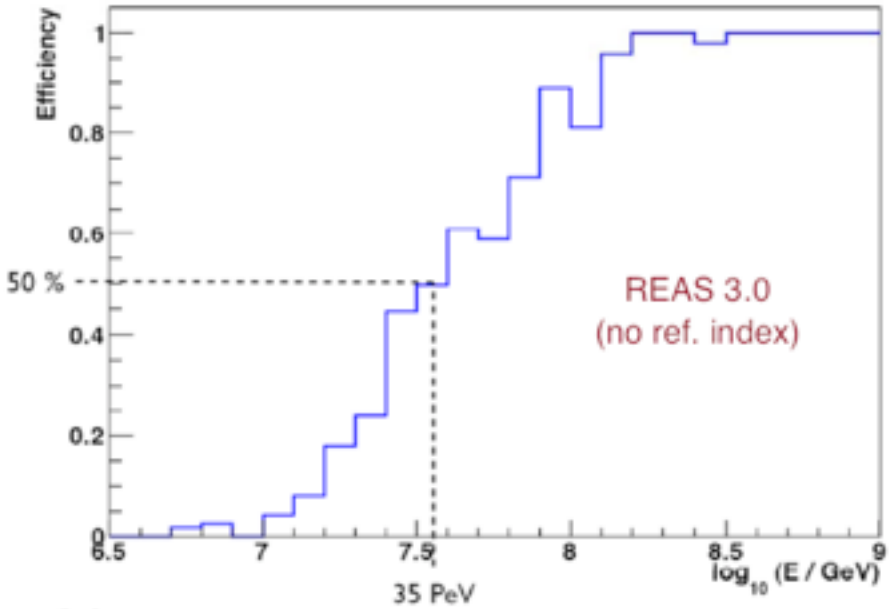
- require 4 stations
- each has (at least one) 5σ RMS signal

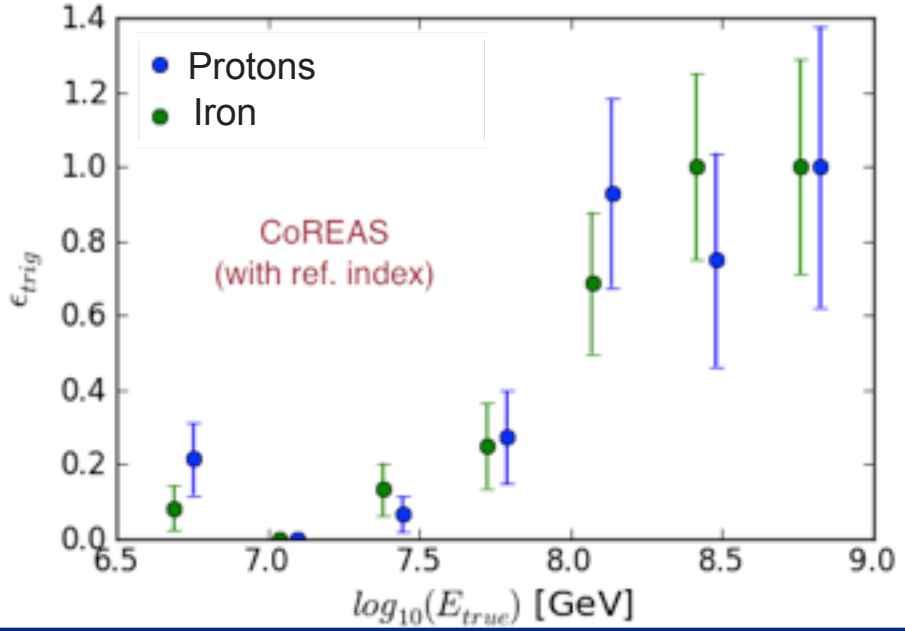
Energy threshold

- 50% efficiency value
  - ➔REAS3.0: ~35PeV
  - ➔CoREAS: ~100PeV
- need to simulate refractive index for dense array geometry close to X_{max}

Event rates

- decrease by $(100/35)^{-2.7} \sim 0.06$
  - ➔coincidence rate does not





Outlook

Radio detection of air showers at South Pole

- complements existing methods
- enhances the sensitivity
- decrease the systematic uncertainties

Exploratory studies @ ARA

- very good / well-understood noise conditions
- working antenna design

Radio Air-Shower Test Array

- threshold ~$10^{16.5\text{-}17}$ eV
- promising simulation results

  ➔ proposal for Radio Air-Shower Test Array (RASTA)

  - twice declined by NSF

RASTA is *ON* ice (rather than *ON THE* ice)

ARA efforts continue

ARA testbed full bandwith