ARA
The Askaryan Radio Array

A new instrument for the detection of highest energy neutrinos.

Hagar Landsman, UW Madison

High energy neutrinos….Why ?

There is a high energy universe out there we know very little about!

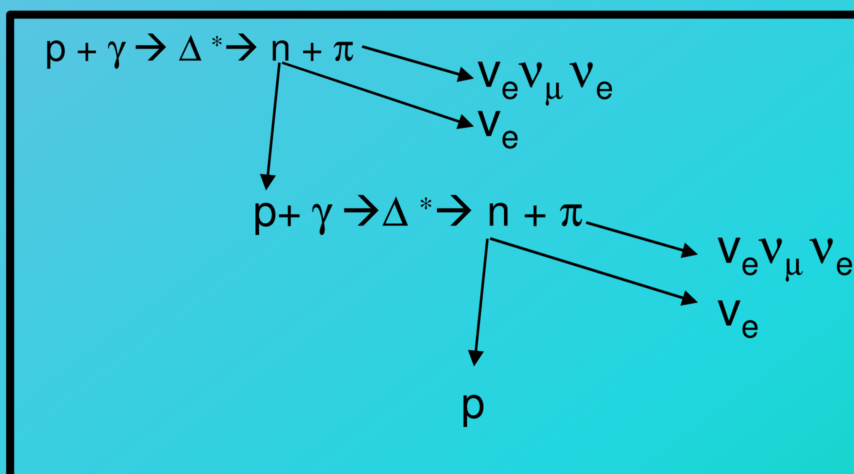
HE Neutrinos are expected to be produced together with photons and protons through pions decay.

- Neutrinos add complimentary information to gamma astronomy
- With neutrinos we can look further away

Cosmic rays with energies of more than 10^{20} eV were observed. Their source, or acceleration mechanism are unknown.

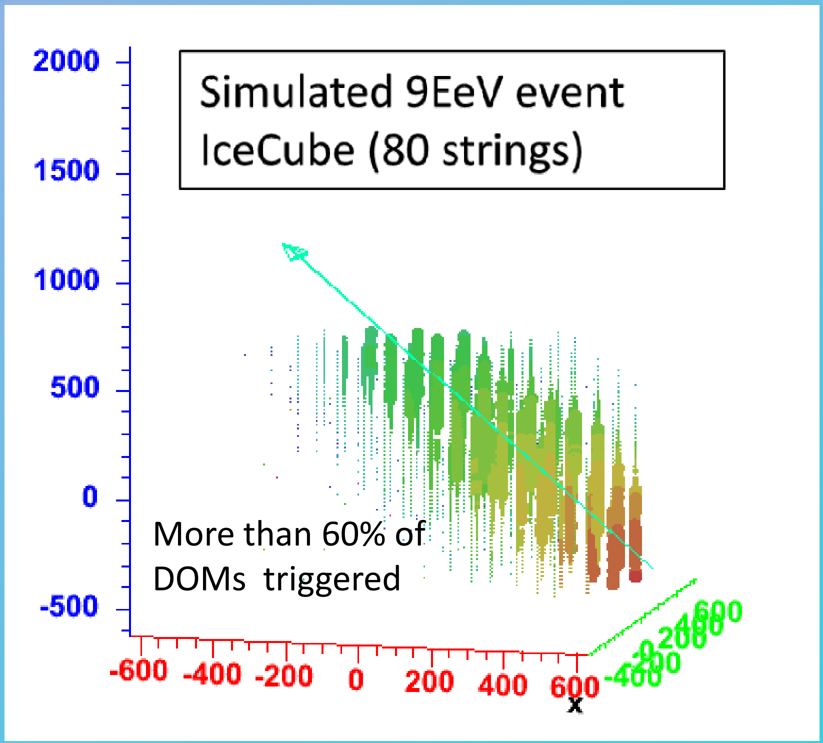
Sufficiently energetic Cosmic rays interact on photon background and loose energy

- No energetic CR from large distances (>50MPc)
- Flux of neutrino : “Guaranteed source”



Why not Build a Larger IceCube?

IceCube can detect cosmogenic neutrinos, but not enough of them …



Current IceCube configuration:

Effective area:

~0.1 km^2 (1 PeV) - ~2km^2 (100 EeV)

Yields less than 1 cosmogenic event/year

Making IceCube bigger is an option:

Some geometry optimization is possible, though:

- Still need dense array scattering
- Still need deep holes for better ice

Any additional string will cost ~1M $*

(See Christopher Wiebusch talk this session)

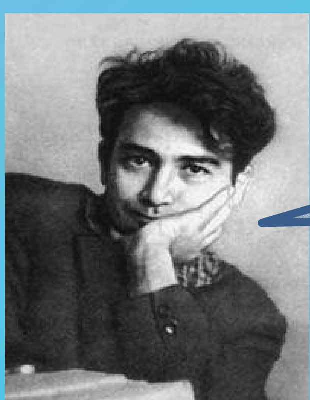
*Rough estimation, Real cost will likely be higher

A larger detector requires a more efficient and less costly technology.

Solution: Use Cherenkov photons in RF

- Longer attenuation length in ice ➔ larger spacing ➔ less hardware
- Less scattering for RF In ice.
  - Cherenkov radiation pattern is preserved
  - Don't need many hits to resolve direction
- No need to drill wide holes
- Better ice at the top. No need to drill deep.
- Antennas are more robust than PMTs.
- The isolated South Pole is RF quite and
- Any EMI activity is regulated
- Deep ice (2.5km) contributes to effective volume
- It is easy to detect RF

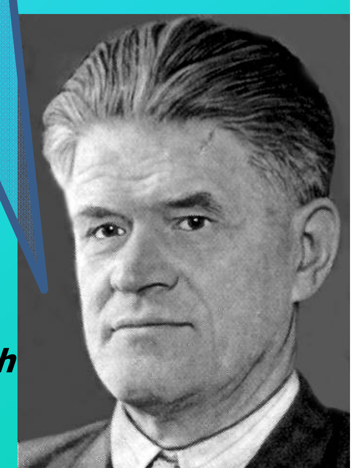
Remember: Less photons are emitted in longer wave length.
Smaller signal in the radio frequencies….



But for high energy cascades this RF radiation becomes coherence and enhanced "Askaryan effect"

Gurgen Askaryan (1928-1997)

Pavel Alekseyevich Cherenkov (1904-1990)



Askaryan Effect Heritage

RICE   Radio Ice Cerenkov Experiment
Array of single dipole antennas deployed between 100 and 300m near the South Pole, covered an area of 200m x 200m. (mostly in AMANDA holes)
Used digital oscilloscope on surface for data acquisition

ANITA ANtarctic Impulsive Transient Antenna :
surveys the ice cap from high altitude for RF refracted out of the ice
(~40 km height of fly, ~1.1M km^2 field of view)

IceCube Radio
Co deployed with IceCube at 30m, 350m and 1400 m. Full in ice digitization.

The Askaryan effect Was measured in a special SLAC experiment .
Extensive simulation of the radiation cone exist, and predictions are in agreement with the measurement.

South Pole Heritage

Obviously the people involved know what they are doing !

The Game Plan

Establish cosmogenic neutrino fluxes → Resolve Energy Spectrum → Neutrino direction Reconstruction → Flavor analysis / Particle physics

Small set of well established events. Coarse energy reco

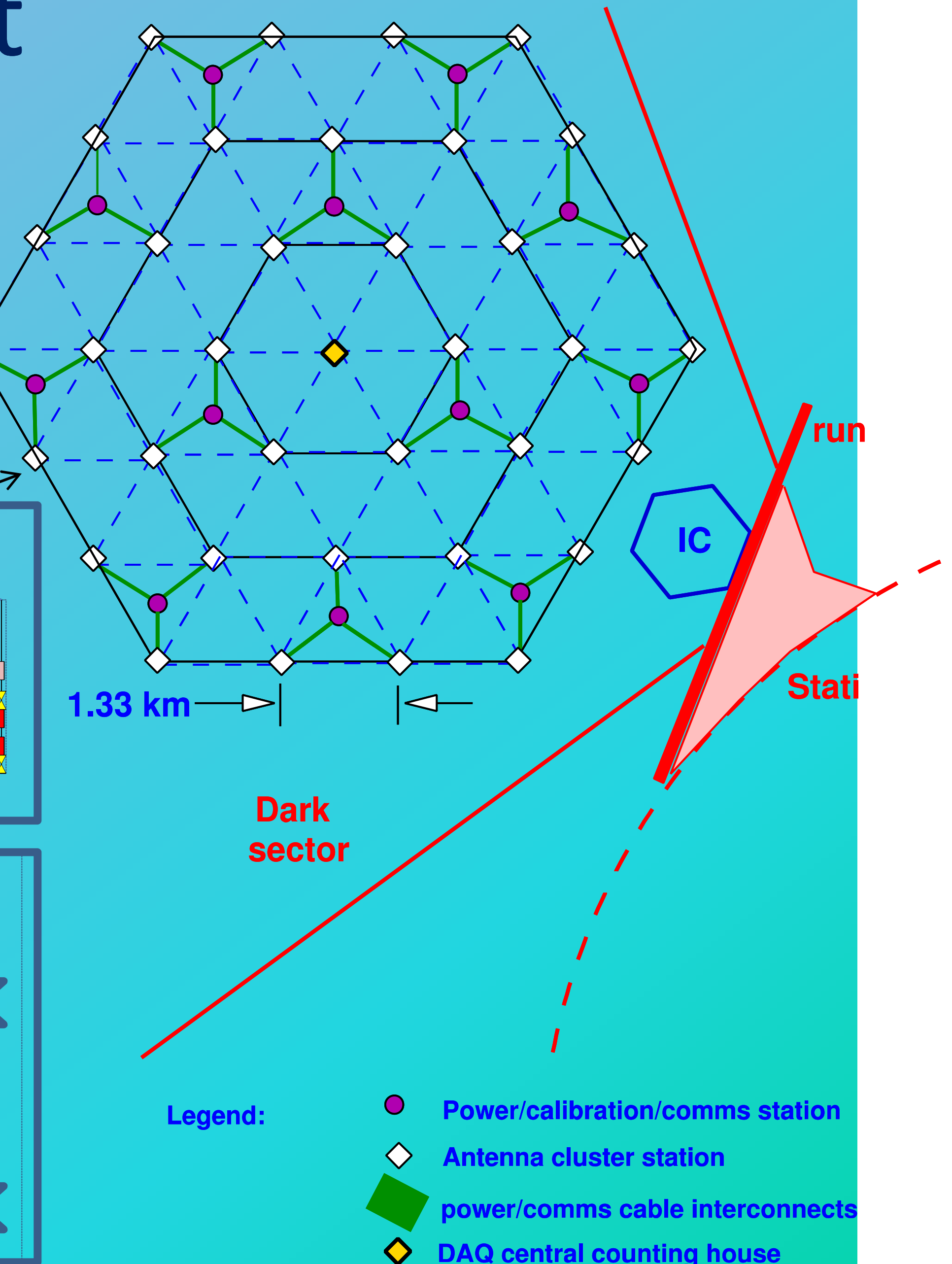
Energy reconstruction by denser sampling of each event

Angular resolution of less than 0.1 rad

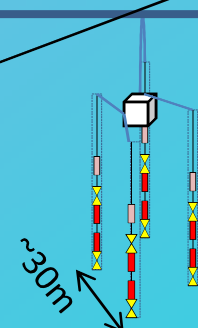
~10 — Events/year — ~1000

ARA Concept

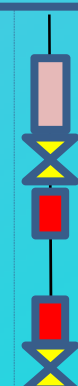
- 80 km^2 area
- 37 stations equally spaced on a triangular grid
- Large separation between stations (1.3km)
- 3 stations forms a “super cluster”
  Sharing power, comms, and calibration source



Station:
- 4 closely spaced strings
- 200m deep
- Digitization and Triggering on surface



String:
- 4 antennas, V-pol and H-pol
- Designed to fit in 15cm holes
- 150-800 MHz sensitivity
- Cable pass through antenna



ARA Concept

The goal is to count events, not reconstruct the angles as would be needed for observatory class instrument

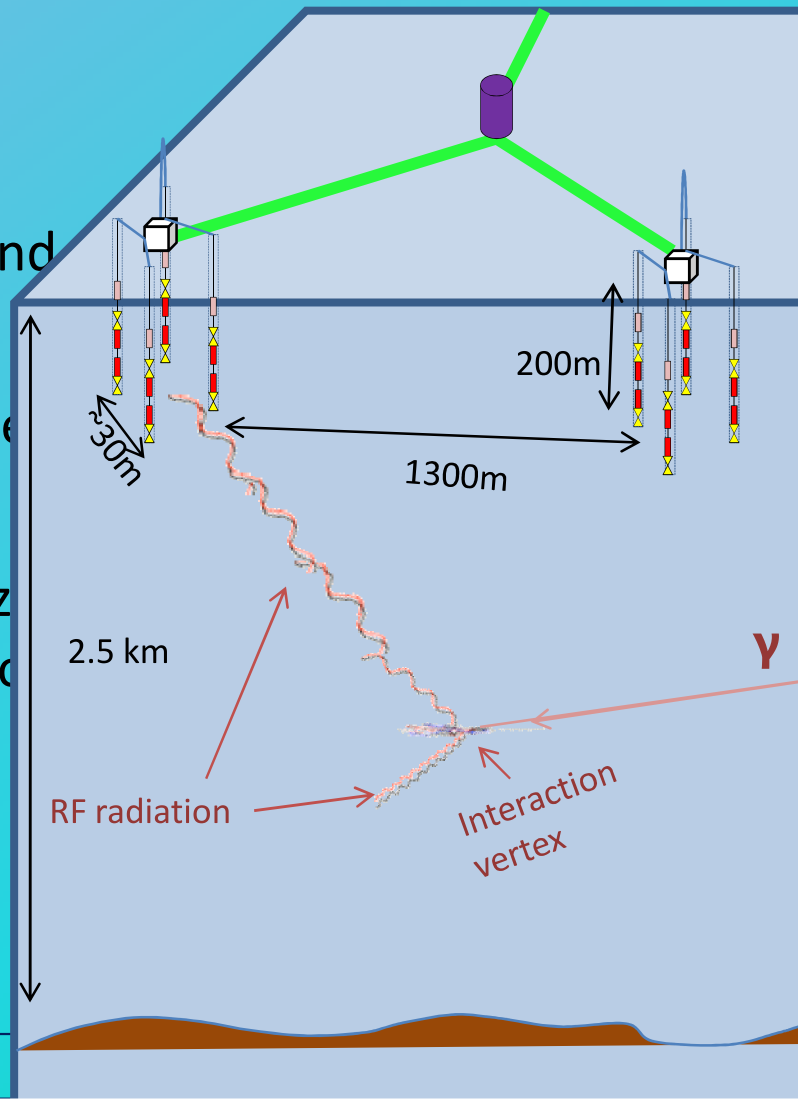
Optimized for neutrino counting:

a single station can provide and form a trigger

- Decreases trig time window, lower background and therefore thresholds.
- Lowers the energy threshold - lowest energie dominated by single string hits

Detecting down-going events: +45 above horiz
(4.4sr) - 5 below horizo

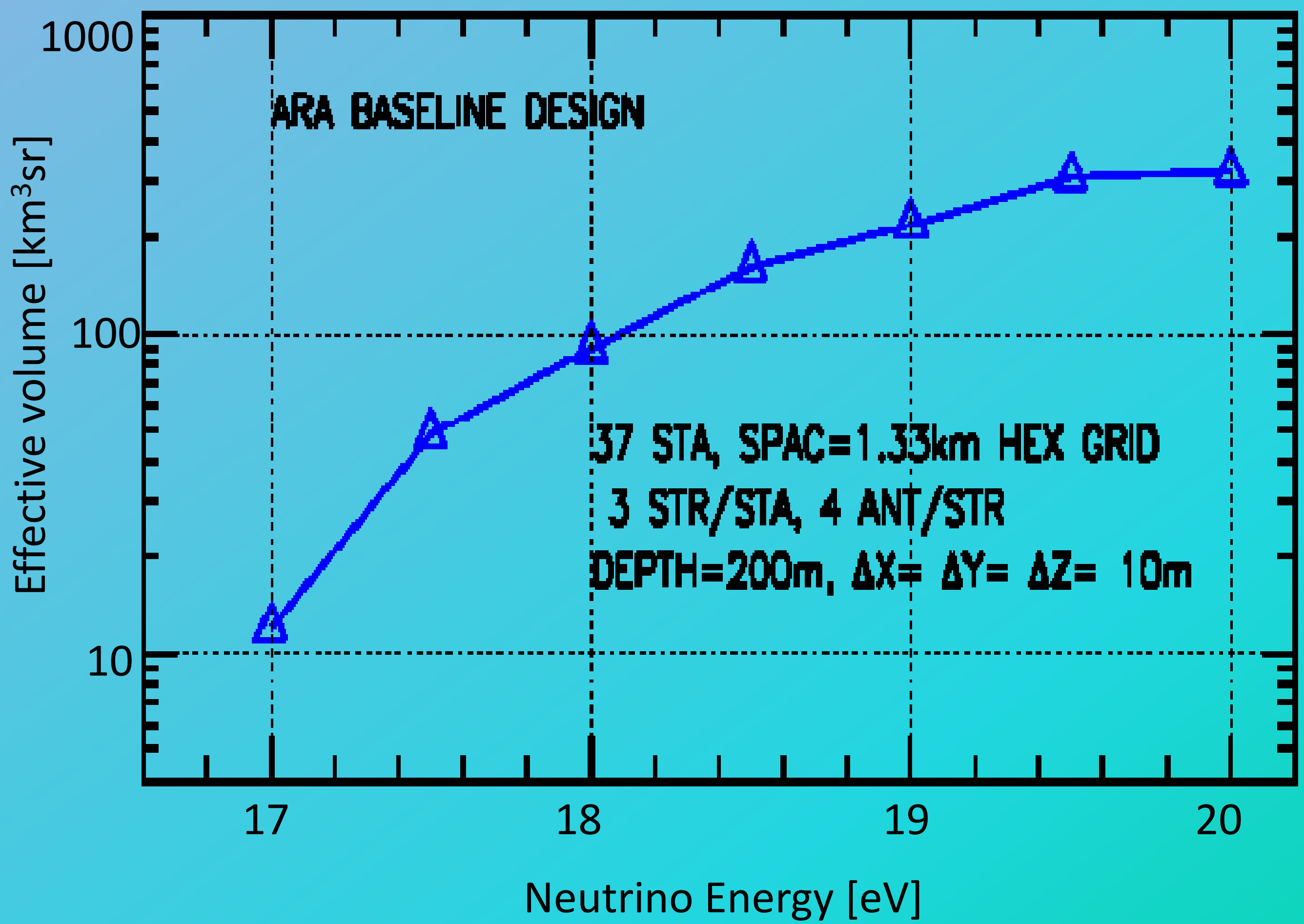
Deep ice contributes in higher energies



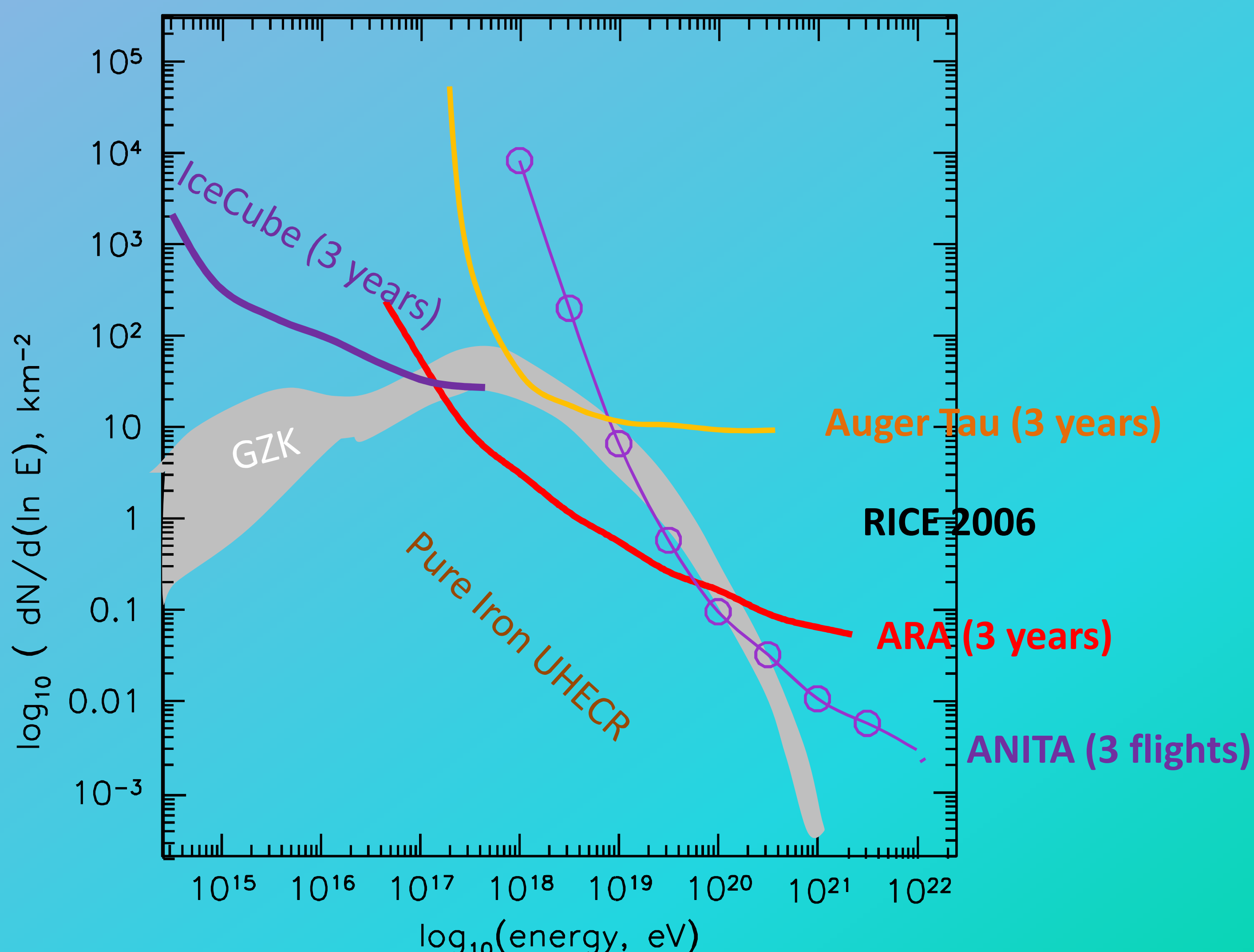
ARA expected performance

Effective volume

Ongoing simulation studies to optimize detector geometry, and make the best use of the 2.5km ice target.



ARA expected performance
detector sensitivities



ARA expected performance

Reconstruction

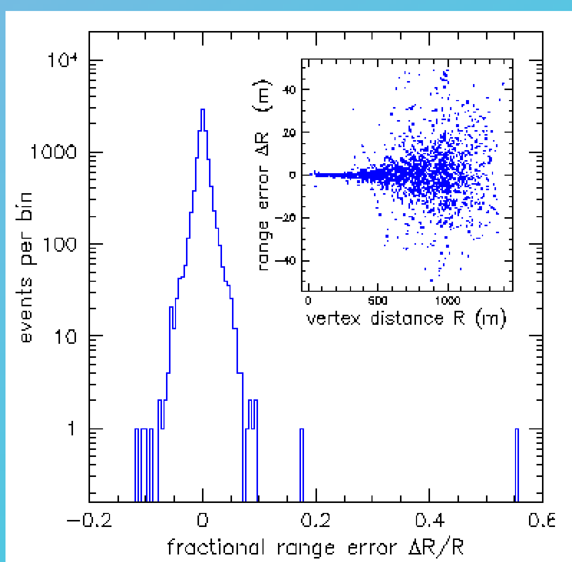
Vertex reconstruction :

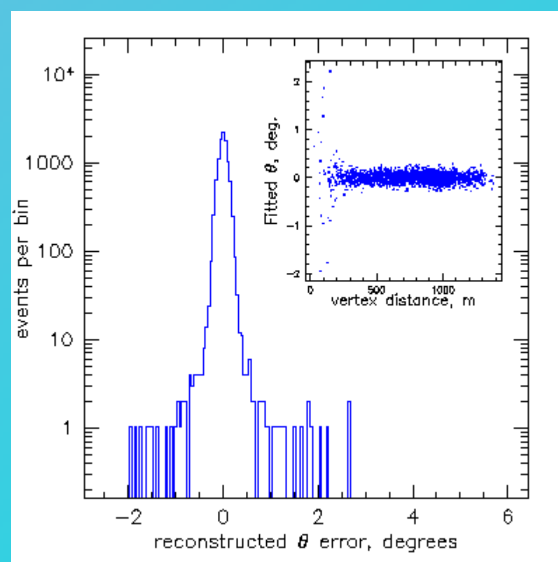
Using timing information from different antennas.

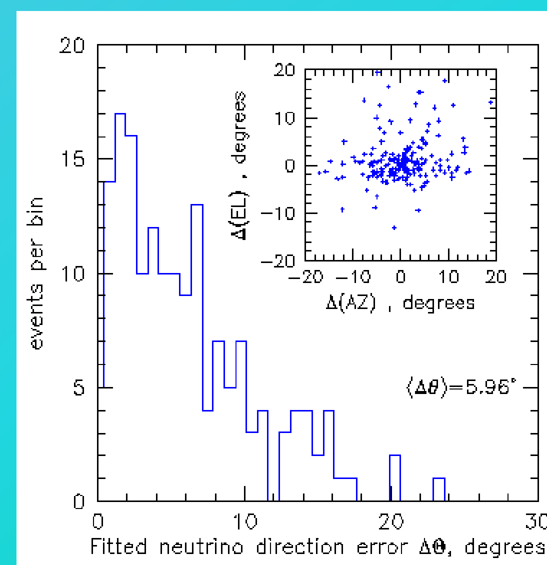
- Distance to vertex (for calorimetry)
- Location of Vertex (Background rejection)

Neutrino Direction and Energy:

Combining amplitude and polarization information with Cherenkov cone models.
ARA is not optimized for this. Simulated Angular resolution: ~6°







ARA - A New collaboration was born

NSF Grant
"Collaborative Research: MRI-R2 Instrument Development of the Askaryan Radio Array, a Large-scale Radio Cherenkov Detector at the South Pole"
phase 1 funded

More than 10 institutions from US, Europe, Taiwan, Japan
Including IceCube & ANITA & RICE leading institutes.

Growing collaboration.

Strong interests from others (Australia, Israel)

Regular collaboration meetings (and phone calls)

http://ara.physics.wisc.edu

Phase 1: 3 years plan

<u>Large array challenges:</u>

- Power source
- Power and communication distribution
- Drilling (size, depth, drilling time)
- EMI

2010-2011

☑ Install testbed

- ➢ EMI survey away from the station
- ➢ Test ice properties
- ➢ Begin testing station prototypes

☑ Calibration activities

- ➢ Install 3 deep RF Pulsers

☑ Conduct Drilling tests

☑ Install 3 Wind turbines for testing

2011-2012

❑ Install ARA in ice station

❑ Install Power/comm hub

2012-2013

❑ Install ARA in ice station

❑ Install autonomous Power/comm hub

This season's on ice achievements

ARA Test Bed

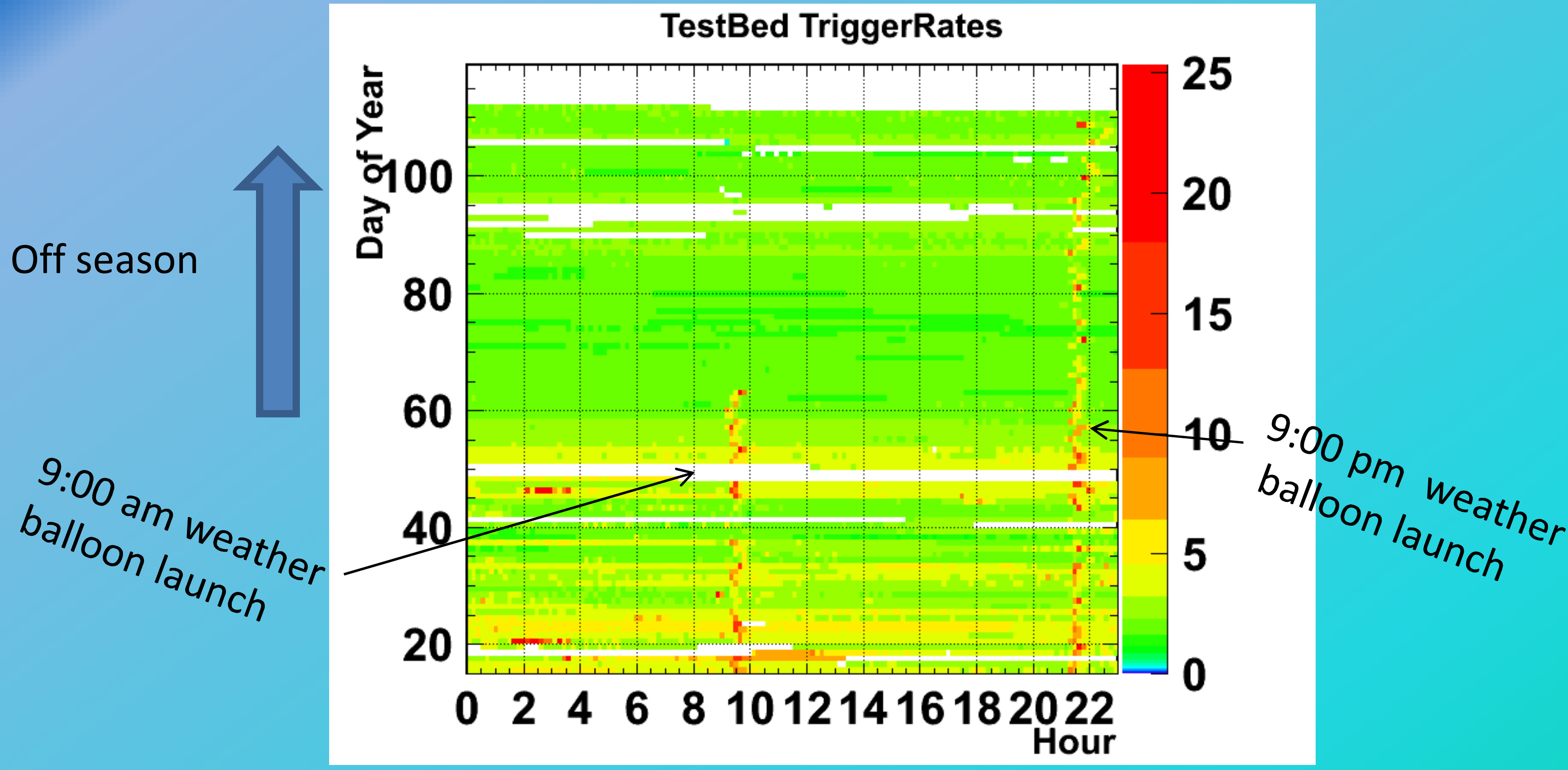
- Successfully installed ~1.6 km away from the South Pole station.
- 16 antennas at different depths, down to ~20m.
- Signal digitization and triggering happens on a central box on the surface.
- Power and comms through cables.

<u>Current status:</u>

- Detector is up and running. Data coming in.
- Very high efficiency and live time.
- No unexpected EMI source.
- Up to now, no evidence for wind generated EMI
- Timing resolution of ~100ps .

This season's on ice achievements

ARA Test Bed – Trigger rates

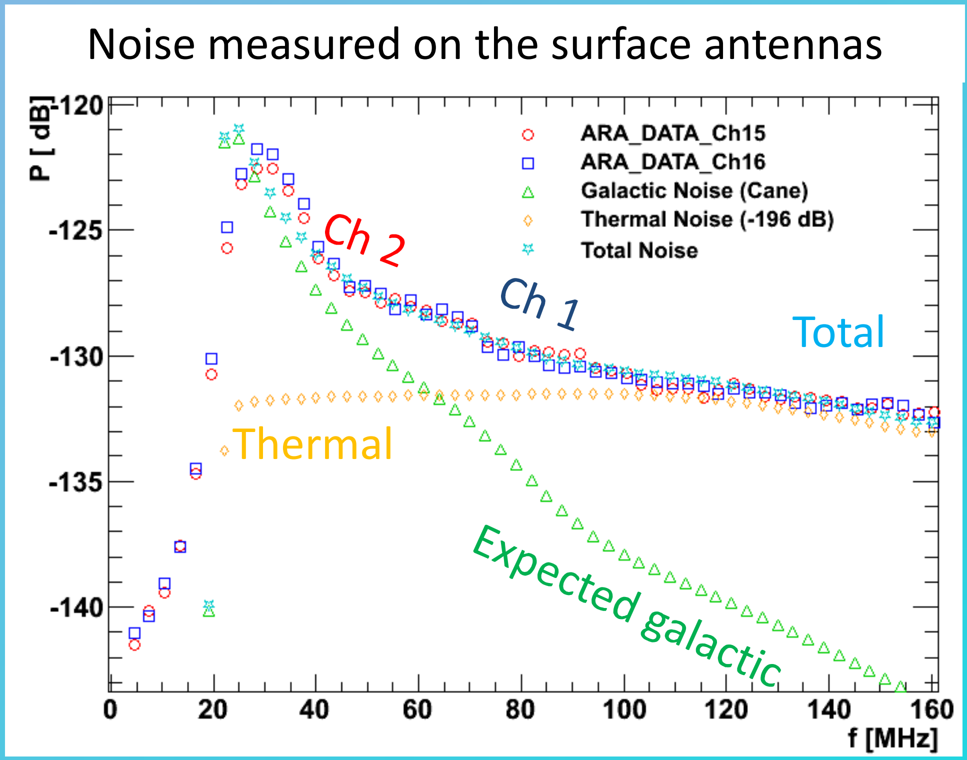


- Test Bed is taking data continuously
- Trigger rates are low and stable – below 4 Hz (out of which 1.5Hz calib)
- Clear winter/summer rate change
- Weather balloon launches CW clearly seen

This season's on ice achievements

ARA Test Bed – Galactic center

Larissa Paul

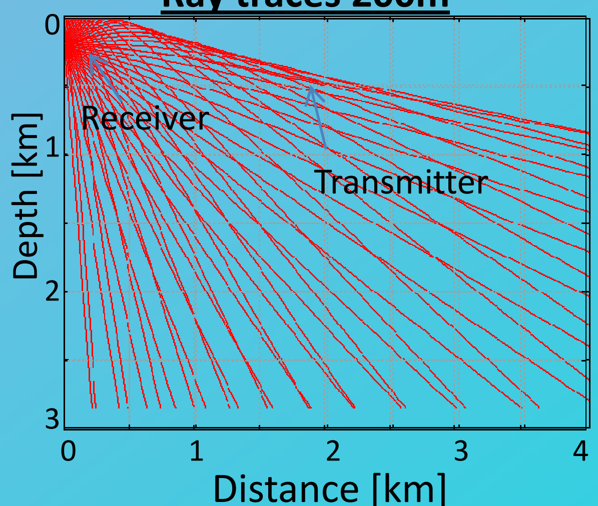


- Data from January 18 to April 14
- Using two surface antennas
- Galactic noise clearly seen

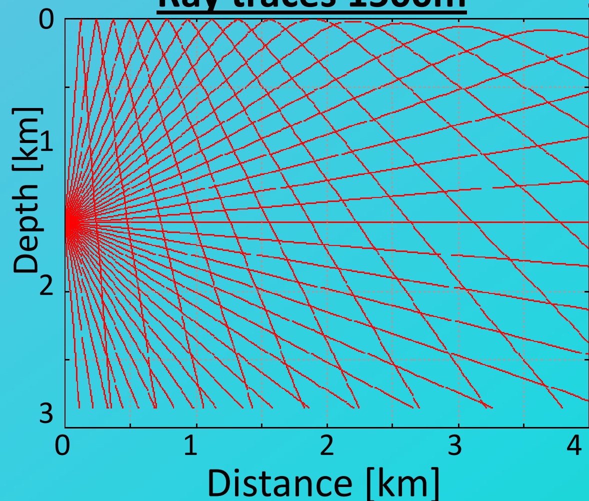
This season's on ice achievements
Deep pulsers on IceCube strings

- Blind spots due to ray tracing. The deeper we get the larger the horizon is.
- This was the last access to deep holes.
- 3 high voltage calibration transmitters installed on IceCube strings.
- 2 at 1450 m ("shallow") and 1 at 2450 m ("deep").
- Azimuthally symmetric bicone antenna -eliminates systematics from cable shadowing effects
- Goals: radio glaciology and calibration

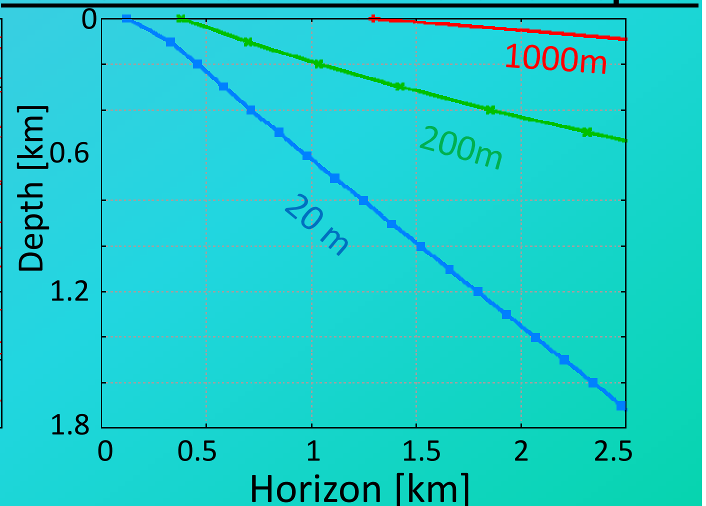
Ray traces 200m



Ray traces 1500m



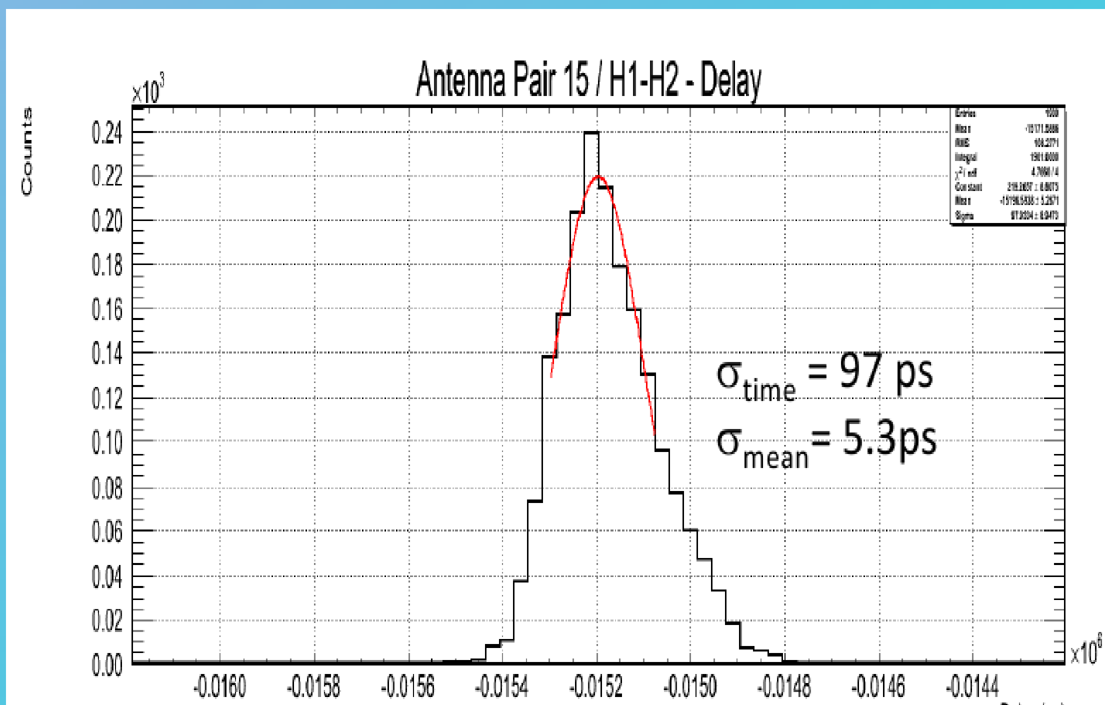
Horizon for 3 different receiver depths

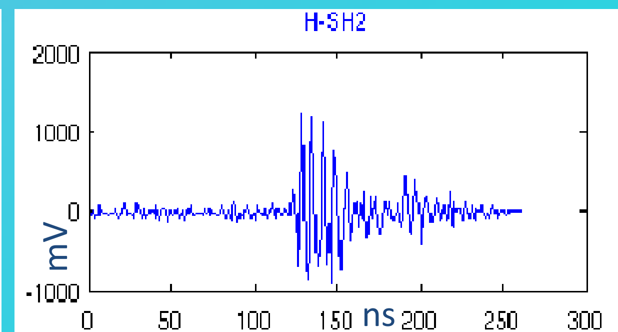


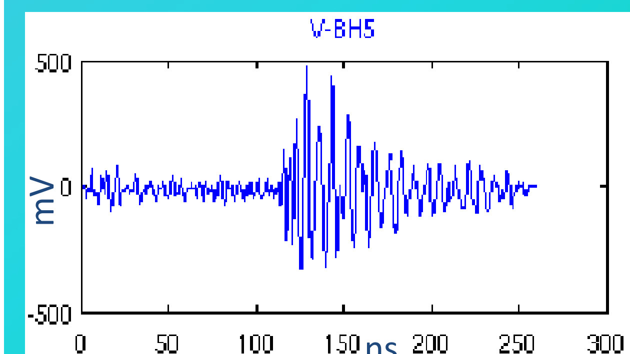
This season's on ice achievements

Deep pulsers on IceCube strings

- Deep (2450m) pulser seen by all antennas in the ARA testbed!
- Testbed is a horizontal distance of ~1.6 km away- total distance 3.2 km.
- Points to an attenuation length of >700m (analysis ongoing).







This season's on ice achievements

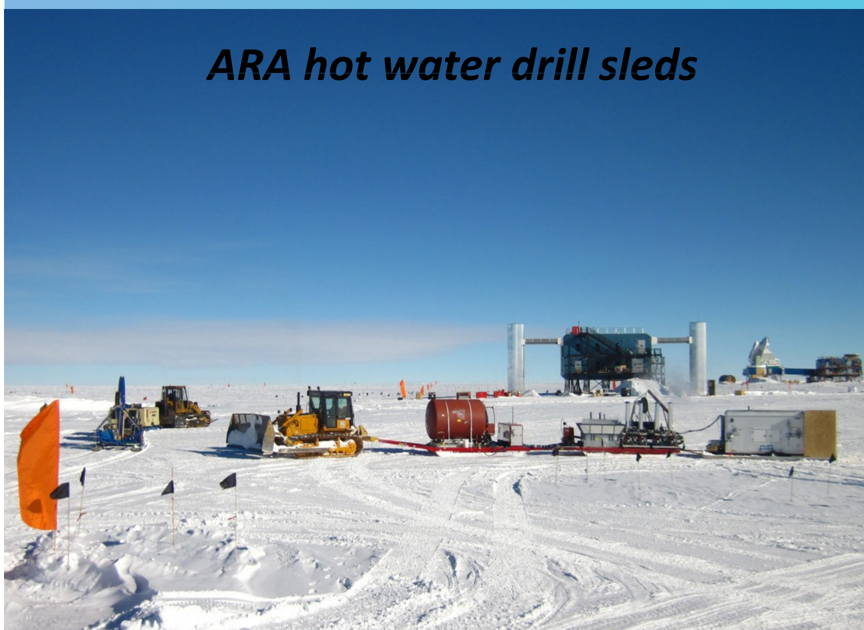
Drill Test 1 : Rapid Air Movement

- Cutter head drill hole-shavings extracted using compressed air
- Extra compressors required at SP altitude
- Lots of cargo to get it to the Pole
- Dry, 4 inch hole
- Deepest holes achieved: ~60 m in less than 1 hour.
- Limited by air pressure leakage through the firn

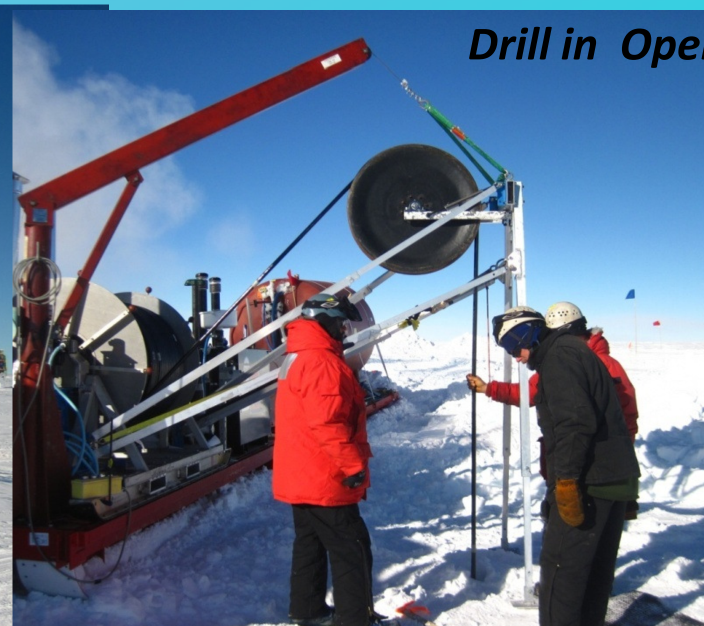
This season's on ice achievements

Drill Test 2 : Hot water drill

- Carried on three sleds pulled by tractor
- 0.5 – 1m per minute / 200m in ~1/2 day
- 6" hole
- Wet hole- must be pumped out or electronic made watertight
- Deepest holes drilled in 10/11: ~160 m



ARA hot water drill sleds



Drill in Operation

This season's on ice achievements

Wind Turbines

- *Three different turbines were installed.*
- *Measuring and comparing wind speed, power yield.*
- *Weather effect to be evaluated next summer.*

Summary

• A collaboration has been formed to build an englacial array large enough to detect cosmogenic neutrinos

• An array concept has been proposed. The first phase funded.

• Fine tuning of instrumentation and detector spacing to be optimized during the development phase

• Successful first South-Pole season

• Facing several challenges in building and operating a large scale detector such as power distributions and fast drilling.

• Work has commenced in preparation for the next season

• Eventual large scale array will determine cosmogenic neutrino flux and tackle associated long standing questions of cosmic rays.

Many thanks to those who drilled, built, wrote, trenched, dag, checked, debugged, shoveled, drove, tested, carried, installed, submitted and resubmitted.

Backup

Antennas design:

- 150-850 MHz
- Designed to fit in 15cm holes
- Azimuthal symmetric

Cables pass through antenna. No shadowing.

This is the perfect time

Askaryan and Simulation

South Pole
Ice Studies
N(z), Atten

Askaryan effect
characteristics

South Pole
EMI/RF environment

Ice Drilling

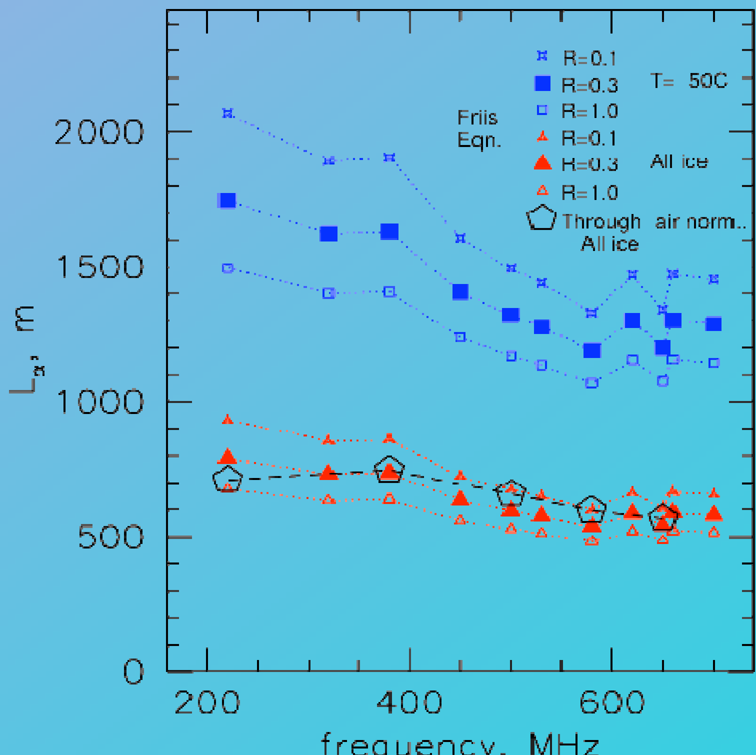
Polar operation

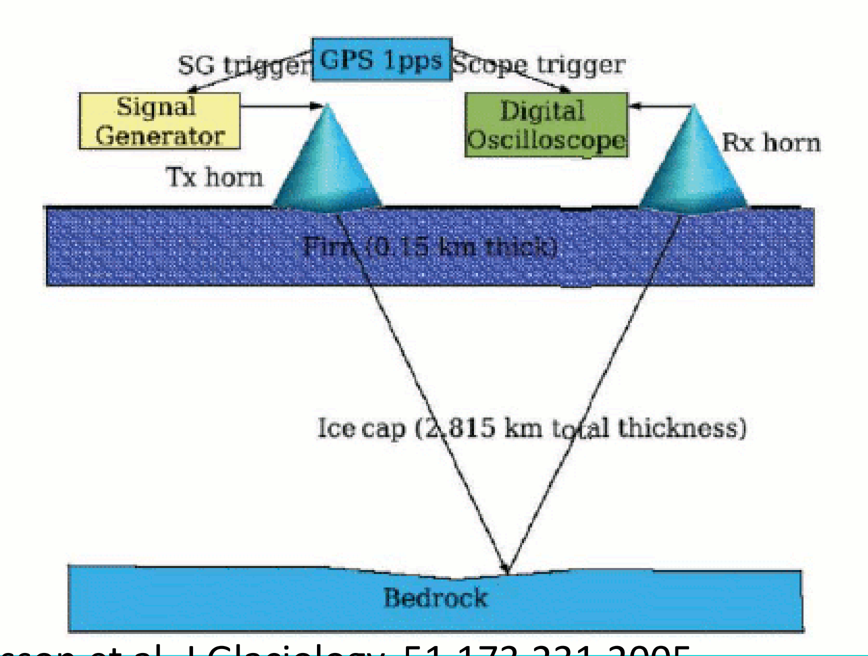
In ice electronics and
hardware design

In ice electronics and
hardware design

Ice Properties: Attenuation length

- Depends on ice temperature. Colder ice at the top.
- Reflection Studies (2004) (Down to bedrock, 200-700MHz): "normalize" average attenuation according to temperature profile.





Besson et al. J.Glaciology, 51,173,231,2005

- 2 on going "point to point" analyses using NARC/RICE and the new deep pulse.

Askaryan effect

Neutrino interact in ice
→ showers
→ Many e^-, e^+, γ
→ Interact with matter
→ Excess of electrons
→ Cherenkov radiation
→ Coherent for wavelength larger than shower dimensions

$$dP_{CR} \propto \nu d\nu$$

Moliere Radius in Ice ~ 10 cm:
This is a characteristic transverse dimension of EM showers.
$\lambda << R_{Moliere}$ (optical), random phases $\Rightarrow P \propto N$
$\lambda >> R_{Moliere}$ (RF), coherent $\Rightarrow P \propto N^2$

Hadronic
EM

Vast majority of shower particles are in the low E regime dominates by EM interaction with matter

Less Positrons:
Positron in shower annihilate with electrons in matter $e^+ + e^- \rightarrow \gamma\gamma$
Positron in shower Bhabha scattered on electrons in matter $e^+e^- \rightarrow e^+e^-$

More electrons:
Gammas in shower Compton scattered on electron in matter $e^- + \gamma \rightarrow e^- + \gamma$

Charge asymmetry: 20%-30% more electrons than positrons.

Measurements of the Askaryan effect

- Were preformed at SLAC (Saltzberg, Gorham et al. 2000-2006) on variety of mediums (sand, salt, ice)
- 3 Gev electrons are dumped into target and produce EM showers.
- Array of antennas surrounding the target Measures the RF output

Results:

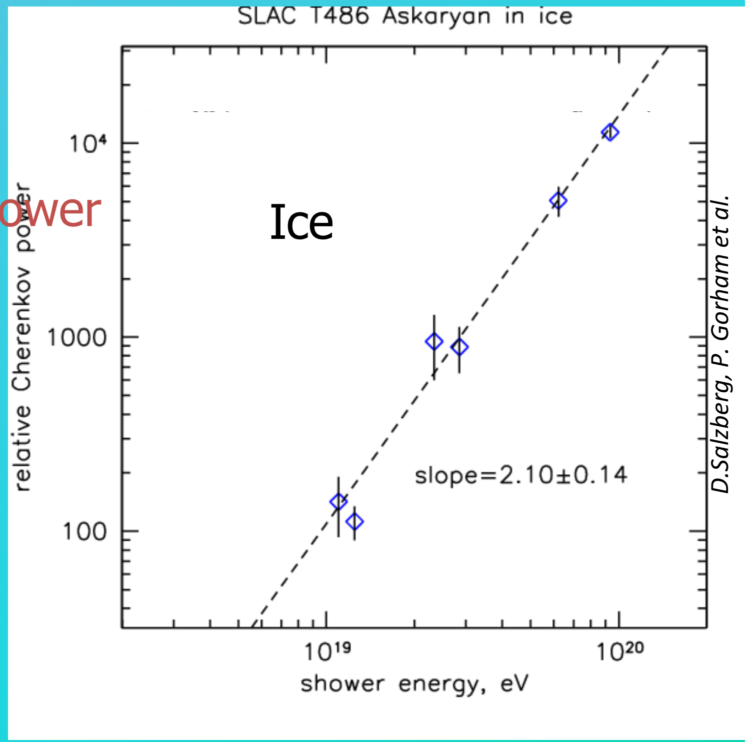
✓ RF pulses were correlated with presence of shower

✓ Expected shower profiled verified

✓ Expected polarization verified (100% linear)

✓ Coherence verified.

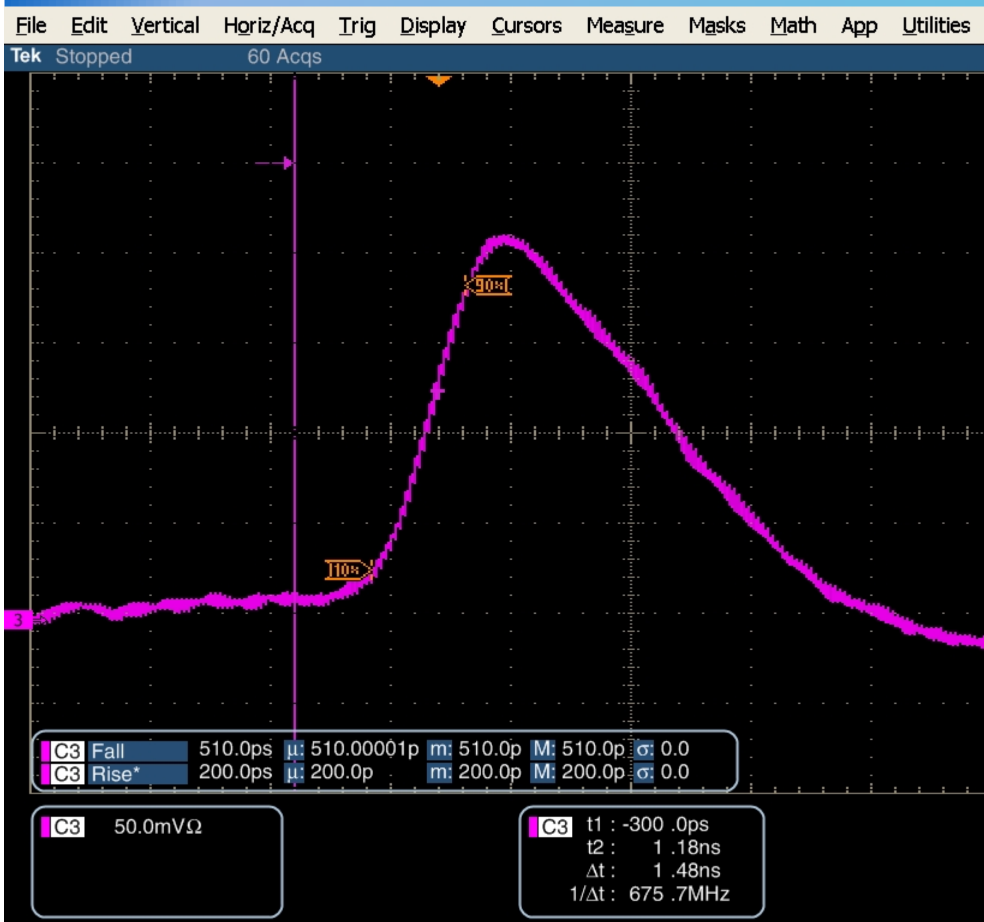
✓New Results, for ANITA calibration – in Ice



PHYSICAL REVIEW D 74, 043002 (2006)

experimental results

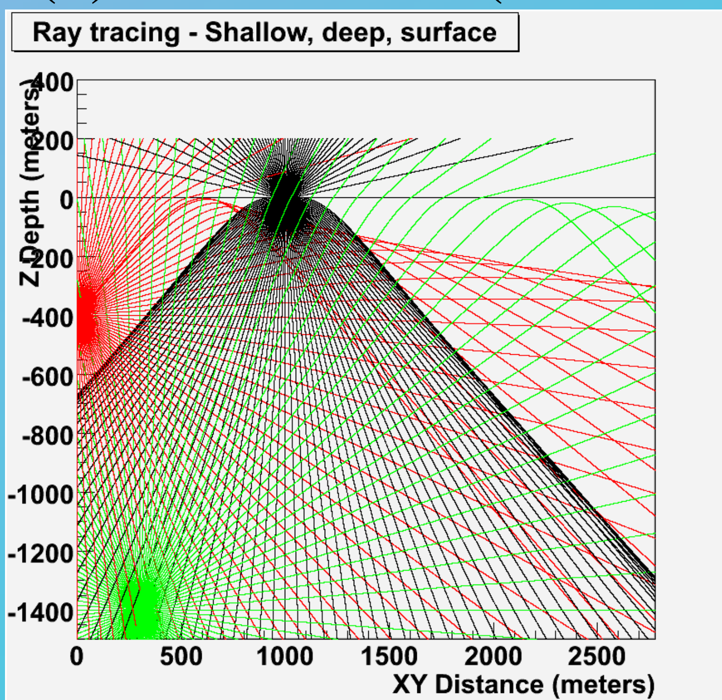
Deep pulser installation

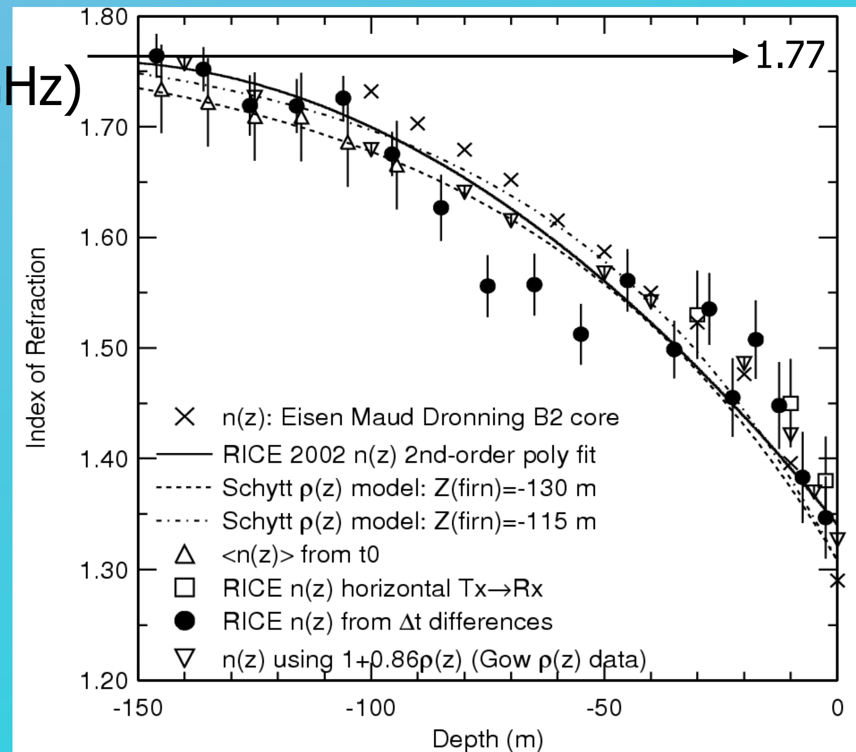


Ice Properties: Index Of Refraction

- RICE Measurements
  (2004, Down to 150 m, 200MHz-1GHz)
- Ice Core Measurements
  (…-1983, down to 237 meters)

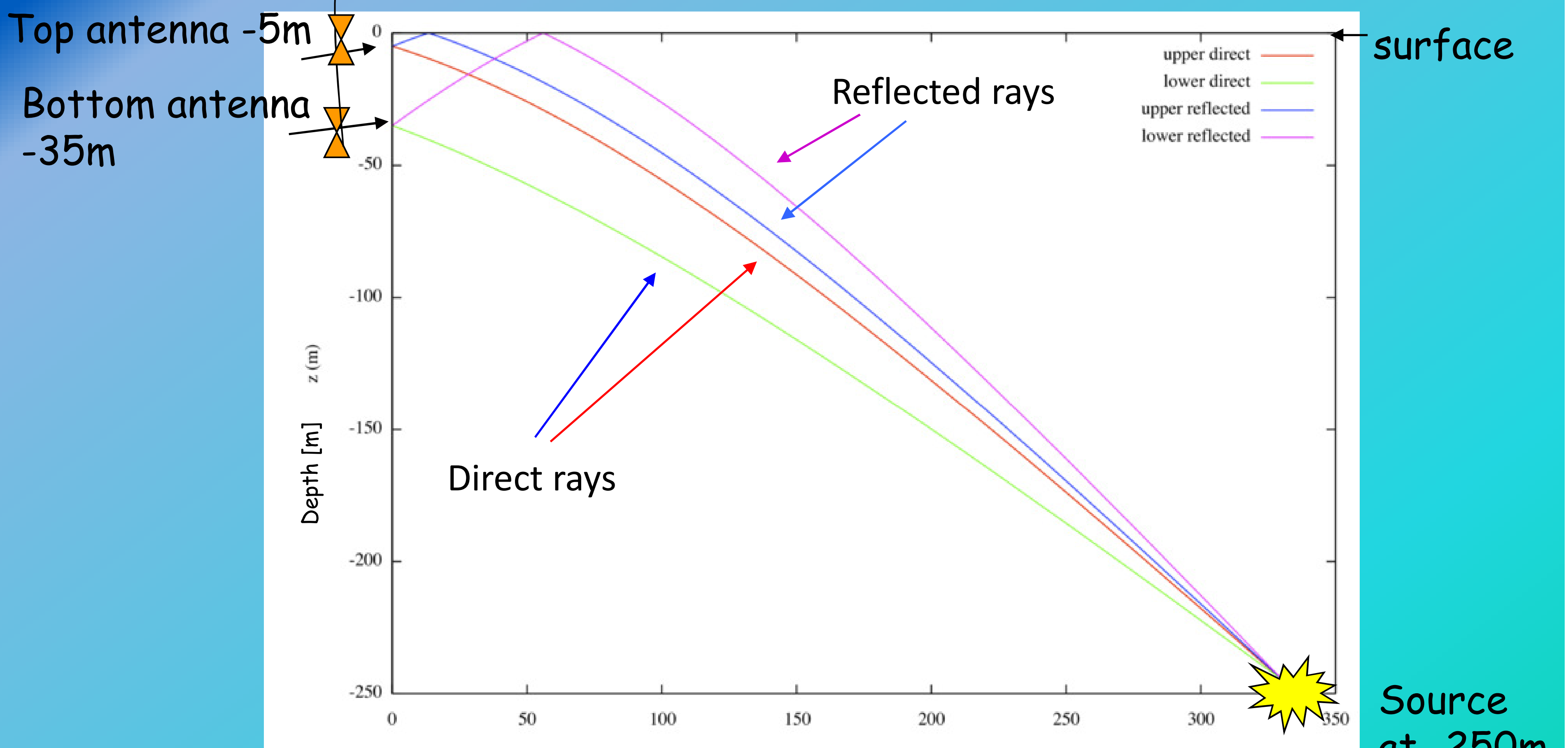
$$n(z) = 1.35 + 0.438(1.0 - e^{-0.0132Z})$$





Kravchenko et al. J.Glaciology, 50,171,2004

Ray tracing from pulser to SATRA

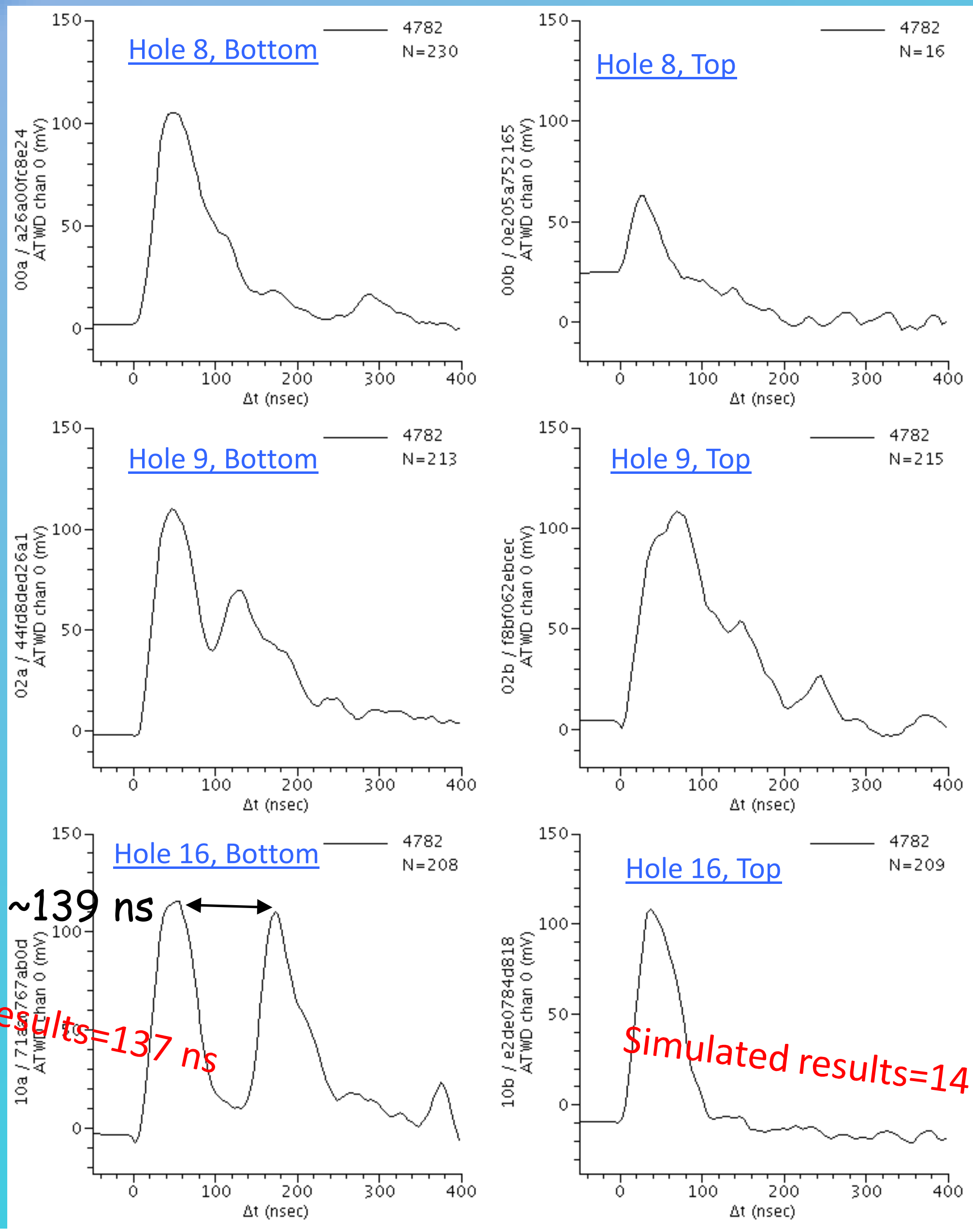


<u>Measured time differences:</u>

Time differences between direct rays

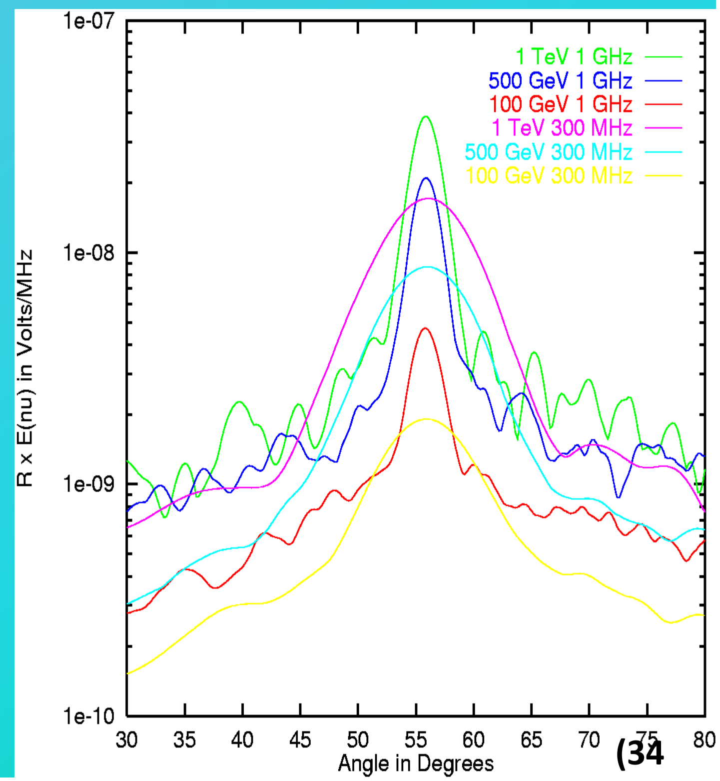
And between direct and reflected rays can be calculated

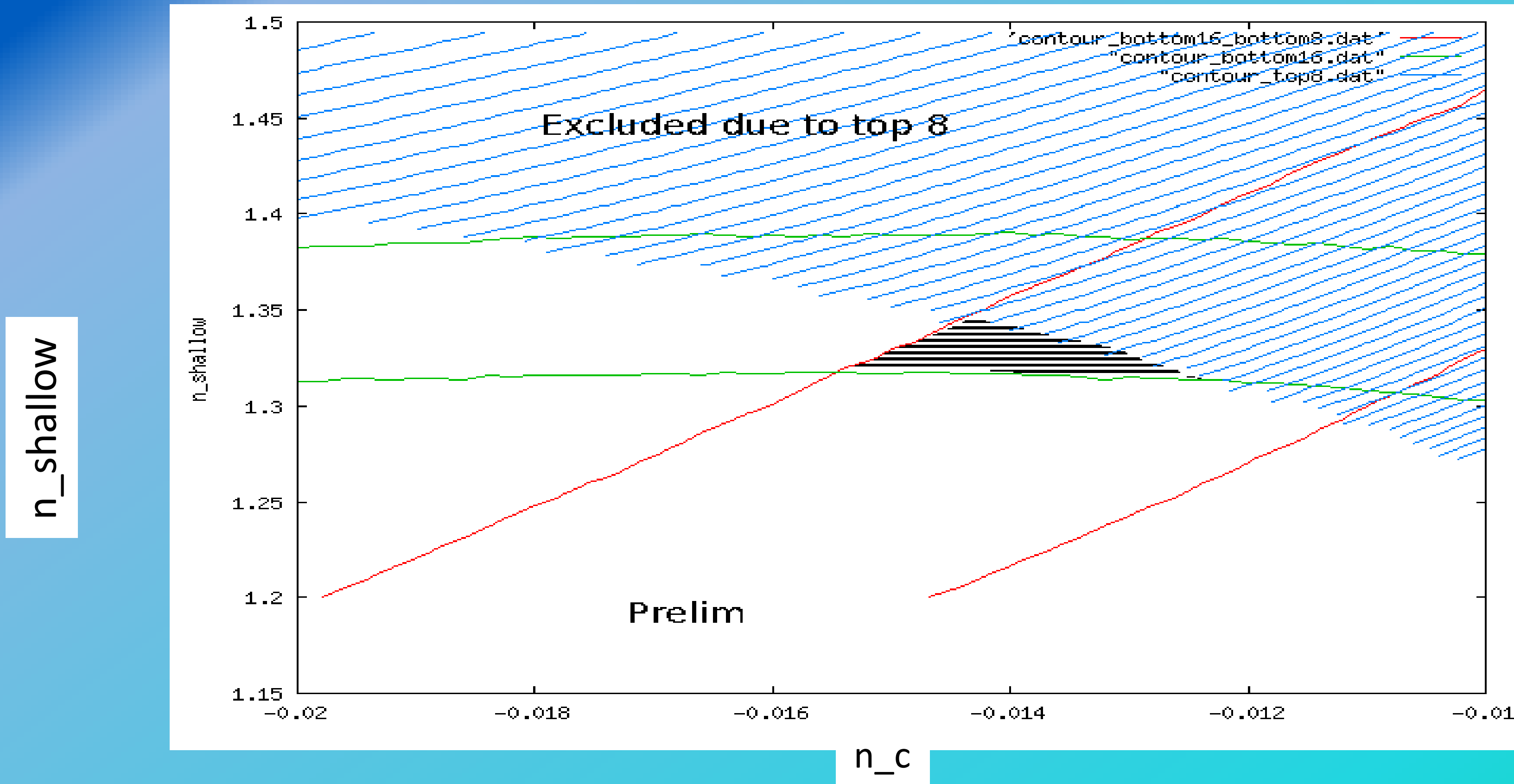
SATRA Average envelope WFs
For In Ice Pulser events



Askaryan effect is for real

- Extensive theoretical and computational modeling work exists.
- Verified in SLAC measurement
- Agreement between both





Based on set of hit time differences between antennas
and between primary and secondary hits on the same antenna,
a limit on the index of refraction model can be obtained.
Systematics taken into account: n_deep, Geometry, timing resolution, WF features