Status of radio detection R&D in Antarctica
Interplay of acoustics & radio

Klaus Helbing, Wuppertal

- IceCube-UHE detection and possible RASTA enhancement
- Existing Askaryan radio projects in Antarctica:
  RICE, AURA, SATRA
- Status of site exploration in Antarctica:
  Refraction, Attenuation, Noise/background
- Forthcoming: ARA, ARIANNA, ANITA, Westerbork
- Conclusions for design of GZK detector

EVENT RATES

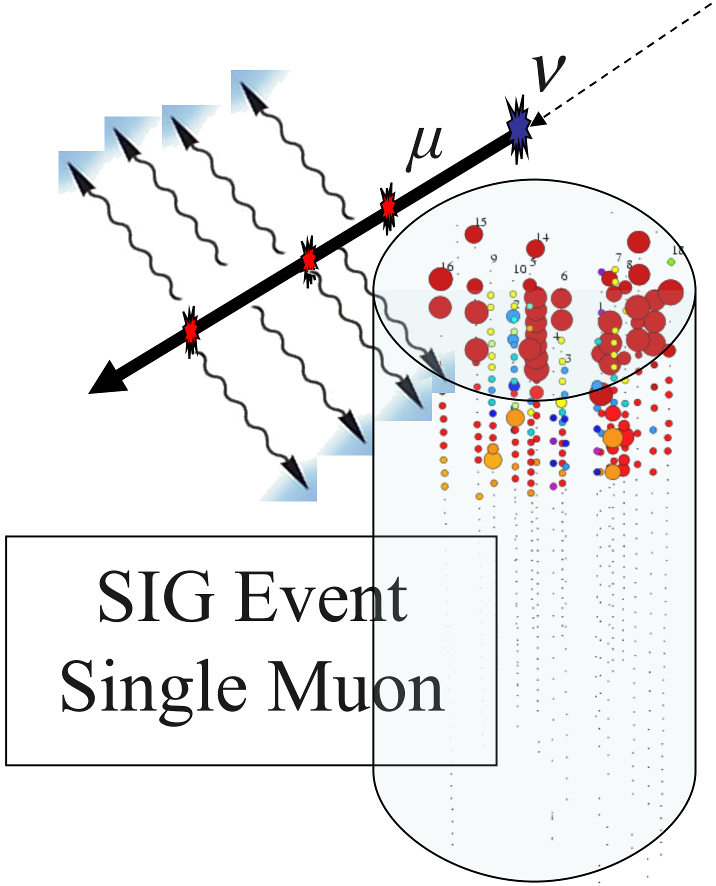
IceCube Collaboration
ICRC**2005**

Detection option	GZK events/year*)
IceCube	0.7
Optical	1.2
Radio	12.3
Acoustic	16.0
Optical+Radio	0.2
Optical+Acoustic	0.3
Radio+Acoustic	8.0
Opt.+Rad.+Acou.	0.1
TOTAL	21.1

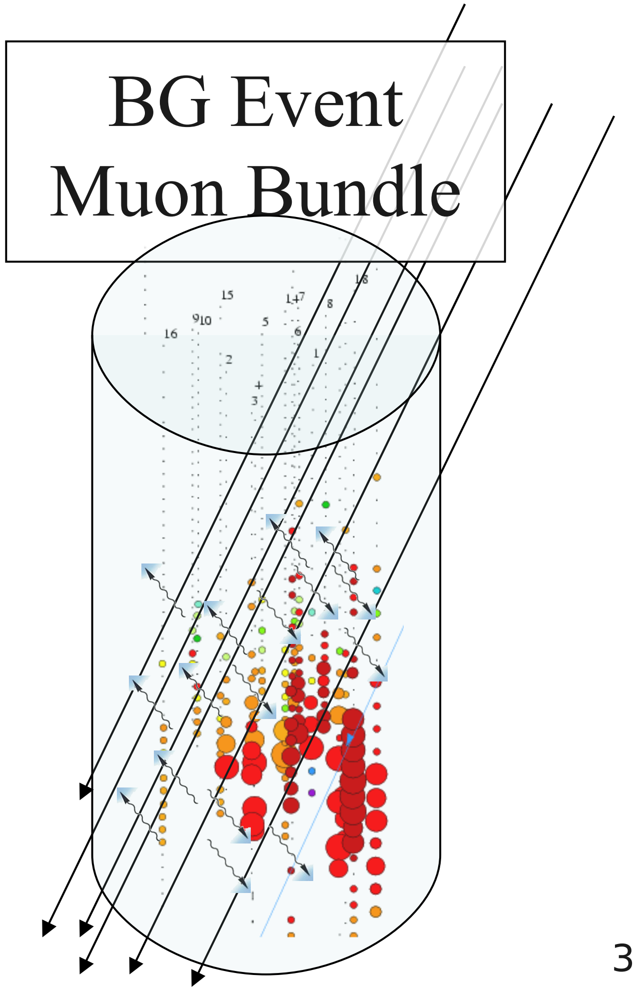
***)Numbers calculated, folding effective volumes with ESS GZK neutrino flux model with $\Omega_{\Lambda} = 0.7$**

UHE detection – **Optical**
BG & SIG Signatures

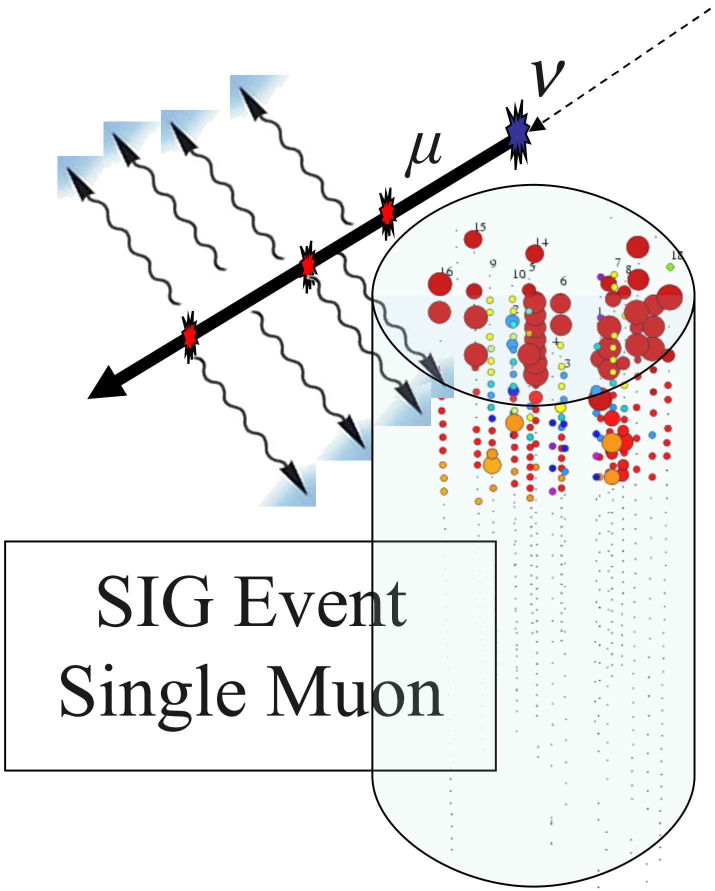
< ~ 1 GZK/yr

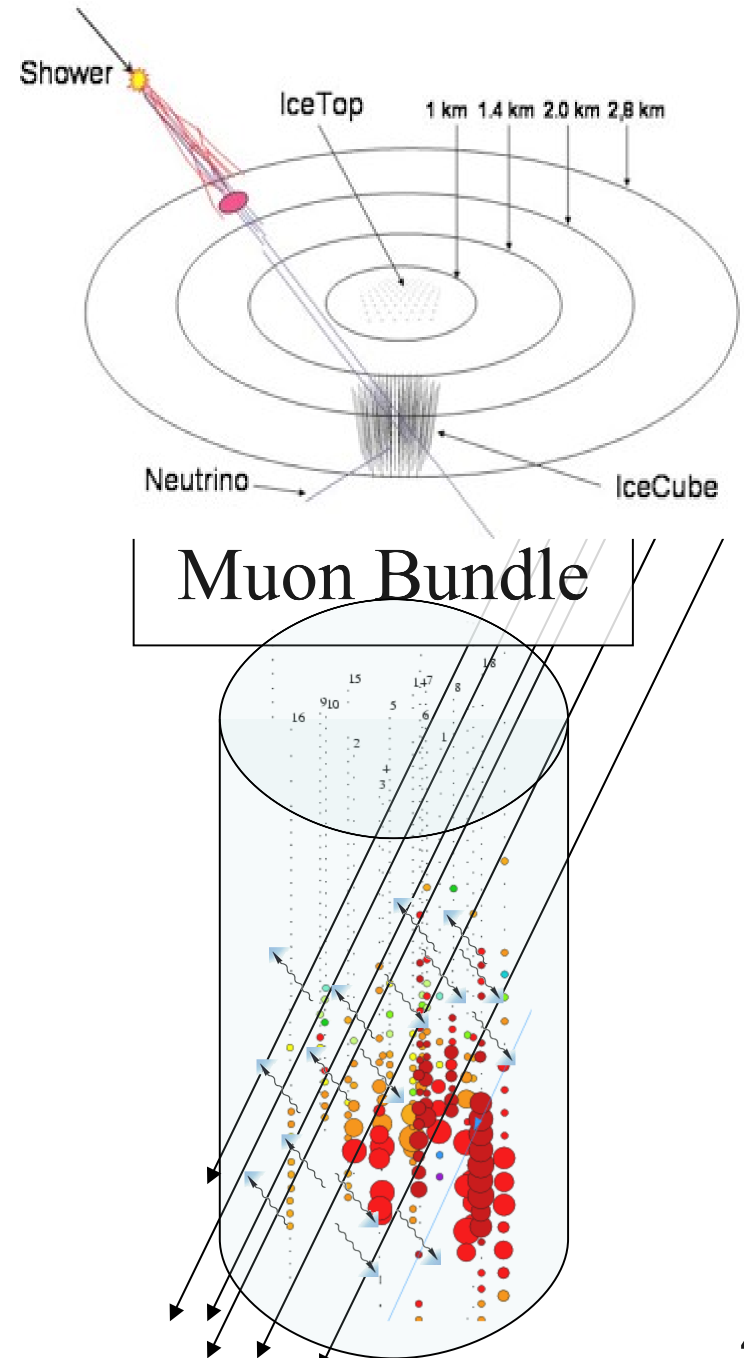


Very similar signatures!

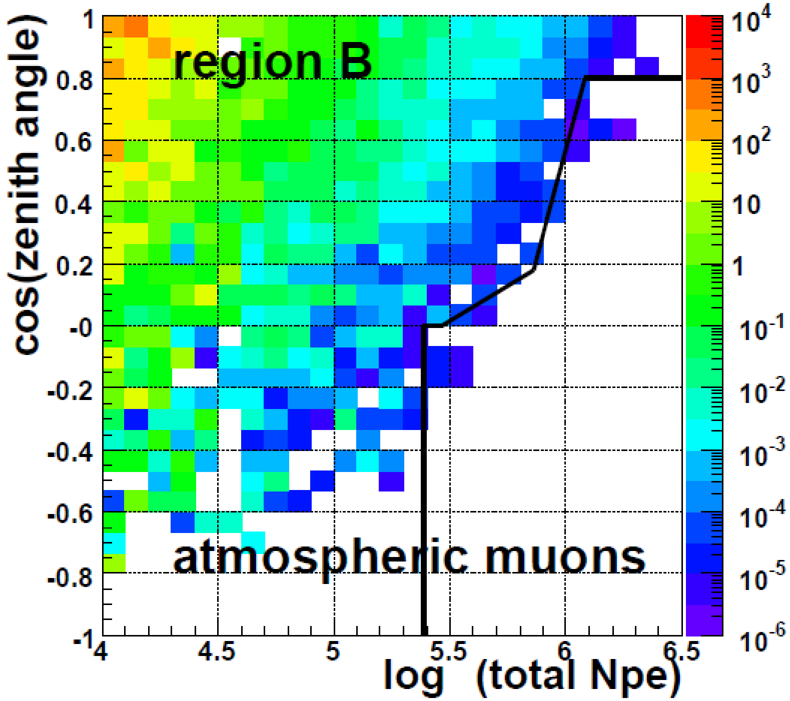


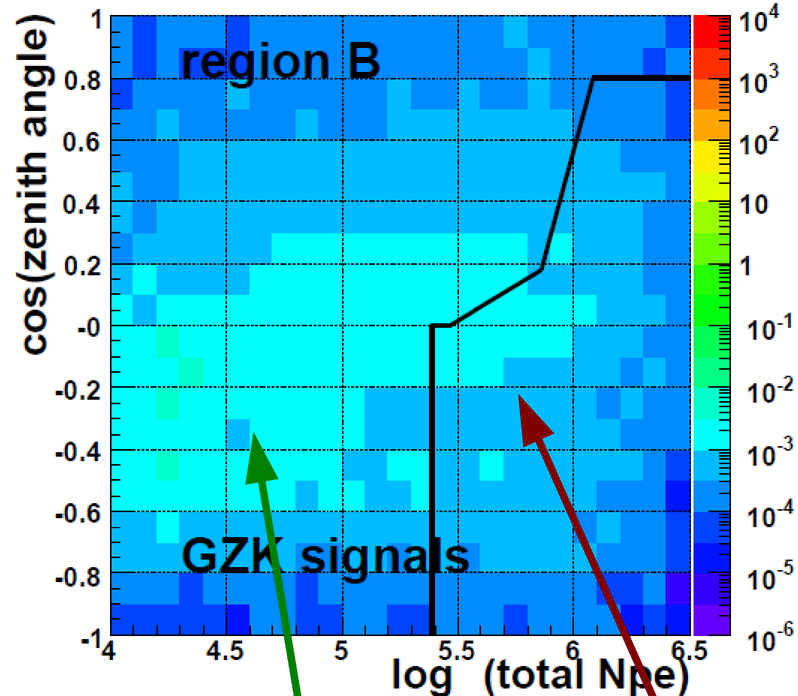
UHE detection – **Optical** with potential EAS veto

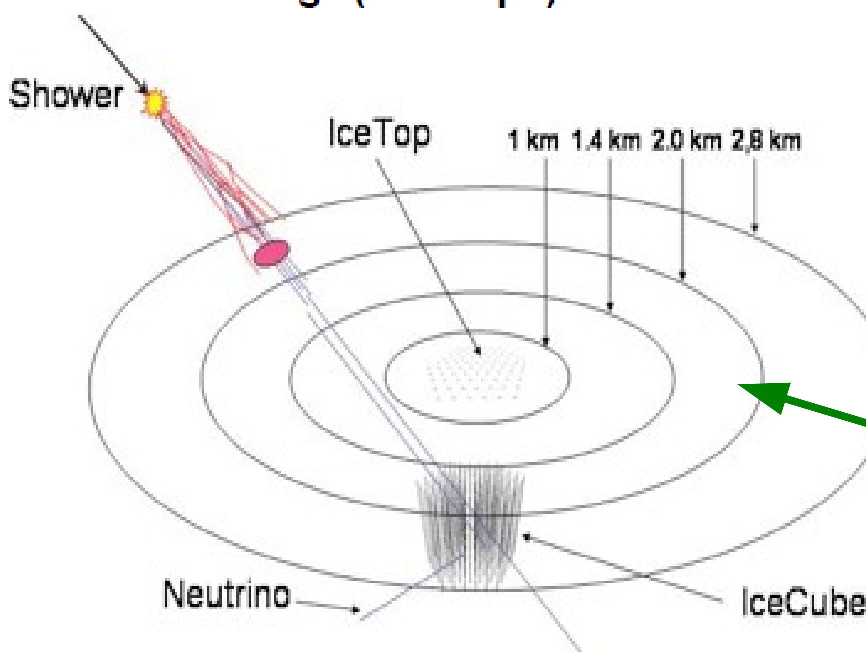




Enhancing optical UHE neutrino detection







preserved GZKs:
- "upgoing"
- very bright

Vetoing atmospheric muons

Enhancing IceCube

IceCube

- measures muons (above ~TeV) in the ice

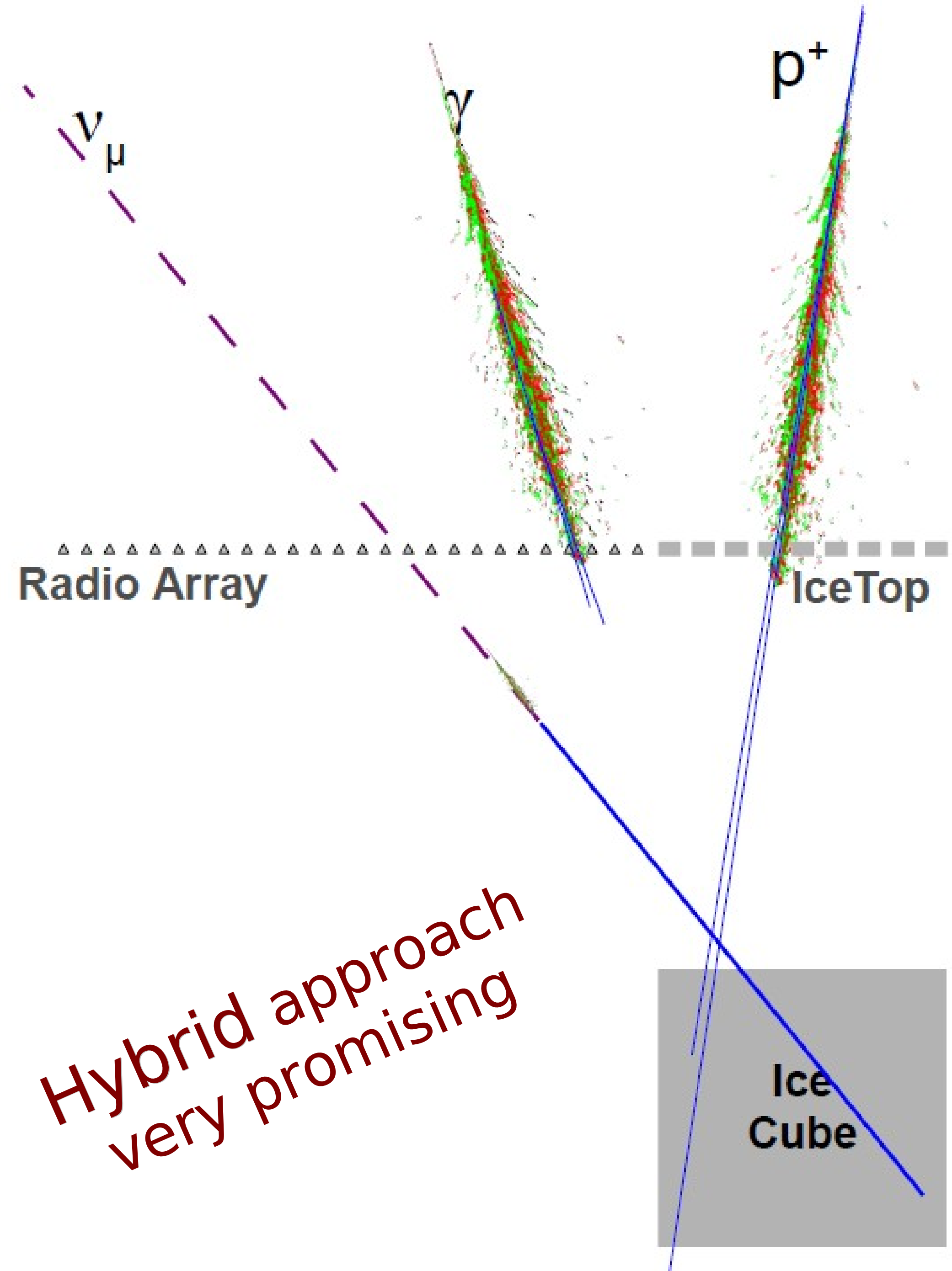
IceTop

- measures electron and muon population on the ground

Radio array

- measures total electron component (muon contribution negligible)

	$e^{\pm}$	~~$e^{\pm}$~~
$\mu^{\pm}$	**Composition**	**Neutrino**
~~$\mu^{\pm}$~~	**Gamma**	



R&D working group in IceCube

- Most general:
  - Extend IceCube and use unique facility and environment/infrastructure at SP:
    Only place to combine ....
    optical & radio & acoustics & air showers
- Primary motivation:
  - GZK neutrinos
  - Expand acceptance of IceCube for EeV neutrinos by orders of magnitude
- Also:
  - determine EHE neutrino cross section
  - air shower physics (inclined, composition, EHE)

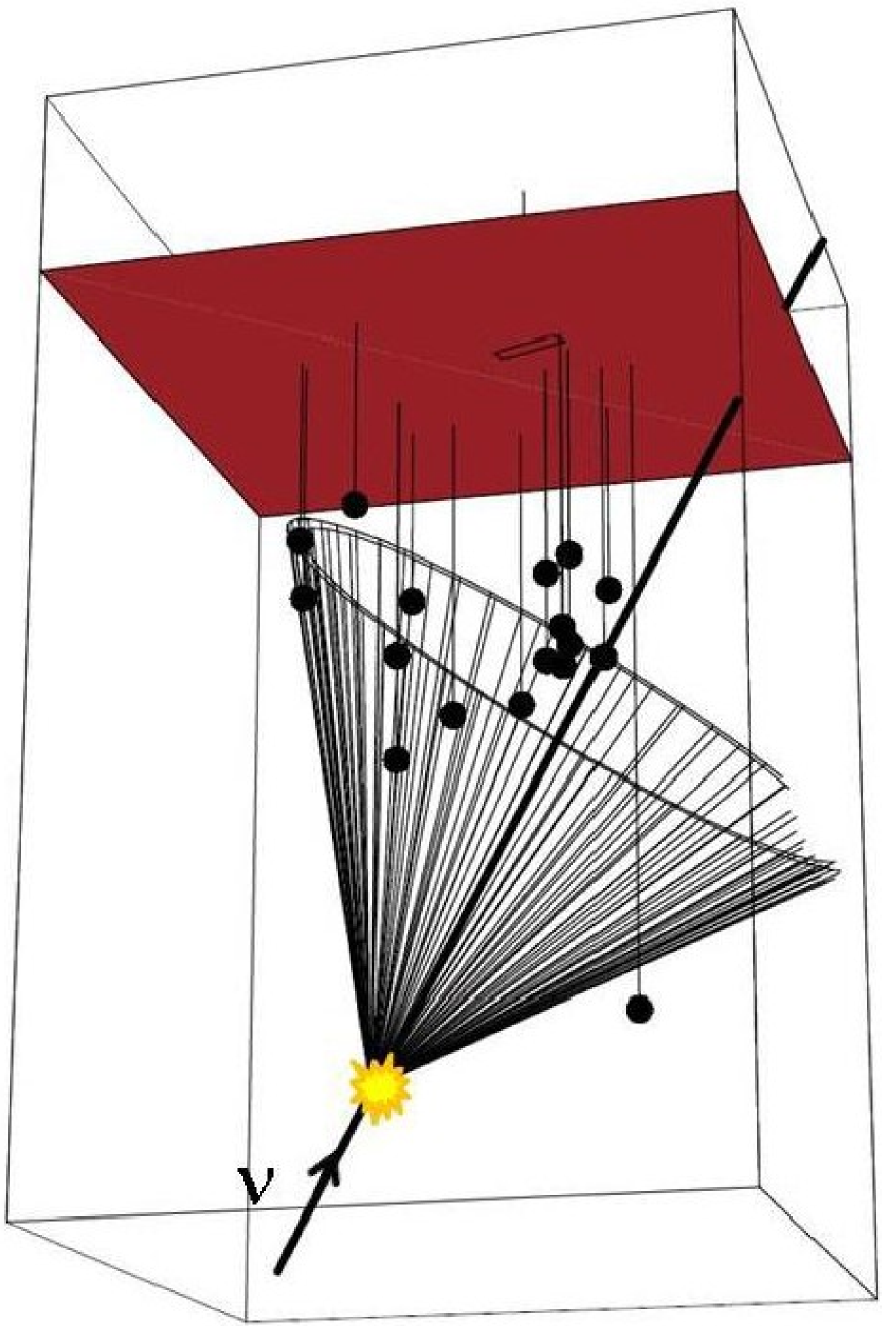
Relation to standard (optical) IceCube

- Benefit from IceCube knowledge and access to South Pole site
- Unique possibilities of combined observations both in-ice and on-ice
- Vision of “guaranteed” neutrino signal ↔ momentum from potential IC discovery
- Keep
  - engineering work force
  - students with inclination towards hardware
  - entrepreneurial aspects of early Amanda/IceCube days

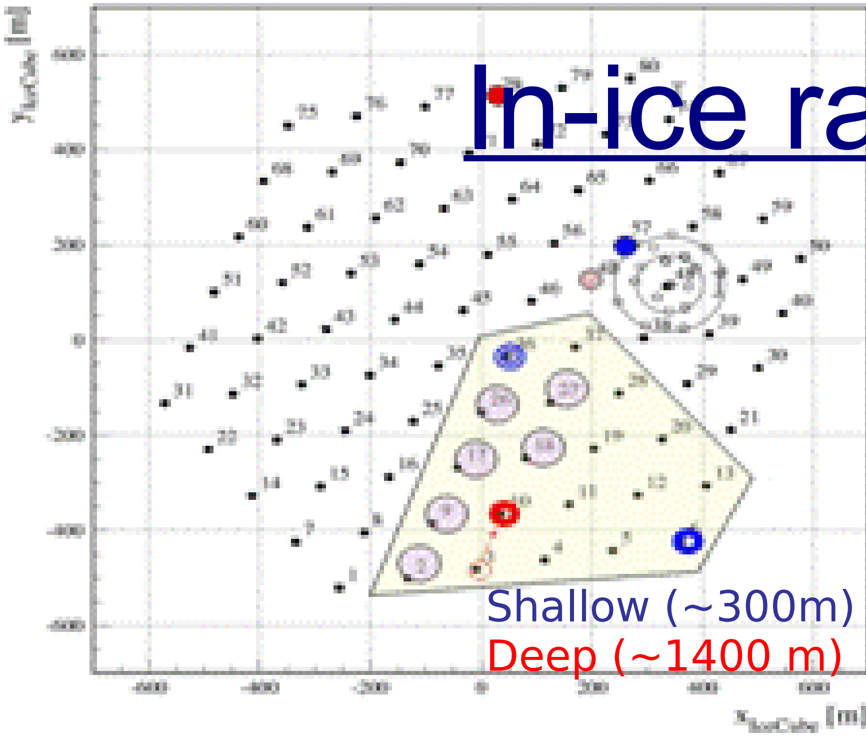
Status of ongoing site studies with ...

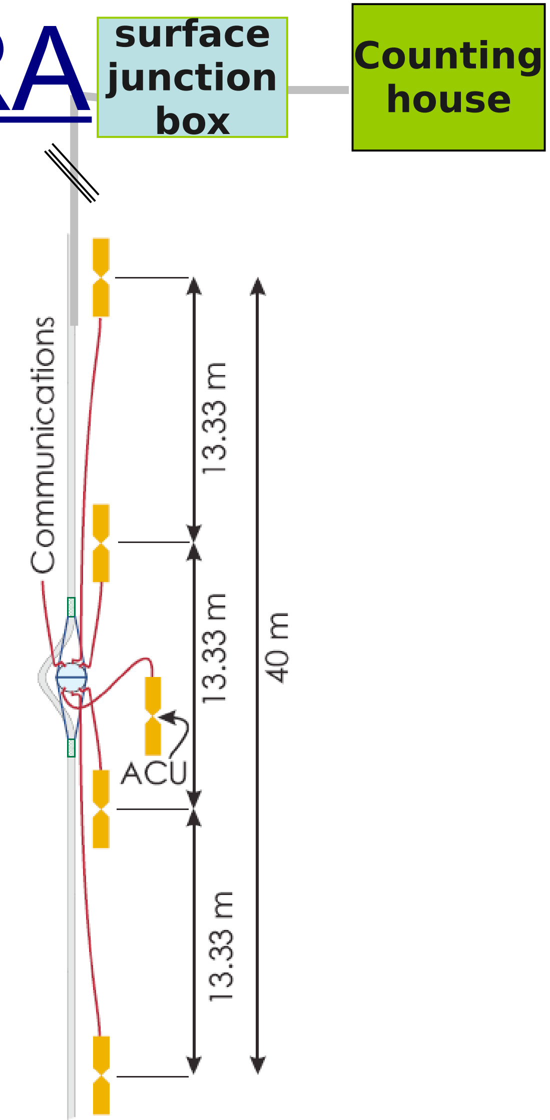
- **SPATS**: South Pole Acoustic Test Setup
- **RICE**: Radio Ice Cherenkov Experiment
- **AURA**: Askaryan Underice Radio Array
- **NARC**: Neutrino Array Radio Calibration
- **SATRA**: Sensor Array for Transient Radio Astrophysics
- **RASTA**: Radio Air Shower Test Array

In-ice radio with RICE



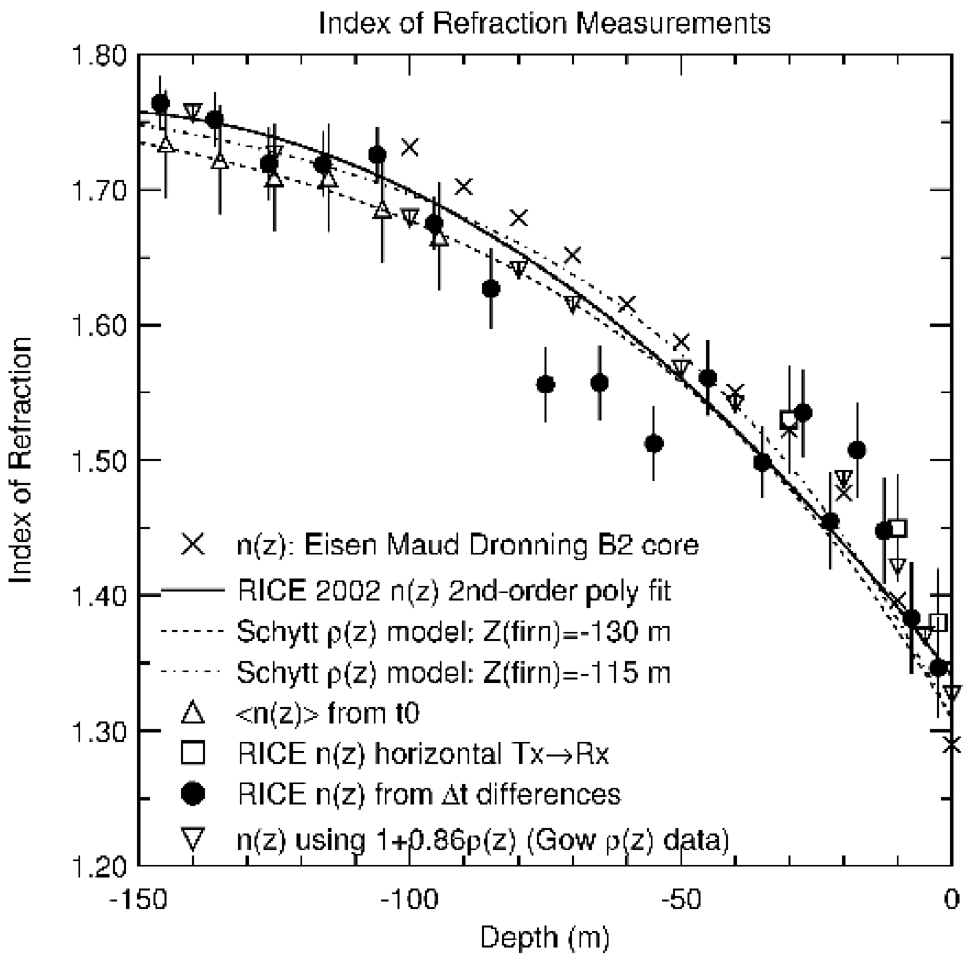
In-ice radio with AURA



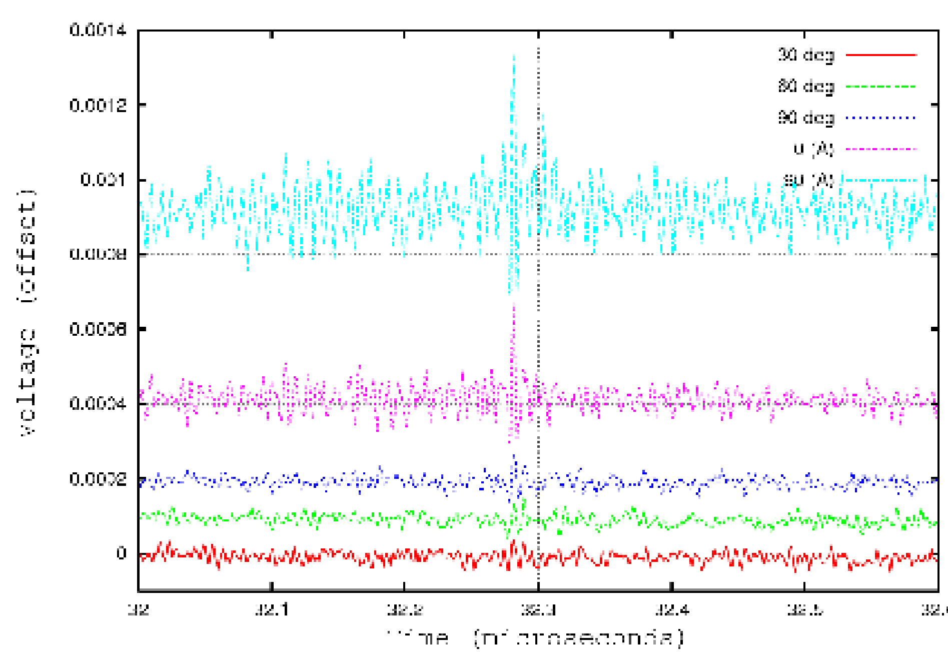


- AURA cluster:
  - Digital Radio Module (DRM) – similar to DOM
  - 4 antennas, 3 Antenna Calibration Units (ACU)
  - IceCube sphere, DOM main board (waveforms)
- 5 clusters: 2 in 06/07; 3 in 08/09 (with NARC)
- 2 channels (“antennas”) down to 100MHz
- 15/20 channels are working

Status in ice radio: Index of refraction



- Changing index helps to reduce surface noise pickup
- ... but shadowing for shallow deployment
- Birefringence under study

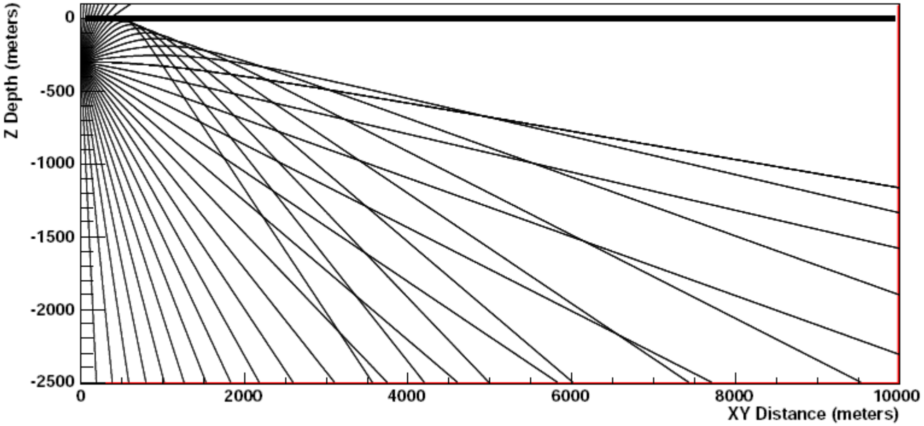


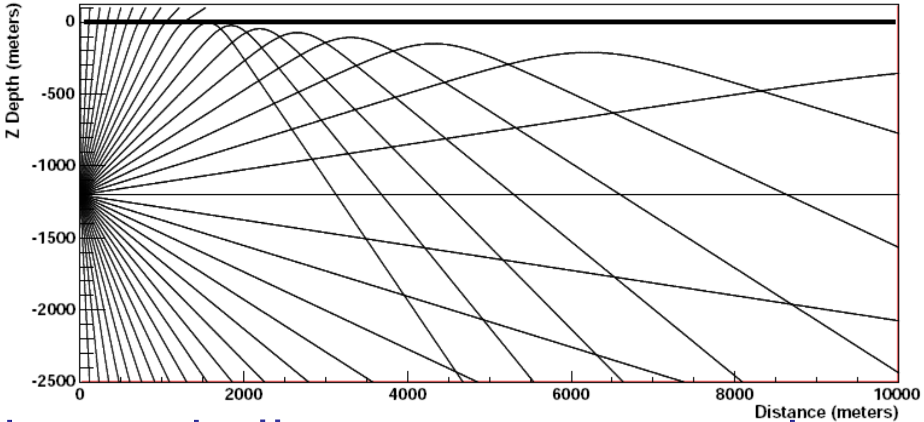
Detector design considerations

- Sensors:
  - Frequency range and band width
  - Antennas type

Unique signature of Askaryan:
short pulse, linearly polarized
- Capture polarization?
- Low freq has wider signal cone but more noise
- Narrow holes effect design

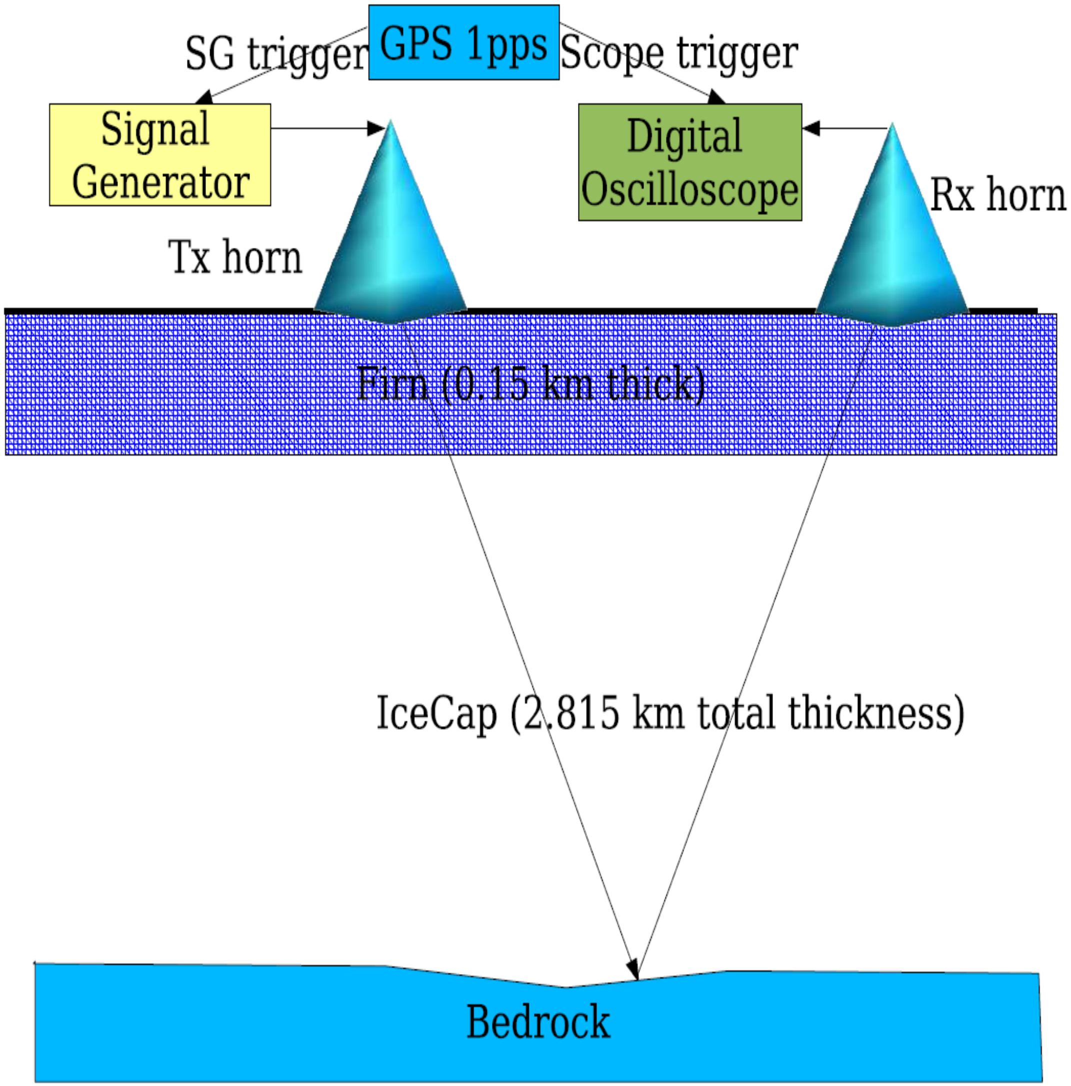
- Geometry:
  - Shadowing effect
    → Deep deployment
  - Ice Temperature
    → Shallow deployment
  - Drilling cost and time
    → Shallow deployment
  - Hole diameter can limit antenna design
  - Wet/dry hole

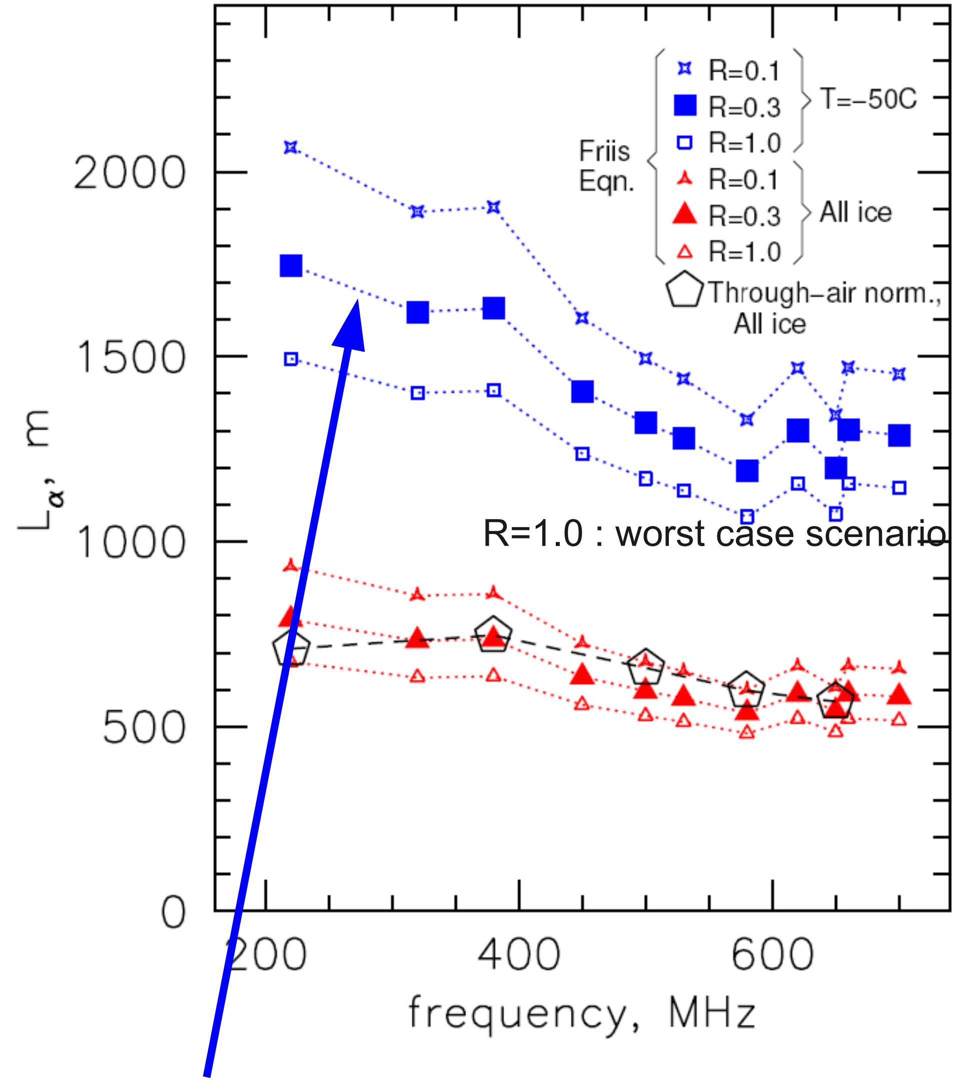




dense shallow versus sparse deep

Radio attenuation





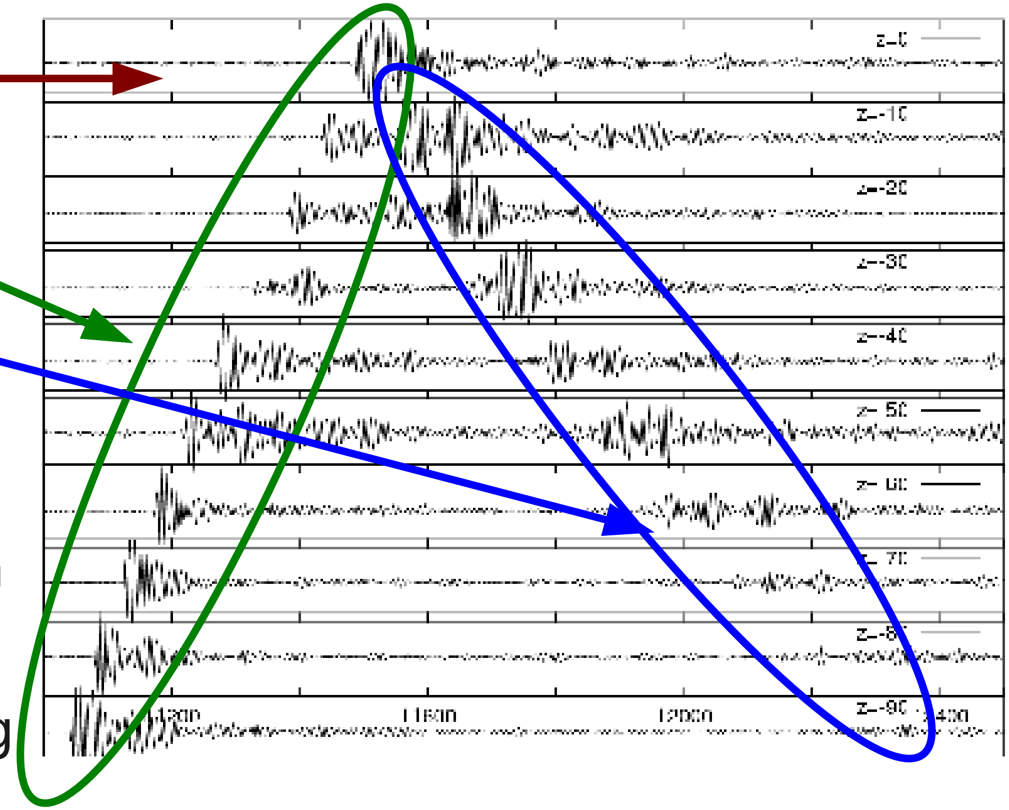
temperature region for shallow deployment

Radio attenuation: Plans for direct on-site measurements

Previous pinging with RICE

direct signal path

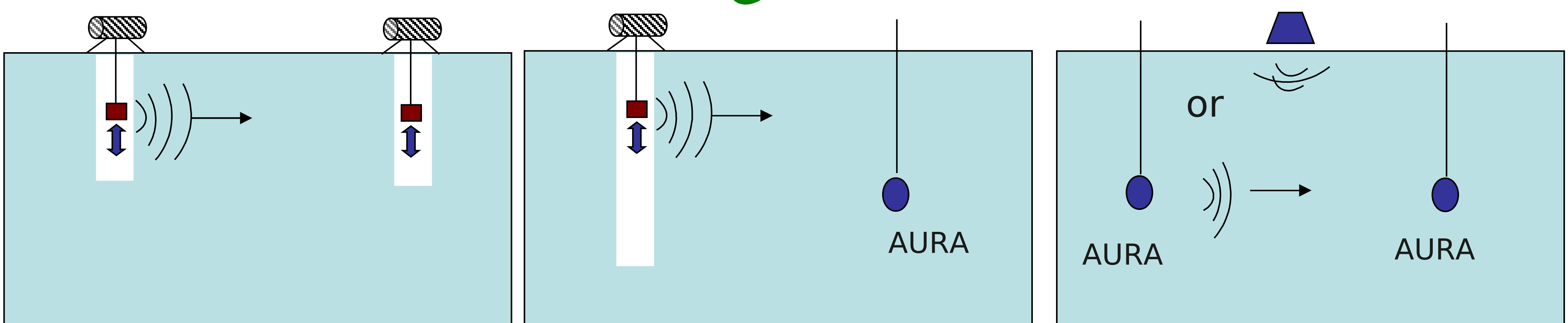
signal path with total reflection



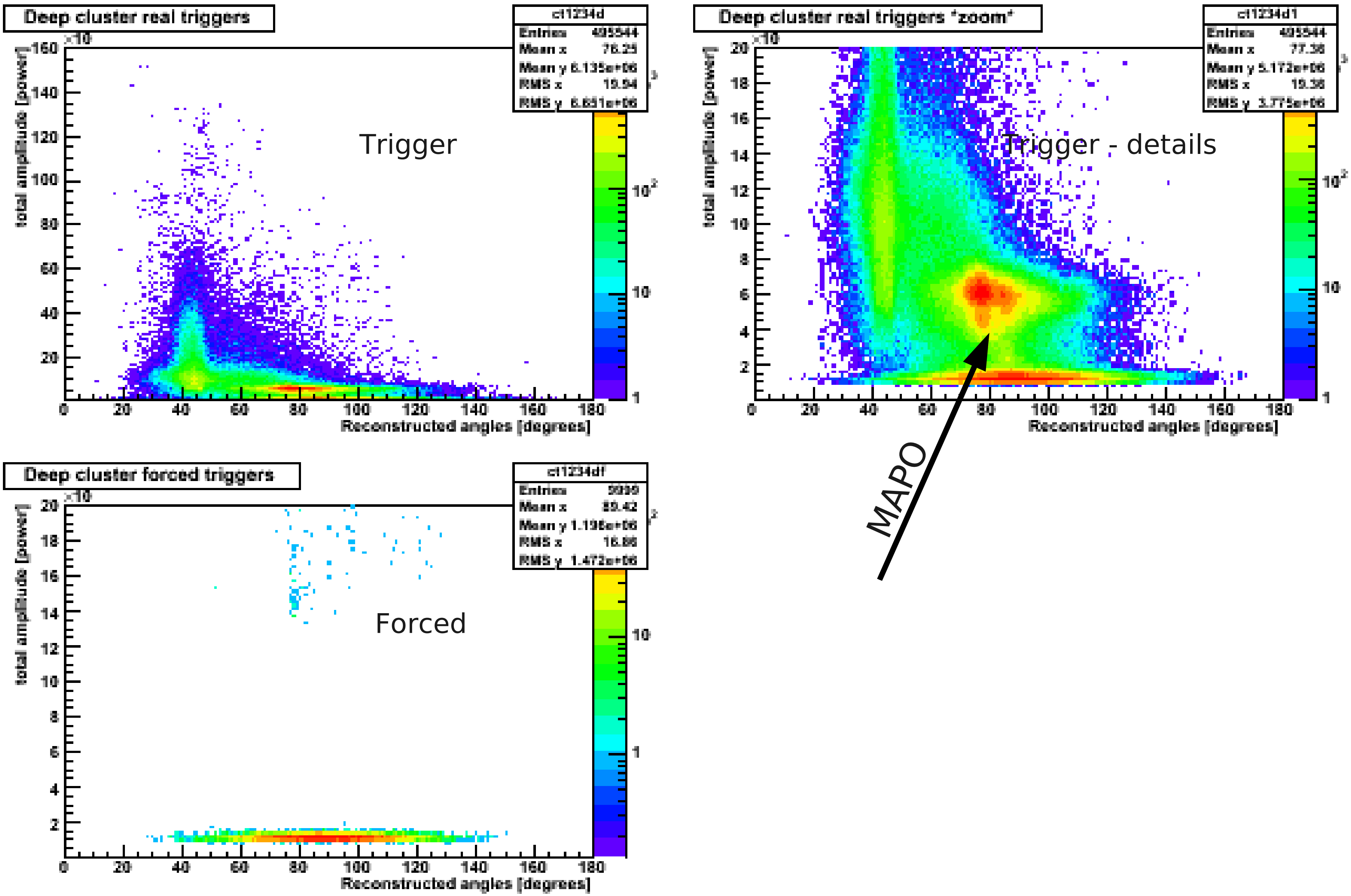
Options:

1. Frozen-In Tx and Rx
   + good coupling; – fixed position

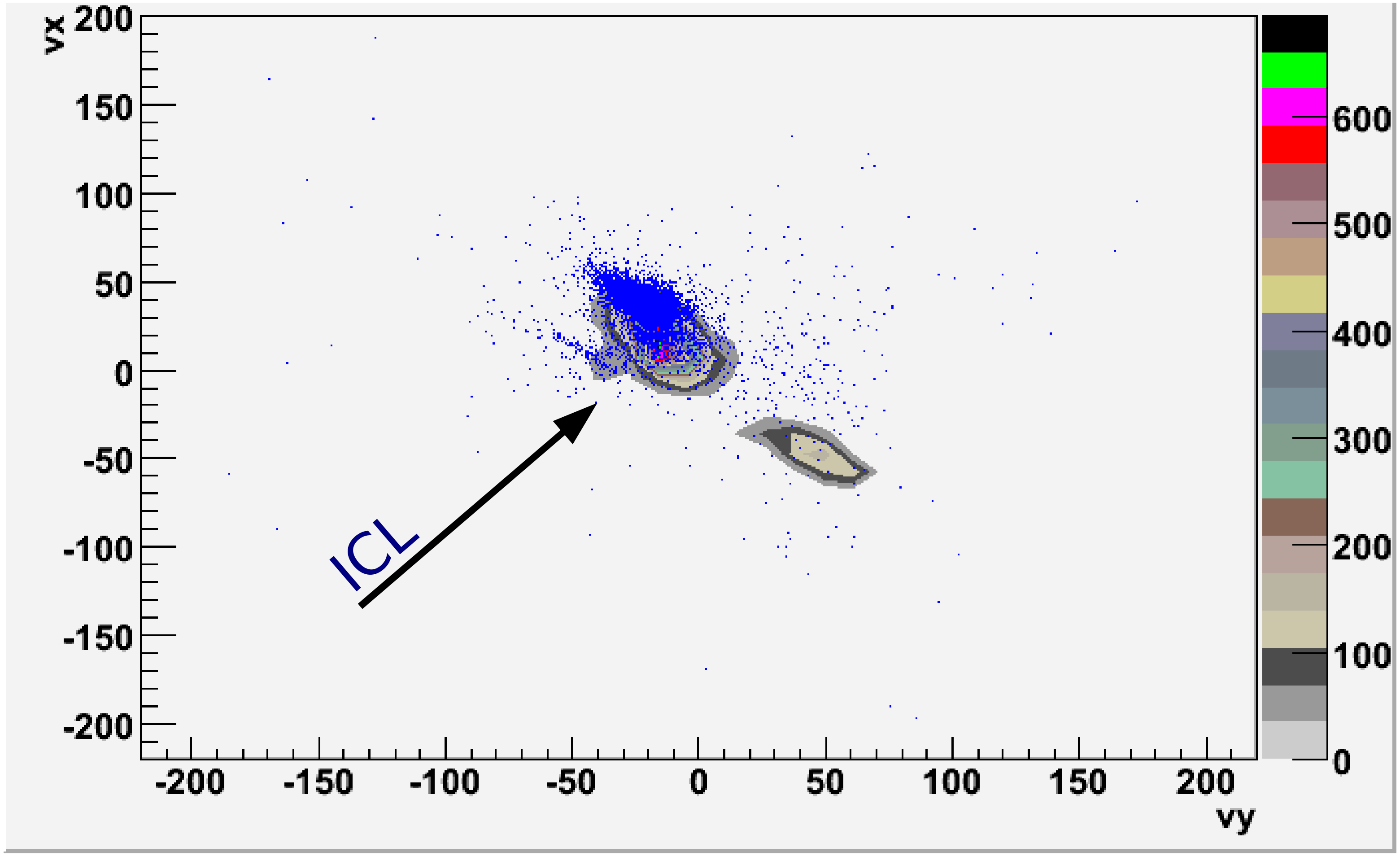
2. IceCube holes pre-deployment
   + many depths; – water coupling



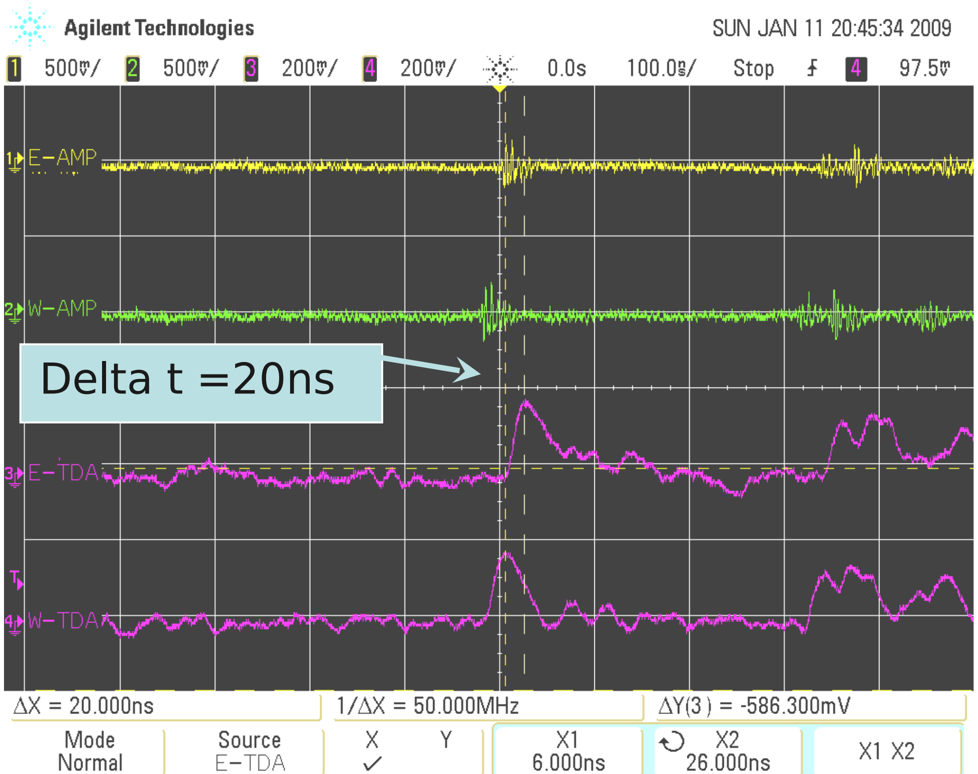
In ice RFI transients with AURA

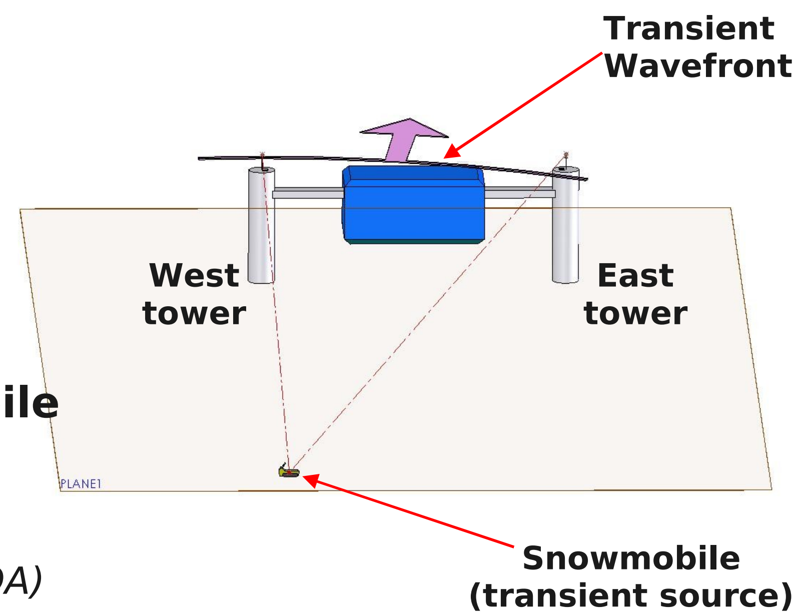


RFI transients with RICE



Envelope / TDA Proof-of-Concept Testing
South-Pole 08-09

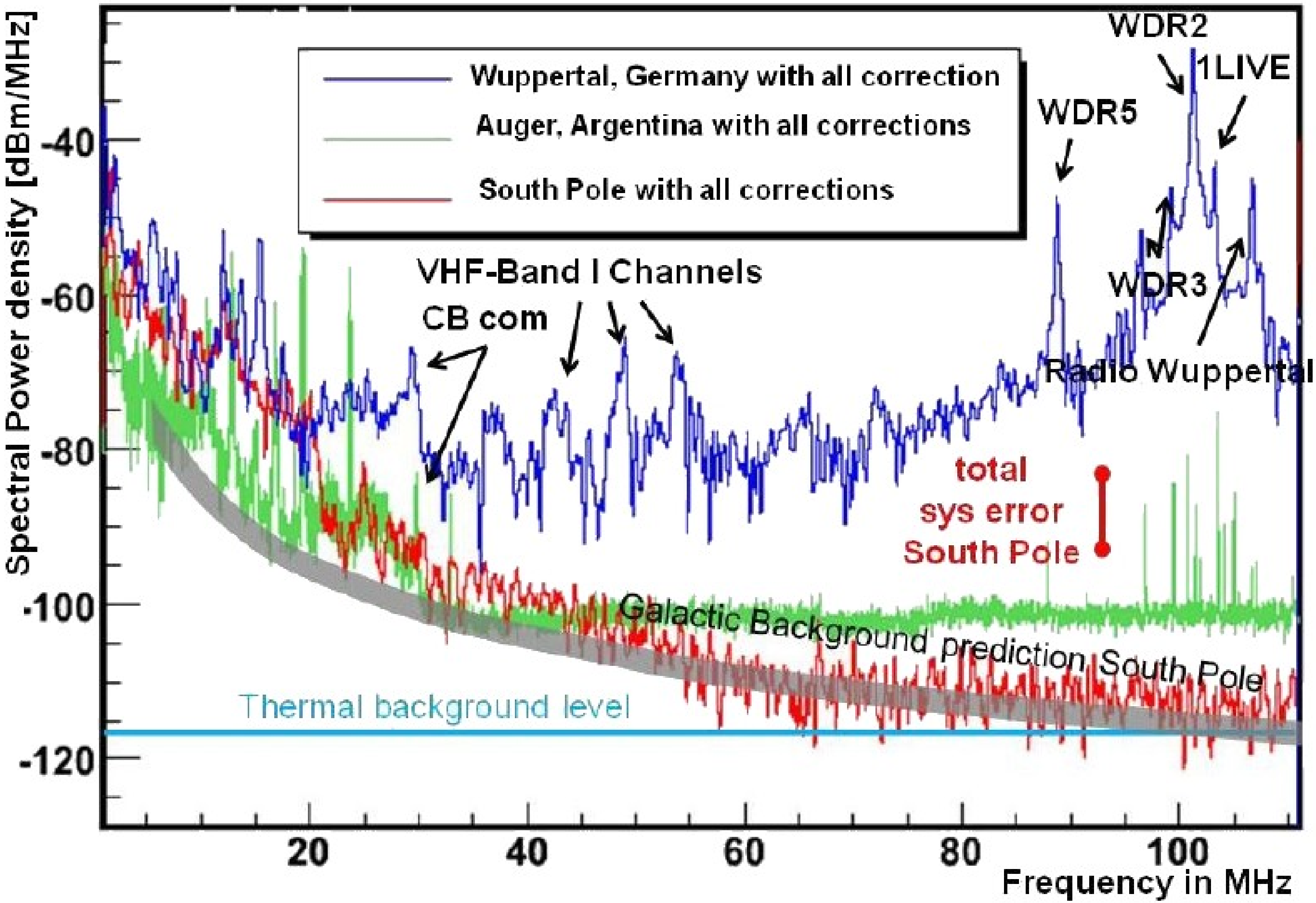




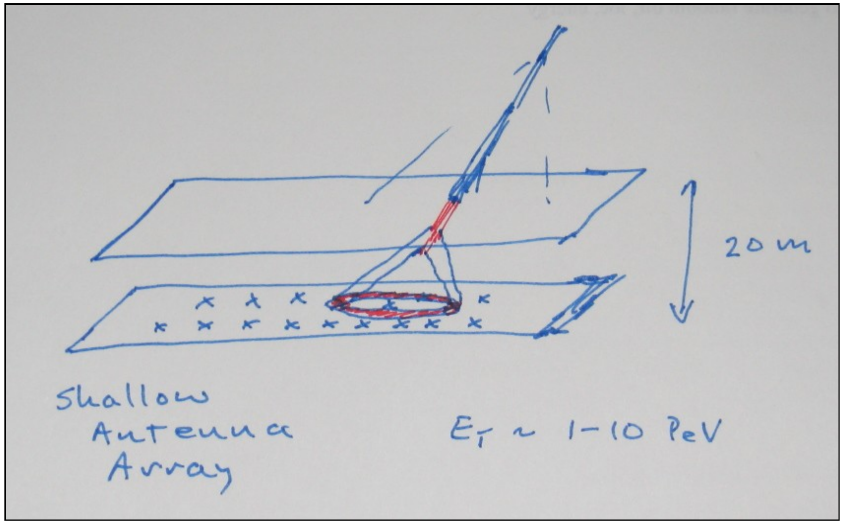
Ignition noise transients from idling snowmobile

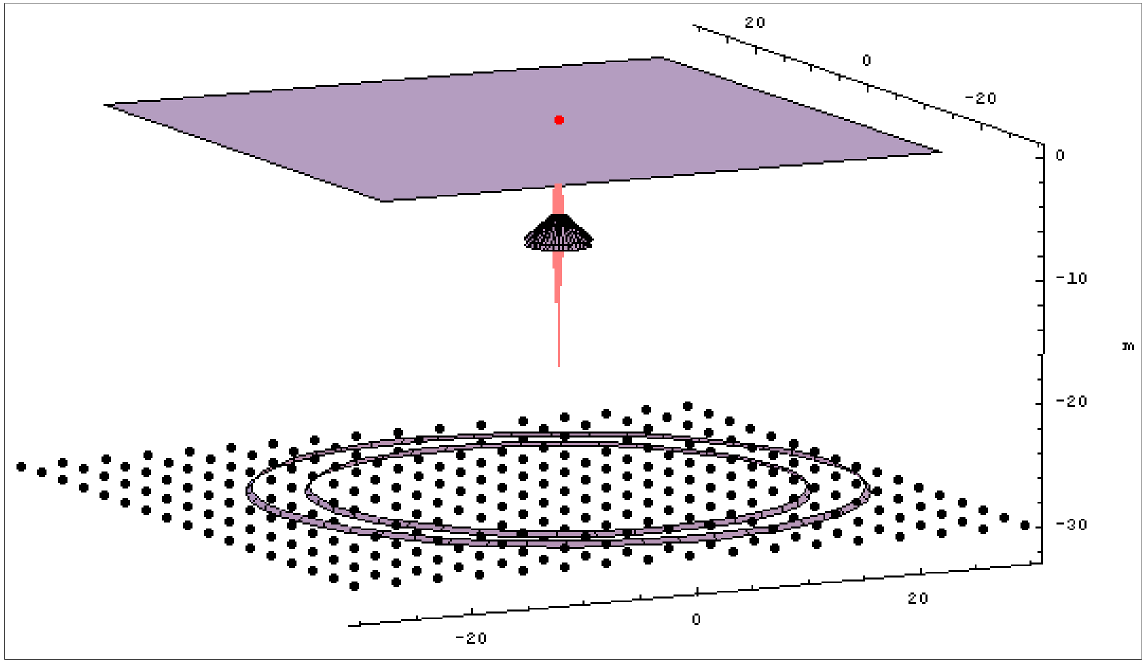
Snowmobile was approximately 100m distance from ICL.
Snowmobile was perpendicular with West tower.
Signals as acquired by ic-scope-ag1
Time Delay=20ns W-E, consistent with Angle-of-Arrival (AOA)

Environment for air shower radio



Askaryan pulses from air shower core





Status summary: **Noise**

- Noise/EMI/background: **significant uncertainties wrt transients** potential cost driver (electronics)
  - Acoustic: constant level of noise favorable (compared to sea), all transients seen so far within array come from known sources
  - In-ice Radio: deserves attention
    - RICE:
      - favorable in winter, challenge in summer
      - transient background rate O(1/minute) in multiplicity
    - air showers could be (additional) transient background
  - Air shower radio (on-ice antennas) could be instrumental to get rid of EMI in-ice ... for itself looks promising, work in progress.

Status summary: **Attenuation**

- **Mostly known**
  - great progress in acoustics with last seasons but unexpected result
  - known from radio reflection of bed rock, direct horizontal on-site measurements needed and on-going
  - Negligible for air shower radio

Status summary: “**Refraction**”

- Refraction, signal speed, depth dependence:
  no evident show stopper but impact on detector designs
  - good knowledge in acoustics, favorable below 200 m
  - in radio uncertainties can still influence detector design
  - E-field needs further attention to understand signal strength, B-field configuration wrt veto coverage of air shower radio.

To-Do list radio in-ice

- Ice attenuation (shallow, horizontal)
- Coincidences with IceCube/IceTop with in-ice and surface antennas
- South pole RFI map vs. time, again with in-ice and surface antennas
- Possibly produce limit on GZK neutrinos:
  - Sensitivity calibration
  - Life time
  - Simulation
- Clearly man power limited so far espy. at PhD and Postdoc level
  - UW, UMD, … hiring e.g. 1 Postdoc changing from Wuppertal starting (06/2010)
  - more to come from DESY?

Current implications from site exploration

- GZK is main science motivation
  long attenuation length for radio signals in ice

  ⇒ Askaryan radio detector in ice main instrumentation and design driver

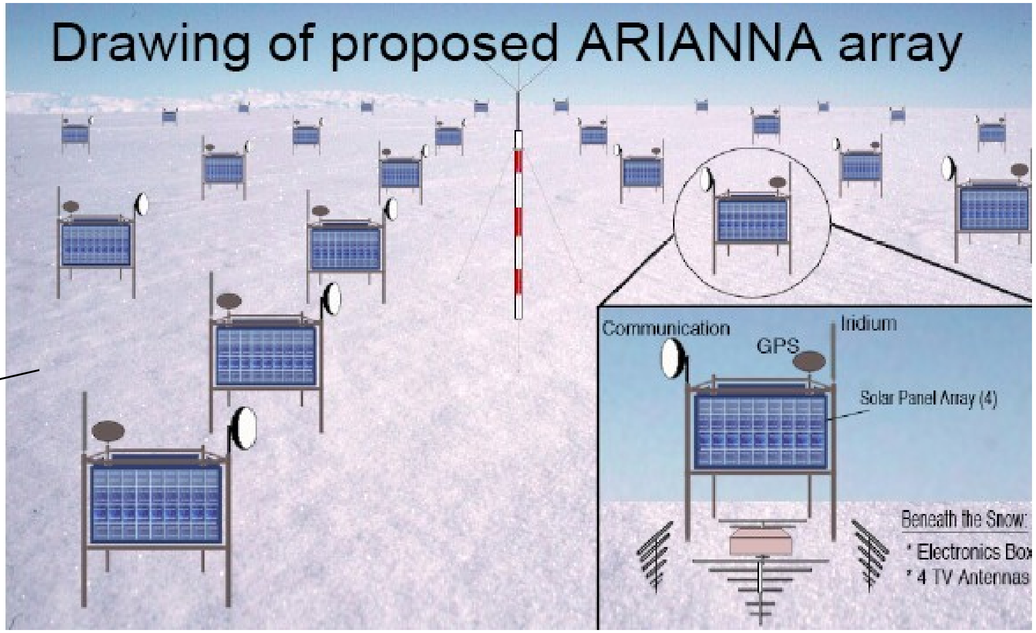
- Pursue integrated approach of air shower radio detection together with neutrino detection for
  - additional (EHE) vetoing
    → increased overlap with optical
  - EMI reduction and monitoring
  - air showers may provide test beam for in ice
  - ... and of course air shower physics
  - use joint infrastructure

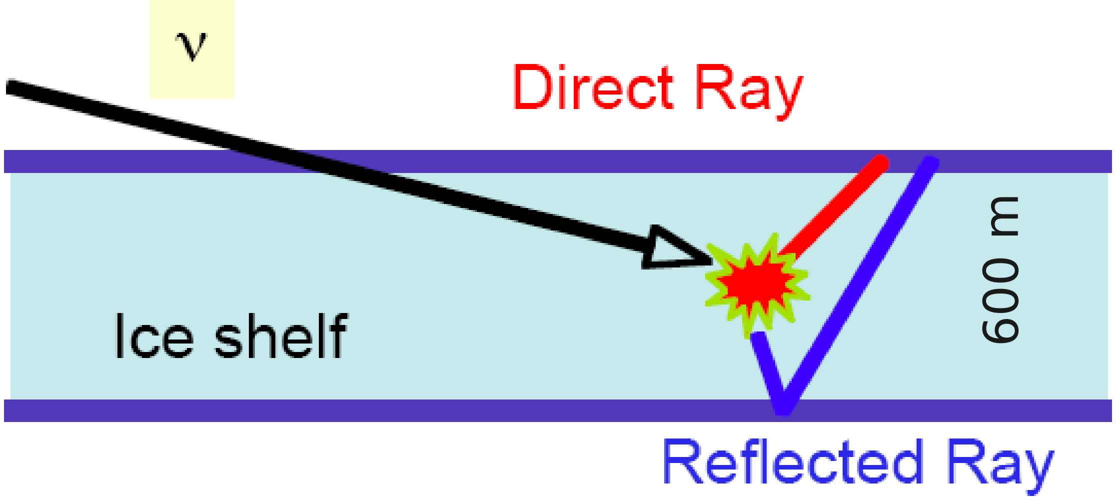
Role of acoustics

- Reevaluation of hybrid option needed in view of shorter than expected attenuation length
- Finish site exploration e.g. understand attenuation mechanism and noise sources
- Acoustics accompanying radio:
  - shallow co-deployment in narrow holes feasible?
  - extra cost reasonably small fraction
    … **then**
  - Hand full of coincidences that no one else in the world can do – independent reco + signal
  - Add <u>independent evidence</u> for neutrinos to radio signals

Forthcoming radio projects: ARIANNA

100 x 100 array [30 km x 30 km]



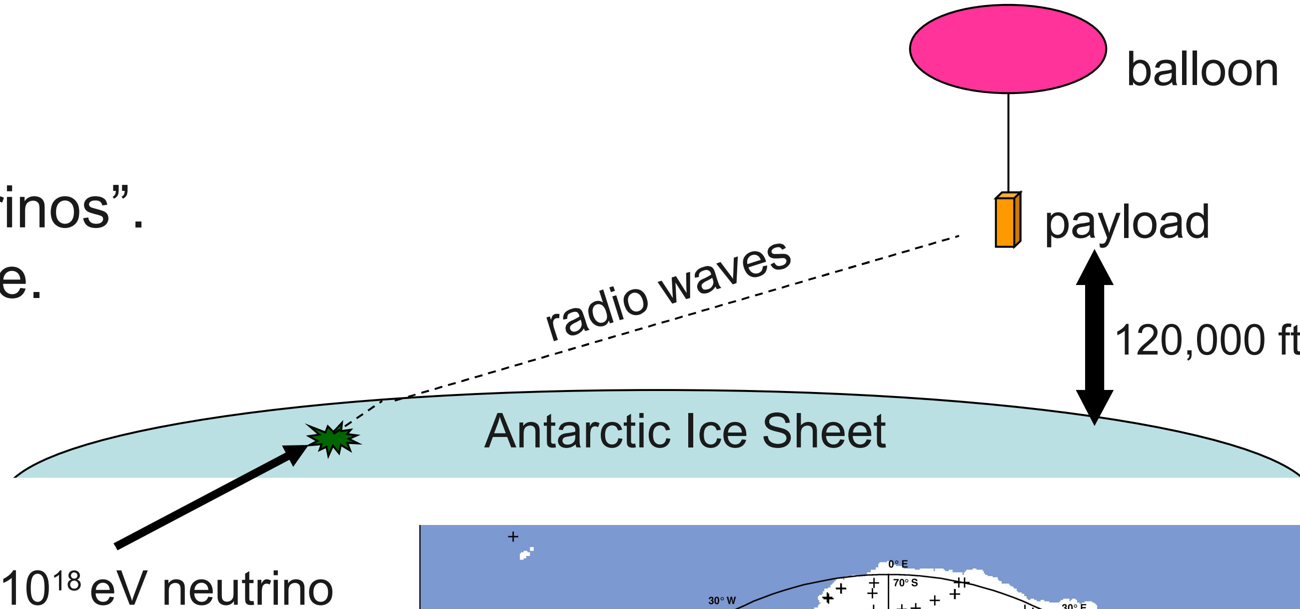


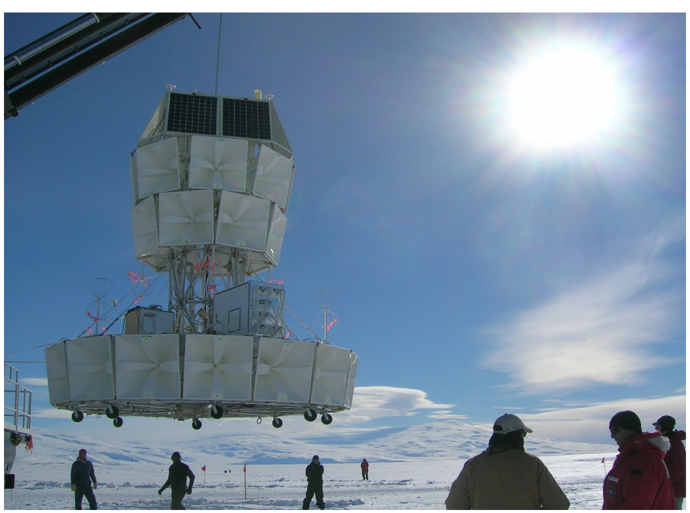
UCI, LBL, OSU, WashU, UCLA, UCLondon

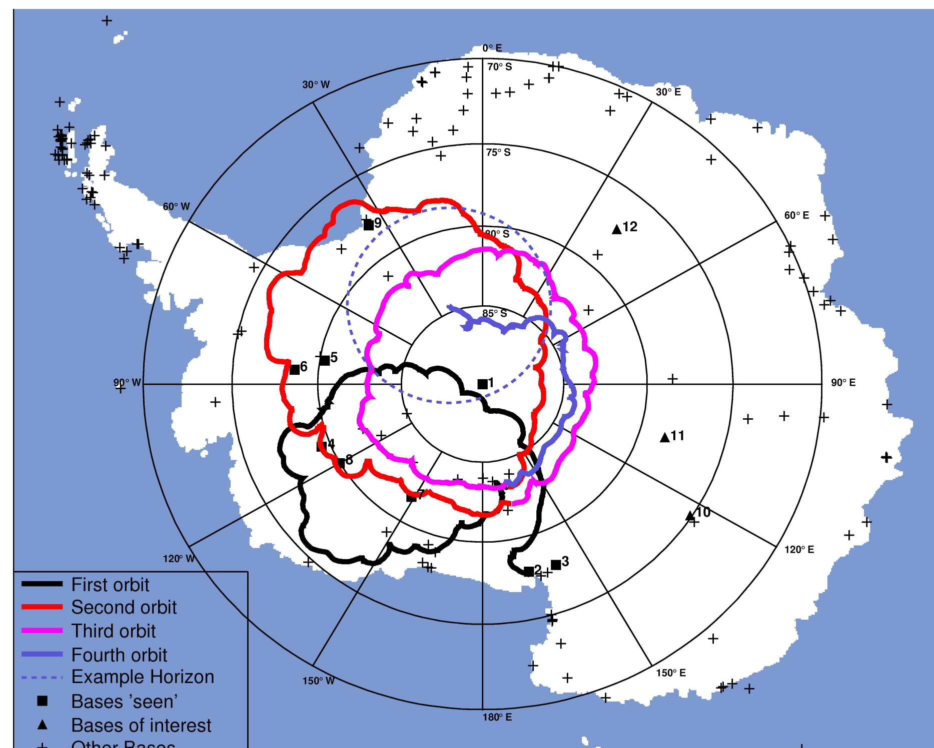
Barwick, astro-ph/0610631

ANITA: Radio detection in/on ice

- Looking for “GZK neutrinos”.
- View 1 Million km^3 of ice.



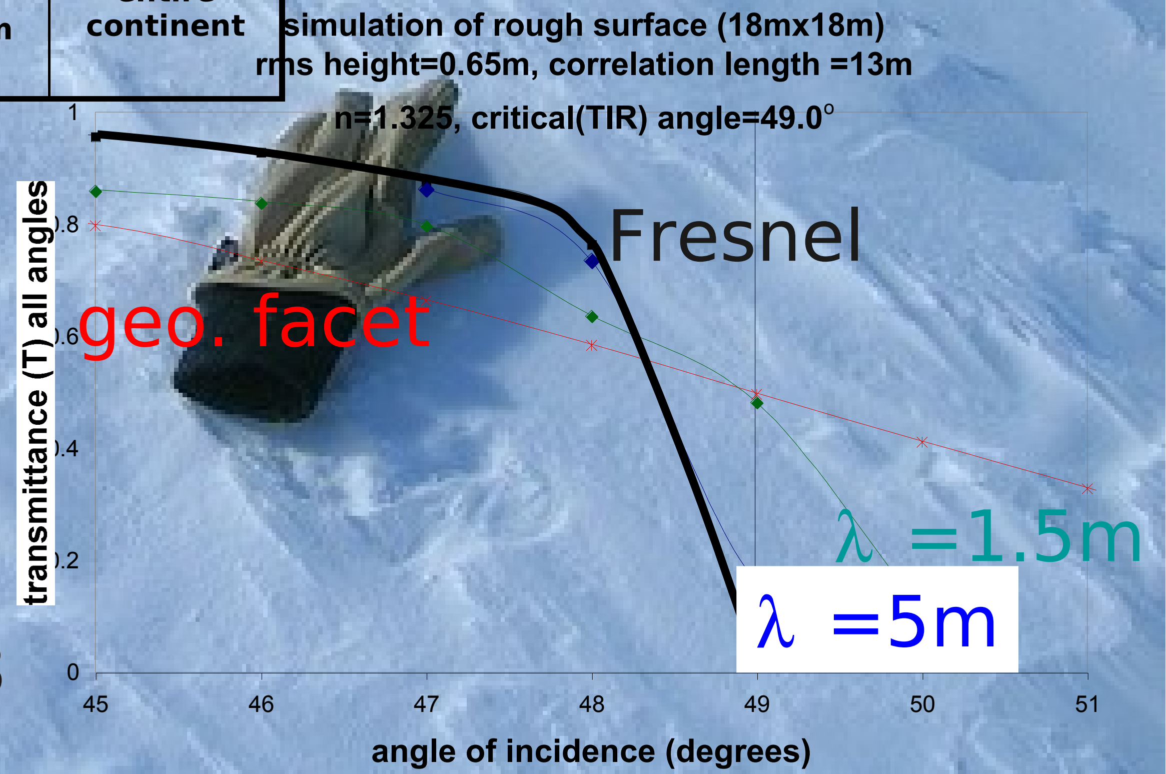




Modeling Surface Roughness

scales	categories	amplitude / rms height	correlation length	coverage
LARGE (meter)	sastrugi	~30cm (average)	8m	about half of the continent
	snow dunes	~70cm (average)	13m	
SMALL (centimeter)	micro-roughness	~few cm	30-60cm	entire continent

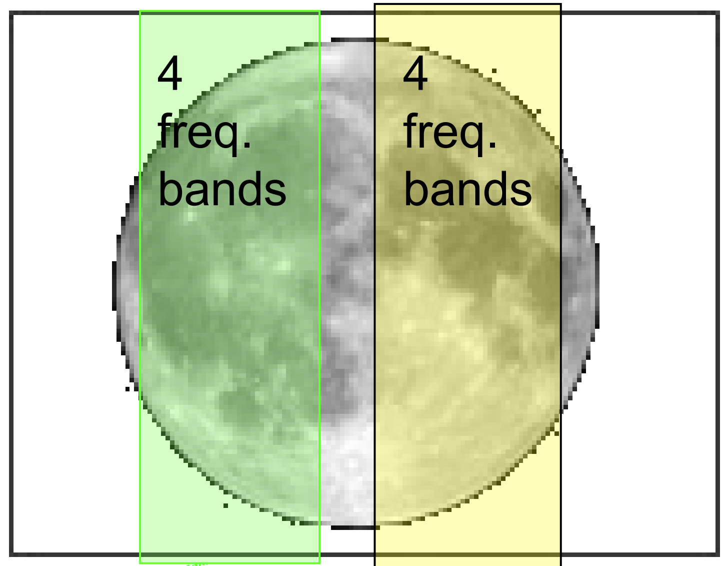
www.physics.ucla.edu/~moonemp/roughness

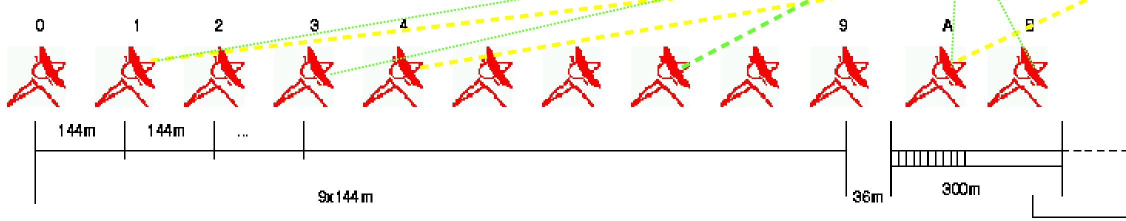


Dookayka, APS08

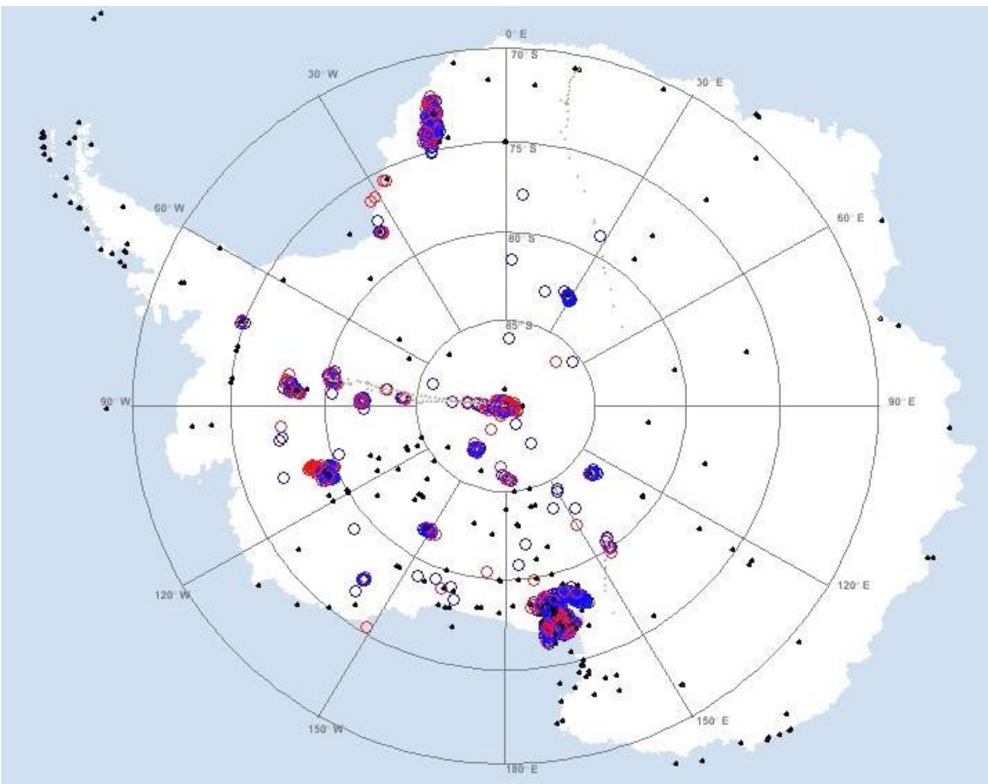
GZK neutrino signals from the moon

Westerbork Synthesis Radio



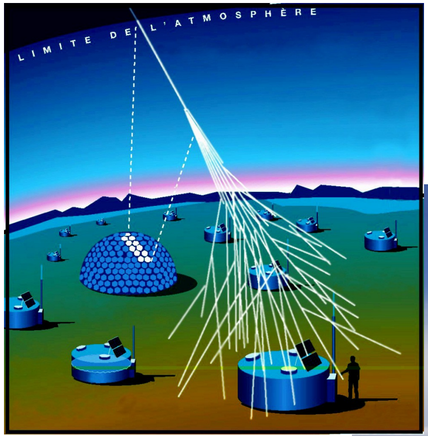


RFI from "civilization", radio from air showers and *2 events*



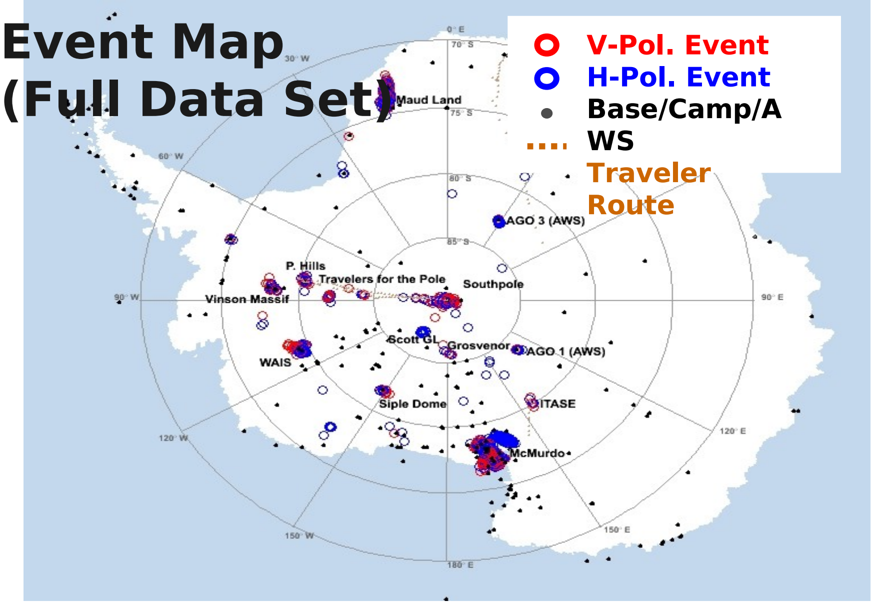
- Almost all events associated with known bases, ...
- Remaining events dominated by horizontal polarization: reflected geosynchrotron from air showers
- ANITA-II: 2 remaining V-pol events on 1 backgrd → new flux limit.

Why Hybrid?



Experience from recent projects:

AUGER (+), ANITA (-)



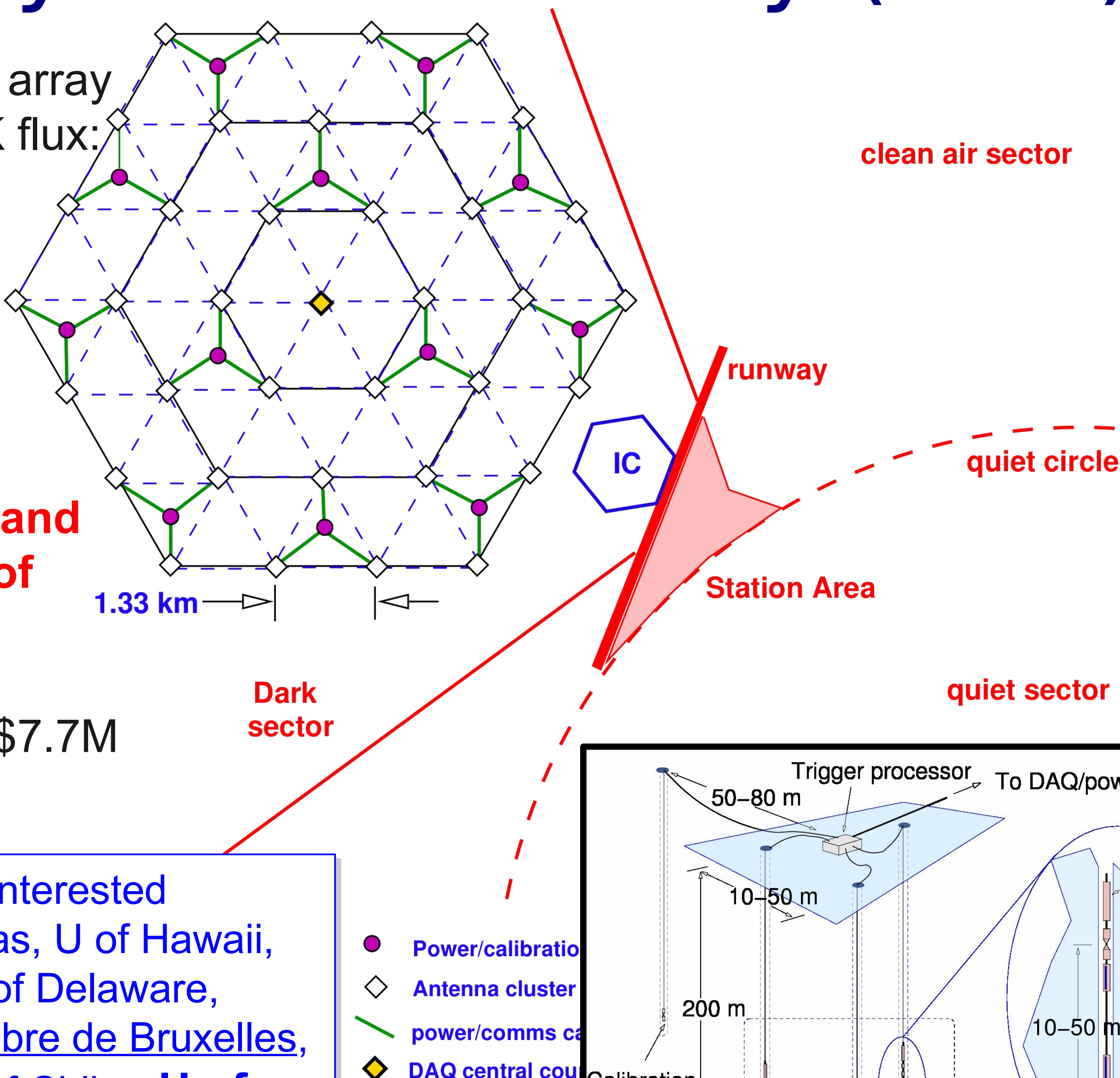
- **Signal Identification**
- **Noise Reduction**
- **Detector Calibration**
- **Event Reconstruction**
- **Energy and Direction Resolution**

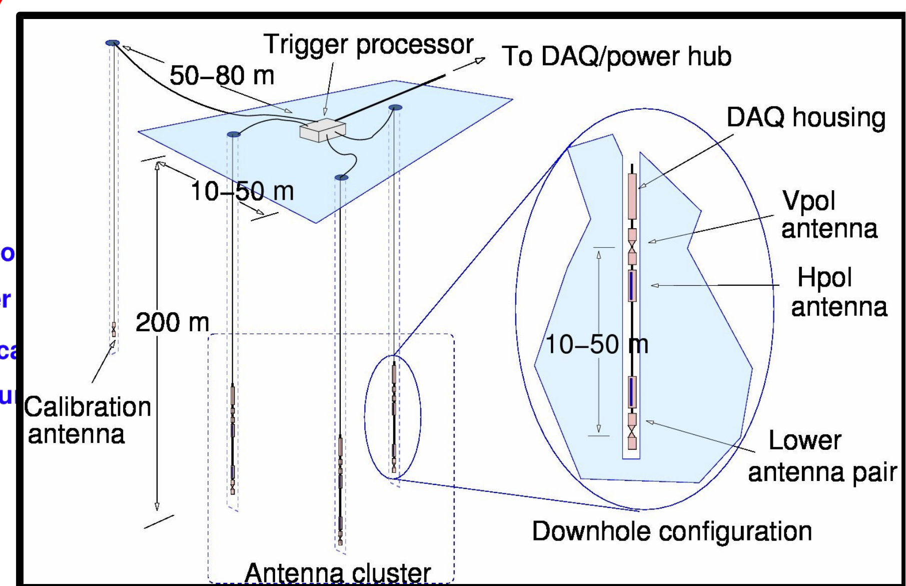
Askaryan Radio Array (ARA)

"Intermediate" scale array to establish the GZK flux: 80 km^2

Proposal submitted to US recovery act "stimulus funds" jointly from the **University of Maryland** and the **University of Wisconsin** for $4M

Total Price of ARA: $7.7M





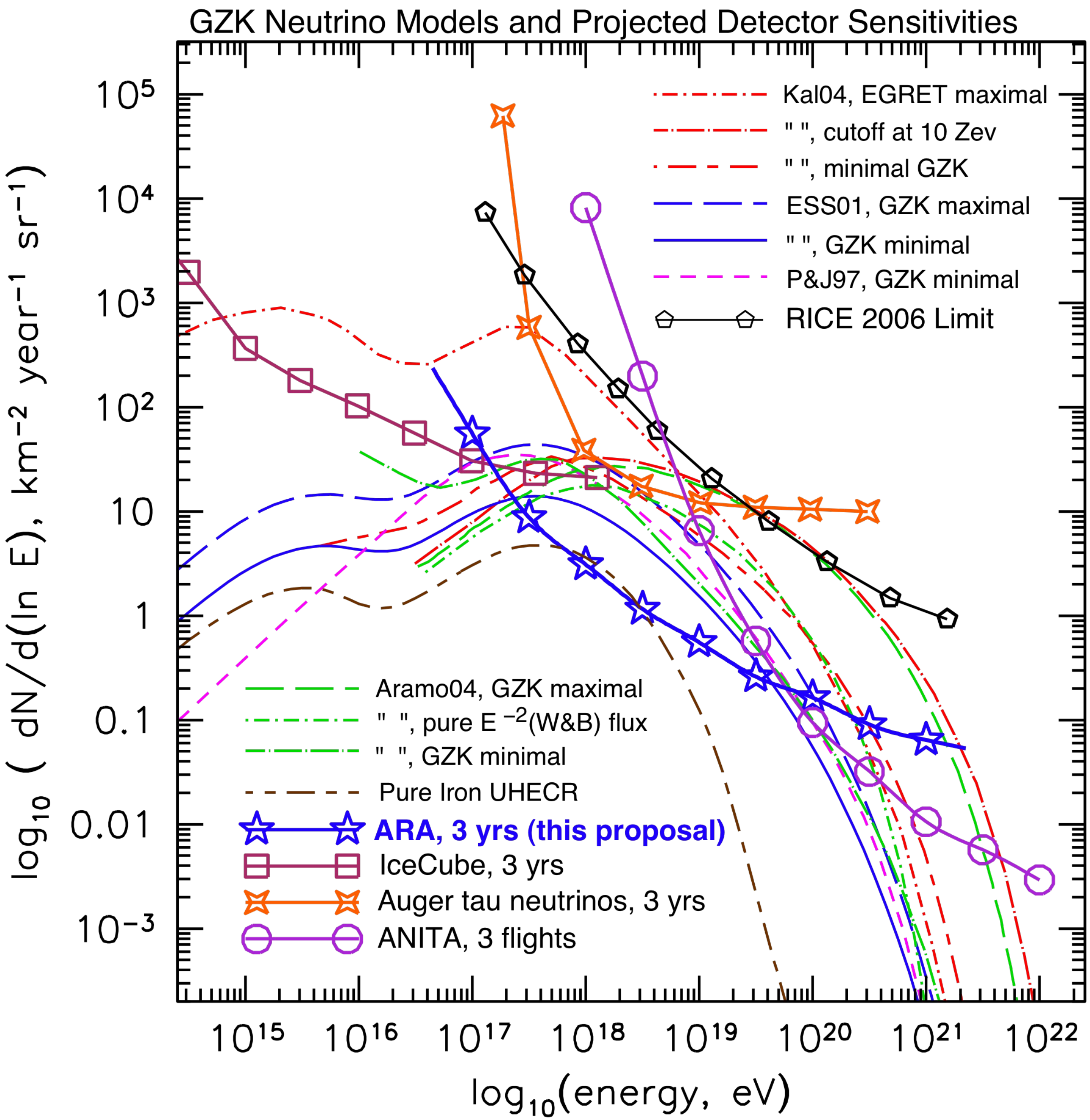
Other collaborating & interested institutions: U of Kansas, U of Hawaii, National Taiwan U, U of Delaware, Colorado State U, U Libre de Bruxelles, U College London, U of Chiba, **U of Wuppertal, DESY Zeuthen ?**

ARA sensitivity

Measure diffuse flux of GZK neutrinos for a wide range of cosmic ray compositions.

Once flux known: Design astrophysical observatory for GZK energy regime.

… possibly including acoustic and air shower radio



Conclusions & Outlook

- Site exploration
  - very prolific (several publications in pipeline)
  - Short attenuation length in acoustics
    → Askaryan radio primary driver
  - Hybrid option being reevaluated
- Upcoming seasons to clarify
  - deployment options (depth, dry/wet)
  - choice of pulse shaping, trigger, digitization
- … head out to extend IceCube and IceTop by factors at the EHE frontier
- **Antarctica is unique place for R&D !!**

Thank you!