# R&D working group report SAC May 2009

Klaus Helbing, Wuppertal & Hagar Landsman, Madison

- Goals and tasks
- Working group structure
- Status of R&D
  refraction, attenuation, background
  - Acoustics
  - air shower radio
  - in-ice radio
- Conclusions for design of extension
- Road forward

# Common goals

- Most general:
  - Extend IceCube and use unique facility and environment/infrastructure at SP:
    Only place to combine optical & radio & acoustics & air showers
    i.e. imitate the IceTop – InIce relation
- 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)

# Tasks of R&D working group

- work out task distribution amongst participating institutions
- establish Letter Of Intent (LOI)
- define interfaces and common infrastructure for different sensors (in/on ice, methods, ...)
- establish milestones for an intermediate scale detector (~ 5 GZK-$\nu$'s/year)
- establish a road map towards a full scale detector (~ 50 GZK-$\nu$'s/year; O(1000) $km^2$ )
- coordinated planning of funding proposals

# Structure of R&D working group

- First common meeting (1-day) at fall meeting 2008
- Formation of WG at last collaboration meeting
  phone calls on common issues, converging plans
- Existing sub-groups continue with dedicated phone calls (focus: specific instruments):
  - radio (Dave Besson)
    - in-ice
    - air shower
  - acoustic (Timo Karg)
  - optical high energy extension (HE, Albrecht K.)
- New IC-members and affiliated groups contribute (e.g. Hawaii and Ohio)
- Upcoming R&D workshop in June

# Relation to standard (optical) IceCube

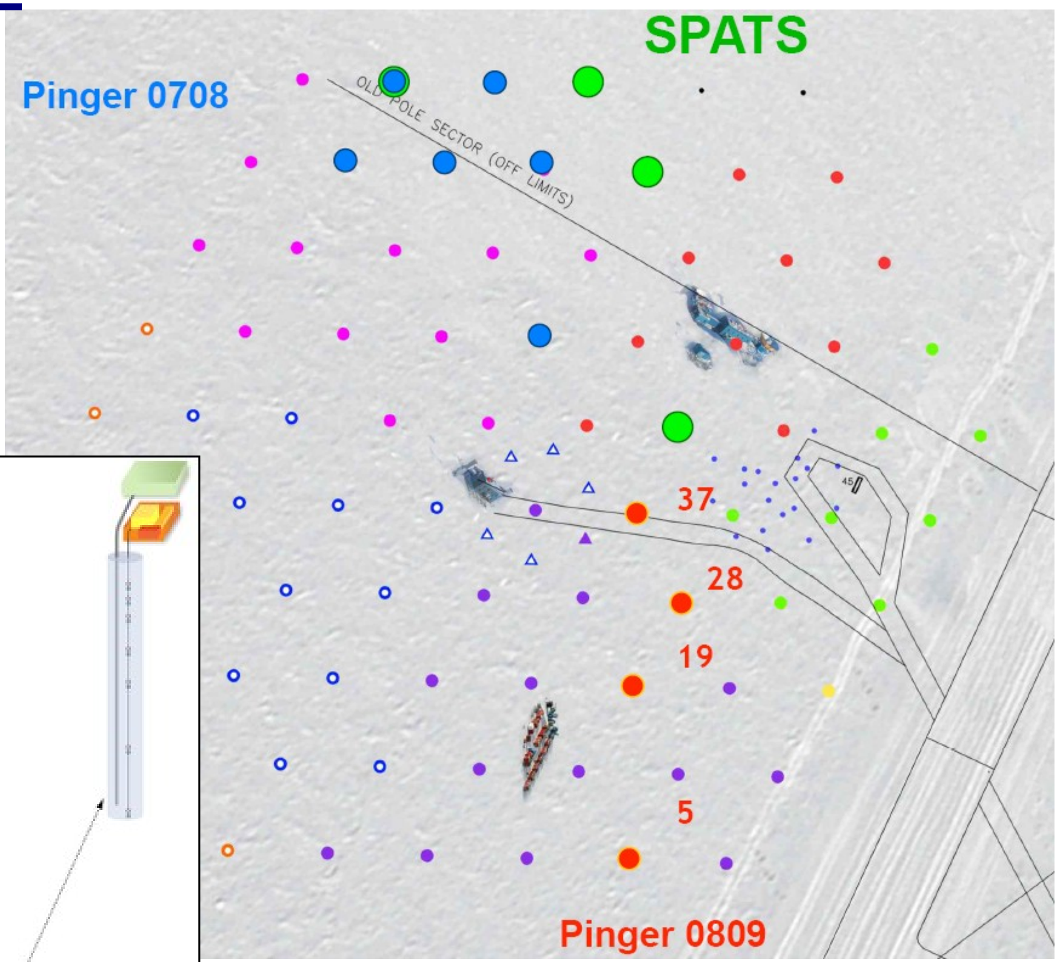
- Benefit from IceCube knowledge and access to South Pole site
- Unique possibilities of combined observations both in-ice and on-ice
- Vision of “guaranteed” neutrino signal ↔ momentum from potential IC discovery
- Keep
  - engineering work force
  - students with inclination towards hardware
  - entrepreneurial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

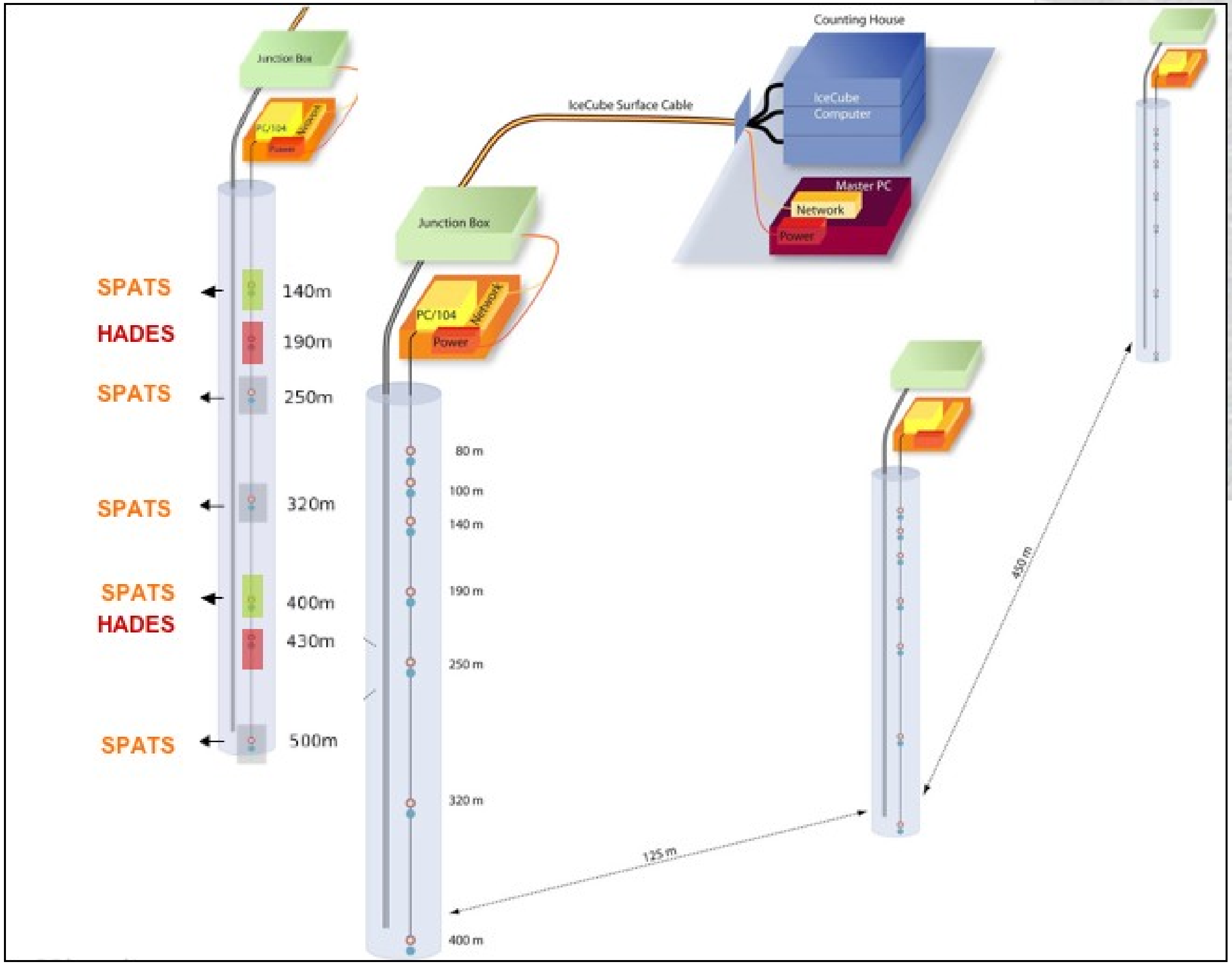
# Status of ongoing site studies with ...

- **SPATS**: South Pole Acoustic Test Setup
- **RICE**: Radio Ice Cherenkov Experiment
- **AURA**: Askaryan Underice Radio Array
- **NARC**: Neutrino Array Radio Calibration
- **Surface radio antennas** (stand alone)

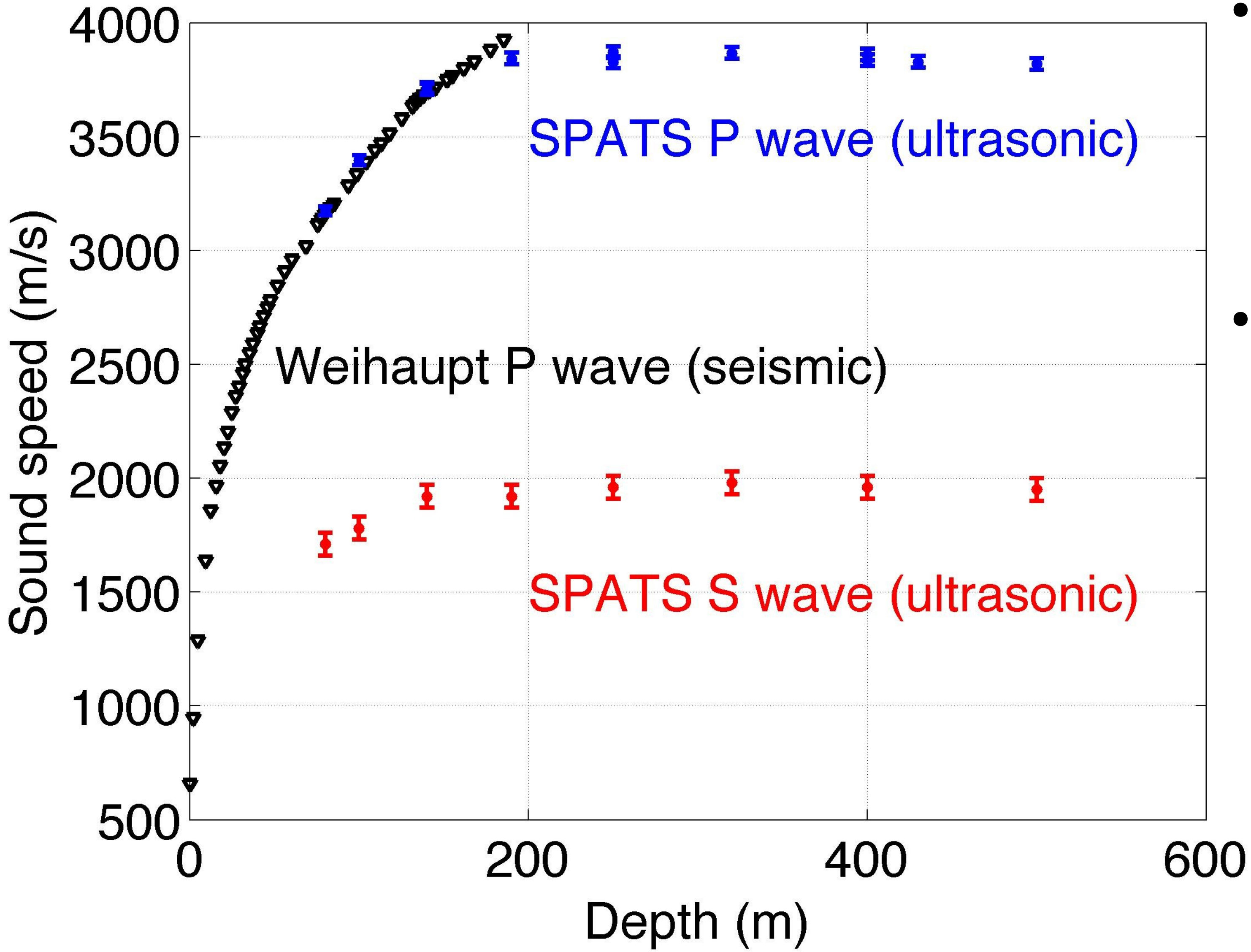
# Status Acoustics

SPATS



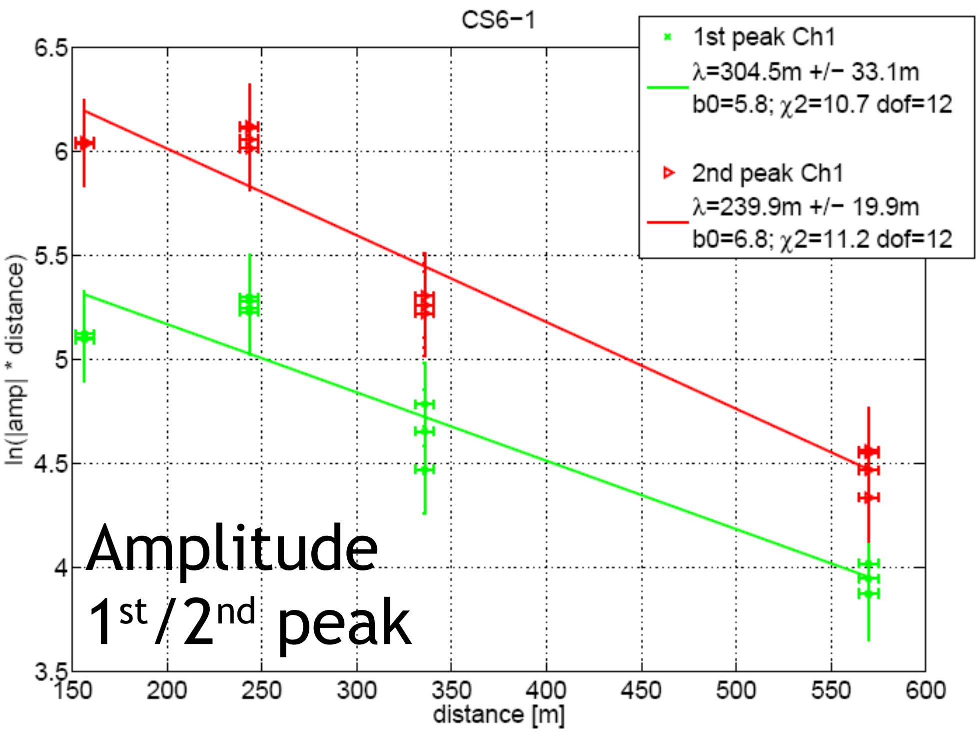



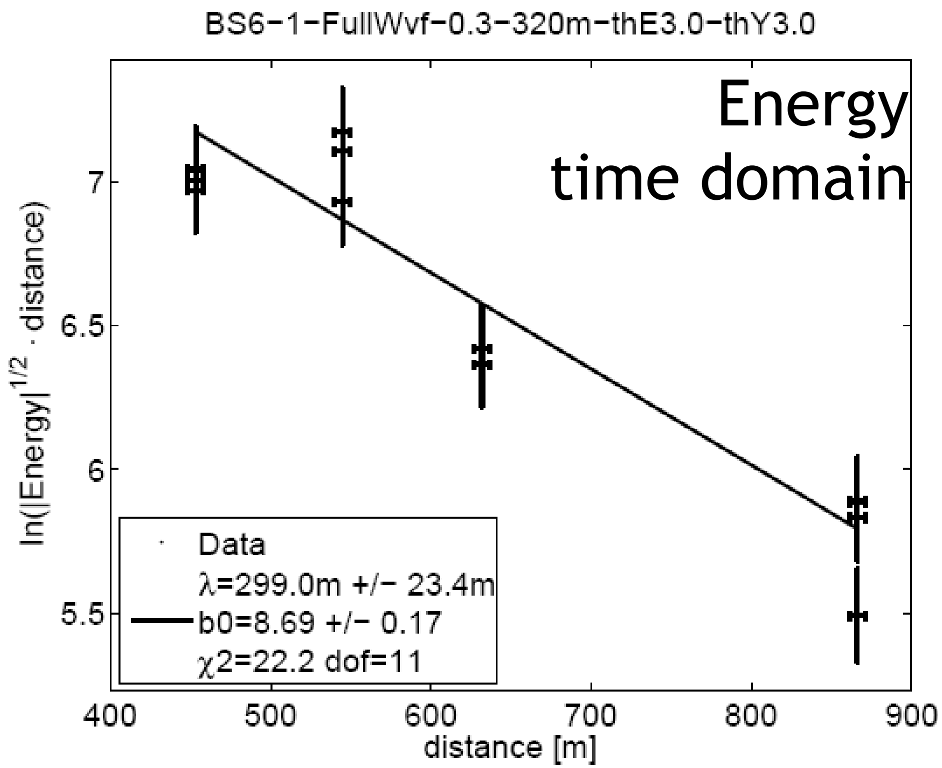
# Speed of sound




- Also shear waves are relevant!
  - helps with reconstruction
- Precision measurement ready for journal publication in ~ weeks

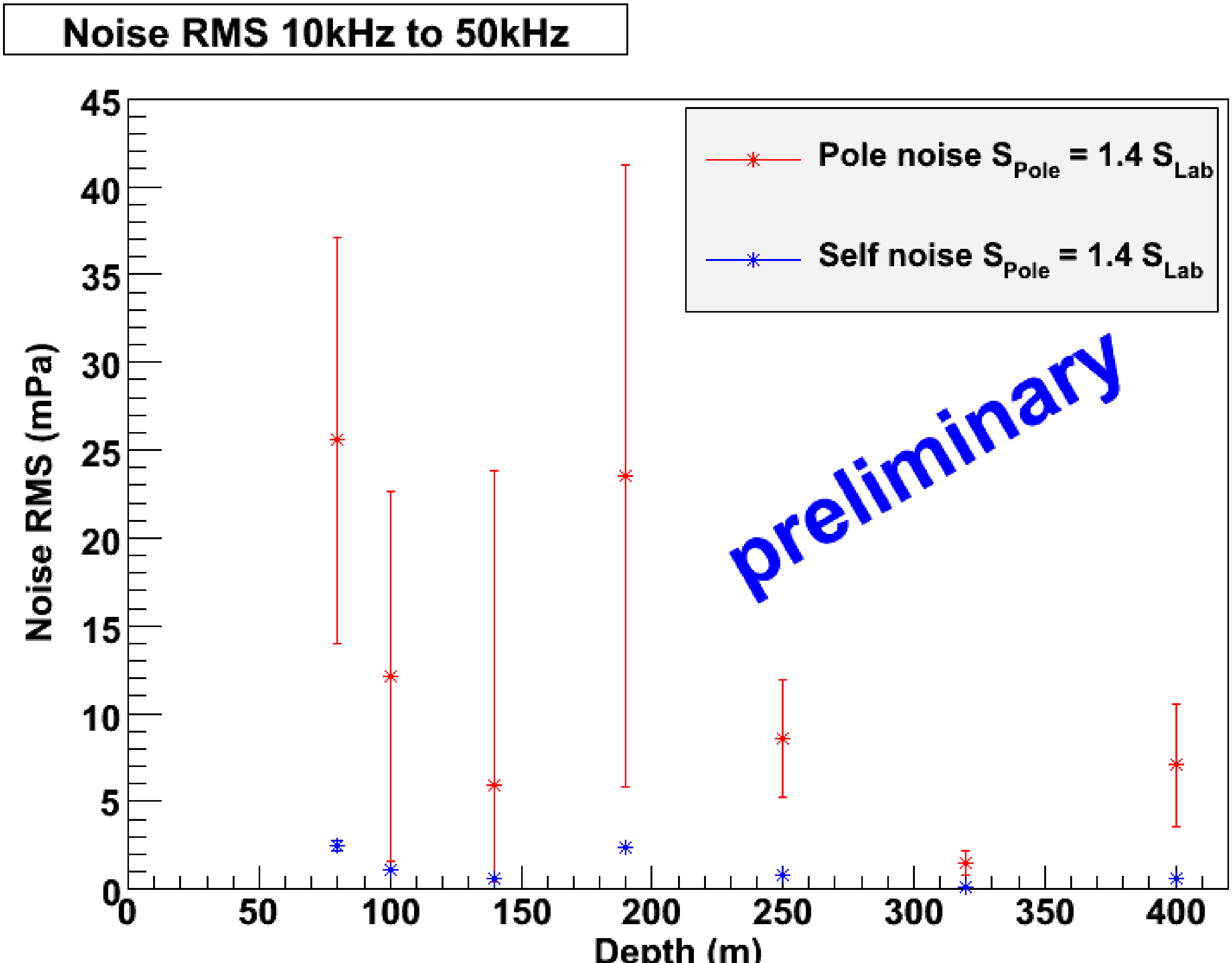
# Acoustic attenuation



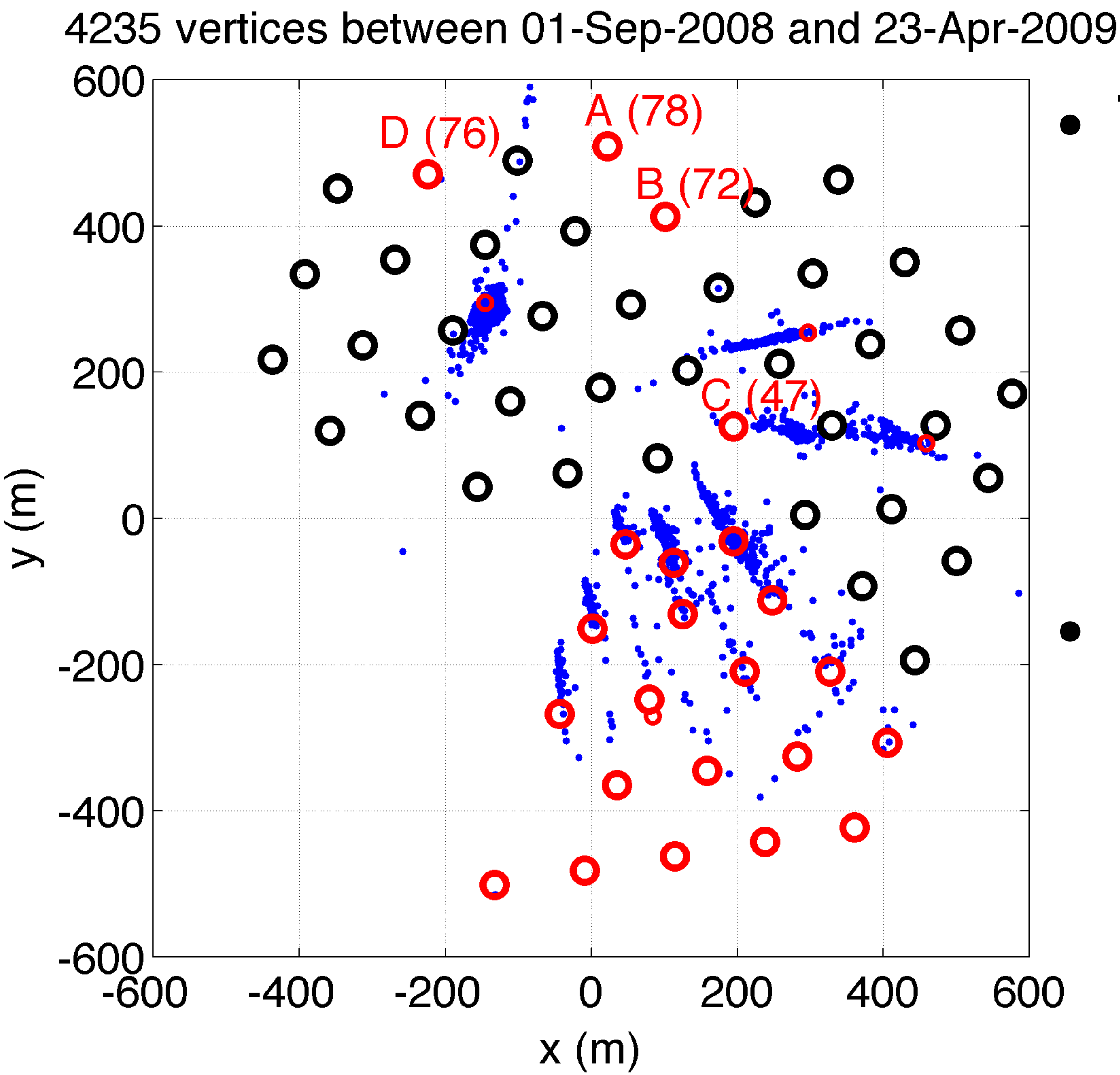

- Ball park: 300m ± 100 m
  *Expectation was kilometers*
- Unclear whether attenuation is short because of absorption or scattering

# Acoustic noise (DC)




Low continuous noise level

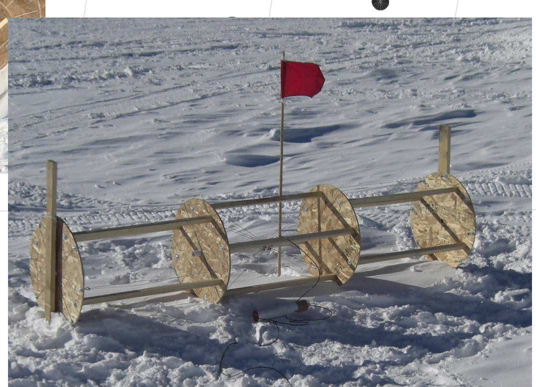
# Acoustic noise, transients

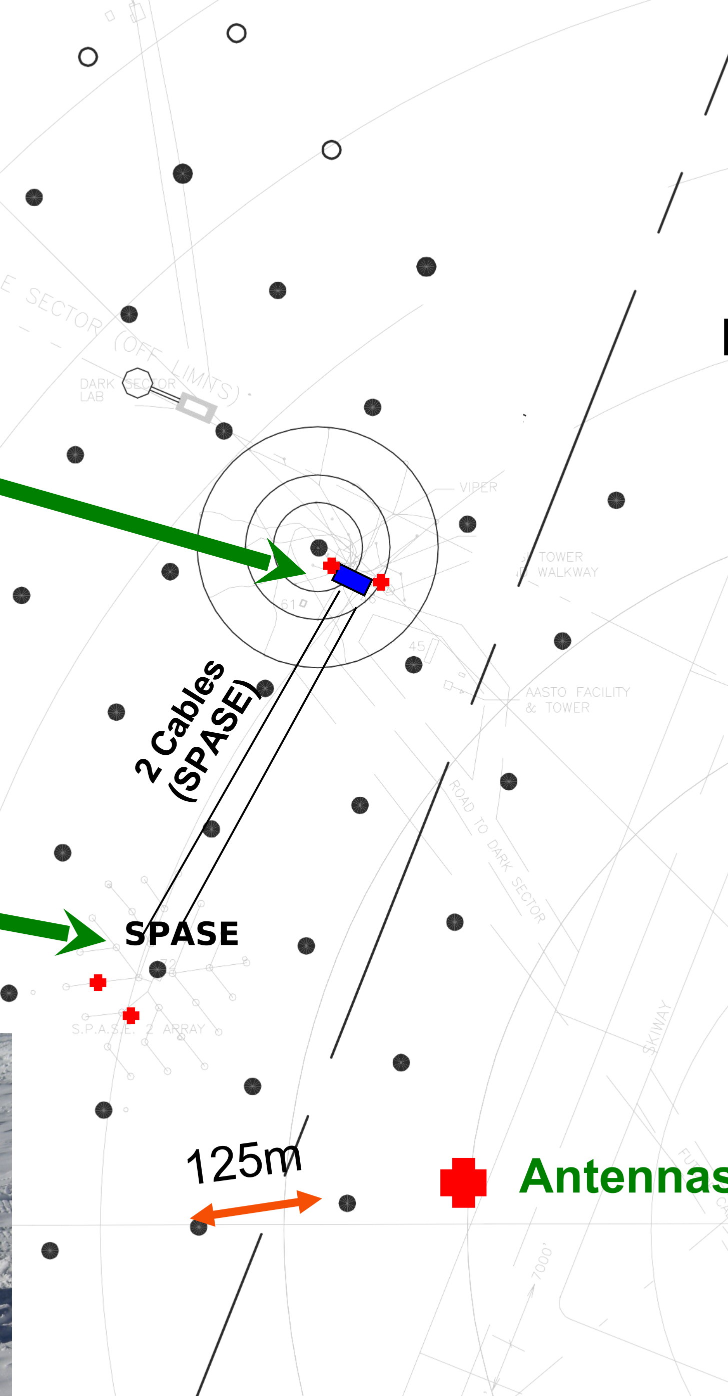



- Transients correlate with
  - Rod wells for drilling
  - freeze in of IceCube holes
- No correlation found with “dry” rod well
  - blind analysis proof

# Status air shower radio

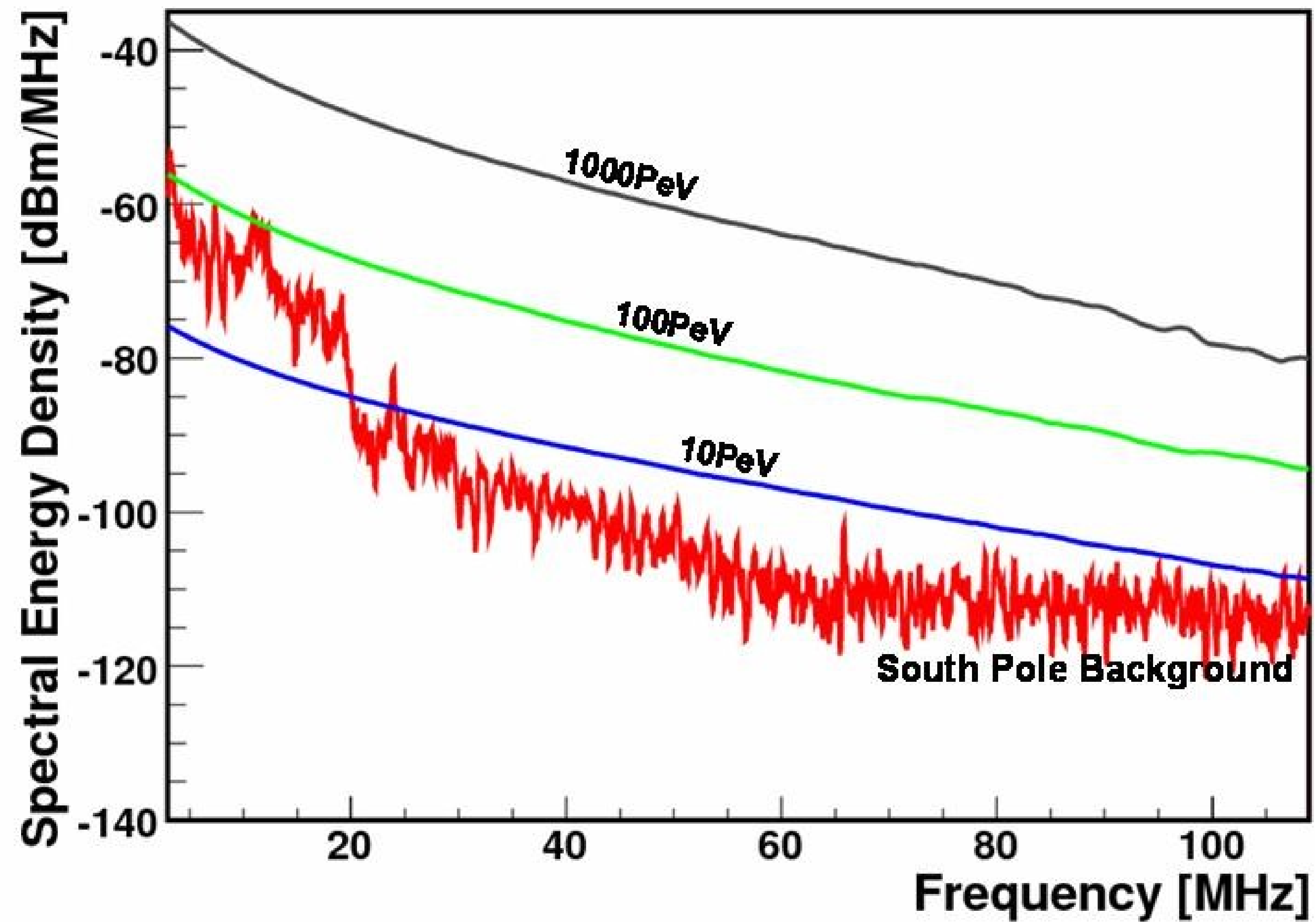

SPASE Building






**Test array:**
4 antennas
read out with
RICE DAQ

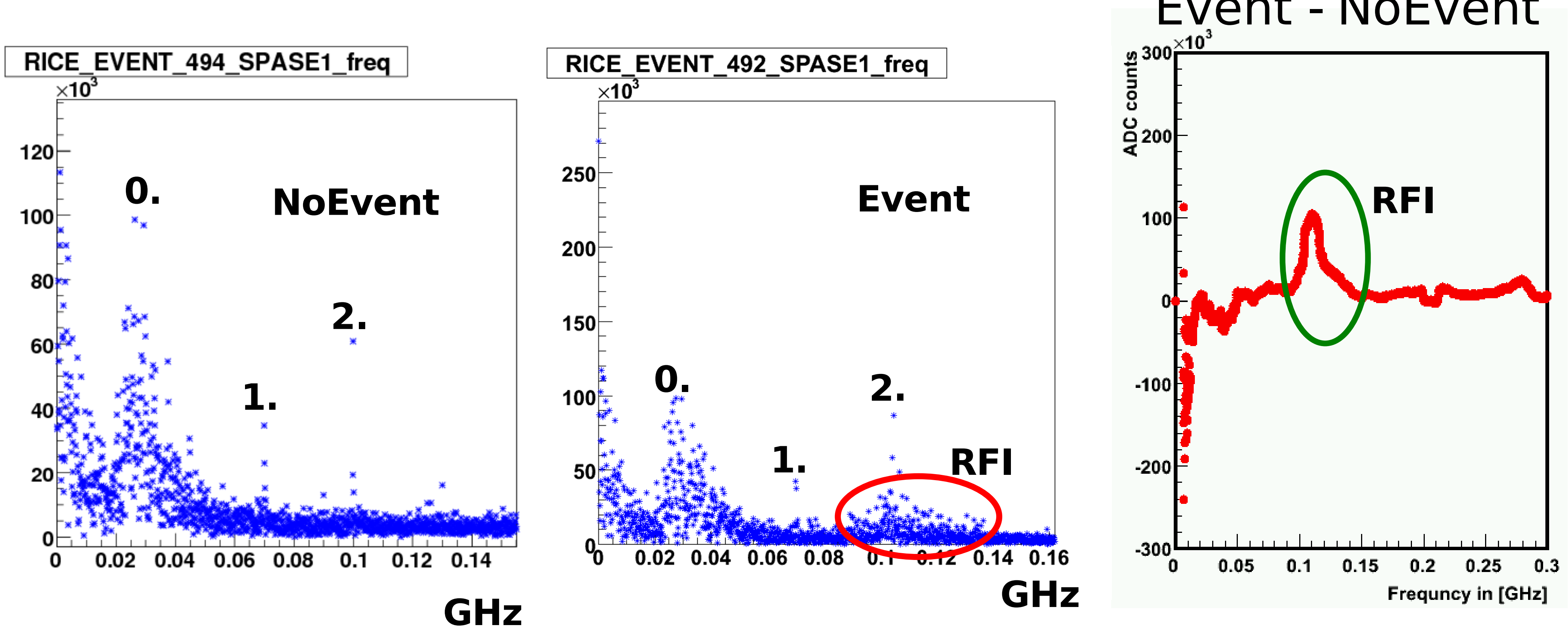
# Surface RFI (DC)




Low continuous noise level

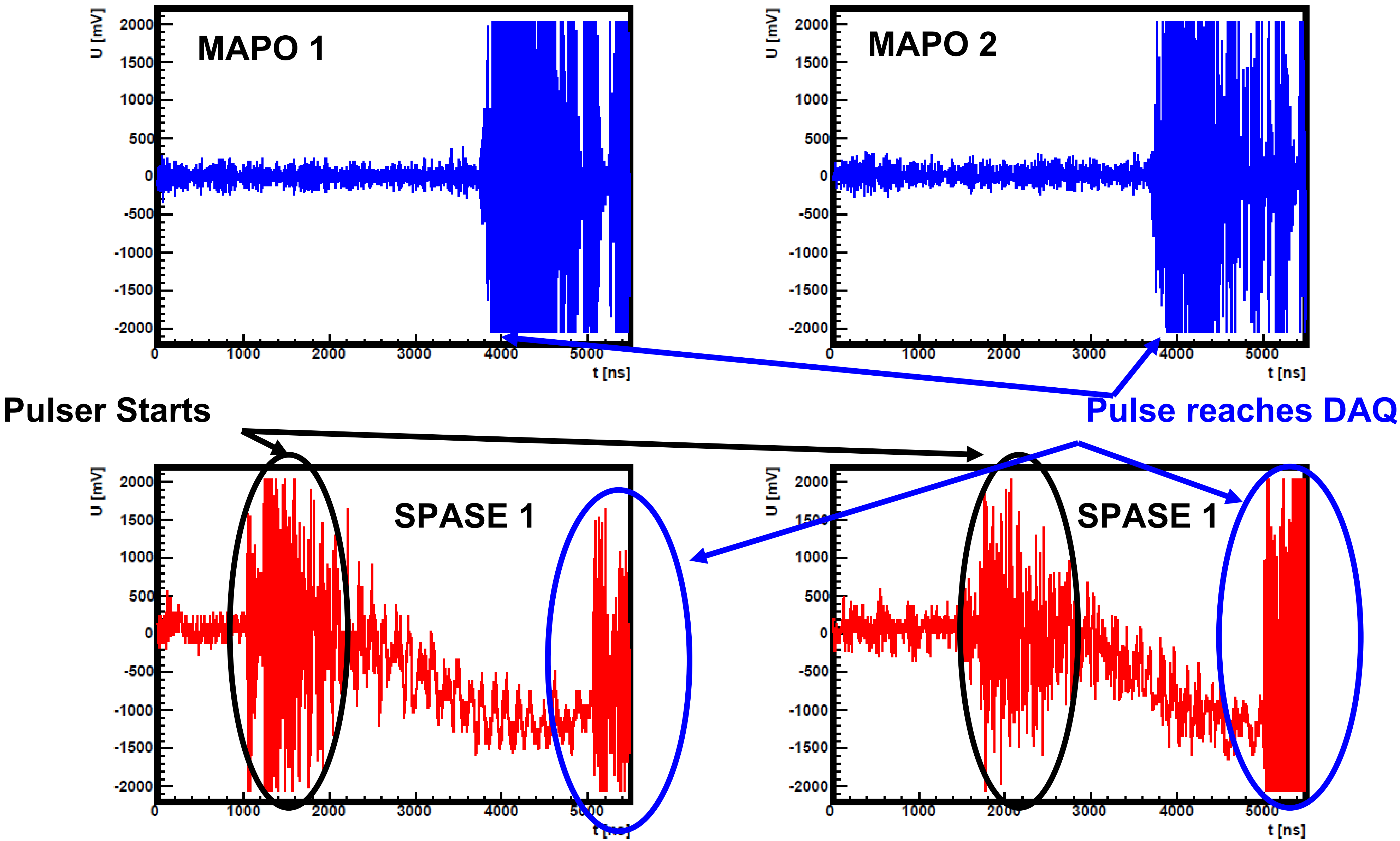
# Transient surface RFI

- uncalibrated -




narrow frequency band of RFI emission
compared to broad band air shower signal

# Pinger Data Reconstruction



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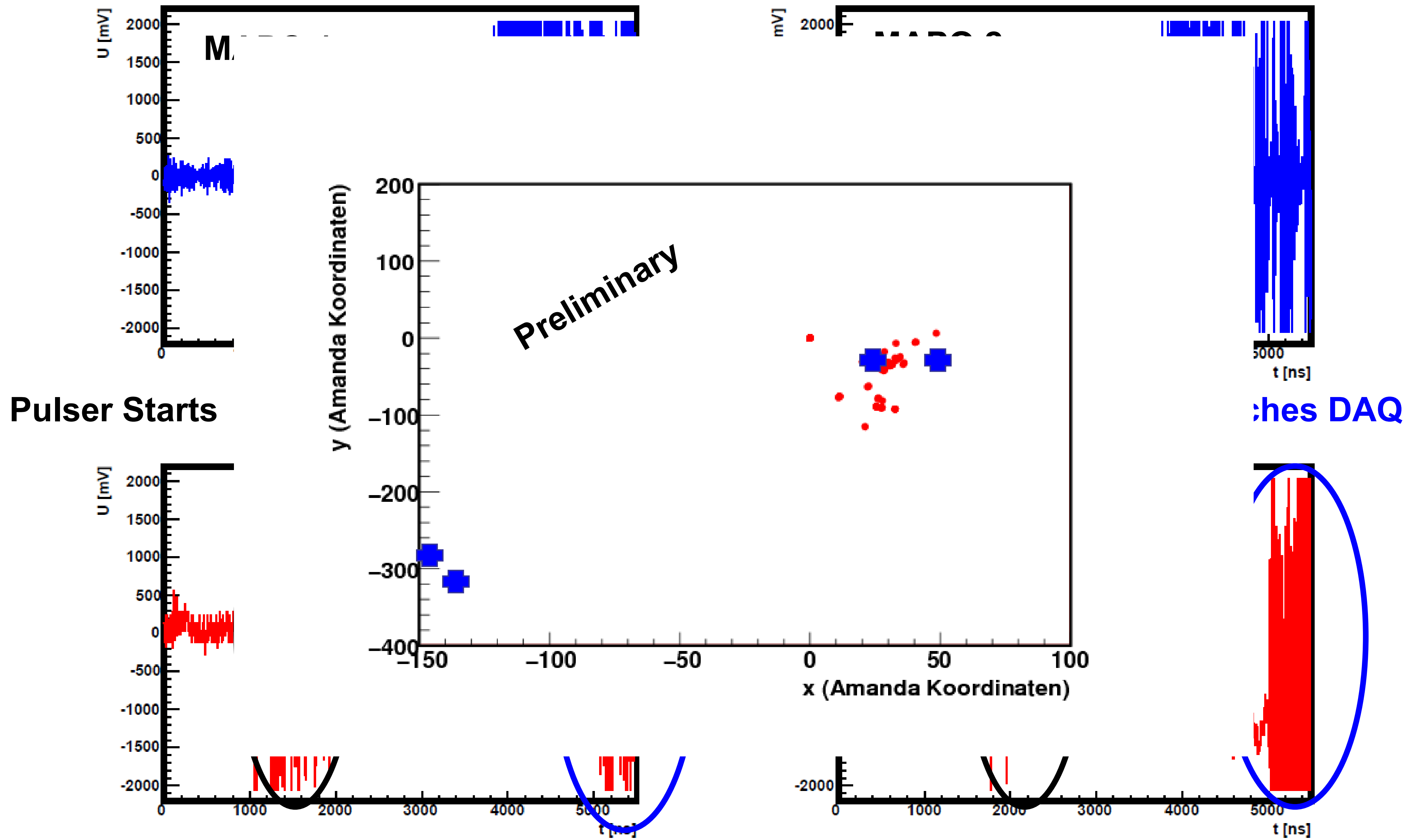
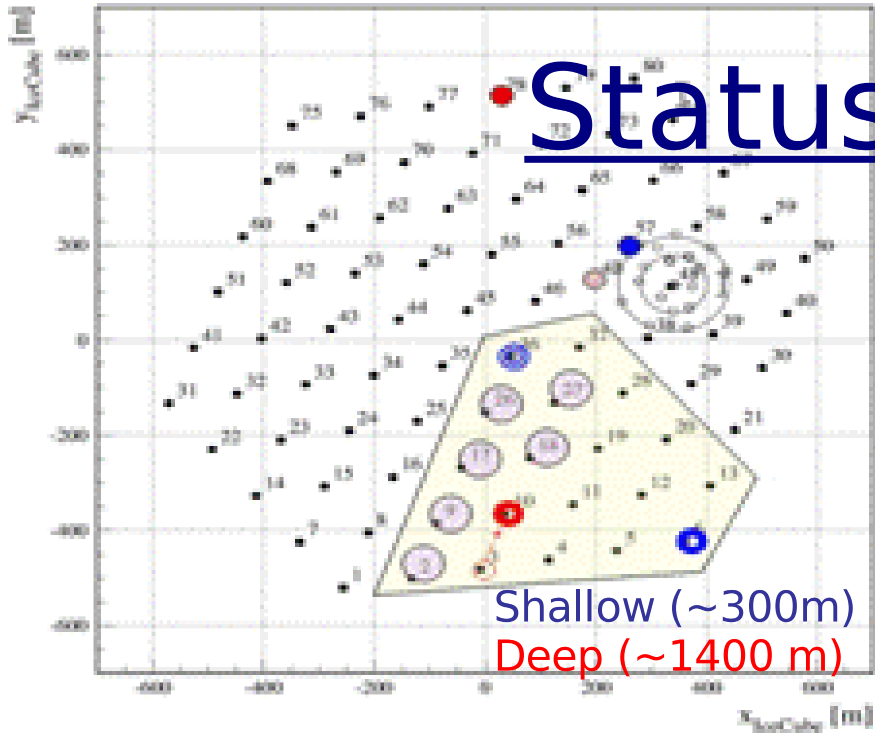
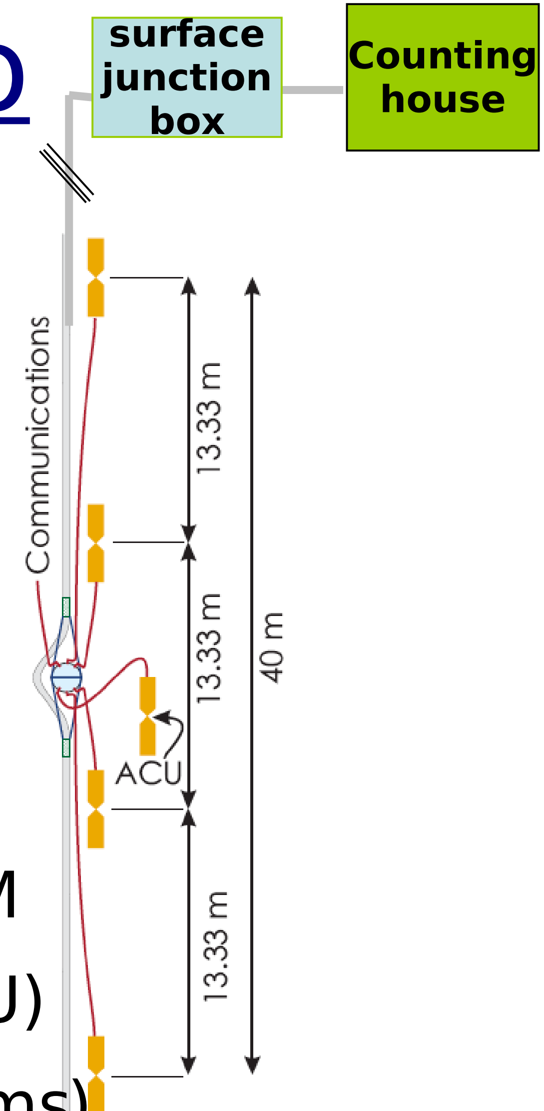


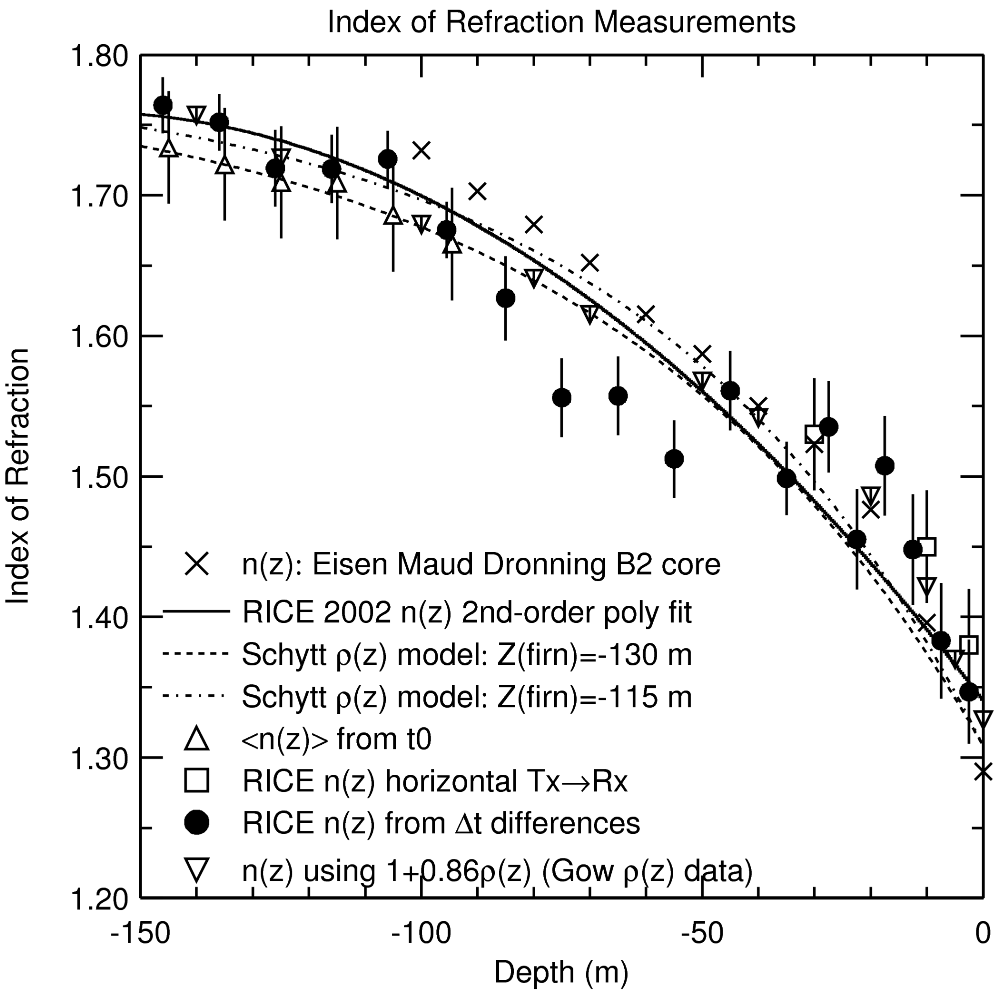
# Status in-ice radio



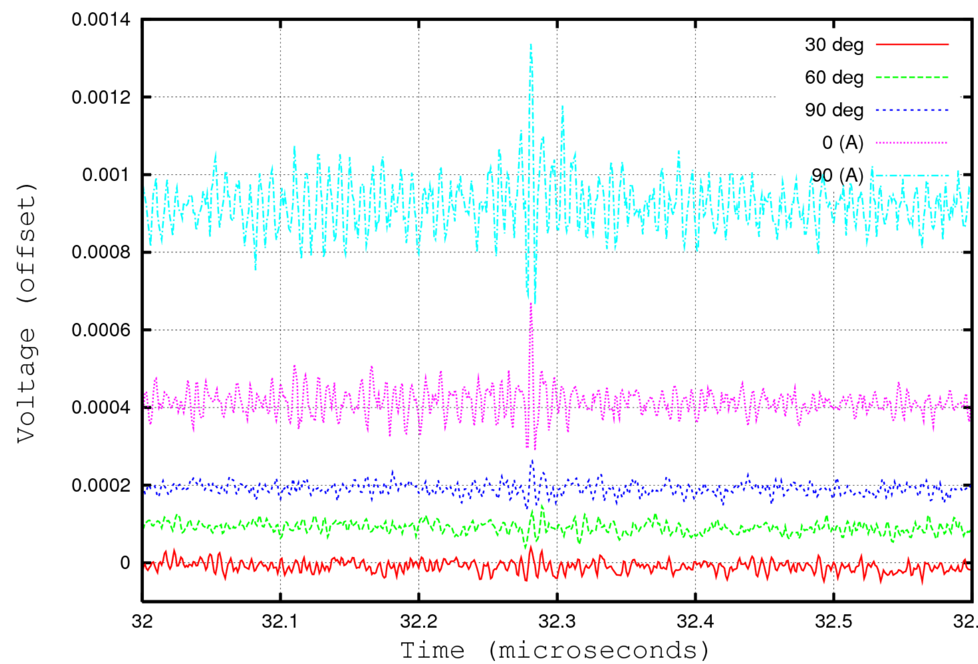




- AURA cluster:
  - Digital Radio Module (DRM) – similar to DOM
  - 4 antennas, 1 Antenna Calibration Unit (ACU)
  - IceCube sphere, DOM main board (waveforms)
- 5 clusters: 2 in 06/07; 3 in 08/09 (with NARC)
- 2 channels (“antennas”) down to 100MHz
- 15/20 channels are working

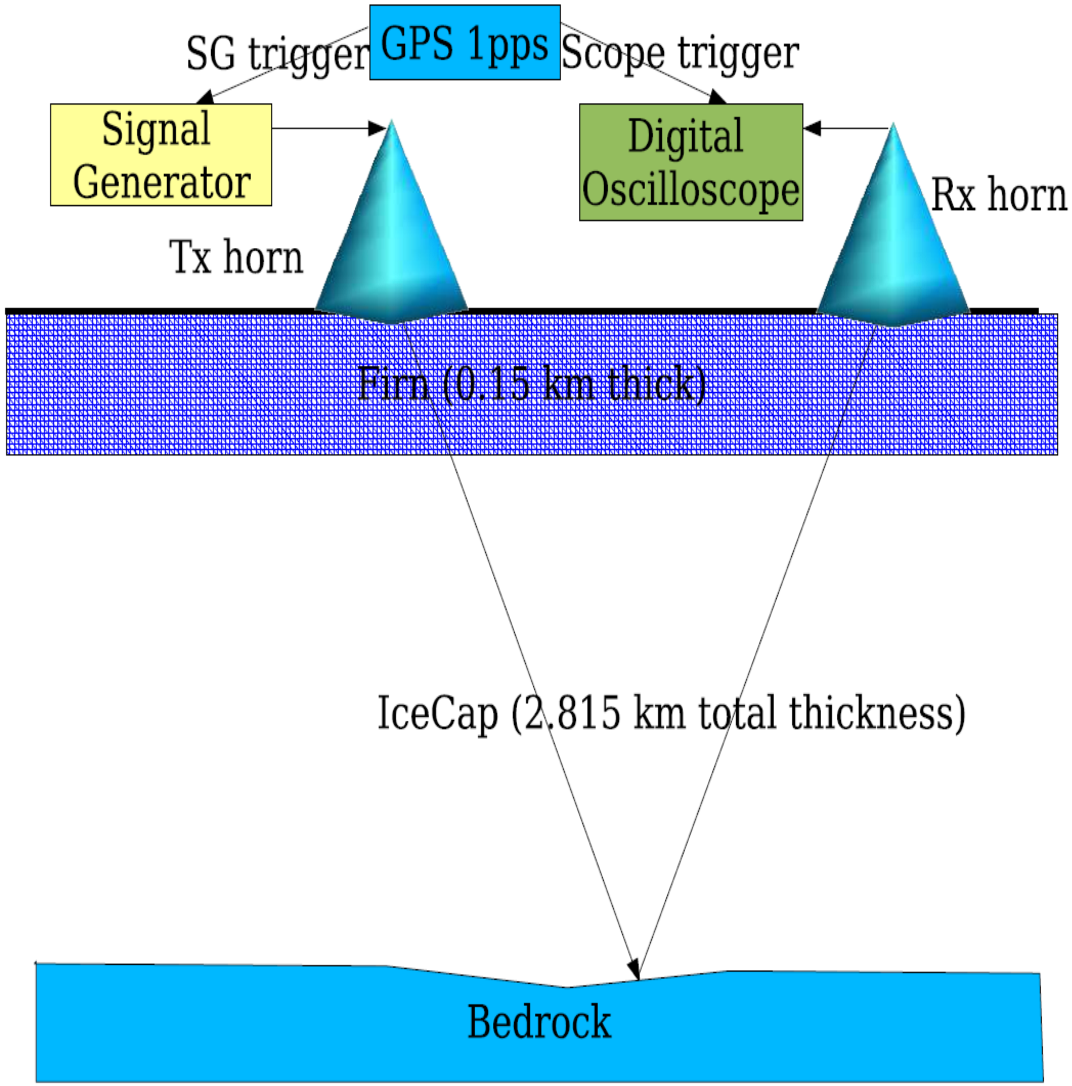
# Status in ice radio: Index of refraction

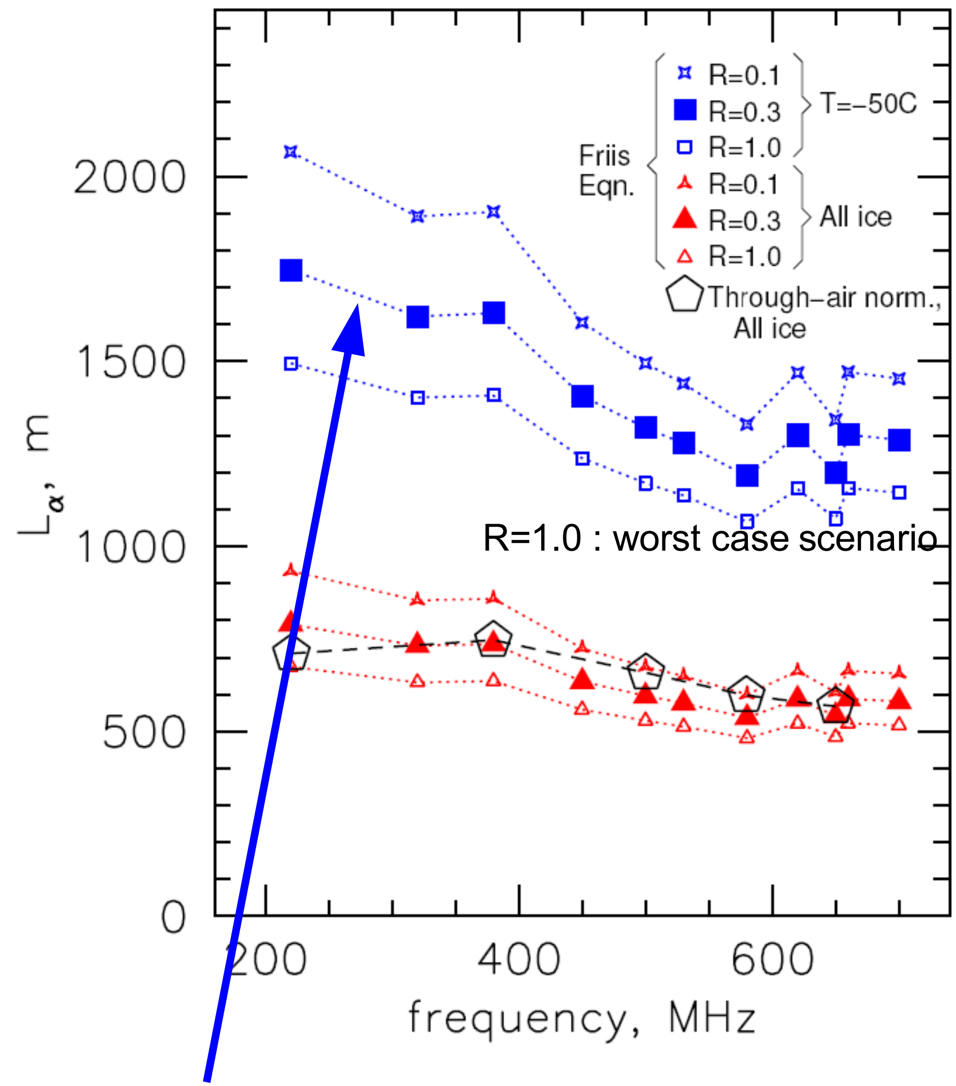



- Changing index helps to reduce surface noise pickup
- ... but shadowing for shallow deployment
- No birefringence



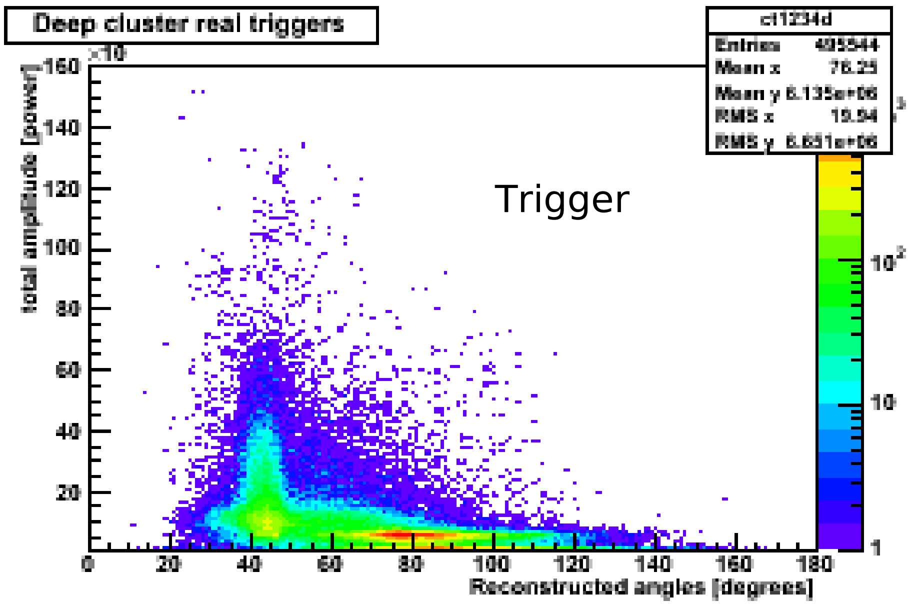
# Radio attenuation

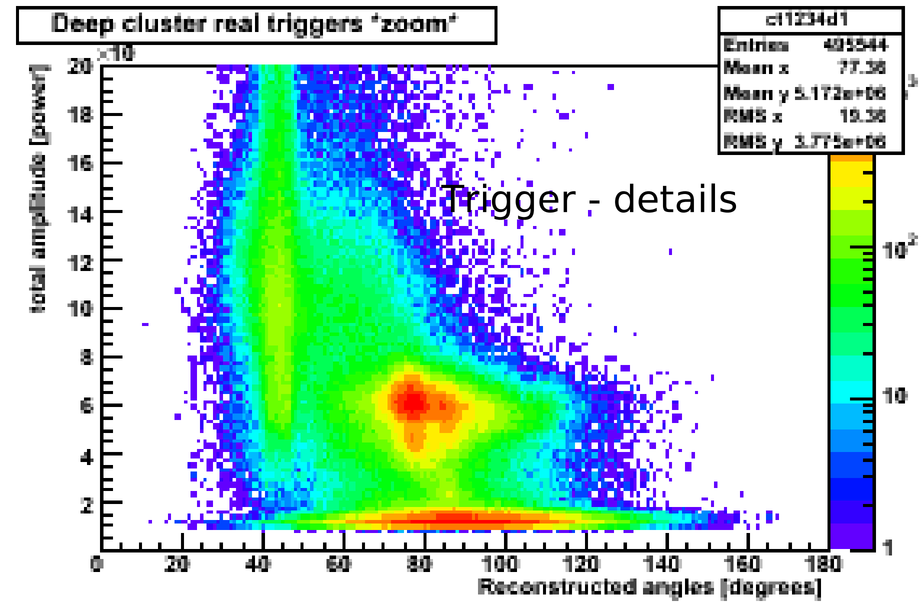


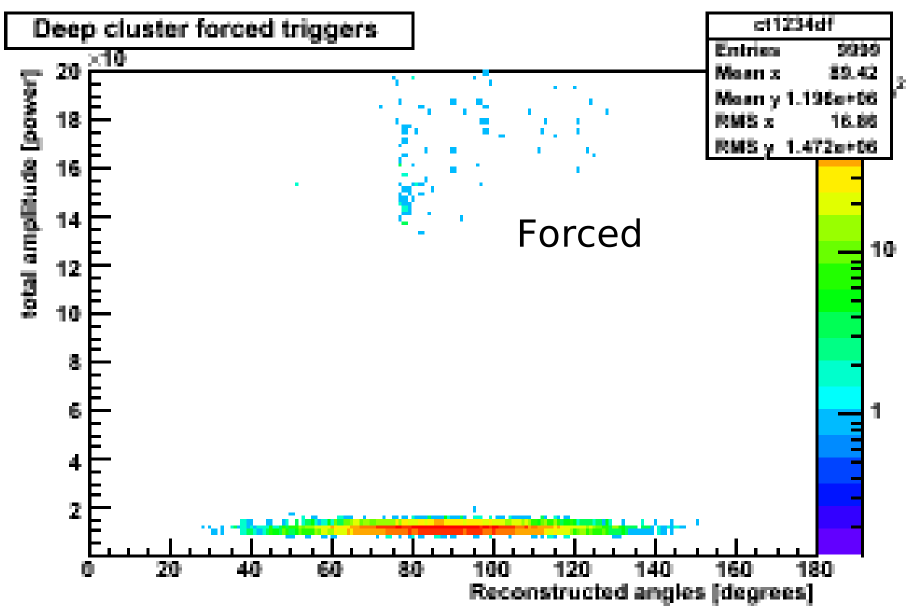




temperature region for shallow deployment

# In ice RFI transients with AURA



# Status summary: **Attenuation**

- **Mostly known**
  - great progress in acoustics with last season but unfavorable result
  - known from radio reflection of bed rock, direct on-site measurements would be nice confirmation
  - 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 but needs additional studies for shallow holes
  - 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.

# Status summary: **Noise**

- Noise/EMI/background: **significant uncertainties wrt transients** potential cost driver (electronics)
  - Acoustic: constant level of noise favorable (compared to sea), most transients 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.

# 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
- In case optimistic scenario prevails
  - scattering accounts for short attenuation *reduces previously diverging vertical demands*
  - 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 independent evidence for neutrinos to radio signals

# Drill options for large array

## Findings from 2 drilling workshops held in Madison 2008

| Drill | Type | Dia (m) | Depth (m) | Speed (m/min) | Fuel (L/ min) | Weight (tons) | Crew Size | Cycle Time | Cost (k$) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| IceCube EHWD | $H_2O$ | 0.65 | 2500 | 1.8 | 800 | 5000 | 30 | 3 days | - | Overkill |
| IceCube EHWD | $H_2O$ | 0.3 | 1500 | 1.8 | 200 | 5000 | 20 | 2 days | - | Modified |
| Amisor | $H_2O$ | 0.25 | 1000 | 1.5 | 50 | 15 | 9 | 1 day | 100 | Australian |
| Caltech | $H_2O$ | 0.25 | 1200 | 1.5 | 50 | 15 | 9 | 1 day | 200 | |
| Shot | Mech | 0.1 | 100 | 4 | - | 10 | 2 | Hours | 100 | Could be modified for larger diameter and deeper hole. Untested at high altitude. |
| Firn | $H_2O$ | 0.65 | 55 | 0.1 | - | 20 | 6 | 1 day | 100 | Dry hole |
| 4" Pico | Mech | 0.1 | 250 | - | - | 1 | 6 | Weeks | | Very slow due to core retrieval |
| Simco | Mech | 0.3 | 45 | 0.3 | - | 5 | 6 | 1 day | | |
| Sonic | Mech | 0.2 | 80? | - | - | 2 | 9 | 10 hr | | Probably very fast. |
| Foundation | Mech | 0.4 | 90 | ? | - | 100 | ? | ? | 1500 | |
| Small Hot Water | $H_2O$ | 0.15 | 100 | 4 | ? | ? | ? | Hours | ? | Cheap |

Current line of thoughts:

- down to **200m** depth at reasonable cost
- Dry holes much easier than wet holes.

# Road forward

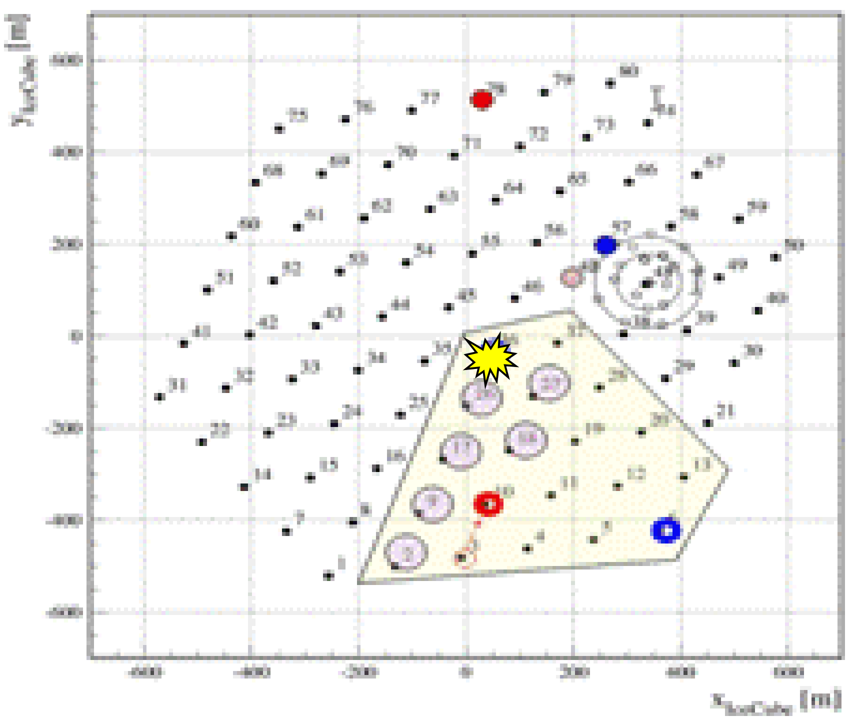
- Use last holes/seasons for
  - prototype sensor co-deployment
  - tests of digitization strategies (e.g. envelope)
  - instrumentation for further site studies
    e.g. retrievable sensors and radio pingers
  - find coincidences of air shower radio with IceTop
- Aim for dedicated (dry) holes to test
  - Deployment methods
  - Couplings of sensors with holes
- Assume maximum drilling depth of up to 200m (cost)
  - acoustic scattering might help reduce previously diverging vertical demands

# Near term time line

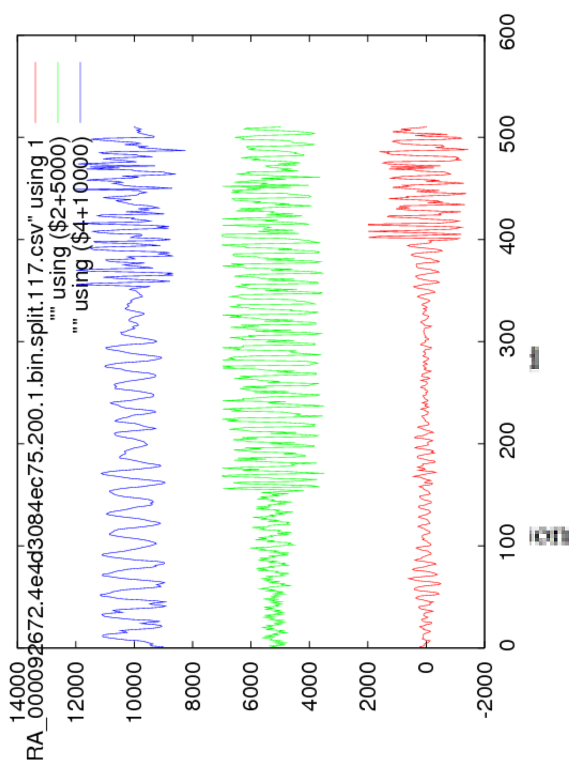
- Clarify role of non-IceCube members 2009
- Start „Letter of Intent“ (LOI) at R&D workshop in June and sign in fall 2009 to demonstrate:
  - serious intent of signing groups (FAs)
  - scientific importance
  - long term time scenario and milestones
- Finish basic exploration of ice properties (season 09/10)
- Start extensive MC studies (fall 09)
- Track down number of different detector options (2010)
- Write „Proposal“ for submission to FA‘s early 2011
  - expand letter of intent based on MC and hardware studies
  - scalable design plan and 2 phase structure
  - work out realistic budget plan

# Immediate future with AURA

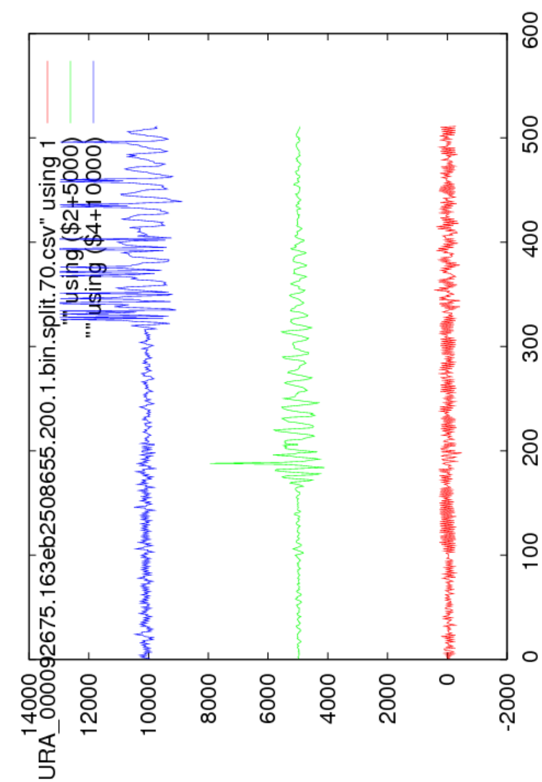
- More RFI studies
- new stronger transmitter
  ⇒ first inter-cluster calibration source



Hole 36, -250 m



Hole 57, -288 m

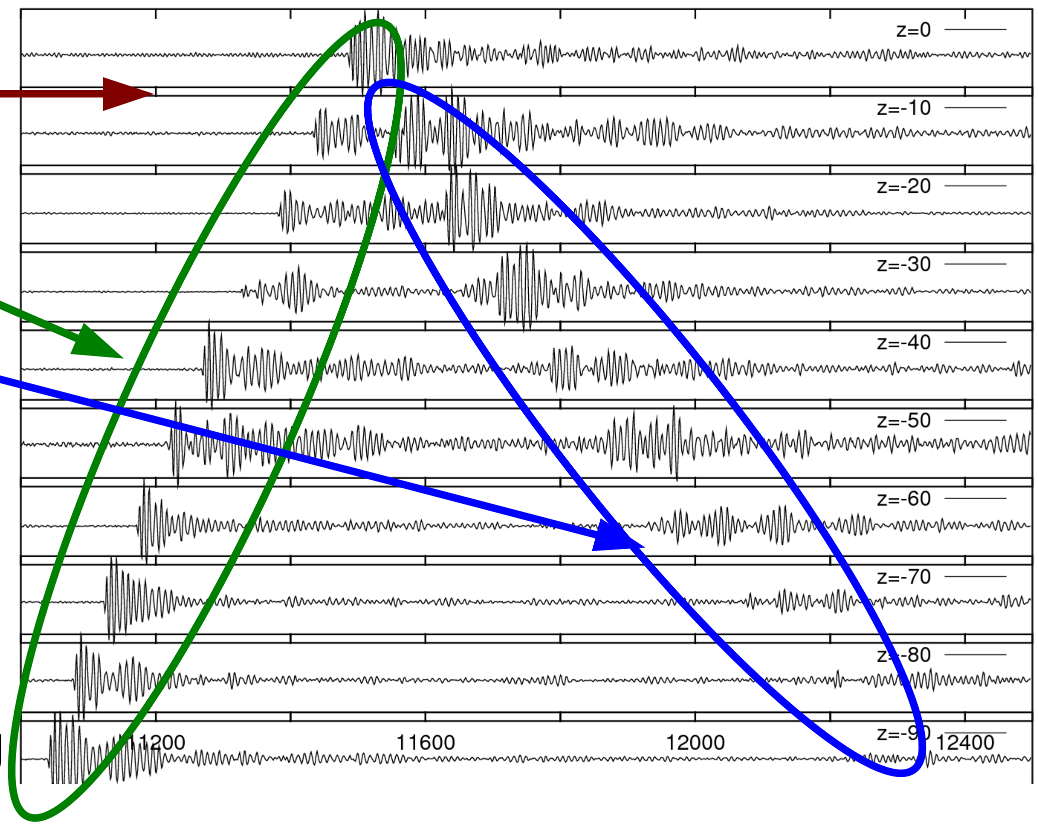


# Radio attenuation: Plans for direct on-site measurements

Previous pinging with RICE

direct signal path

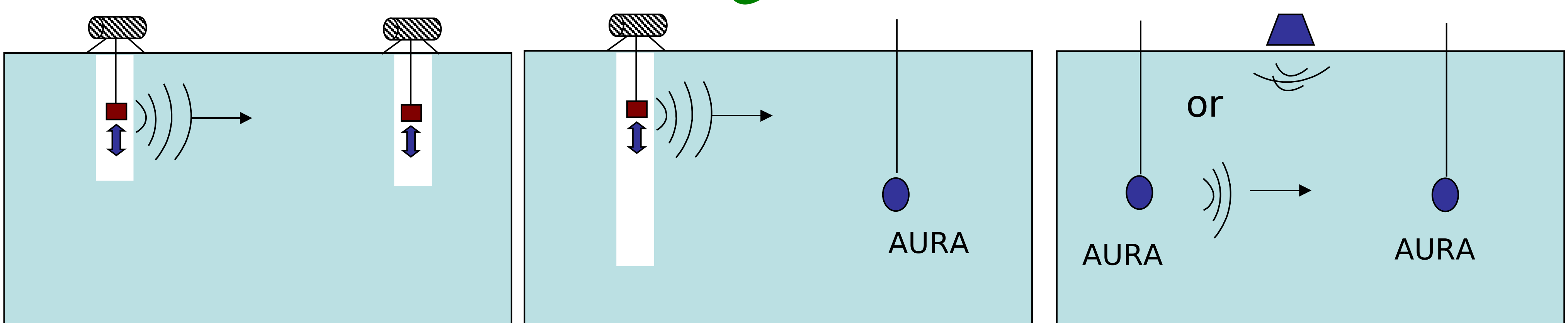
signal path with total reflection




Options:

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

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



# To-Do list radio

- 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

# Season 09/10 plans for acoustic

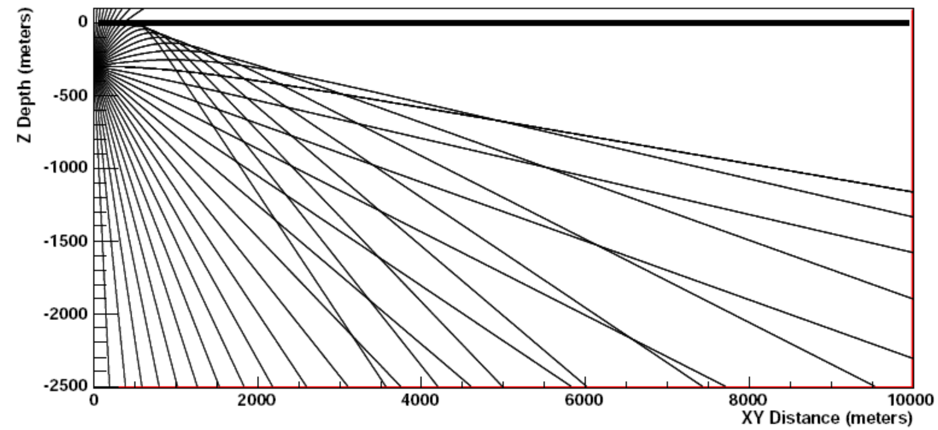
- Attenuation (if scattering) strongly frequency dependent
  - Test with broadband pinger
  - Confirm attenuation in perpendicular direction
- No transients below ~300 m
  - No sources? – Unlikely
  - Mechanism quieting deep sources (relevant to radio?)
  - Lower pinger to deeper depths (~1000 m)
- New set of pinger runs in 2009/2010!
- Collect data needed to publish ice properties

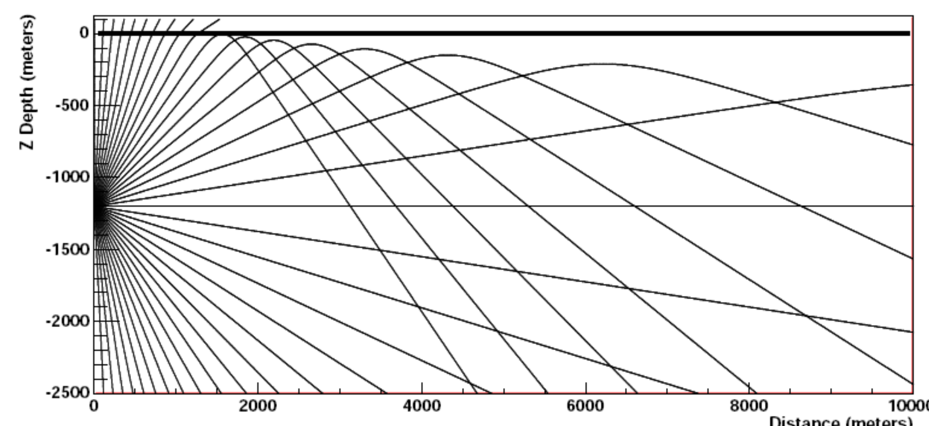
# Detector design considerations

- 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

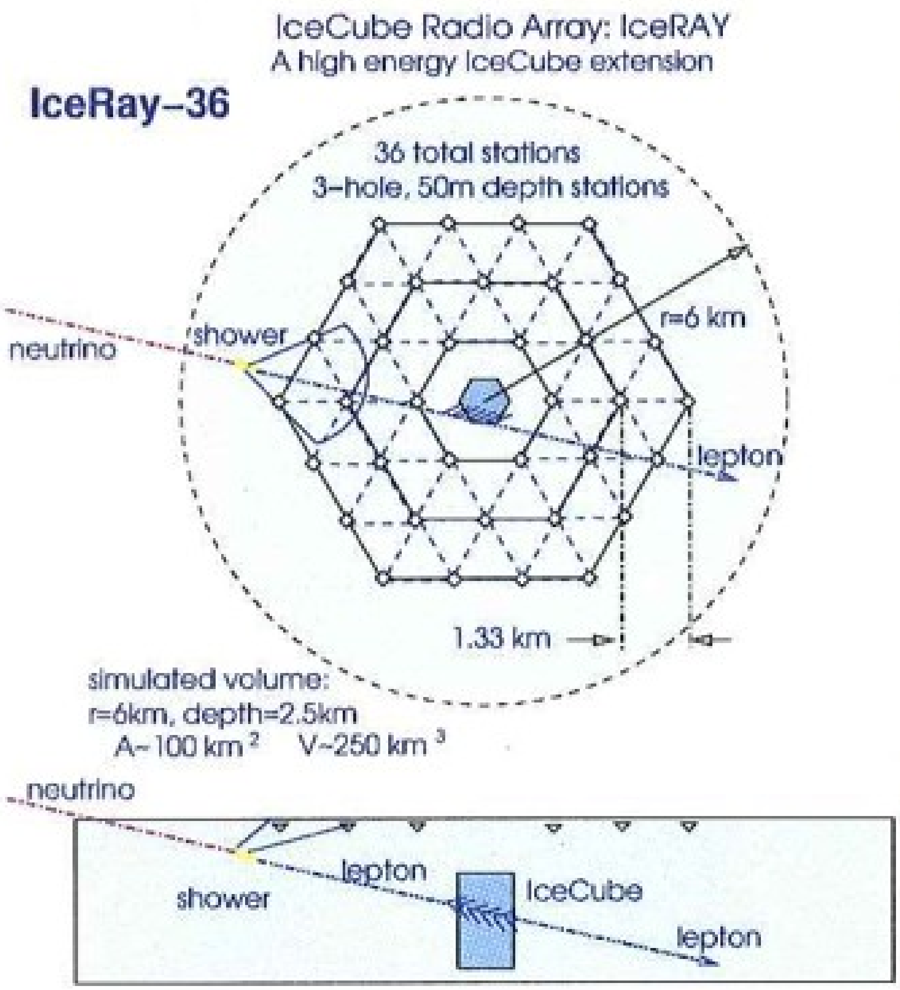


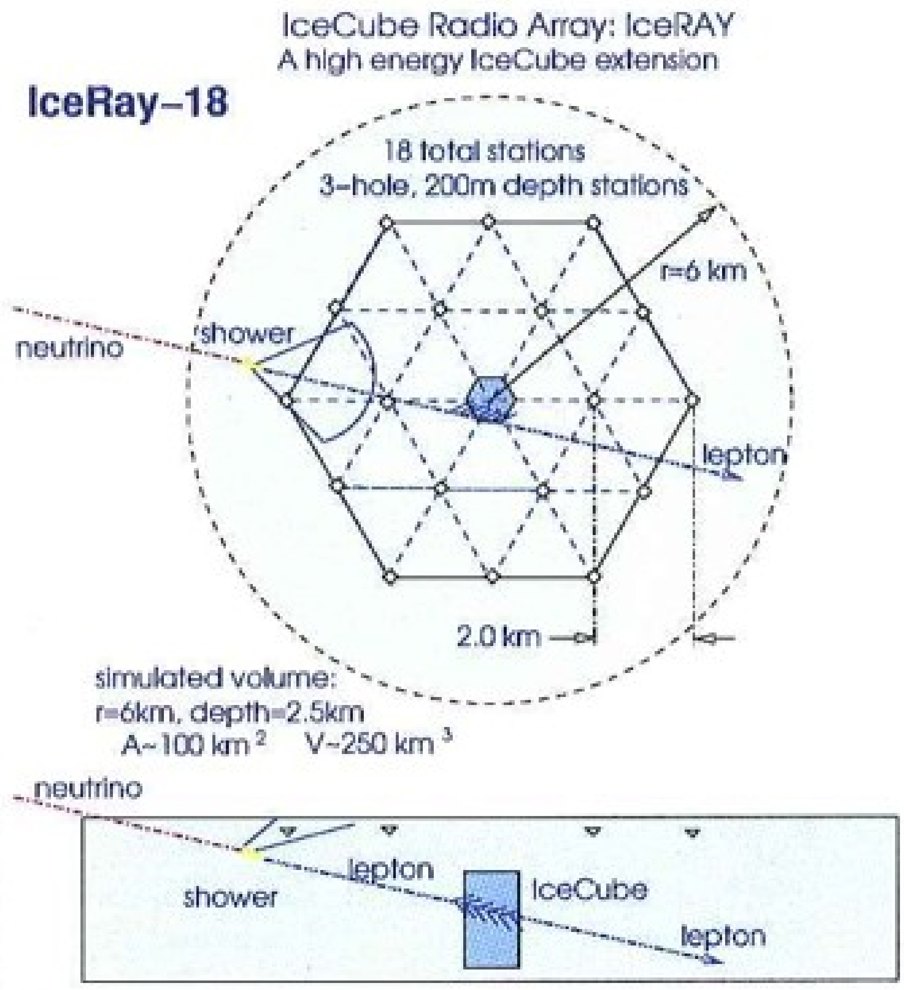




dense shallow versus sparse deep

# Case study IceRay

## – fully digitized waveforms, 50 km² –




Comparison: High density, shallow (50 m) versus sparse, deep (200m )

3-9 GZKs per year (“standard flux”), 0.3-2 coincidences with IceCube

**⇒ develop plan to scale beyond 100 km² by factors**

# Example for technology choices

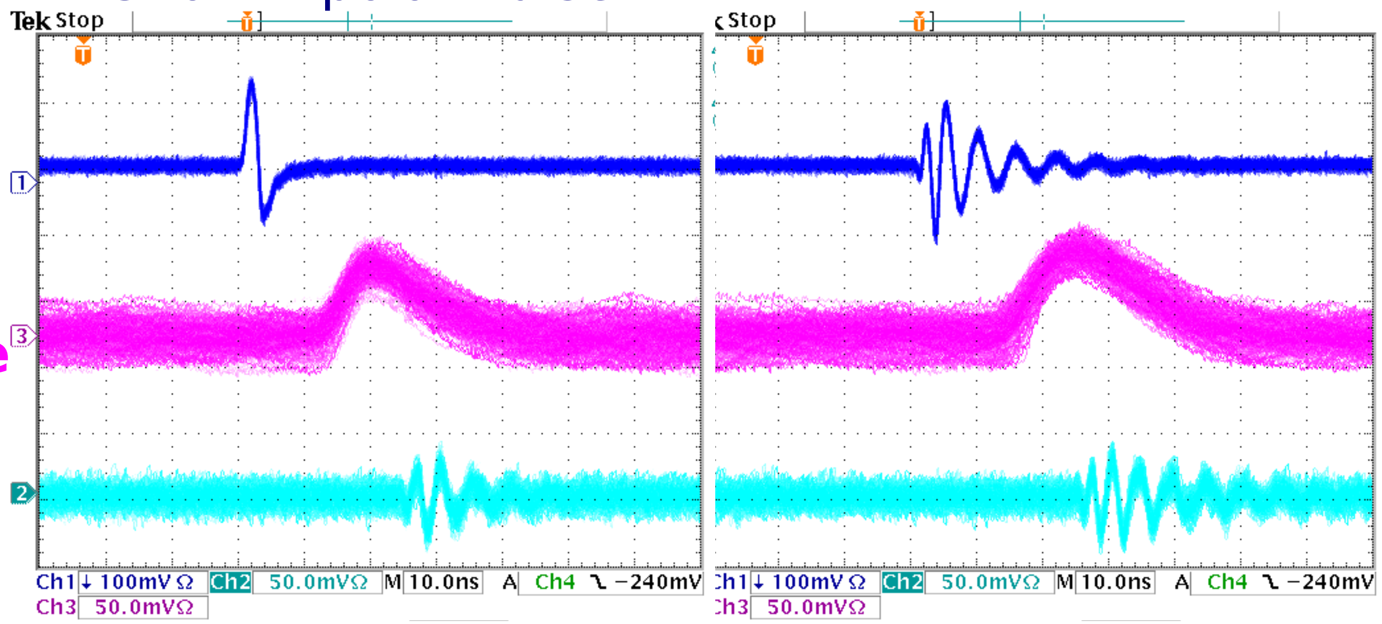
## Pulse shaping and triggering versus waveform capture

Short Bipolar Pulse

“Antenna-like” Transient

shaped pulse

AURA waveform

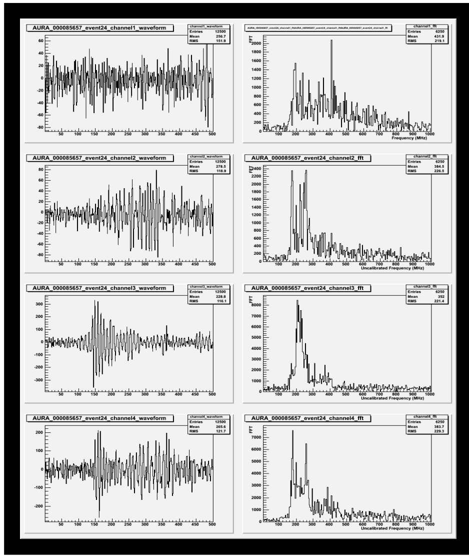


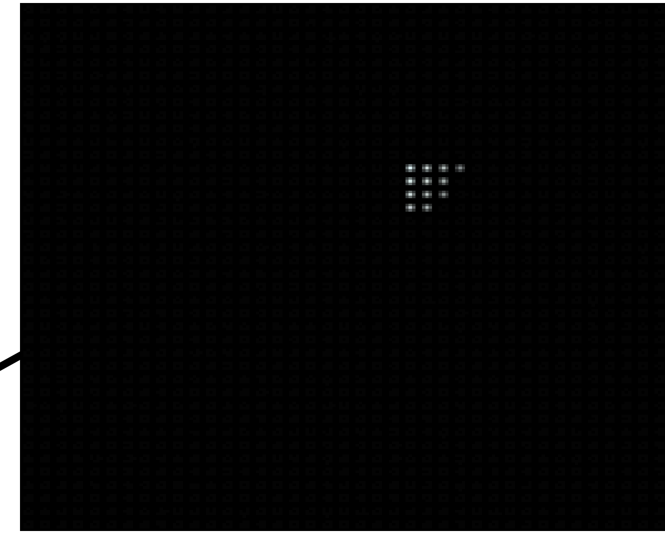

If only envelope gets sent to surface:

- Digitization speed can be lowered
  - ➔ towards demands of air shower radio and acoustic
- no interference with several antennas in a hole
  - ➔ use loop through signal cable

Only feasible if RFI is well behaved

# Data acquisition considerations





**fully digitized waveform array**

Pros:
+ good timing, full frequency info
+ Method proven by ANITA and RICE

Cons:
– Expensive, more complicated units
– power consumption

Challenges:
Handling large amount of data

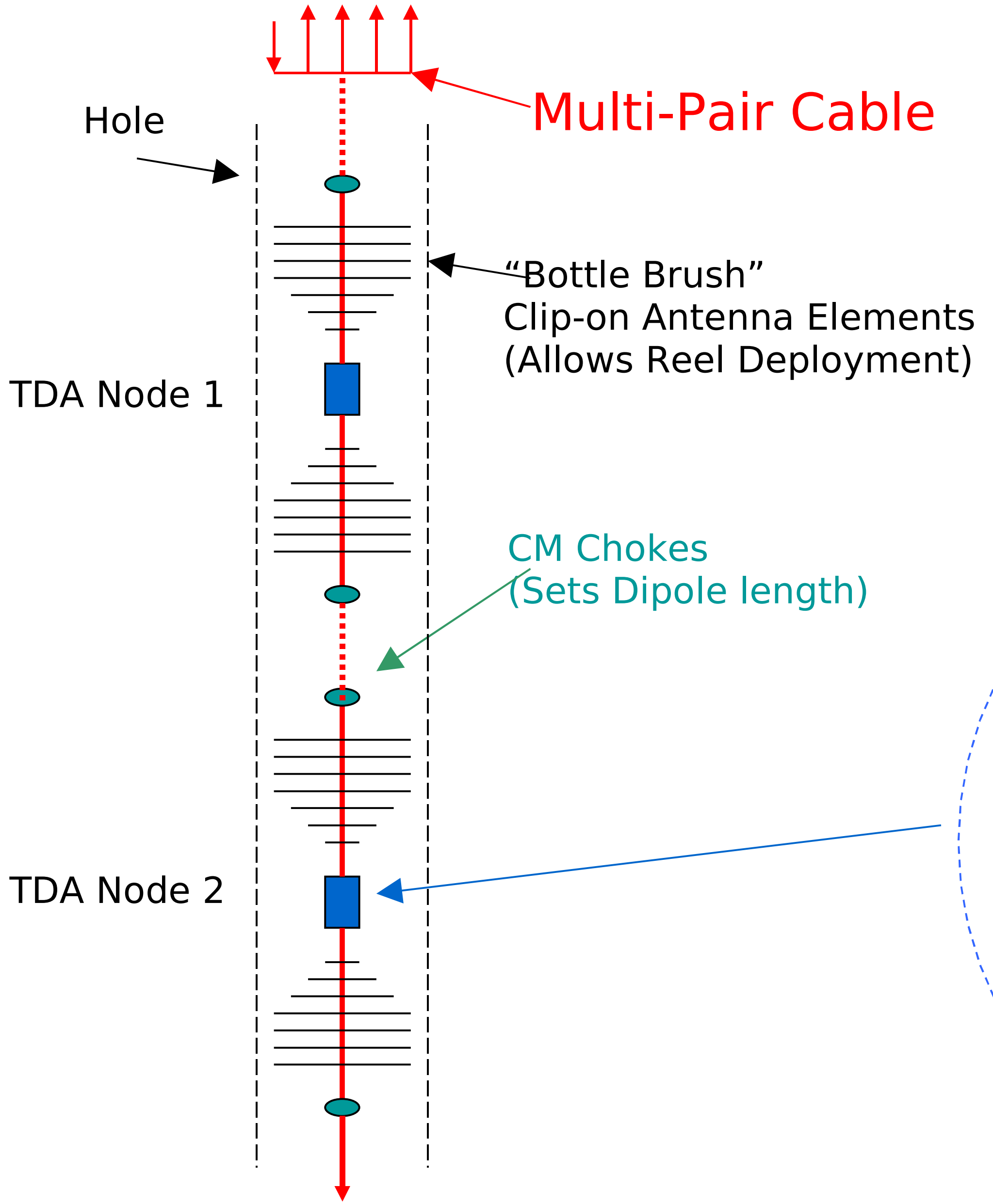
**Pulse shaping & envelope trigger**

Pros:
+ cheaper units → large array
+ Simpler detector

Cons:
– Limited information

Challenges:
information sufficient to reject background and detect GZKs ?

# Sensor String Configuration (here: in ice radio)

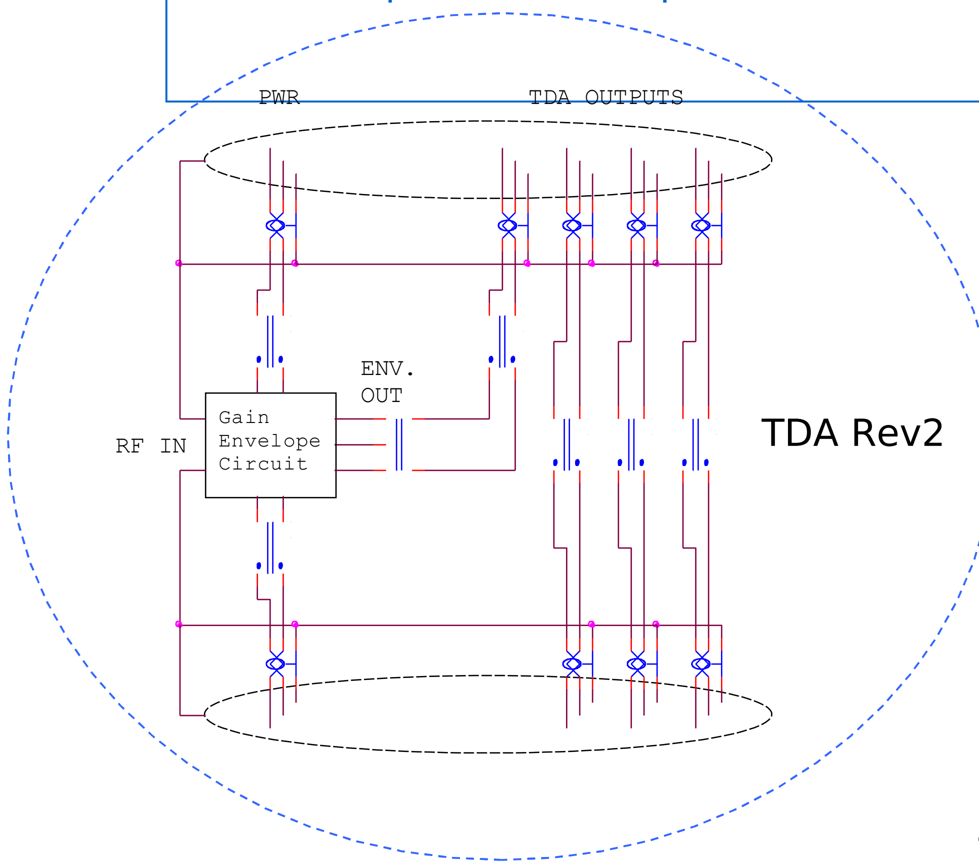



**“Common Mode” TDA Node:**

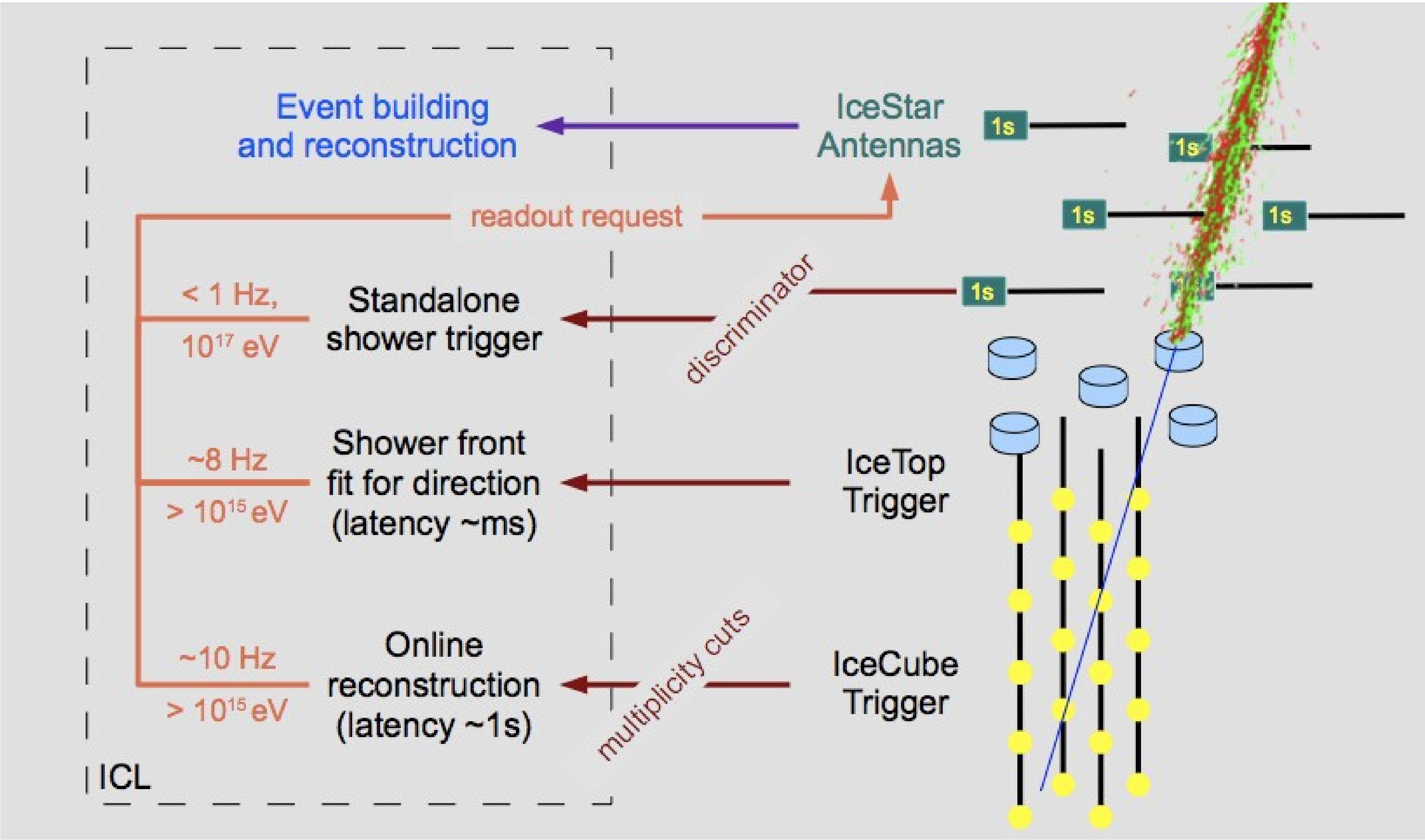
- Signal Cable Shield = Antenna Element
- Envelope BW minimizes crosstalk
- Multi-sensors on one cable possible
- Azimuthal asymmetry is avoided

~1” diameter bump in cable

~500 mW power consumption



# Look-back buffer read-out for detector components (here surface)



# Technology choices

- DAQ and triggering strategy
  - pulse shaping versus waveforms
  - simple local threshold versus local clusters with phased array type of trigger
- Energy distribution
  - centralized with cables
  - local with solar panels, wind, peltier effect
- Signal propagation to central hub
  - cable versus wifi (Auger style)
- Surface antennas in self trigger mode versus trigger from IceTop and in ice 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
- Institutional responsibilities to be worked out at upcoming R&D meeting
- ... head out to extend IceCube and IceTop by factors at the EHE frontier

Thank you!

# Backup

- Backup

# AURA Radio Cluster

## Askaryan Under ice Radio Array

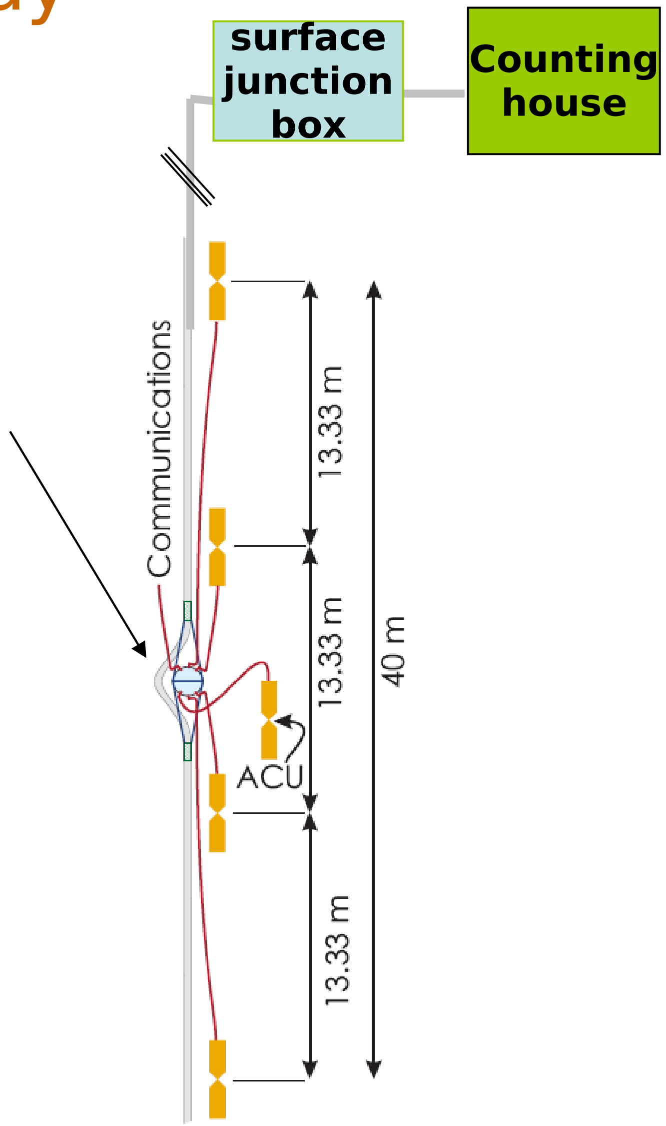
Use IceCube’s resources: holes, comm. and power

- Each Cluster contains:
  - Digital Radio Module (DRM) – Electronics
  - 4 Antennas
  - 1 Antenna Calibration Unit (ACU)

- Signal conditioning and amplification happen at the front end

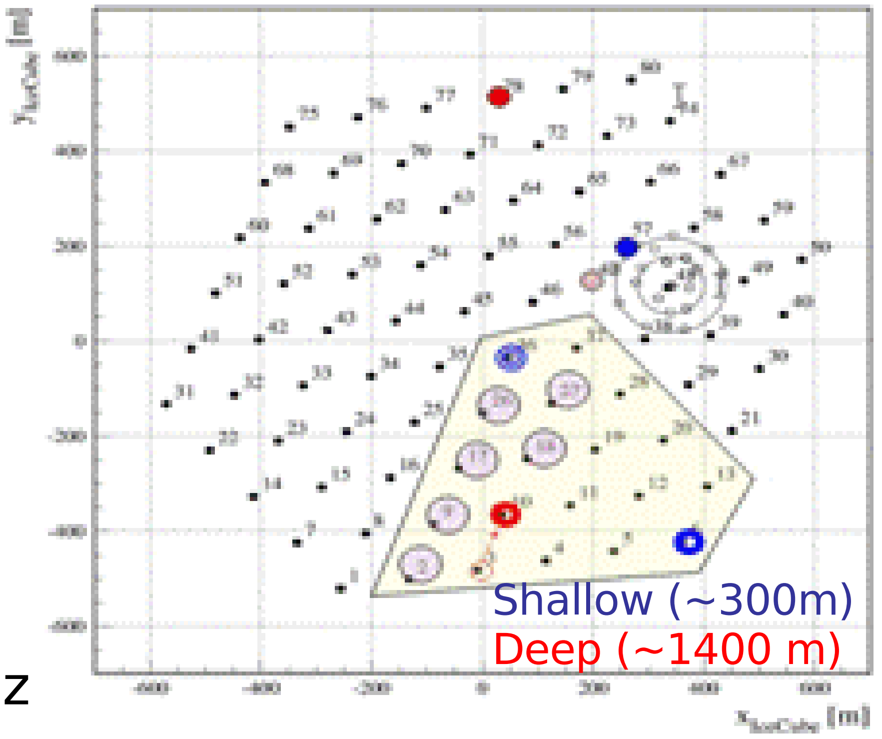
- Signal is digitized and triggers formed in DRM

- A cluster uses standard IceCube sphere, DOM main board and surface cable lines.



# AURA Radio Cluster

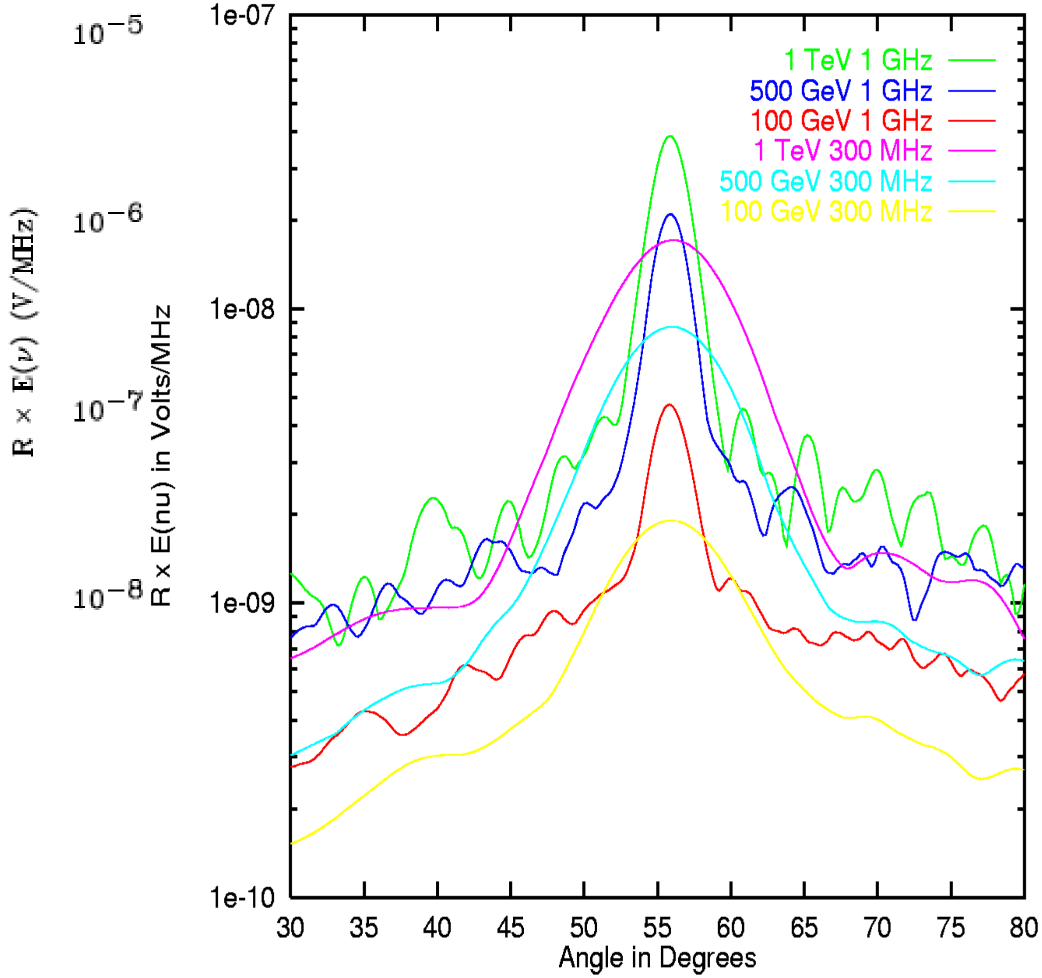
## What's new in the last season



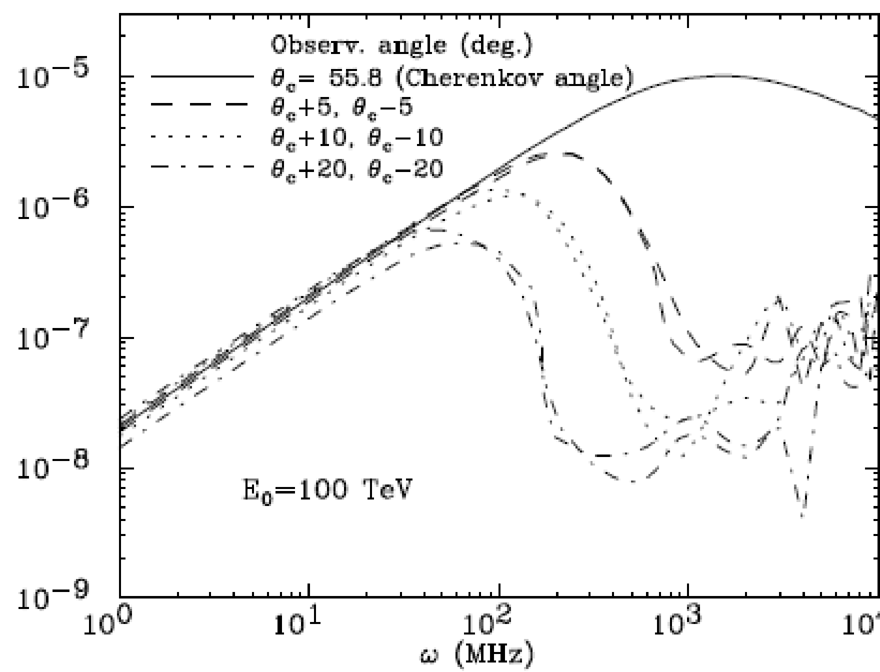

- An array of 5 clusters:
  2 clusters 2006-2007
  +3 clusters 2008-2009
  *(part of the of the NARC initiative)*
- 2 channels ("antennas") down to 100MHz
- **15/20 channels are working**
- Stronger and/or more sophisticated in ice pulsers (support CW and pulses)
- IceCube-like DAQ (based on pdaq)
- Strong surface pulser

# Askaryan Signal

Electric Field angular distribution

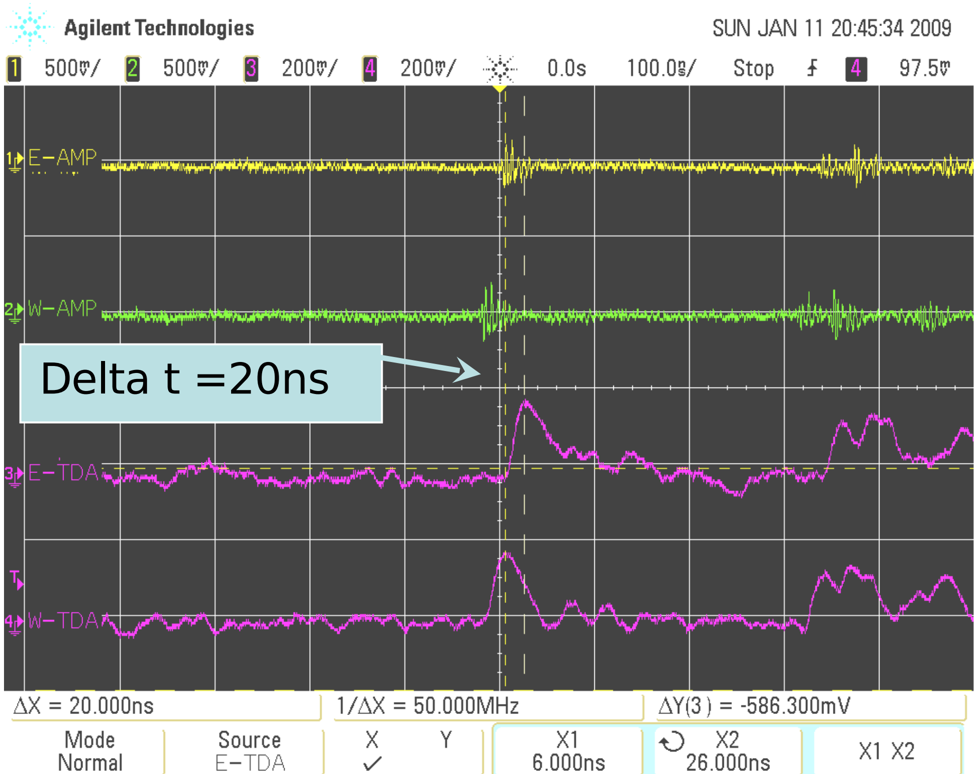



Electric Field frequency spectrum

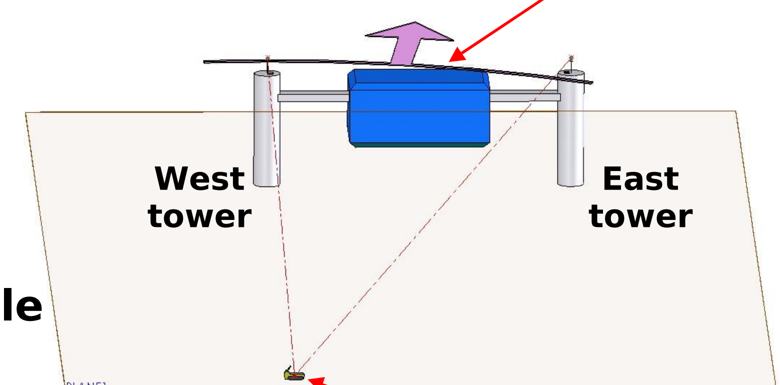



*Astro-ph/9901278 Alvarez-Muniz, Vazquez, Zas 1999*

# Example Transient (from snowmobile ignition)





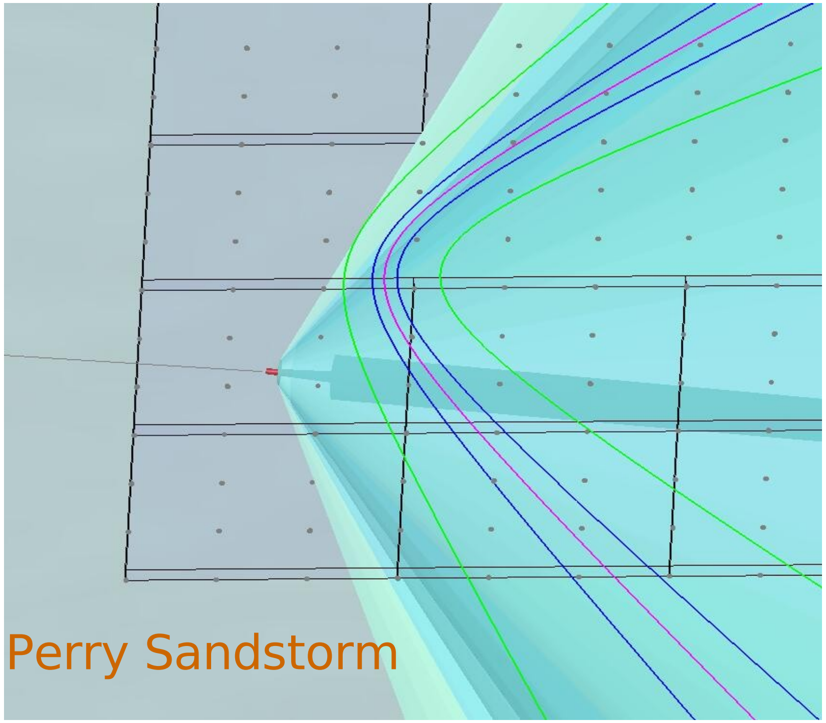



**Ignition noise transients from idling snowmobile**

*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)*

# Transient sensor array

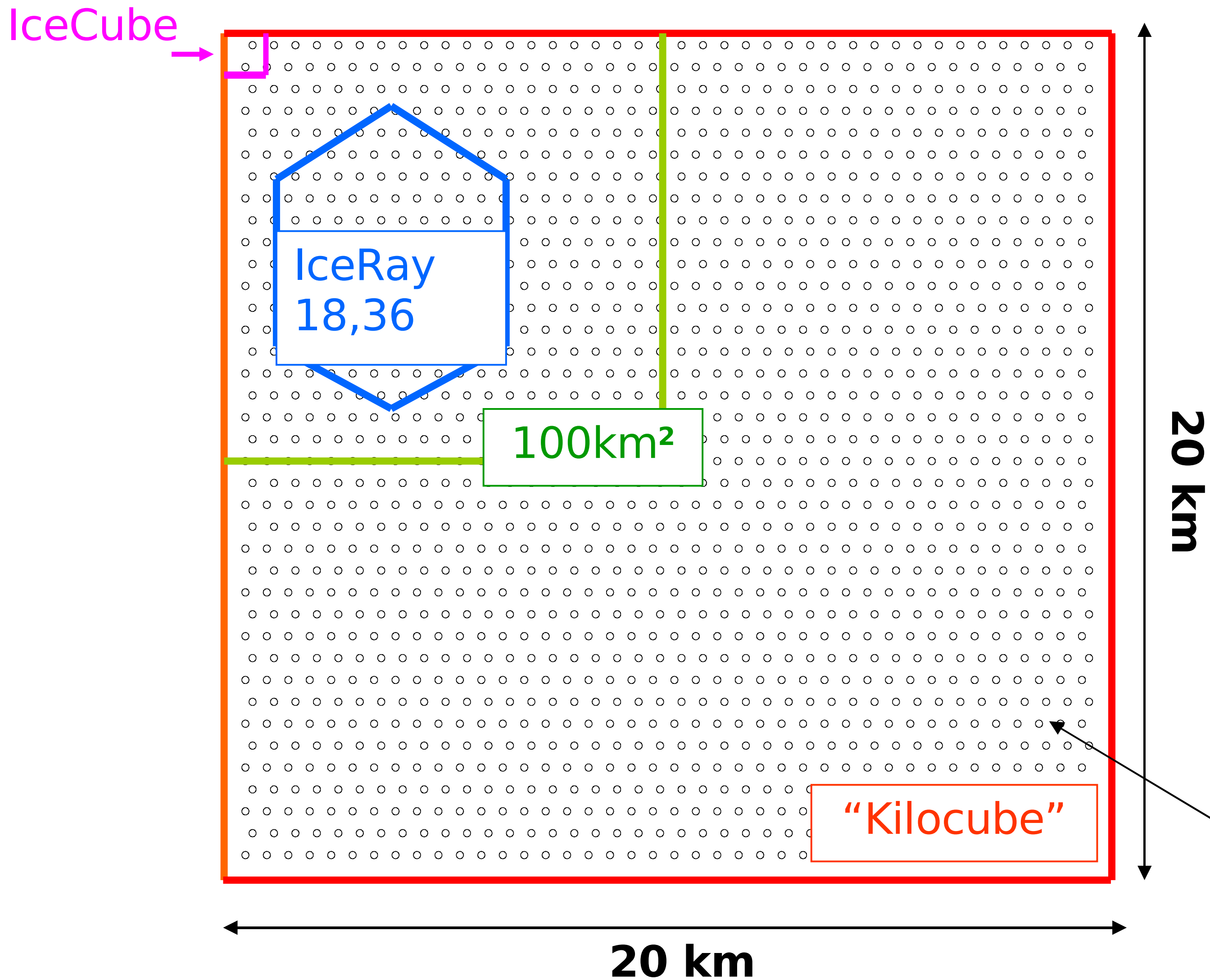
Many “simple” sensors to provide a snap shot of an Askaryan pulse.
Wide dynamic range, low power, simple output



Perry Sandstorm

Kael Hanson

# Case study: Transient Detector Footprints




"Kilocube"
# of Sensors vs. Density:

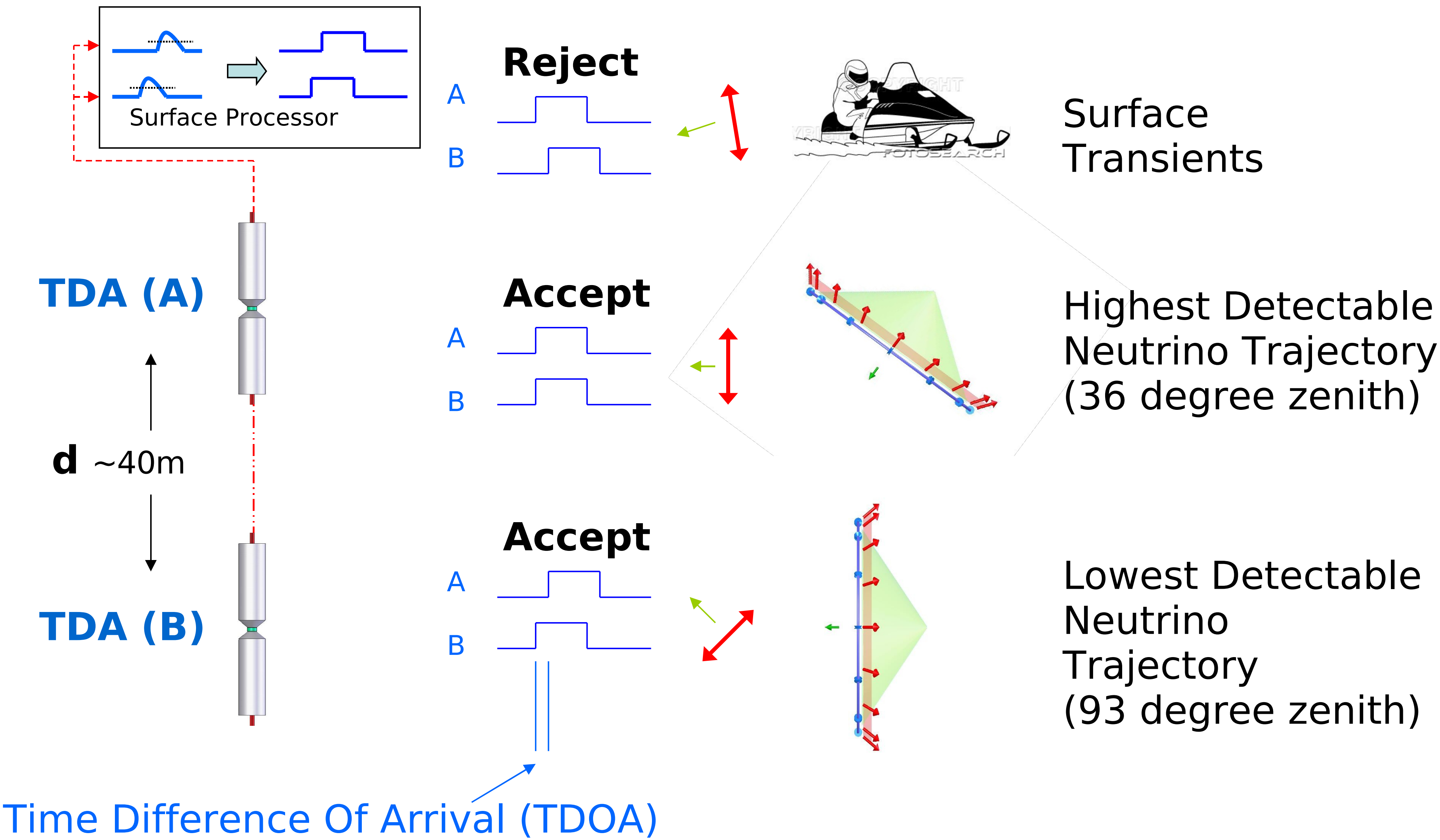
| X Spacing (meters) | Y Spacing (meters) | Total # of Sensors |
|---|---|---|
| 1000 | 1000 | **400** |
| 500 | 500 | **1600** |
| 333 | 333 | **3600** |
| 333 | 1000 | **1200** |

*500m x 500m sensor spacing shown*

# Downward Rejection

## via Priority, Coincidence

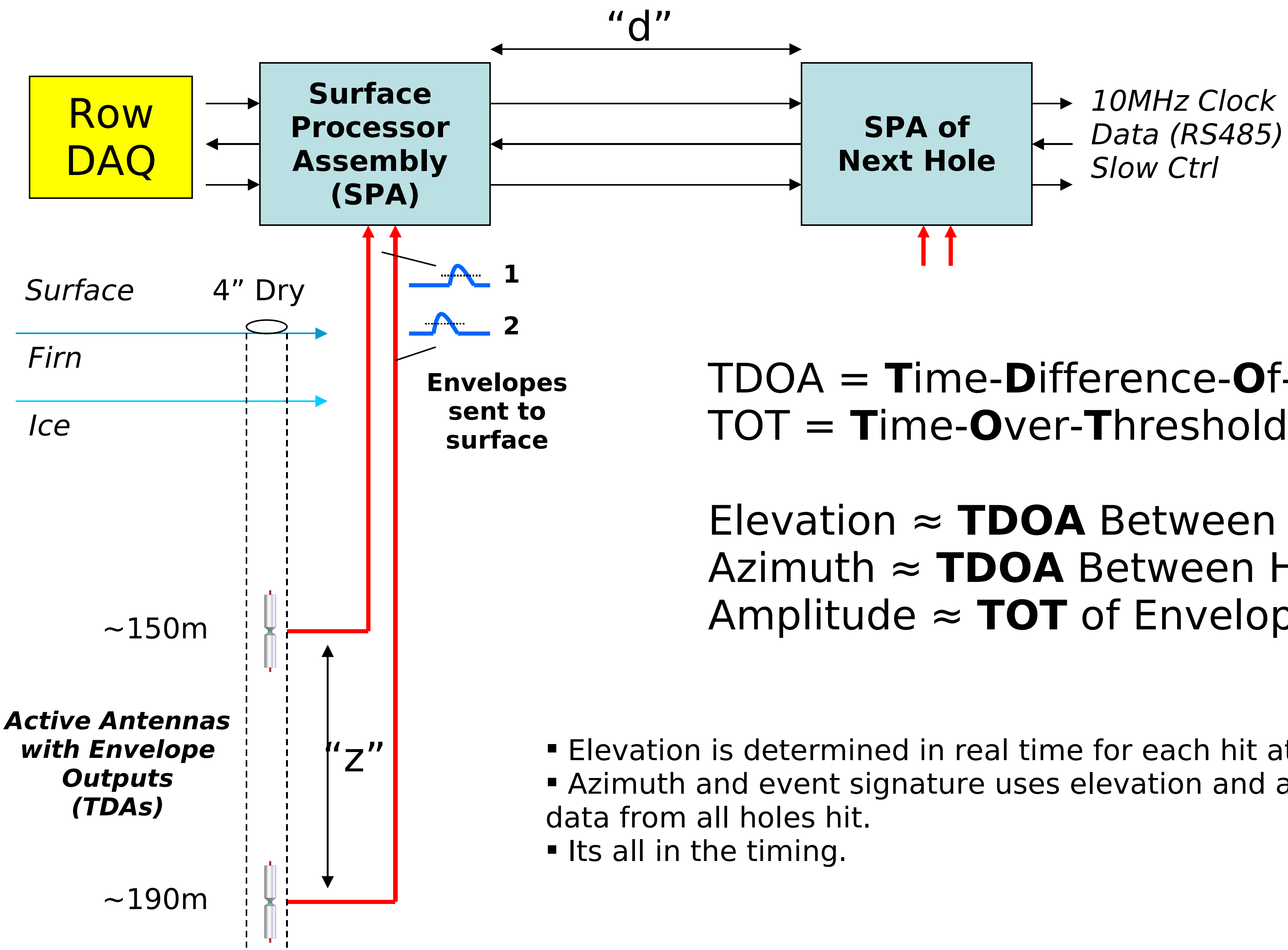
## **Real-Time, Simplest “Elevation Gating”**



# SATRA Functional Blocks
# – another case study –

(Sensor Array for Transient Radio Astrophysics)

# Radio Transient Sensor Instrumentation
## *Baseline Configuration*




TDOA = **T**ime-**D**ifference-**O**f-**A**rrival
TOT = **T**ime-**O**ver-**T**hreshold

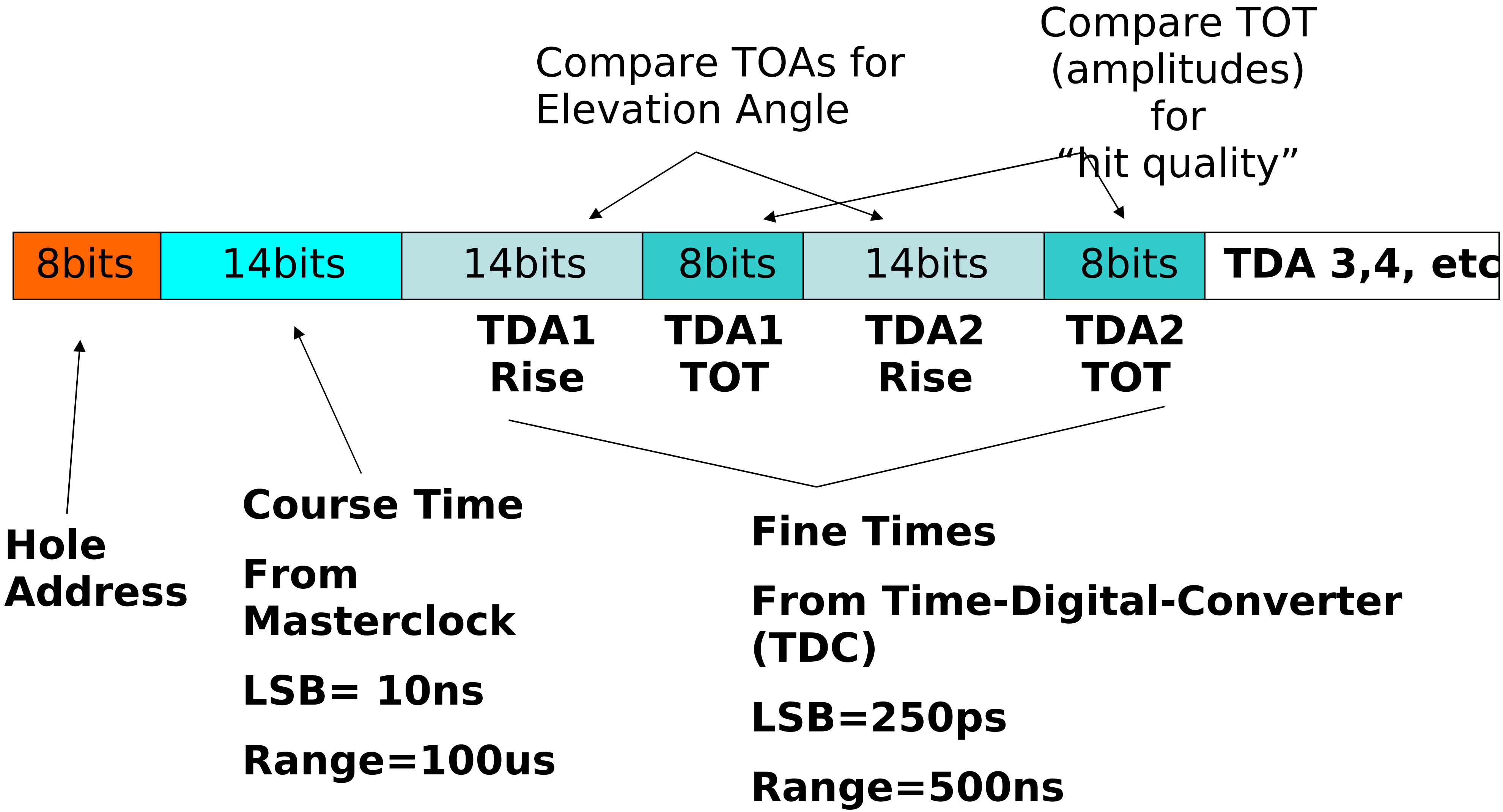
Elevation ≈ **TDOA** Between TDAs (z)
Azimuth ≈ **TDOA** Between Holes (d)
Amplitude ≈ **TOT** of Envelopes

- Elevation is determined in real time for each hit at each hole.
- Azimuth and event signature uses elevation and amplitude data from all holes hit.
- Its all in the timing.

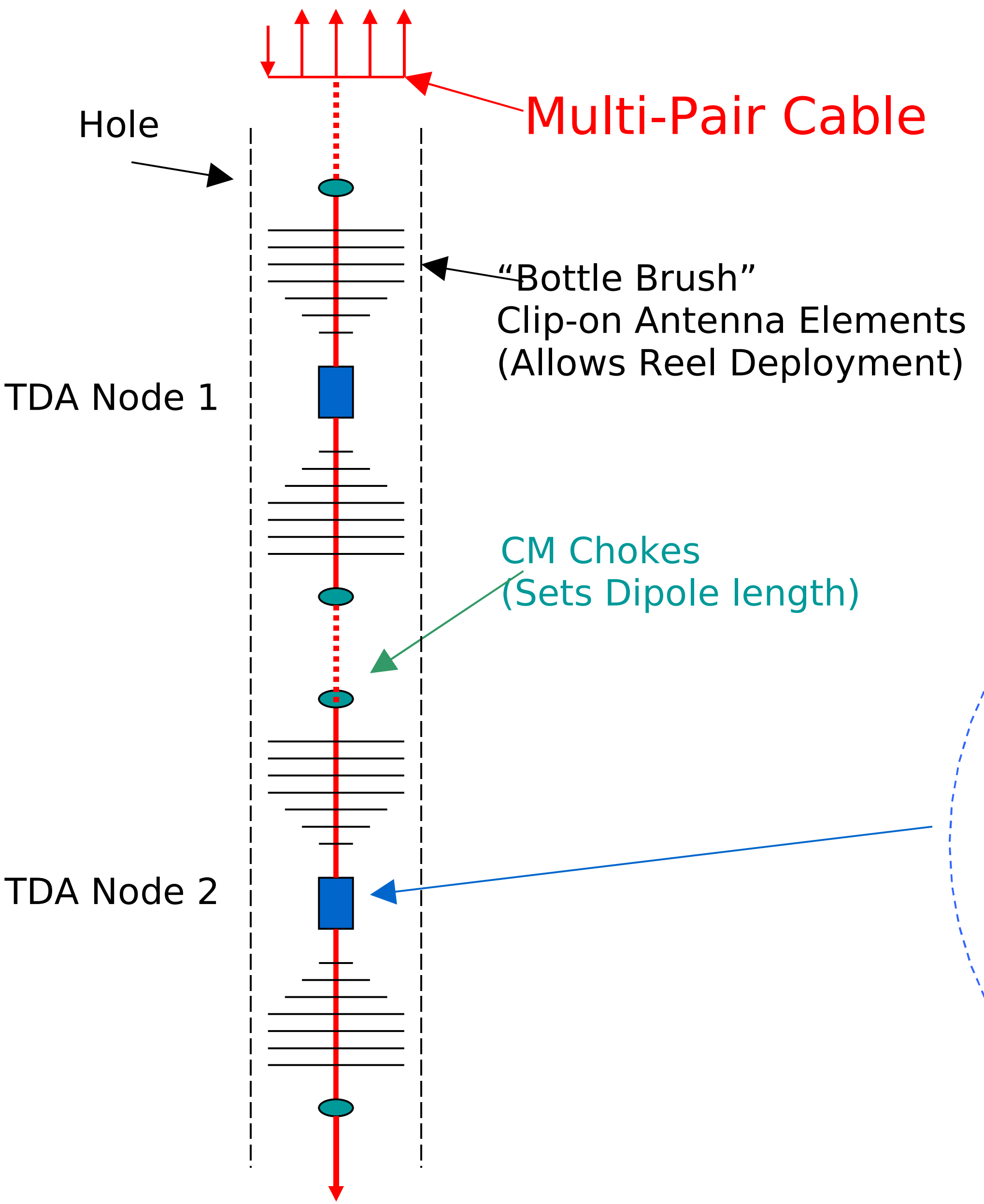
# Sensor Array System-Level R&D

- Source modeling
- Nominal array sizes needed for event detection and/or limits
- Array geometry optimization
  - Vertical, Horizontal spacing
  - Number of sensors per string
  - Size of Array
- Sensitivity Analysis
  - Antenna bandwidth
  - Envelope/discriminator bandwidth
  - Noise; KT, RFI, CR
- Optimized data format for transmission, filtering, storage
- Event simulation and filtering
- Data processing requirements for online filtering
- DAQ for each row and combiner from all row-DAQs

# Example data from each hole



# Sensor String Baseline Configuration

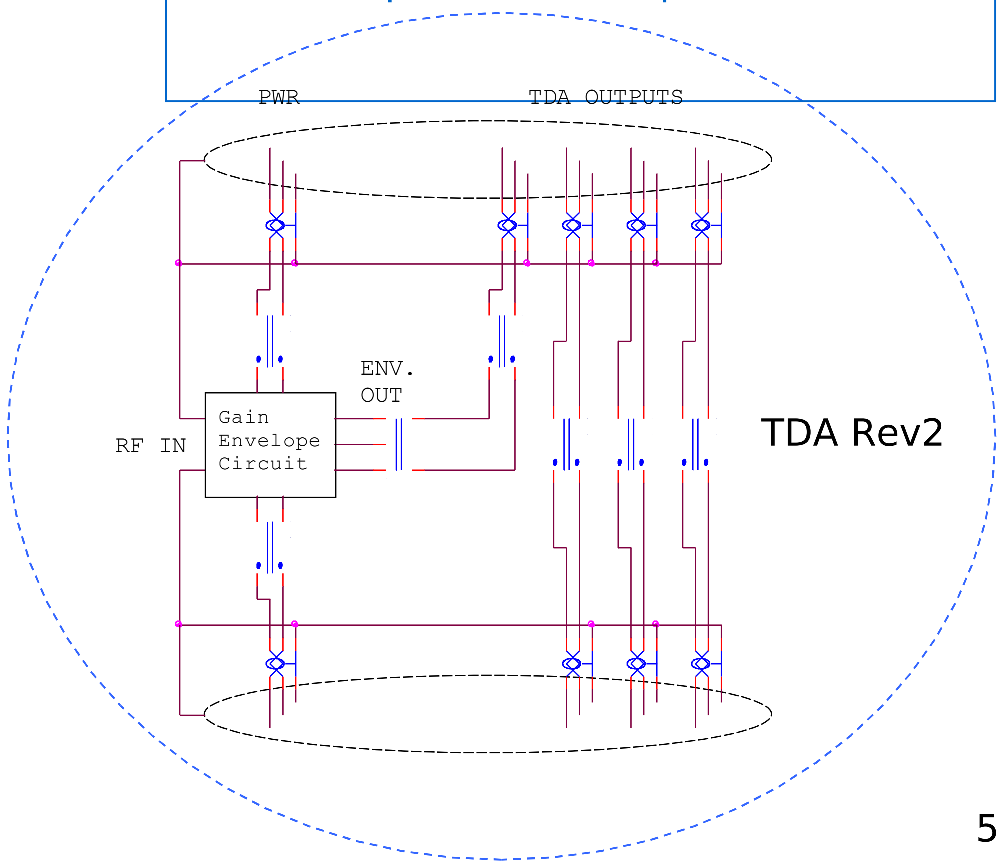



**"Common Mode" TDA Node:**

- Signal Cable Shield = Antenna Element
- Envelope BW minimizes crosstalk
- Multi-sensors on one cable possible
- Azimuthal asymmetry is avoided

~1" diameter bump in cable

~500 mW power consumption

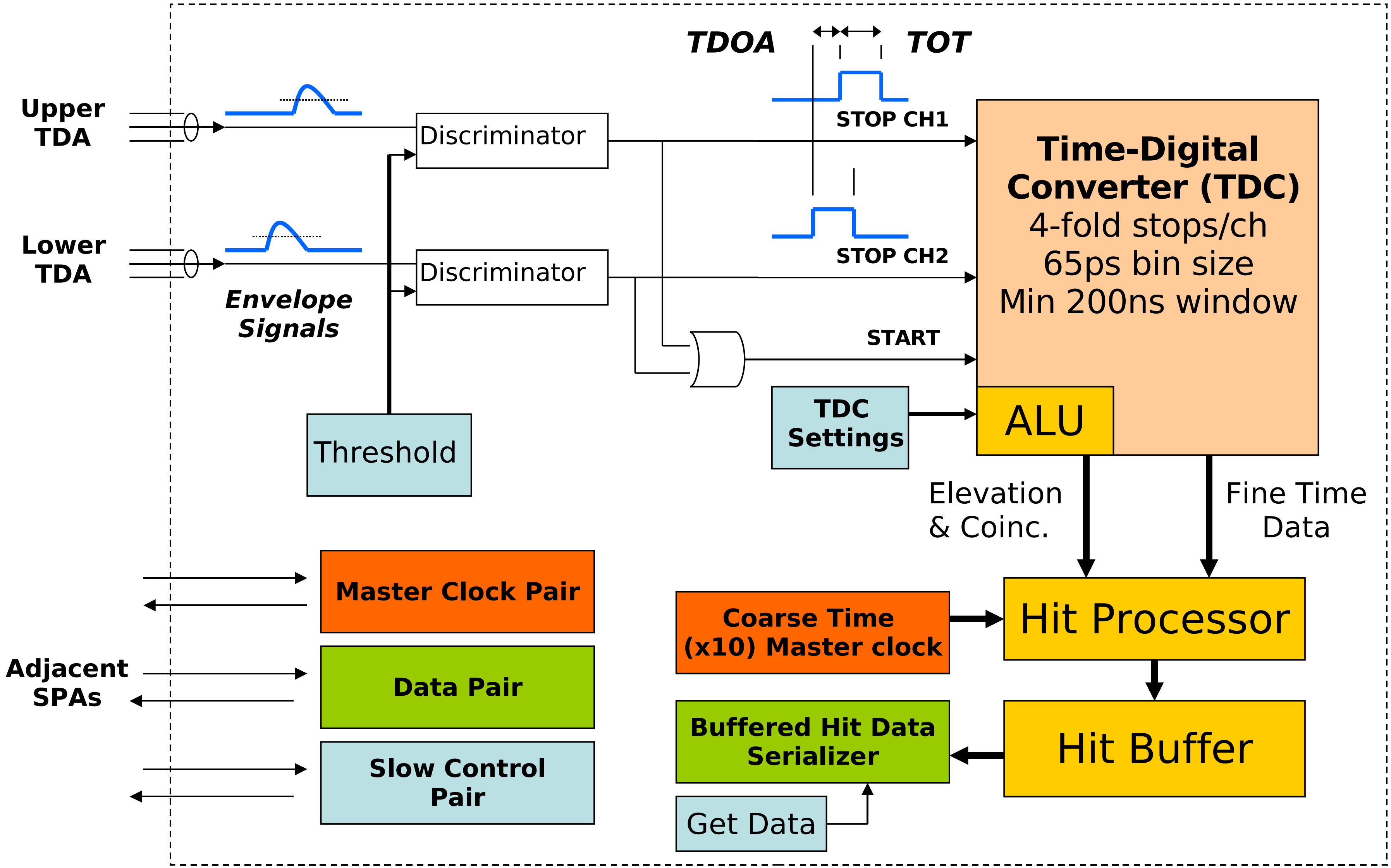


# Sensor String Development
## *separable activities/disciplines by color*

- TDA PCB
  - Circuit topology
  - Parts selection
  - Schematic Capture
  - PCB layout, potting, mechanical attachment
  - Spice optimization of antenna match
- Common Mode Antenna
  - XFTD modeling of elevation response
  - NEC modeling of elevation response
- Cable
  - Spice or Qucs simulation of envelope transmission
  - String fabrication and deployment

# SPA Baseline Configuration

## (Elevation by hi-res TDOA, Amplitude by TOT)



# SPA Development

*separable activities/disciplines by color*

- Surface Cable and Interface
- Discriminator
- TDC (or simple elevation gate for ’09-’10 expmt)
- Hit Processor (µProcessor or FPGA)
- PLL & Course-Time Counter
- Data Format and Buffer
- DC-DC Converter/ Head-end PSU requirements
- Enclosure and Integration

# SATRA South Pole Testing

- Proof of Concept for Envelope Detection **’08-’09 (done)**
  - **Goals:** Show feasibility of TDOA technique for background rejection using envelope signals from TDA
  - **Setup:** Two TDAs connected to Horizontally-separated antennas on ICL Towers.
  - **Enables:** Continued transient background monitoring with programmable oscilloscopes
- Real-time elevation gating with vertically-separated TDAs **’09-’10**
  - **Goals:** Background Rate vs. (elevation & threshold)
  - **Setup:** single test string in multiple IceCube firn and/or rod well holes, simplified SPA. Measure sensitivity to surface and AURA transmitters
  - **Enables:** comparison of candidate TDA / antenna configurations, verification of envelope discriminator and basic elevation gating.
- Small test array (3km x 1km); (~10x3 holes) **’11-’12**
  - **Goal:** (Rate & amplitude) vs (elevation & azimuth & threshold) DAQ verification
  - **Setup:** Upgraded RAM Drill, 30 strings, 30 full-function SPAs, 30 surface links, 3 “Row” DAQs
  - **Enables**: Verification of TDC and course timing circuitry, Optimization of SPA comms, initial sensitivity calibration. Optimization of RAM drill. DAQ and filter testing, Optimize TDA-TDA and Hole-Hole spacing
- Large test array (3km x 2km); (~10x6 holes) ’**12-’13**
  - **Goals:** Verify changes to RAM drill and Instrumentation; grid spacing should conform to final geometry
  - **Apparatus:** Upgraded RAM drills, 60 strings, 60SPAs, 60 surface links, 6 Row DAQs
  - **Enables:** verification of configurations and procedures for large-scale drilling and deployment, Establish Flux Limits and possible event detection.
- SATRA KiloCube (20km x 20km); (400-1600 holes) **‘13-’16**
  - **Goals:** Detect significant number of GZK events
  - **Apparatus:** $15-20M
  - **Enables:** Event detection and confirmation by spatiotemporal signature.

# Transient Detector Array South Pole Testing – time line

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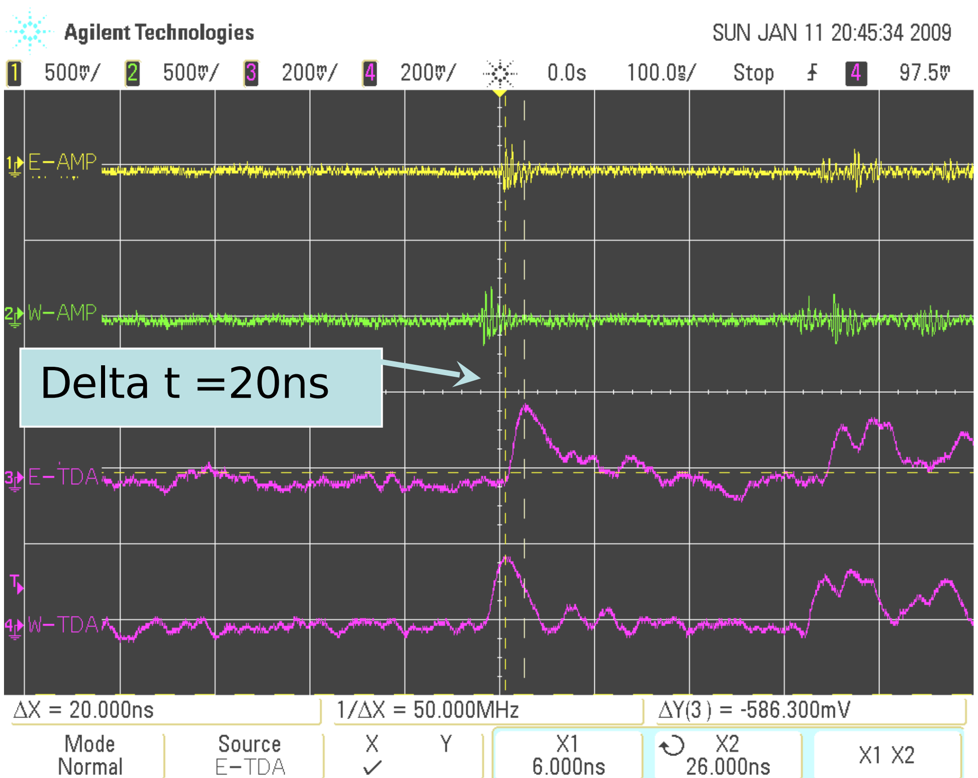
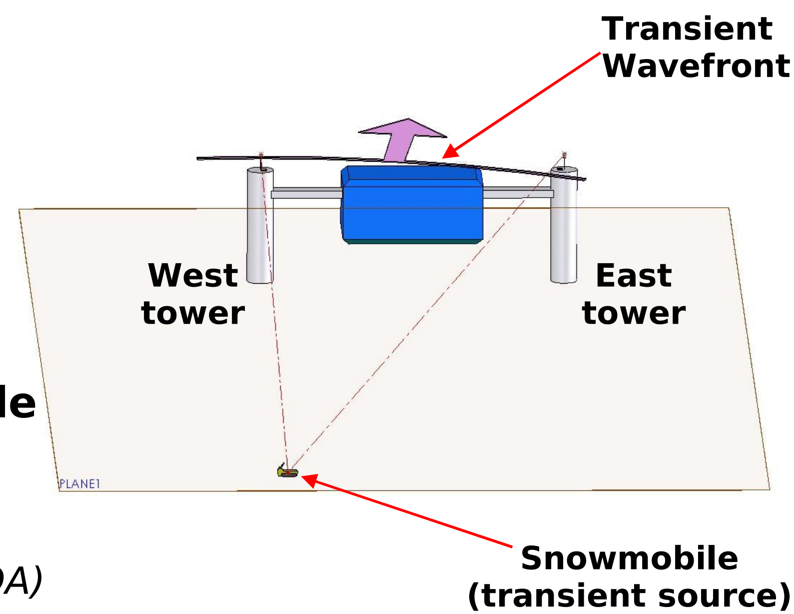
# Envelope / TDA Proof-of-Concept Testing
## *South-Pole 08-09*





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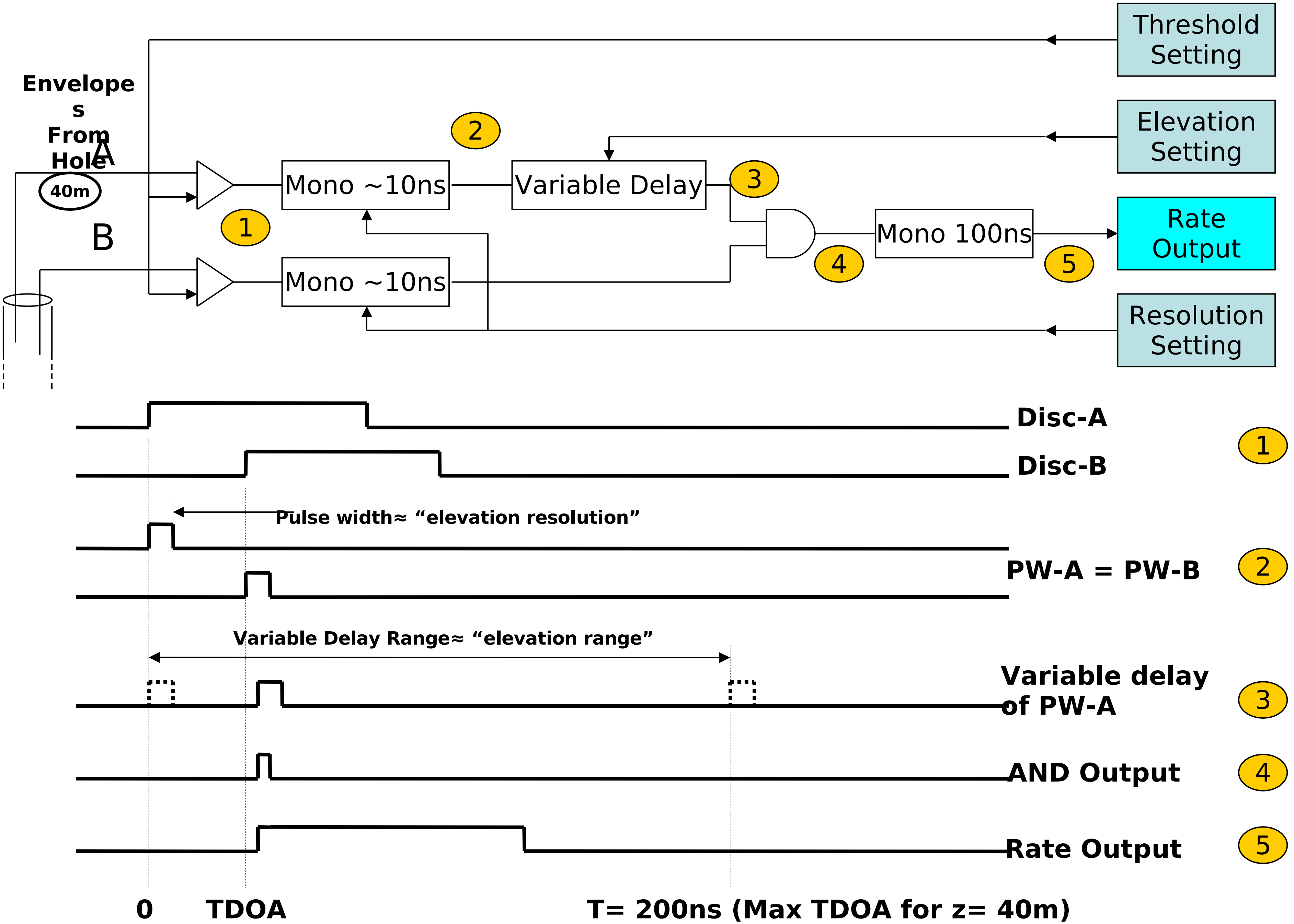
*Snowmobile was perpendicular with West tower.*
*Signals as acquired by ic-scope-ag1*
*Time Delay=20ns W-E, consistent with Angle-of-Arrival (AOA)*

# Sensor experiment for ’09-’10

## *Rate vs. (Threshold, Elevation)*

- Goals:
  - Test Common-Mode antenna/TDA design
  - Optimize envelope/discriminator parameters for rejection of background transients by virtue of their elevation
  - Get low-threshold data regarding SP background transients
- Basic vertical string with two Rev2 TDAs
  - Temporary, self-contained apparatus (e.g. battery powered)
  - Can be moved from hole-hole (e.g. IC firn holes before drilling)
- Simplified Surface Processor (SPA)
  - Acquires background rates vs. (threshold, elevation)
  - Simplified design allows low thresholds with ~MHz hit rates
  - Threshold scan is repeated at each elevation increment.
  - Complete threshold/elevation scan should take a few hours.

# Simplified SPA -Elevation Scan for ’09-’10



# Askaryan pulses from air shower core