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-ν's/year)
- establish a road map towards a full scale detector (~ 50 GZK-ν'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

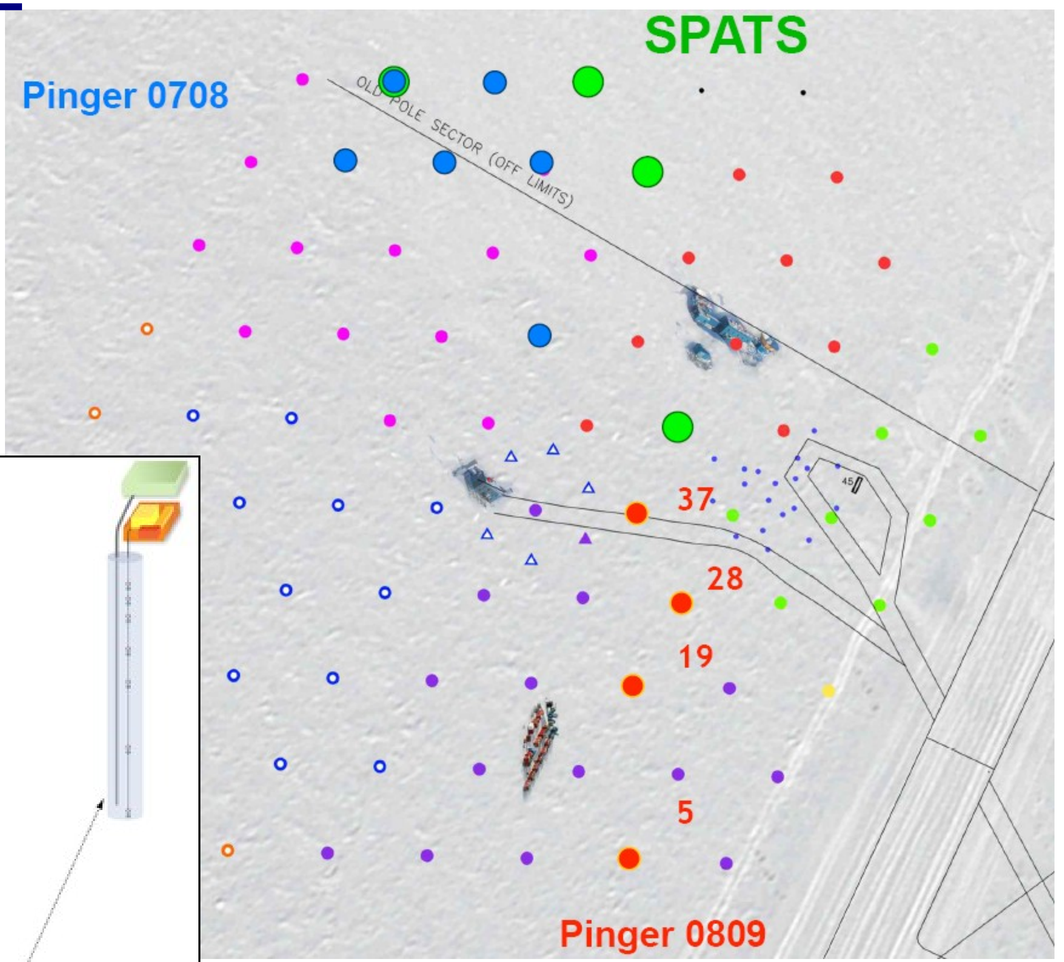
- Benefit from IceCube knowledge and access to South Pole site
- Unique possibilities of combined observations both in-ice and on-ice
- Vision of “guaranteed” neutrino signal ↔ momentum from potential IC discovery
- Keep
  - engineering work force
  - students with inclination towards hardware
  - entrepreneurial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

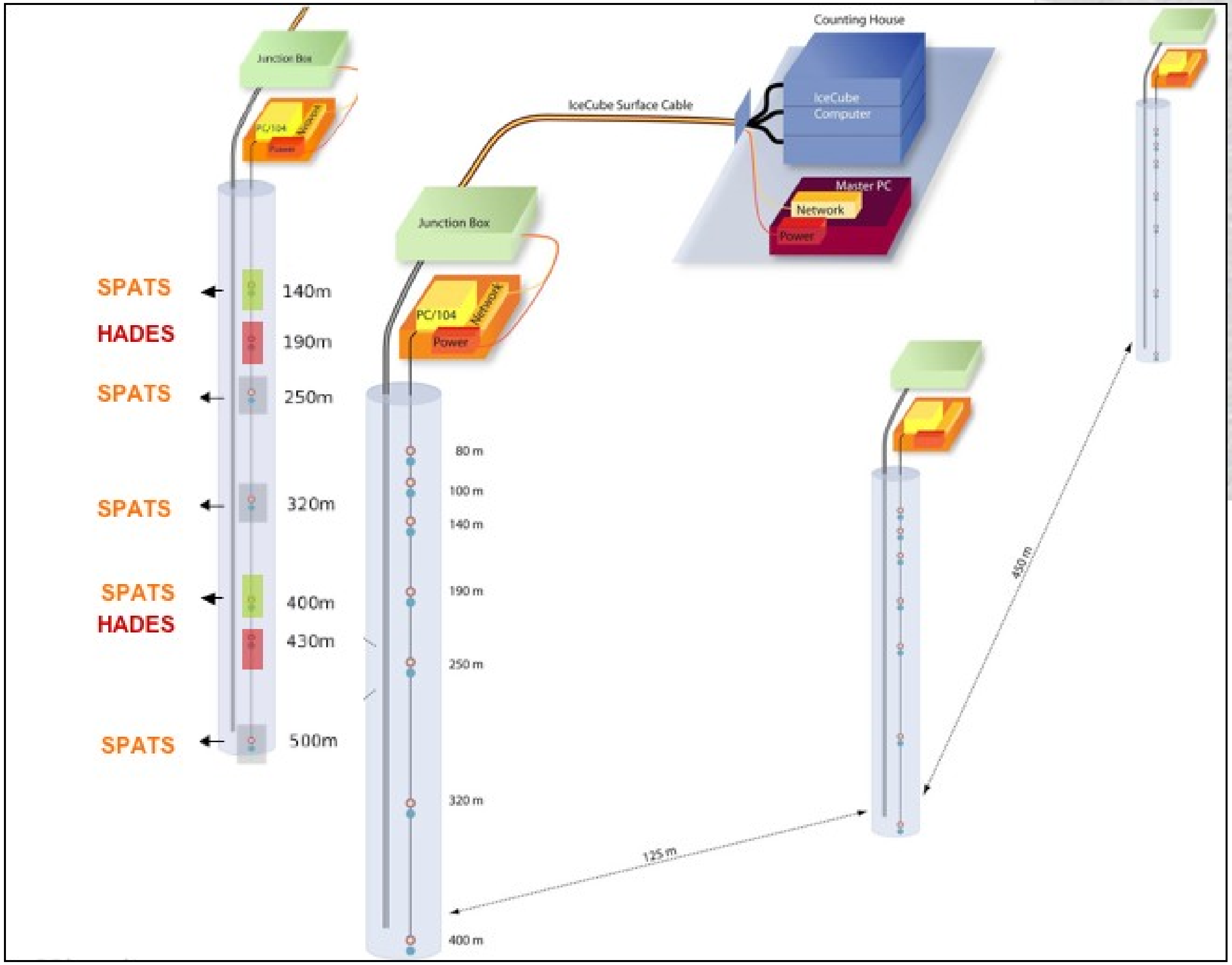
Status of ongoing site studies with ...

- **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)

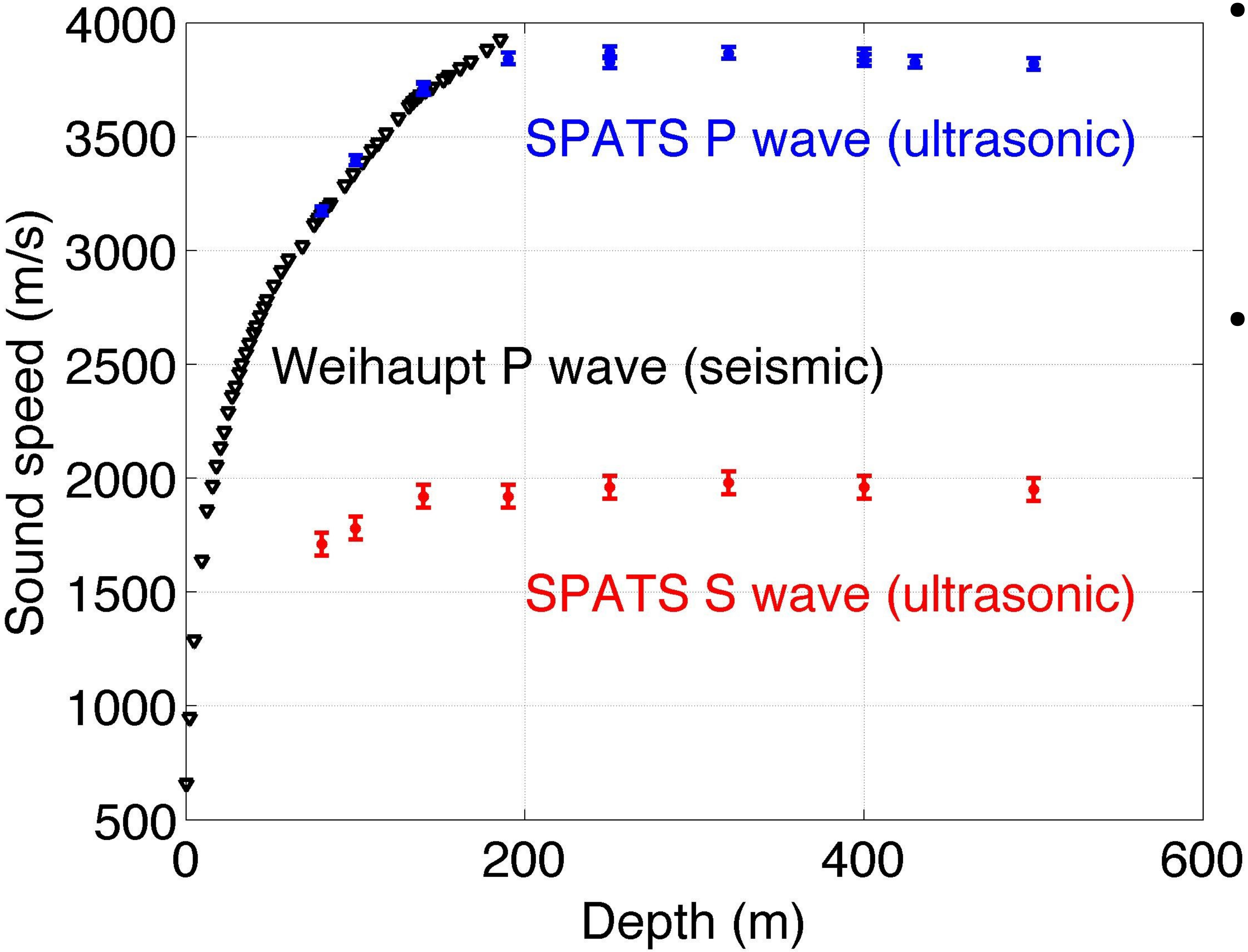
Status Acoustics

SPATS



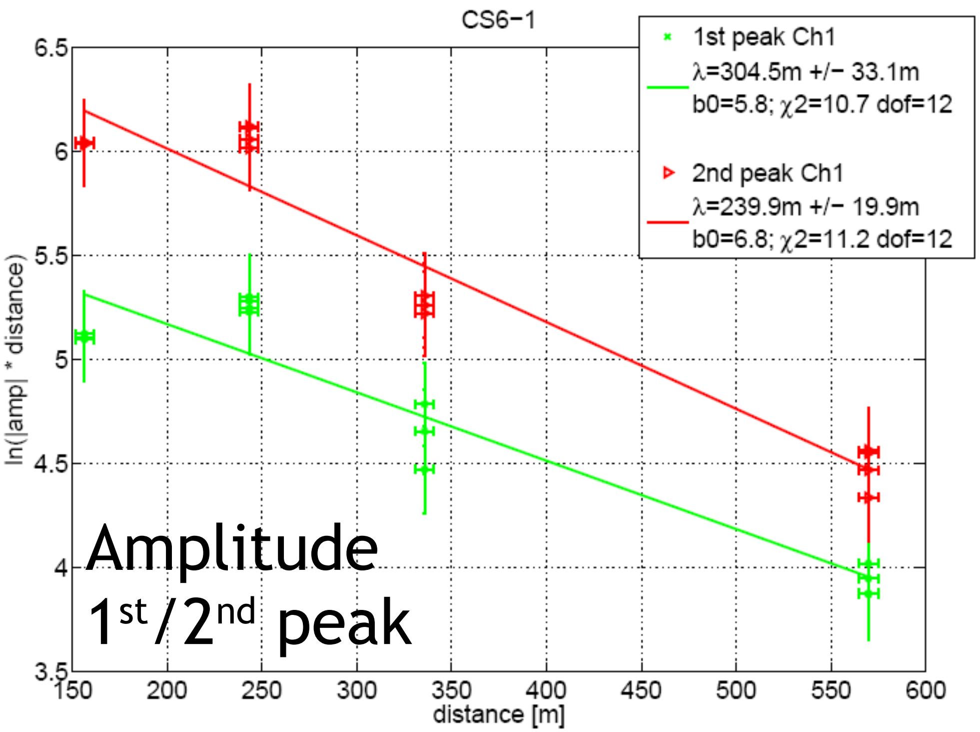


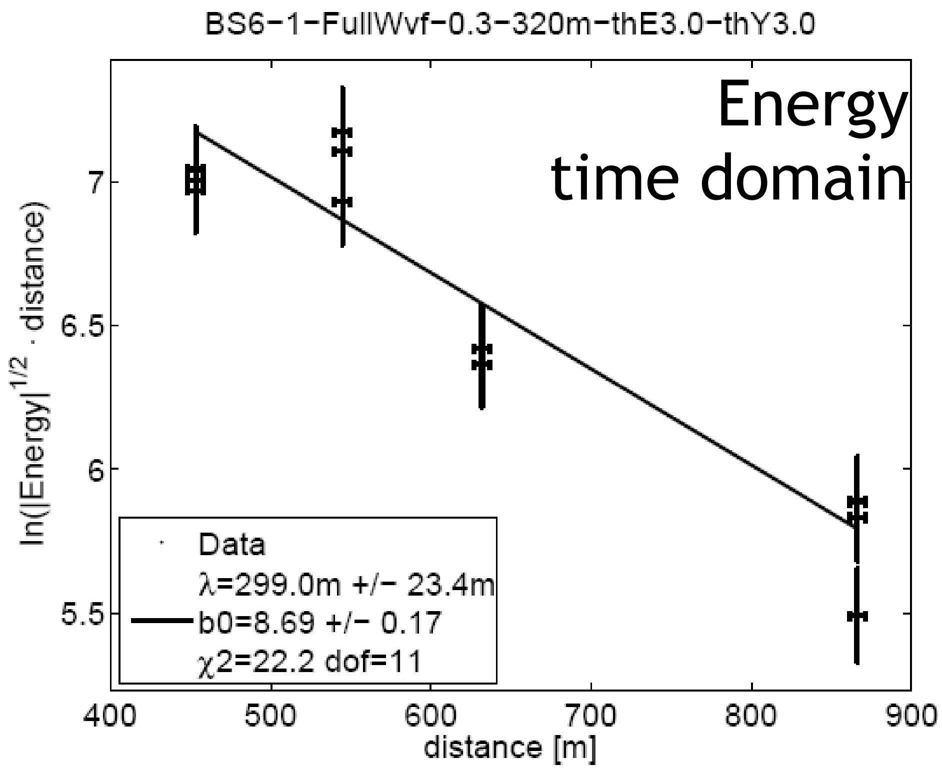
Speed of sound



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

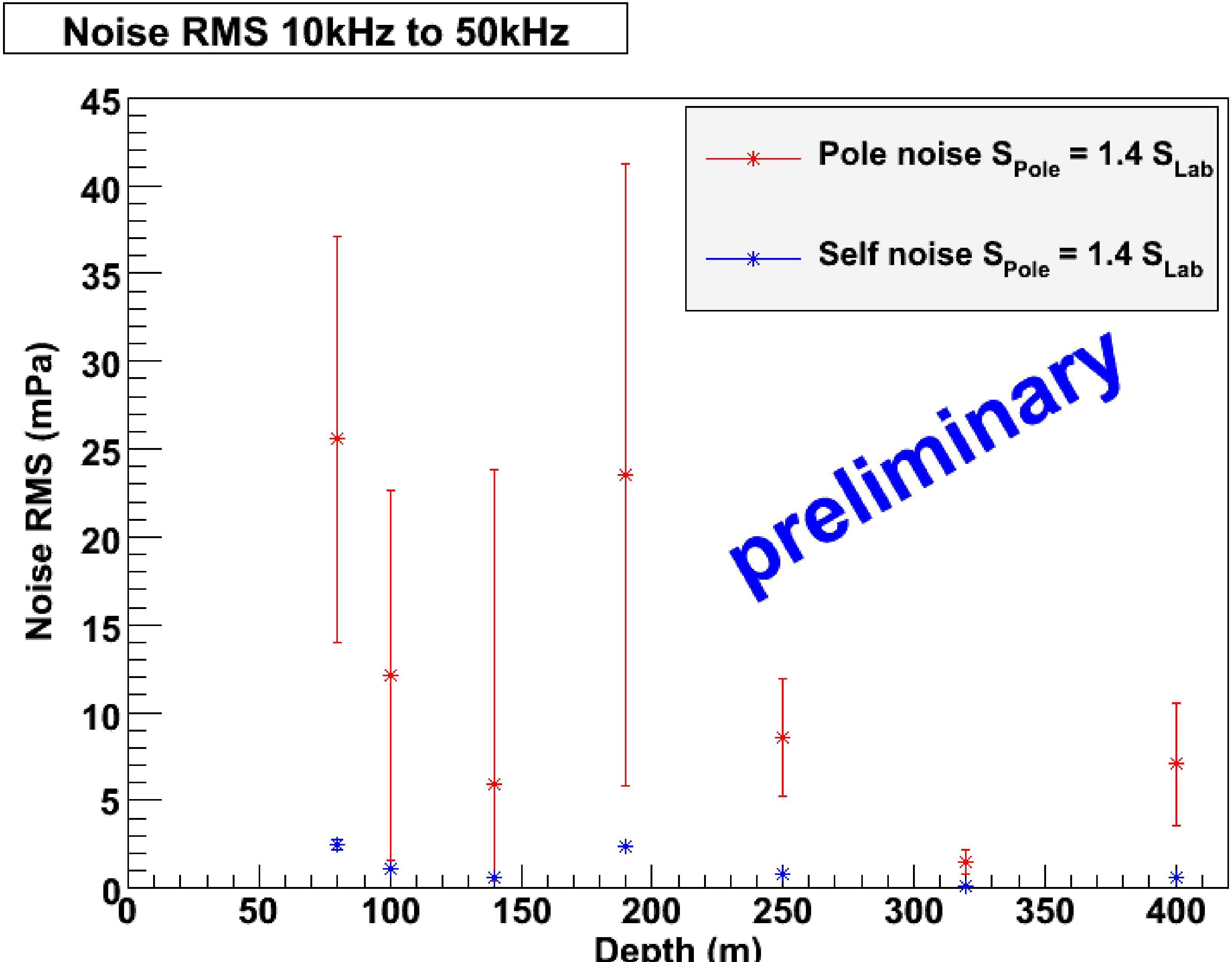
Acoustic attenuation





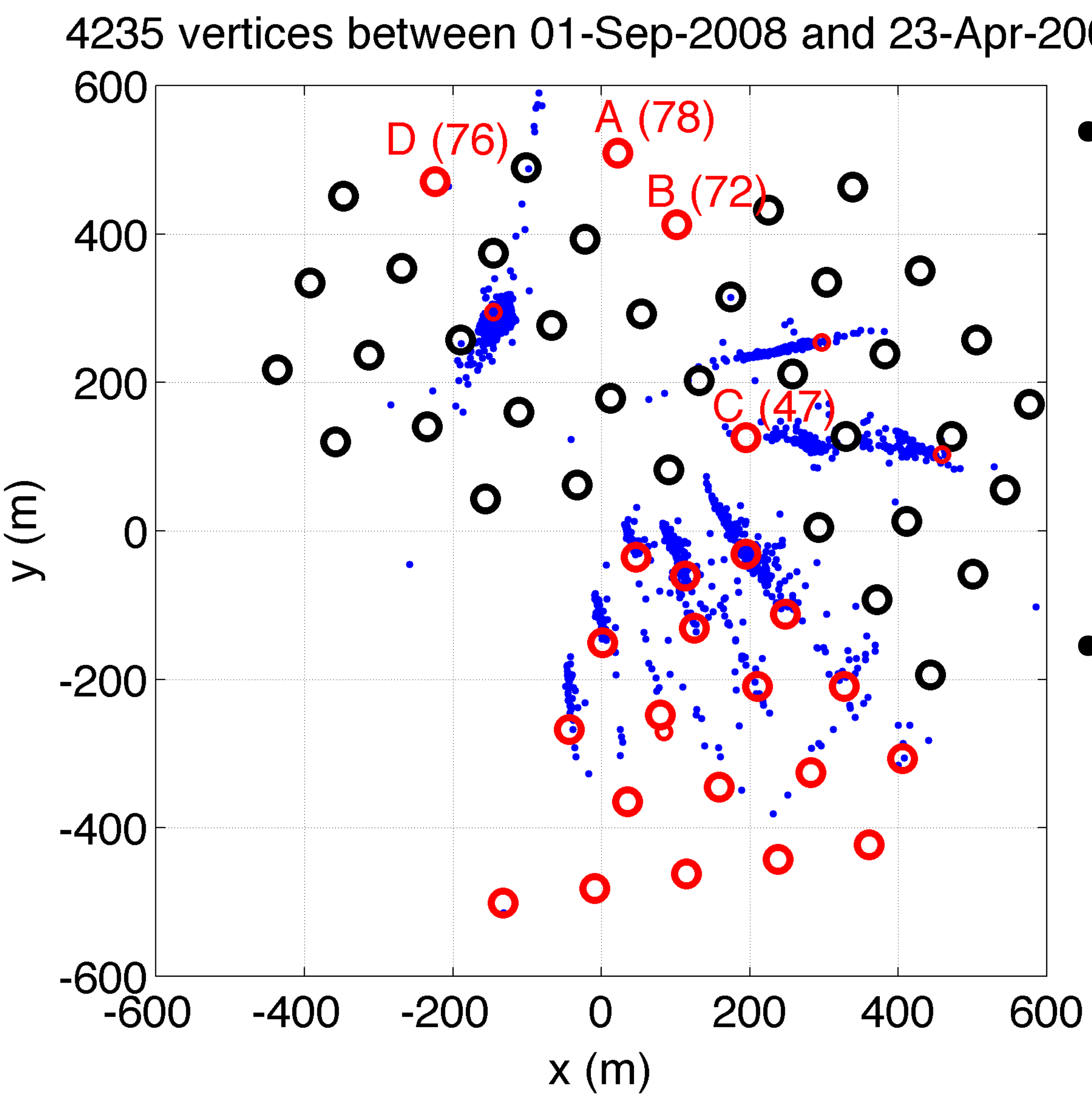
- Ball park: 300m ± 100 m
  Expectation was kilometers
- Unclear whether attenuation is short because of absorption or scattering

Acoustic noise (DC)



Low continuous noise level

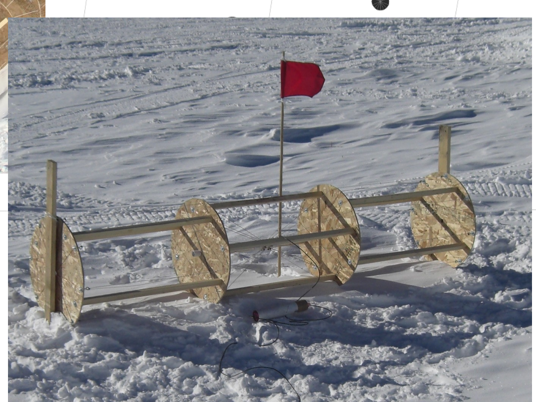
Acoustic noise, transients

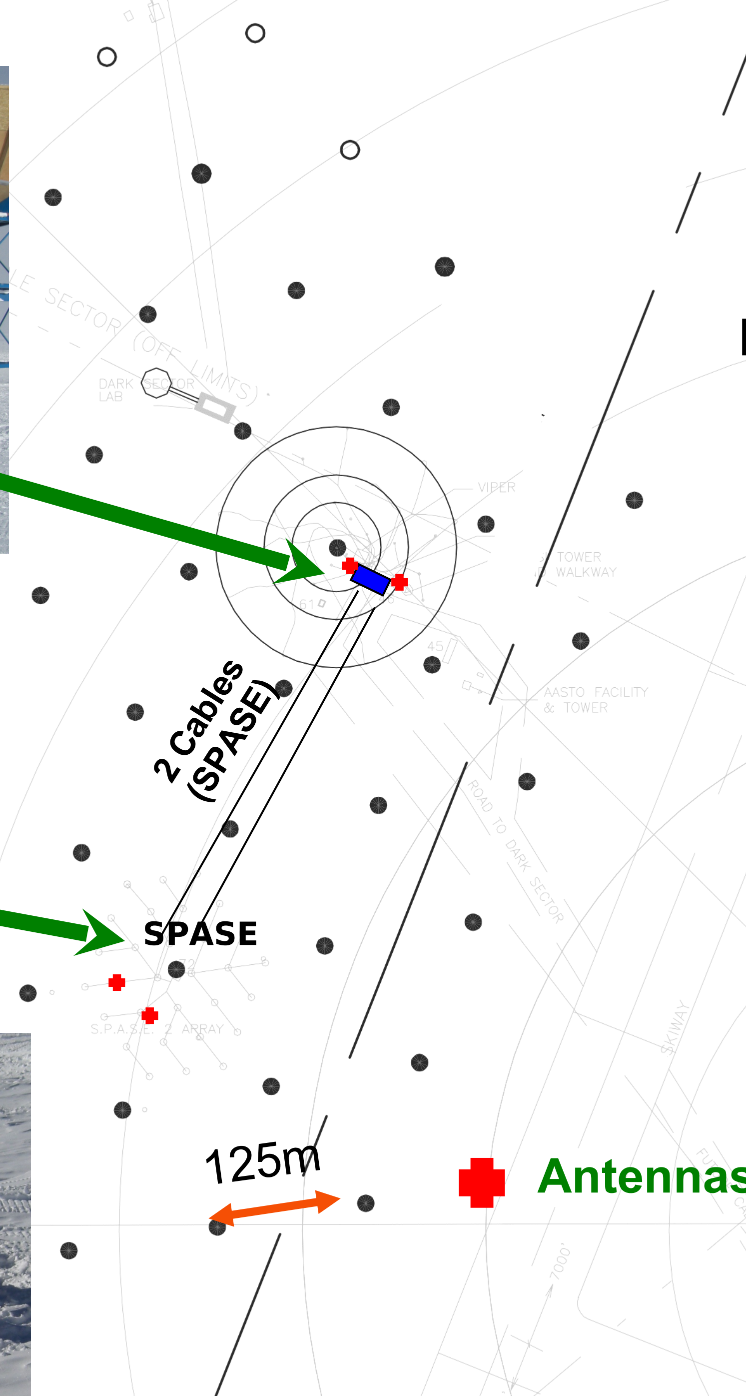


- Transients correlate with
  – Rod wells for drilling
  – freeze in of IceCube holes
- No correlation found with “dry” rod well
  – blind analysis proof

Status air shower radio

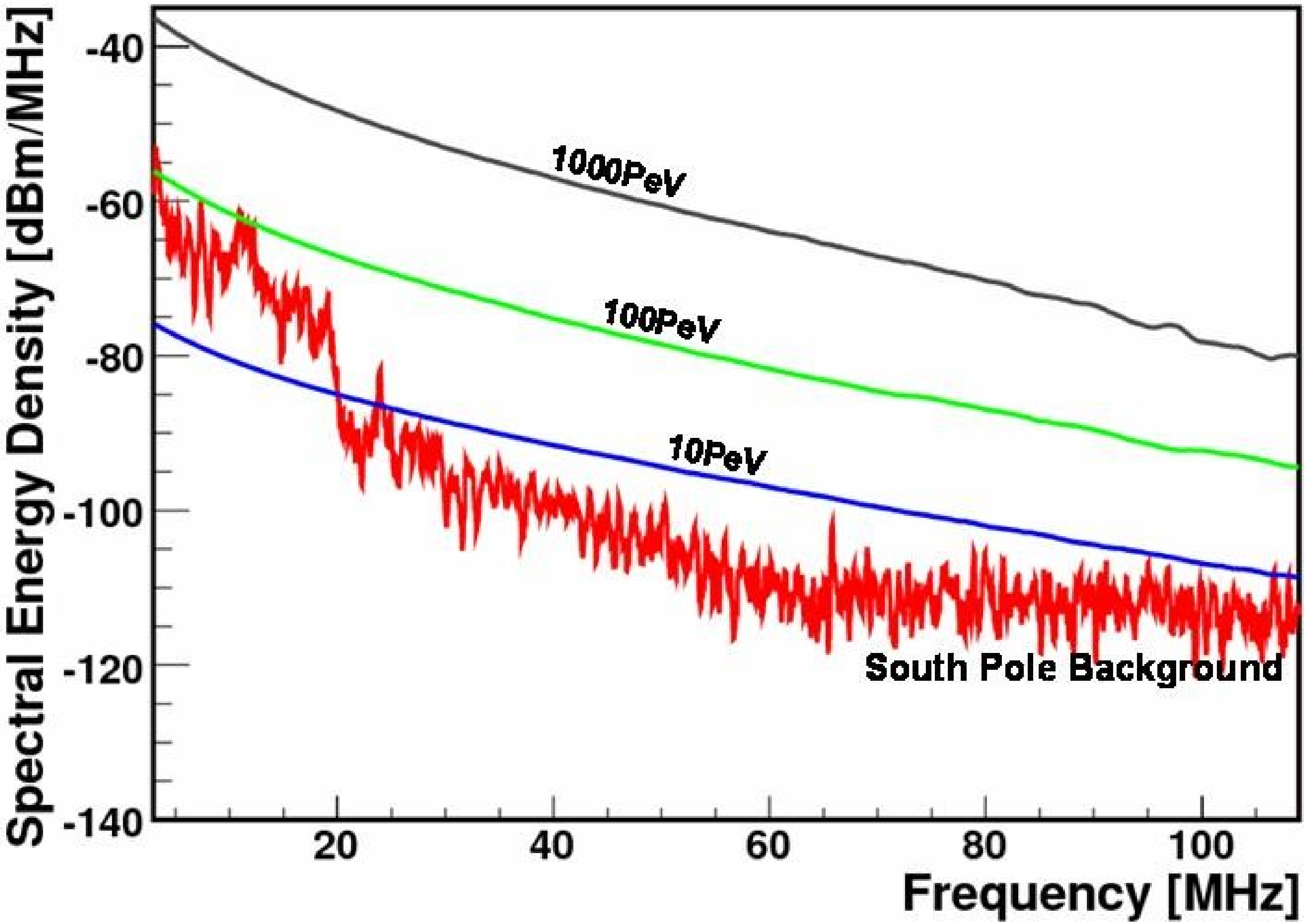
SPASE Building





Test array:
4 antennas
read out with
RICE DAQ

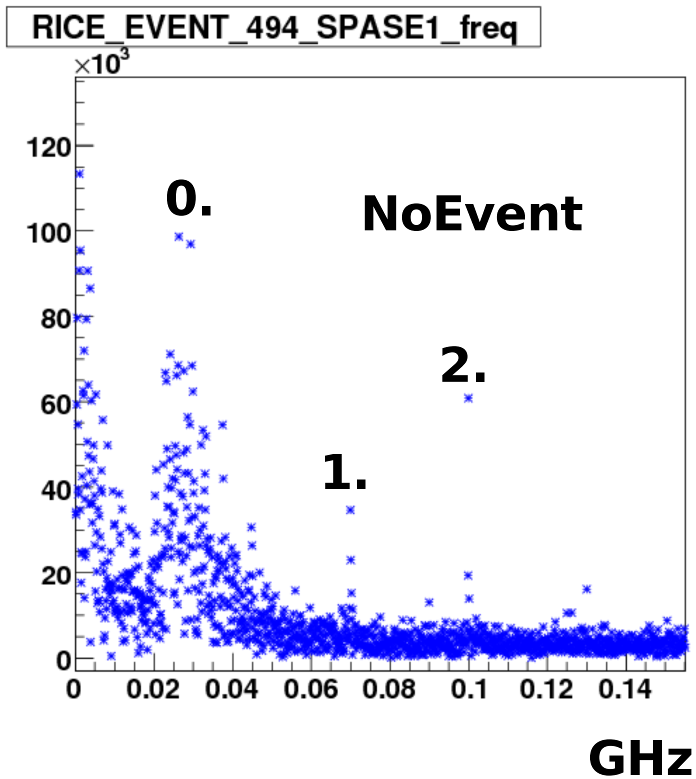
Surface RFI (DC)

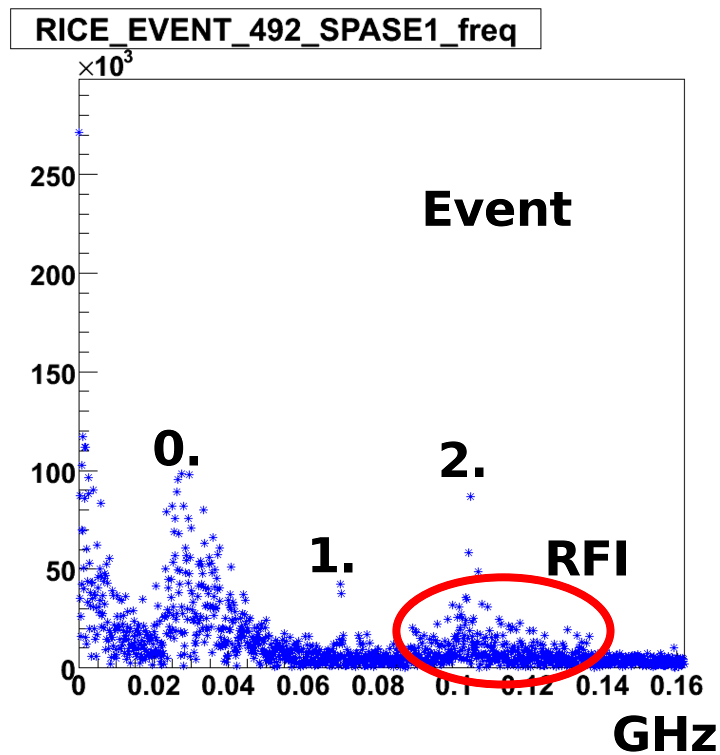


Low continuous noise level

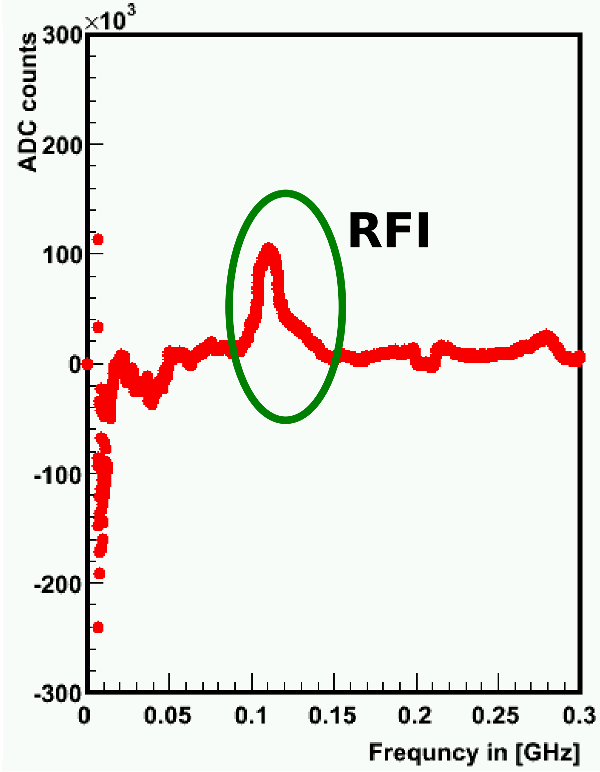
Transient surface RFI

- uncalibrated -



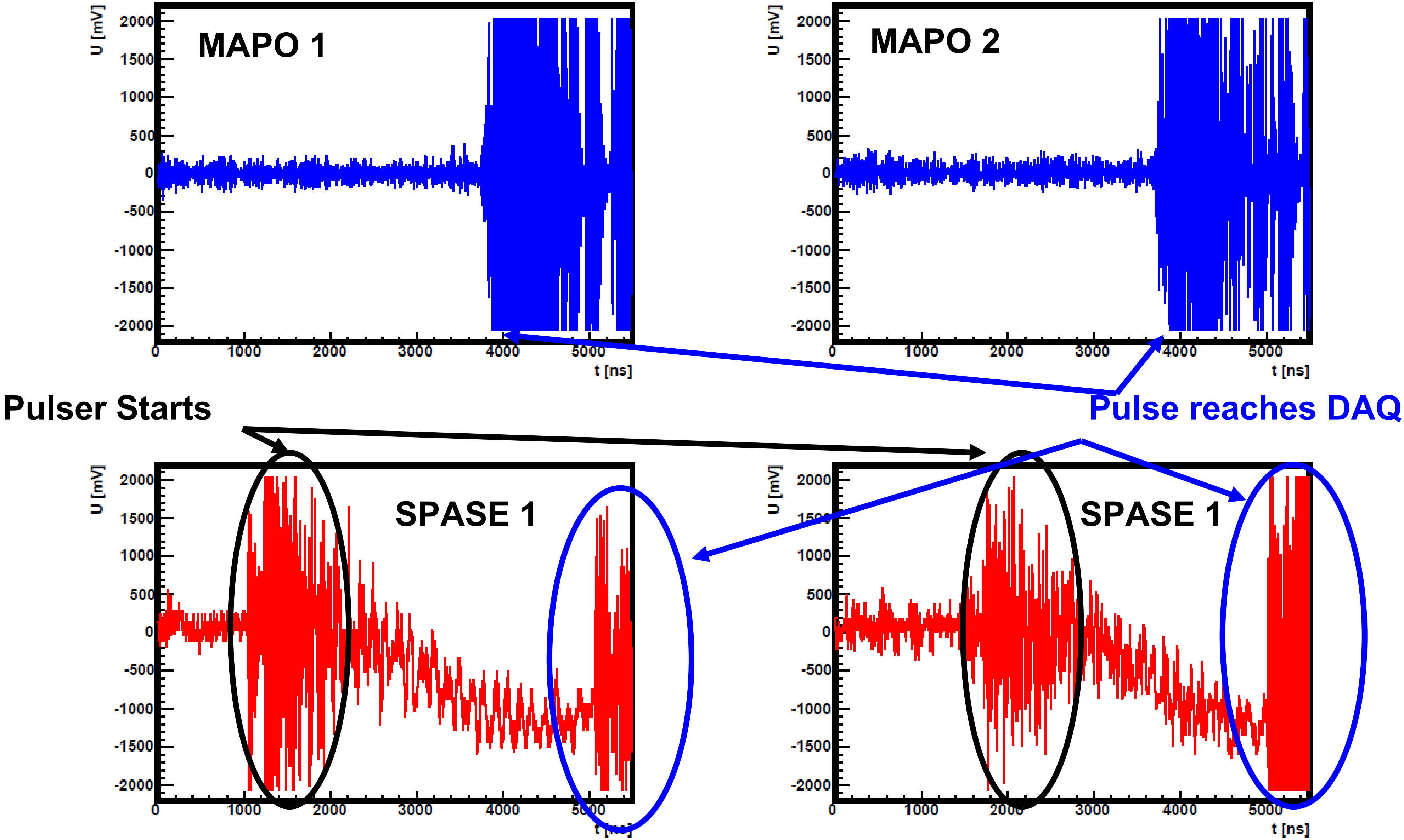


difference
Event - NoEvent

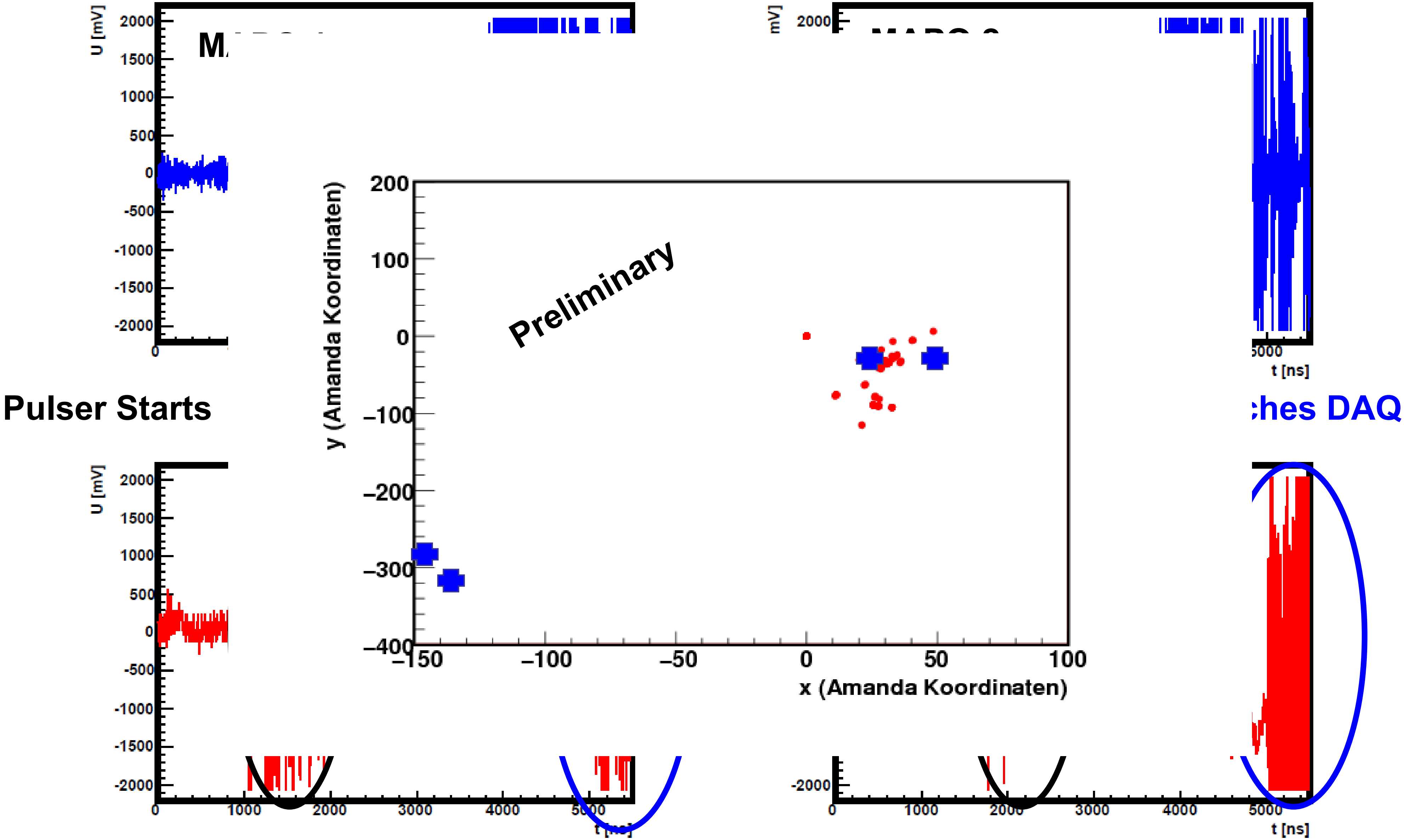


narrow frequency band of RFI emission
compared to broad band air shower signal

Pinger Data Reconstruction

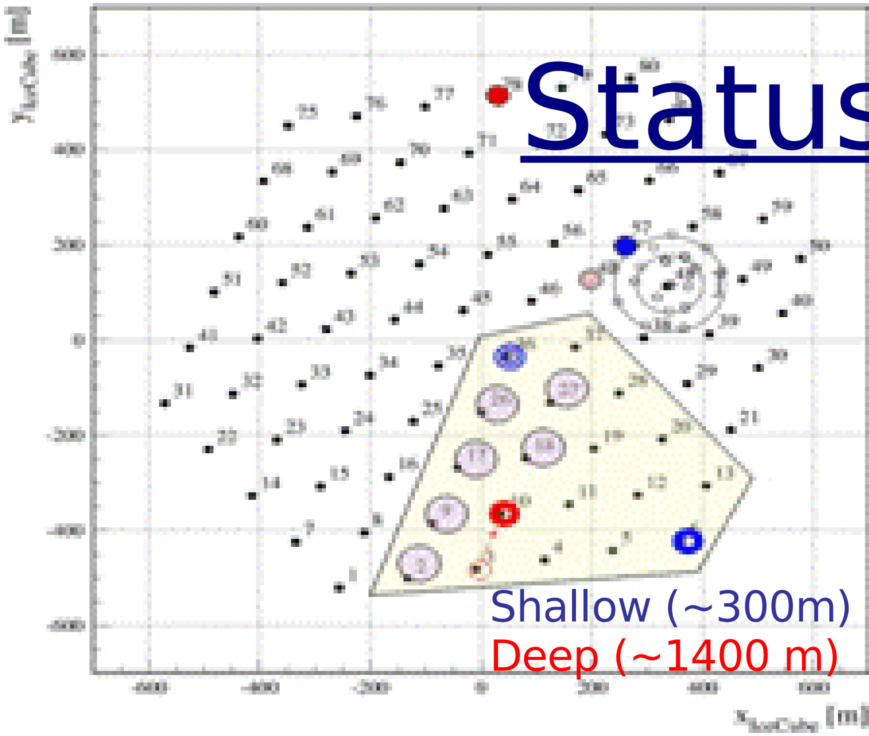


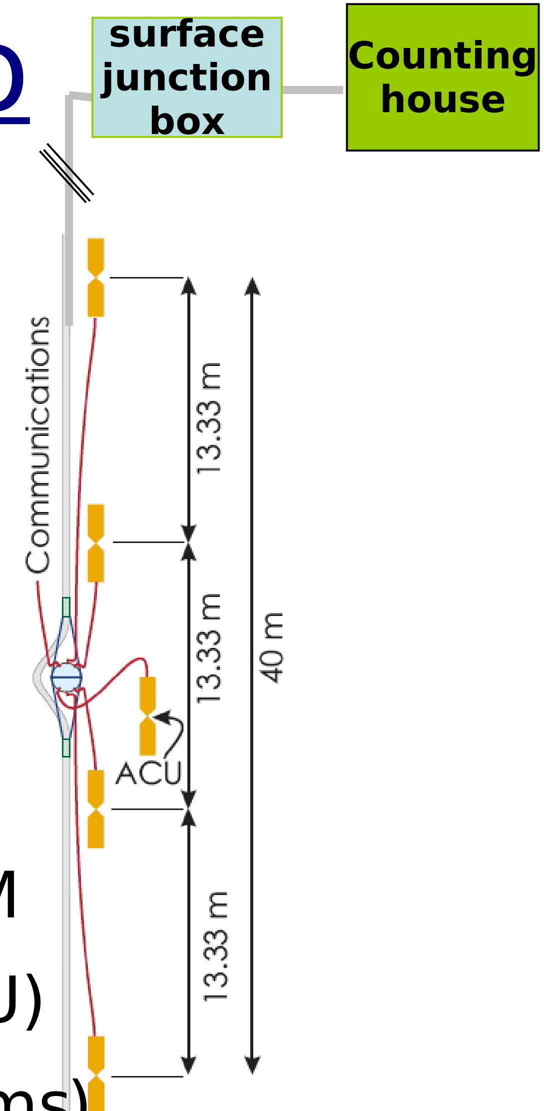
Pinger Data Reconstruction



RMS of reconstruction ~ 3 m

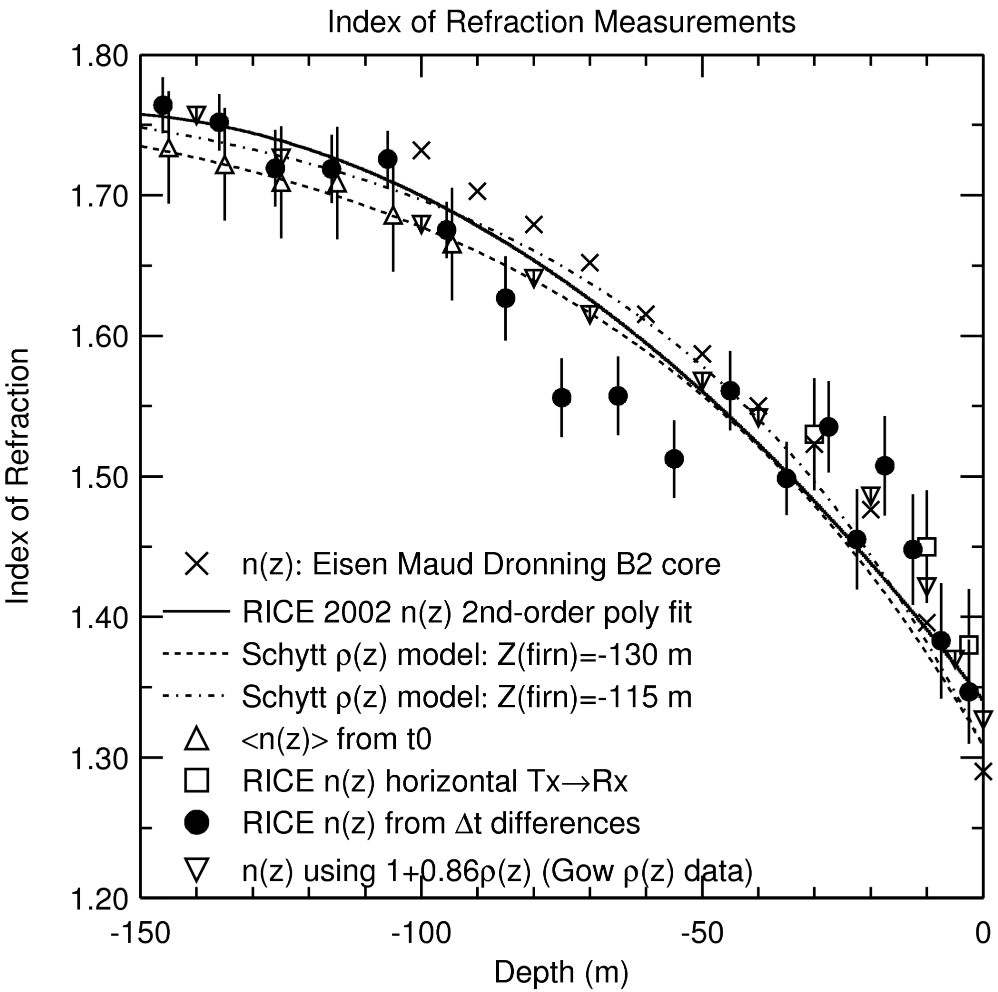
Status in-ice radio



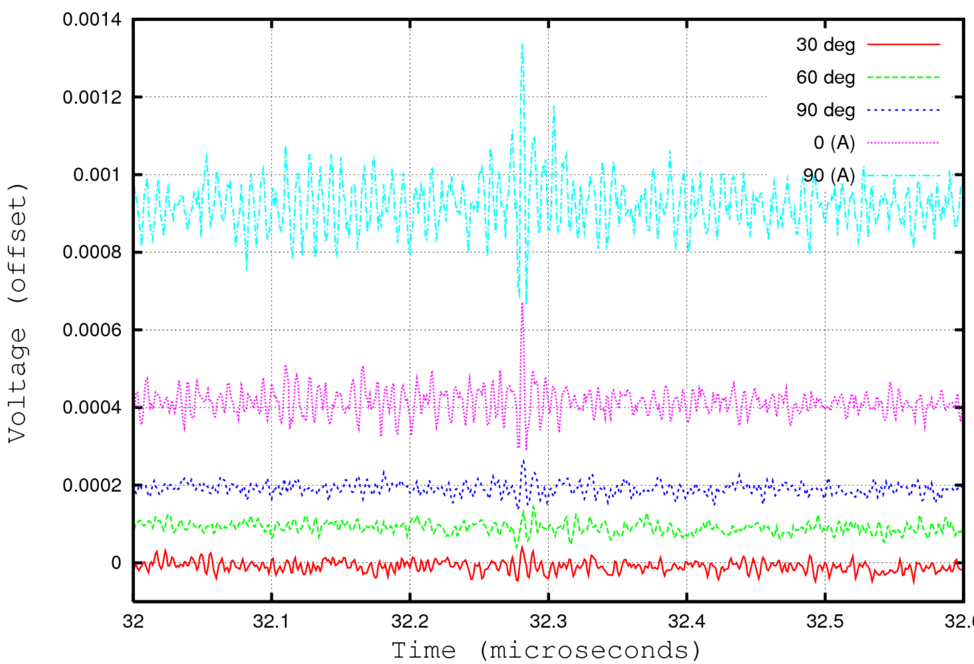


- AURA cluster:
  - Digital Radio Module (DRM) – similar to DOM
  - 4 antennas, 1 Antenna Calibration Unit (ACU)
  - IceCube sphere, DOM main board (waveforms)
- 5 clusters: 2 in 06/07; 3 in 08/09 (with NARC)
- 2 channels (“antennas”) down to 100MHz
- 15/20 channels are working

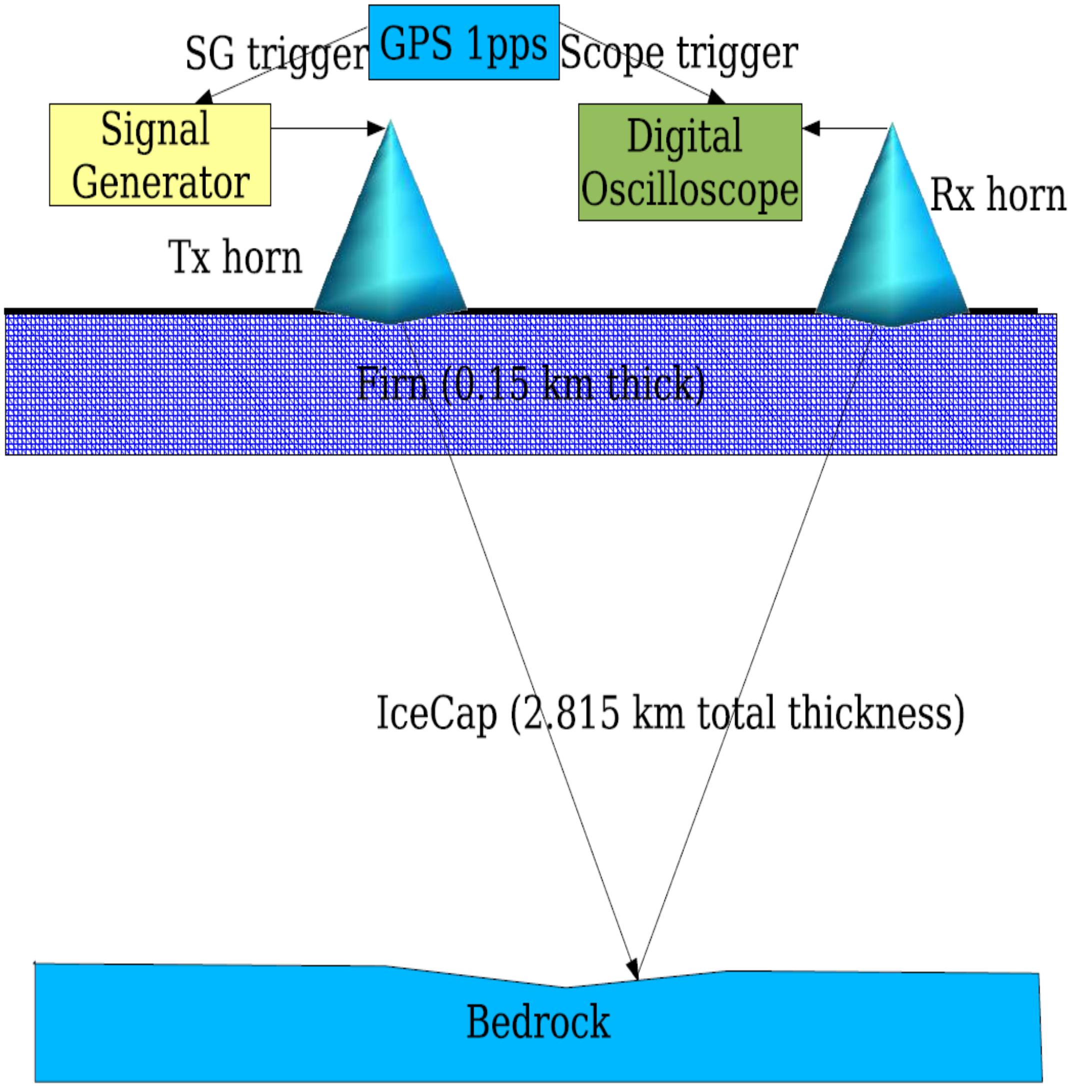
Status in ice radio: Index of refraction

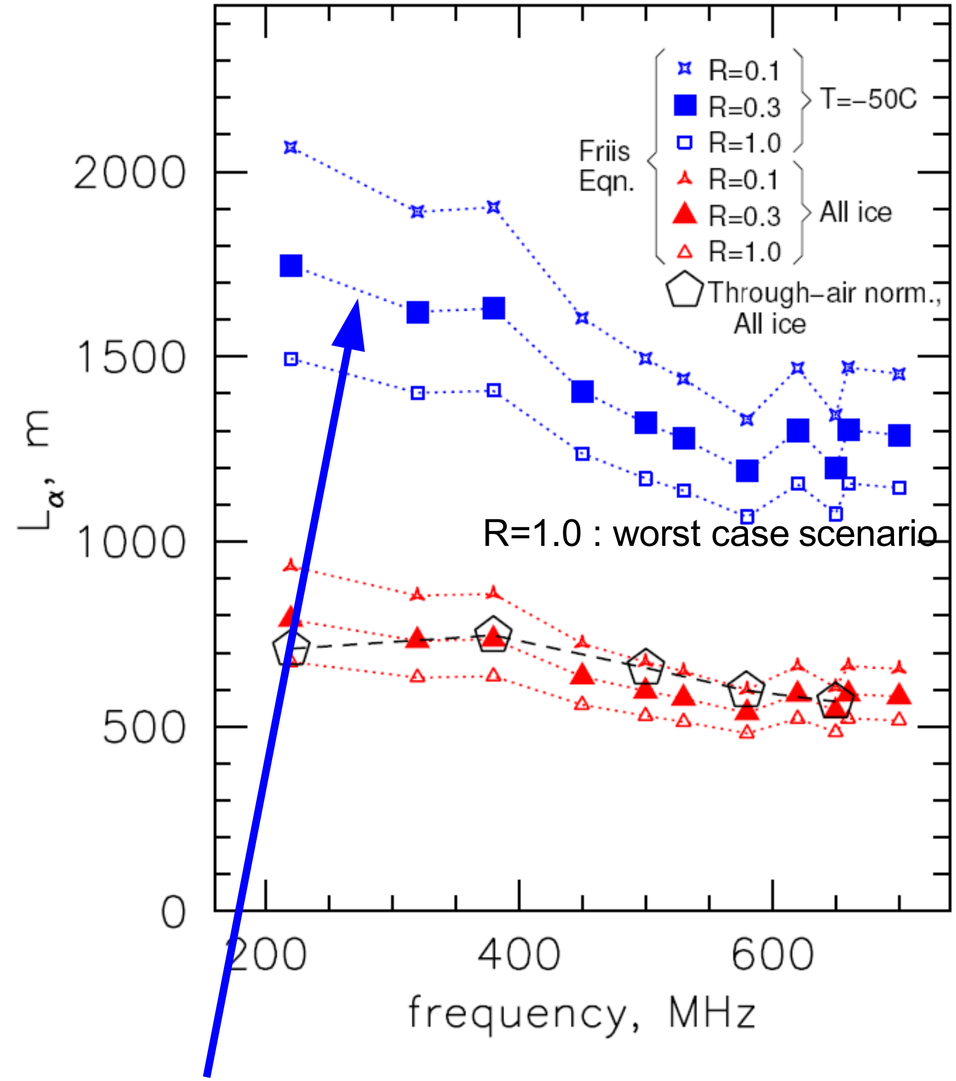


- Changing index helps to reduce surface noise pickup
- ... but shadowing for shallow deployment
- No birefringence



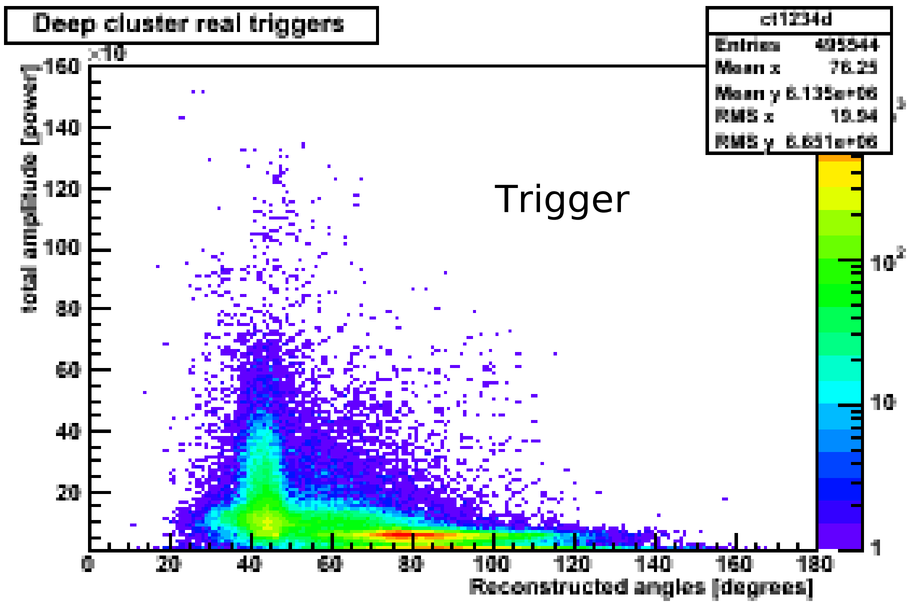
Radio attenuation

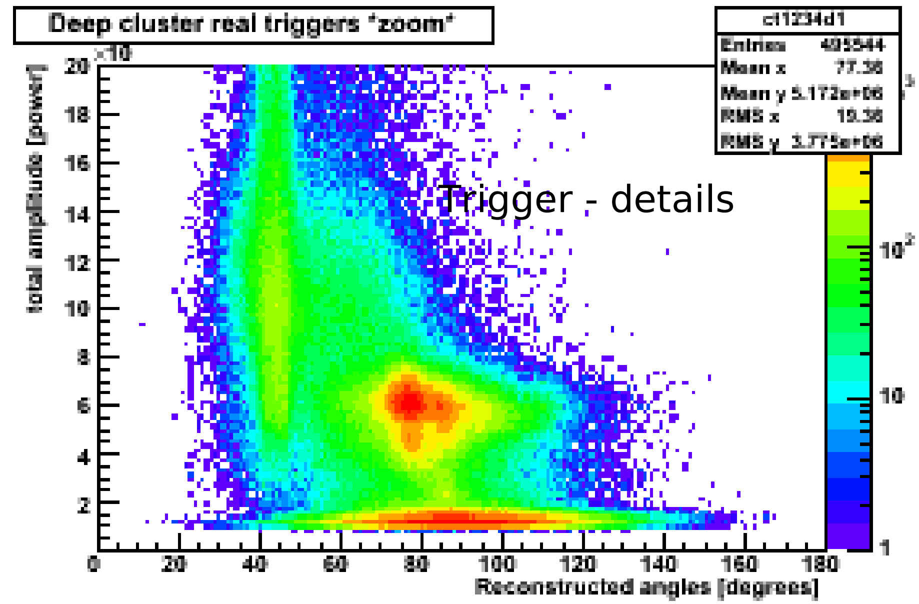


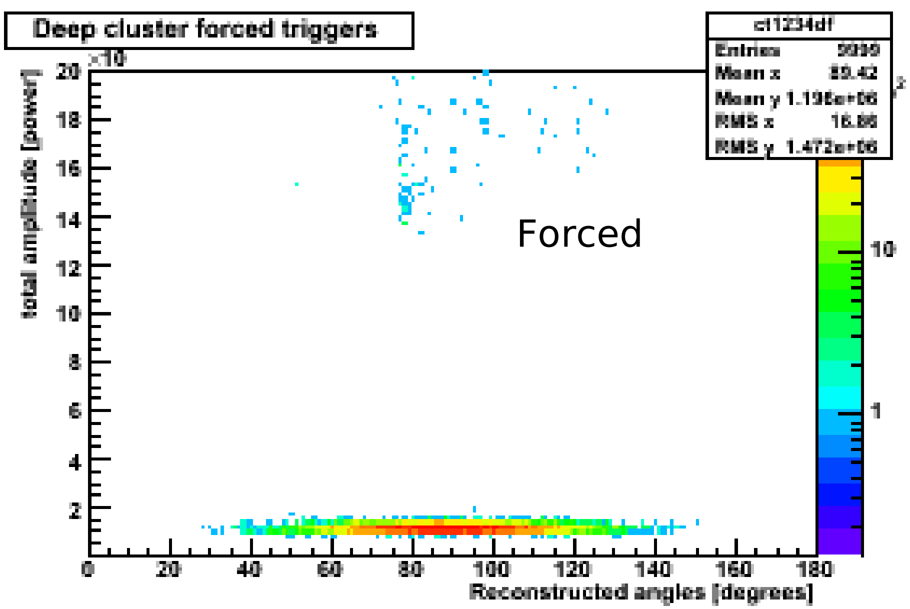


temperature region for shallow deployment

In ice RFI transients with AURA







Angular resolution:
few degrees

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 <u>independent evidence</u> 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

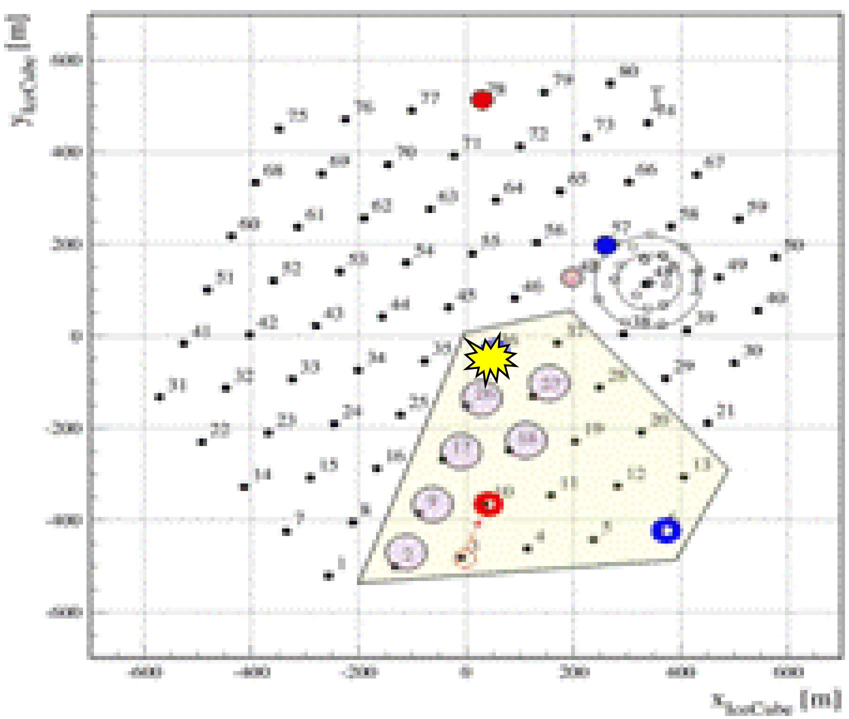
- Use last holes/seasons for
  - prototype sensor co-deployment
  - tests of digitization strategies
  - instrumentation for further site studies
    e.g. retrievable sensors and radio pingers
  - find coincidences of air shower radio with IceTop
- Aim for dedicated (dry) holes to test
  - Deployment 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

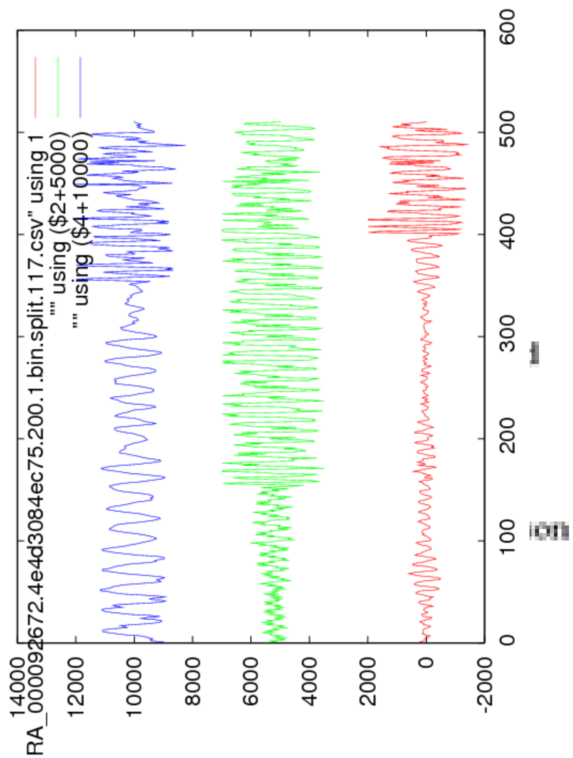
- Clarify role of non-IceCube members 2009
- Start „Letter of Intent" (LOI) at R&D workshop in June and sign in fall 2009 to demonstrate:
  - serious intent of signing groups (FAs)
  - scientific importance
  - long term time scenario and milestones
- Finish basic exploration of ice properties (season 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

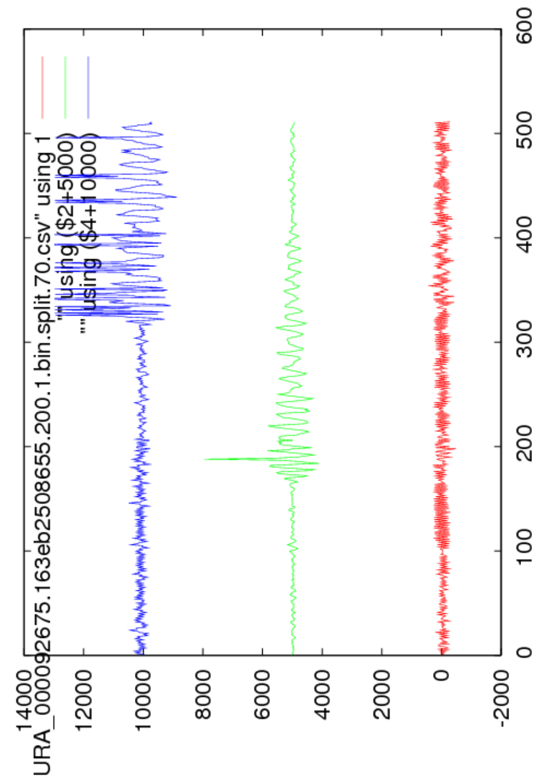
- More RFI studies
- new stronger transmitter
  ⇒ first inter-cluster calibration source



Hole 36, -250 m



Hole 57, -288 m

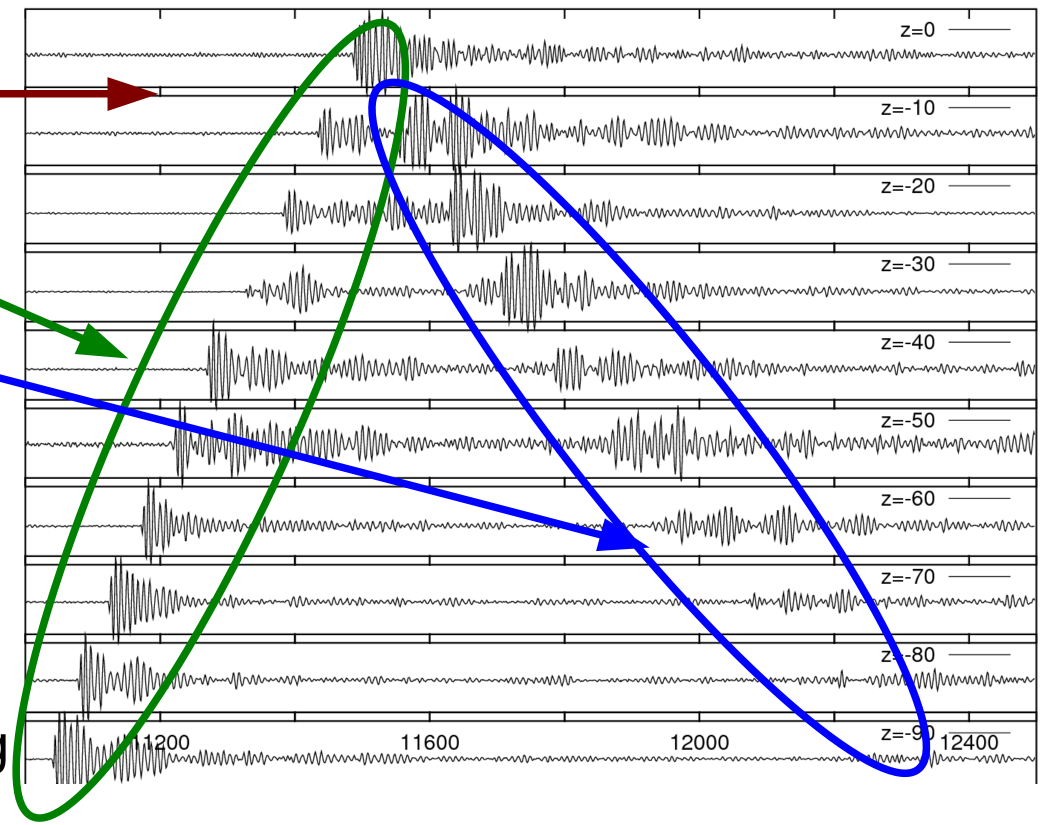


Radio attenuation: Plans for direct on-site measurements

Previous pinging with RICE

direct signal path

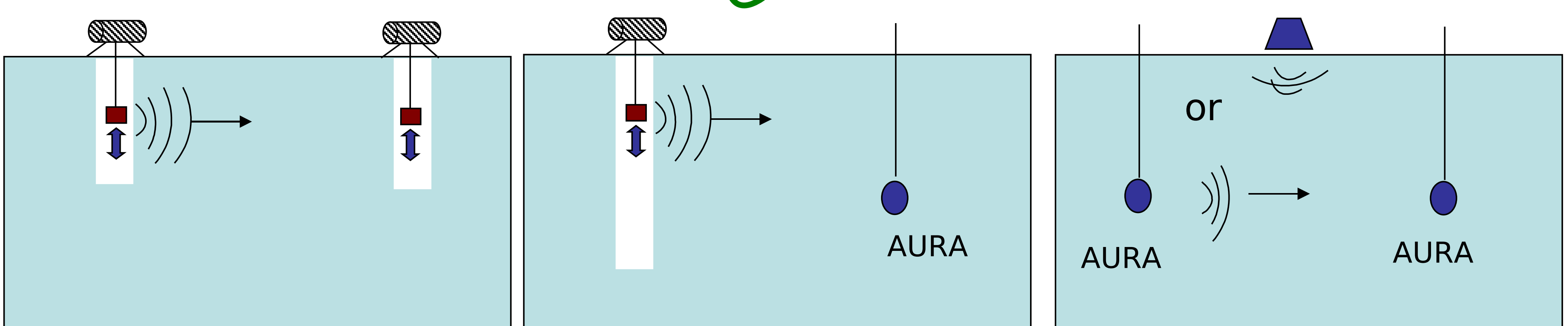
signal path with total reflection



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
- South pole RFI map vs. time
- Possibly produce limit on GZK neutrinos:
  - Sensitivity calibration
  - Life time
  - Simulation

Season 09/10 plans for acoustic

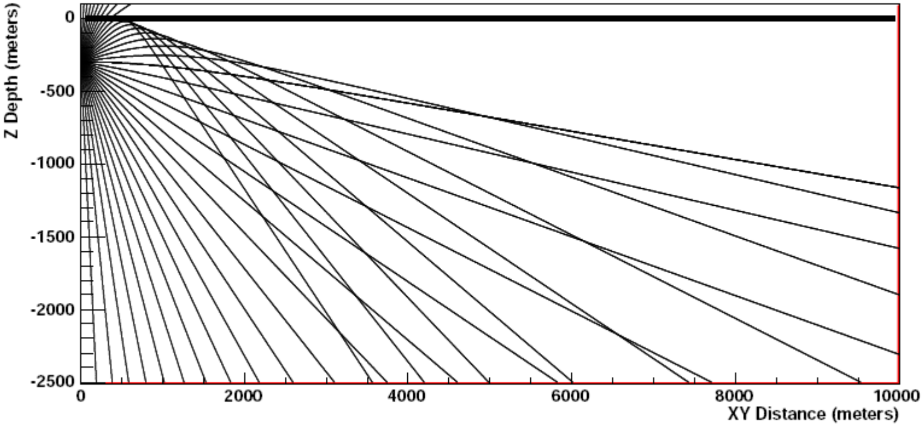
- Attenuation (if scattering) strongly frequency dependent
  - Test with broadband pinger
  - Confirm attenuation in perpendicular direction
- No transients below ~300 m
  - No sources? – Unlikely
  - Mechanism quieting deep sources (relevant to radio?)
  - Lower pinger to deeper depths (~1000 m)
- New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

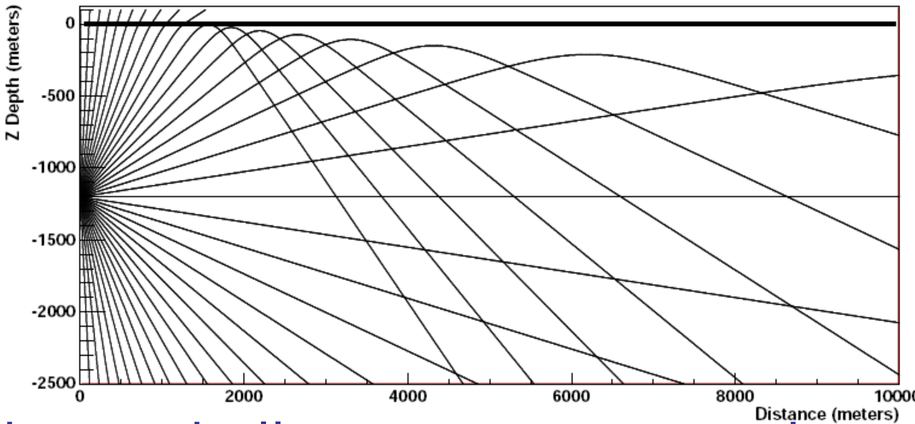
Detector design considerations

- 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

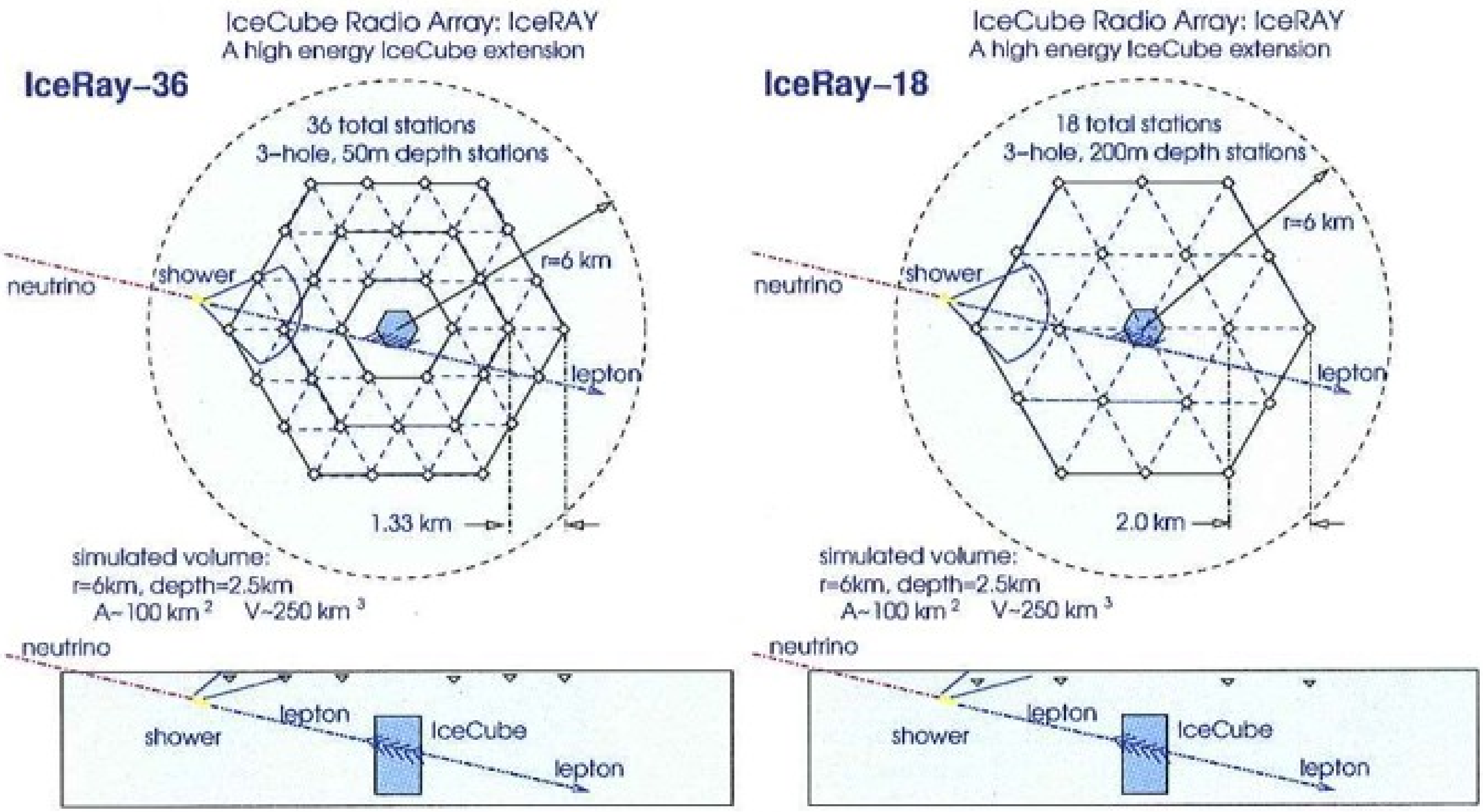




dense shallow versus sparse deep

Case study IceRay

– fully digitized waveforms, 50 km^2 –



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 km^2 by factors**

Example for technology choices

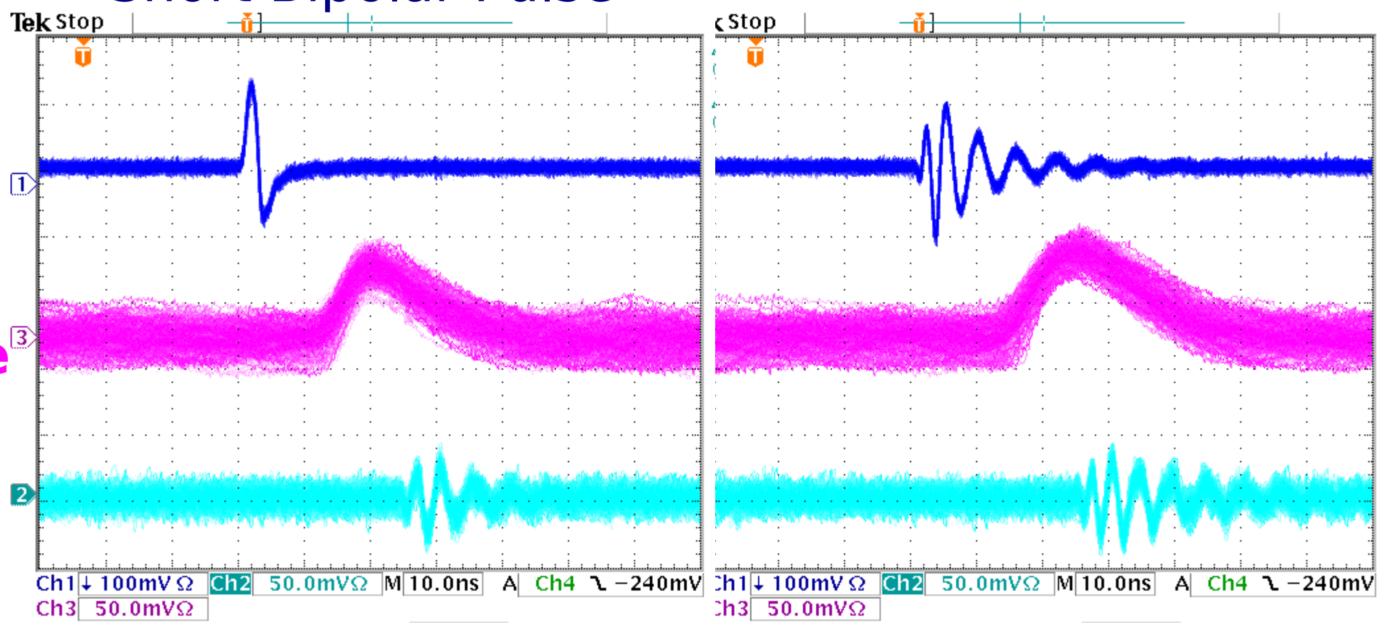
Pulse shaping and triggering versus waveform capture

Short Bipolar Pulse

“Antenna-like” Transient

shaped pulse

AURA waveform

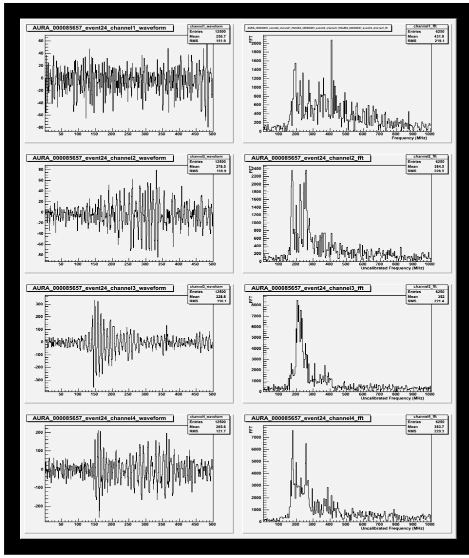


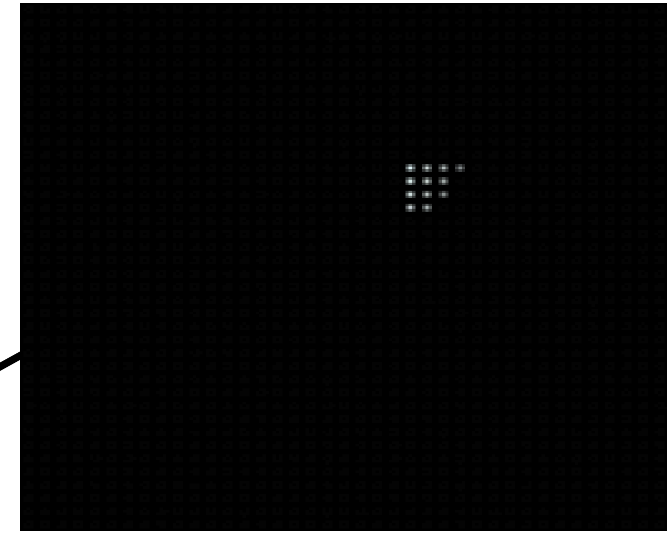
If only envelope gets sent to surface:

- 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

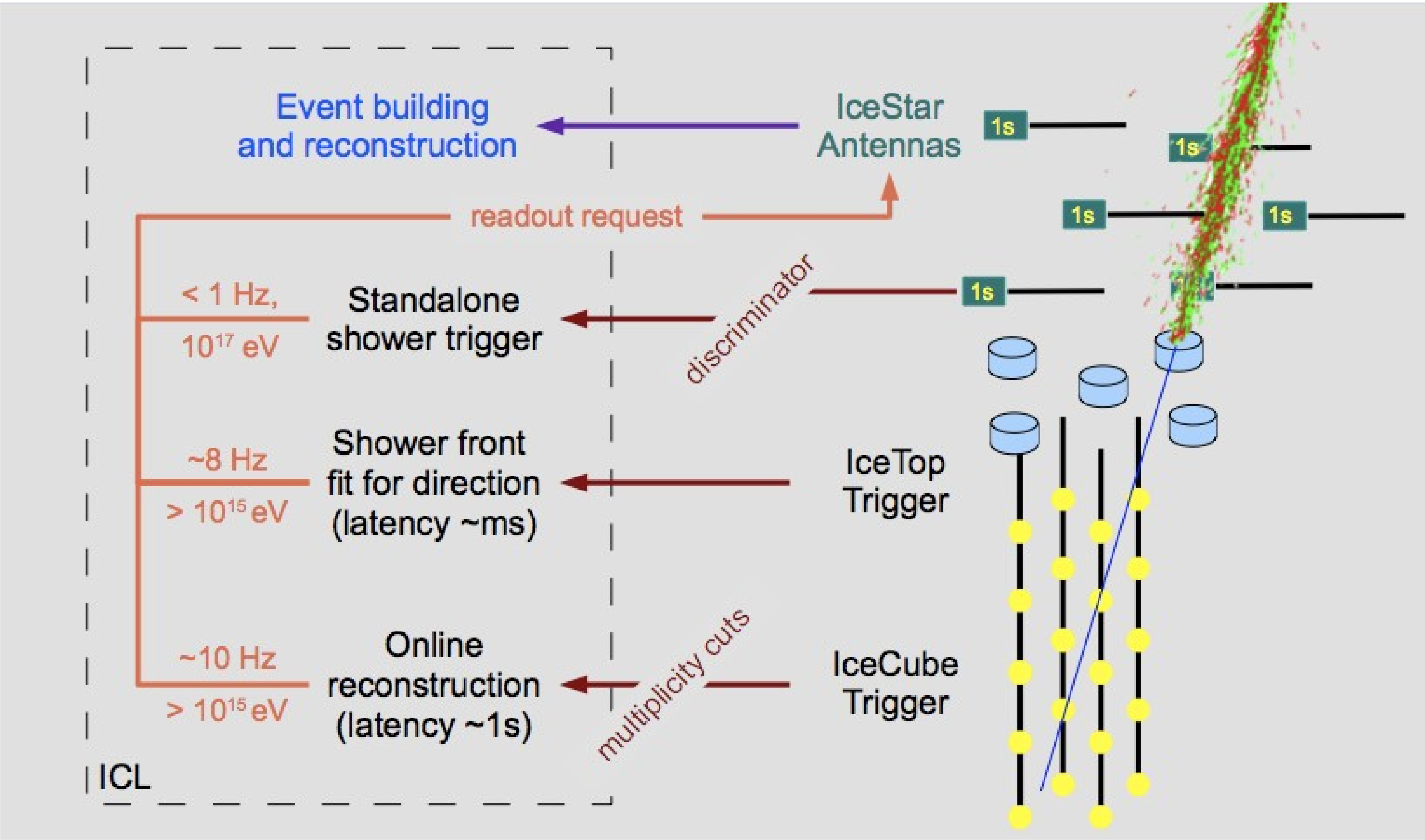
Pulse shaping & envelope trigger

Pros:
+ cheaper units → large array
+ Simpler detector

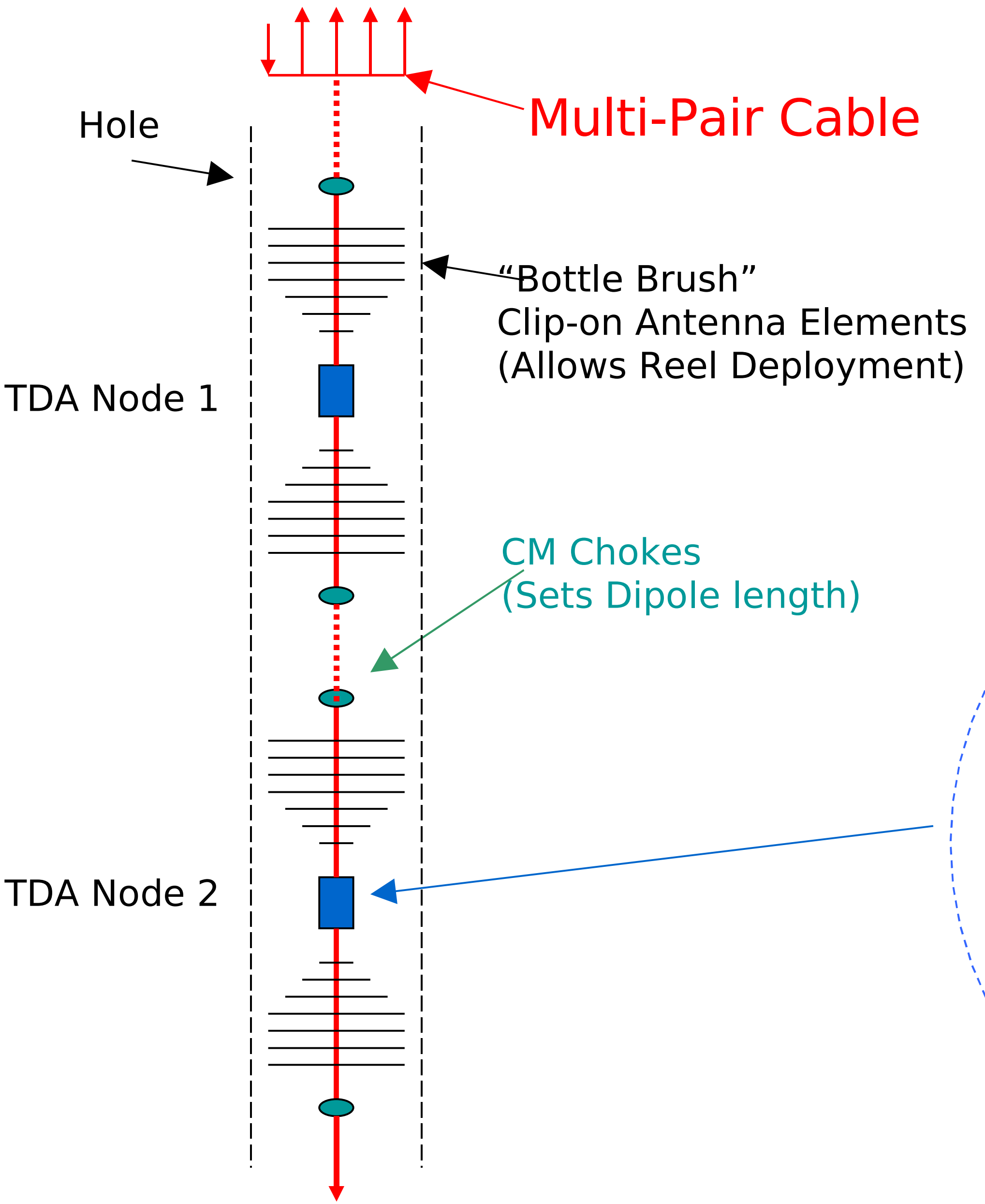
Cons:
– Limited information

Challenges:
information sufficient to reject background and detect GZKs ?

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



Sensor String Configuration (here: in ice radio)

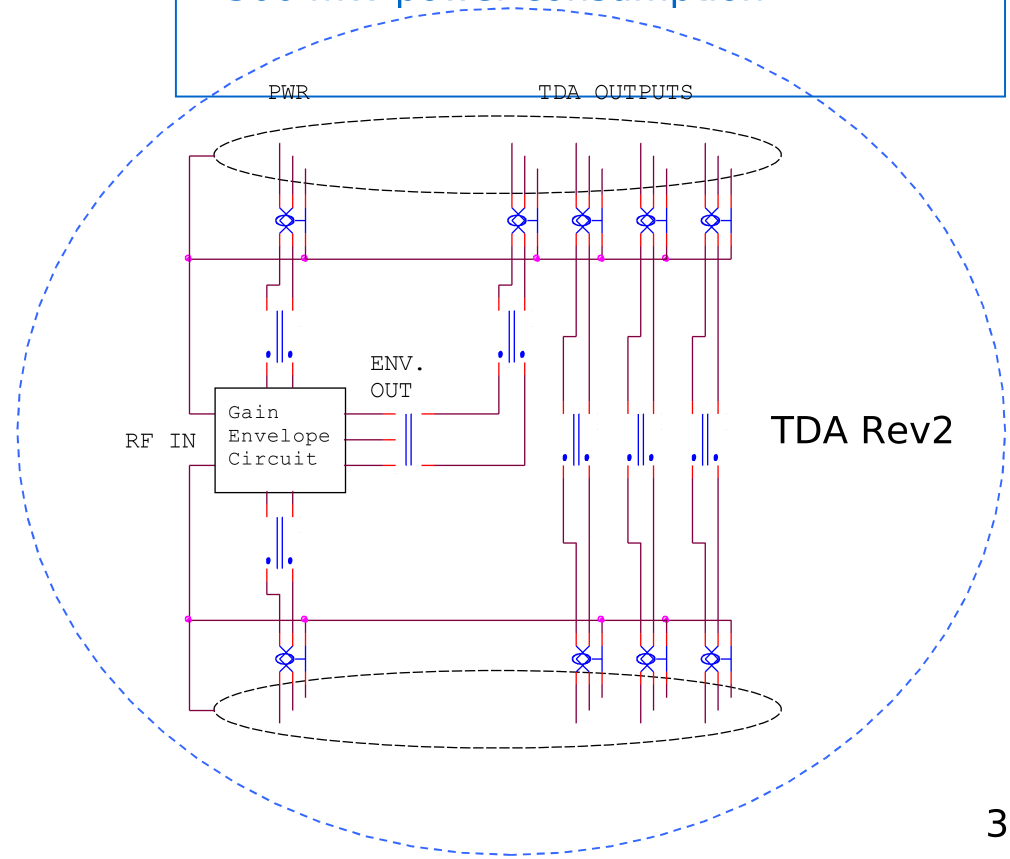


"Common Mode" TDA Node:

- 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



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

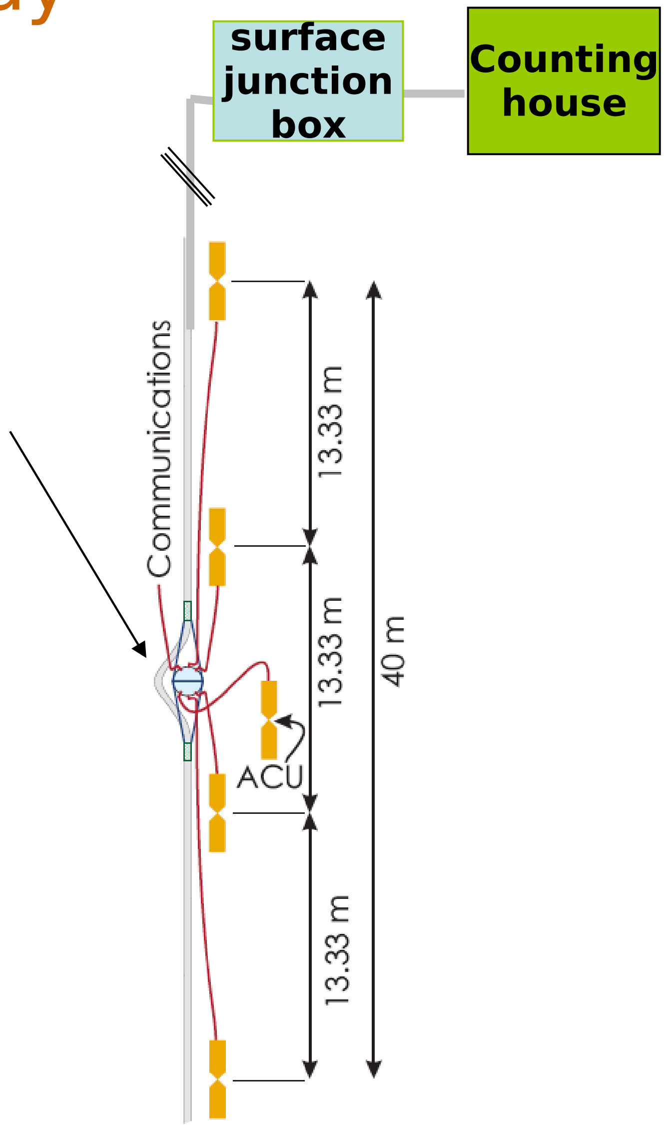
Use IceCube's resources: holes, comm. and power

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

- Signal conditioning and amplification happen at the front end

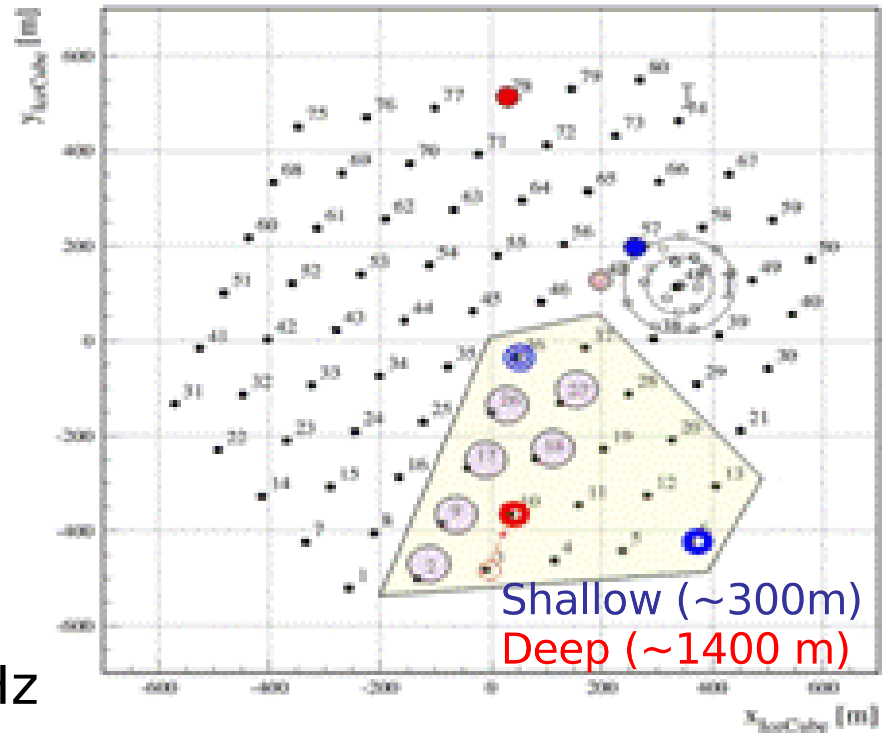
- Signal is digitized and triggers formed in DRM

- 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

From Utrecht premeeting

Possible near term timeline:2008-2009-2010

- Working group and collaboration building -> in progress

-Write „Letter of Intent“ and sign in spring 2009 to demonstrate:

serious intention of signing groups to in- and out-side world (FA)
scientific importance in comparison to other topics
expected improvement to previous experiments
time scenario and milestones (Hawaii, identify man power)

- Finish basic exploration of ice properties (existing hardware, new deploy?)

- Agree on deployment scheme already here (?)

- Start extensive MC studies of different detector options (using above)

- Start sensor and electronic prototyping

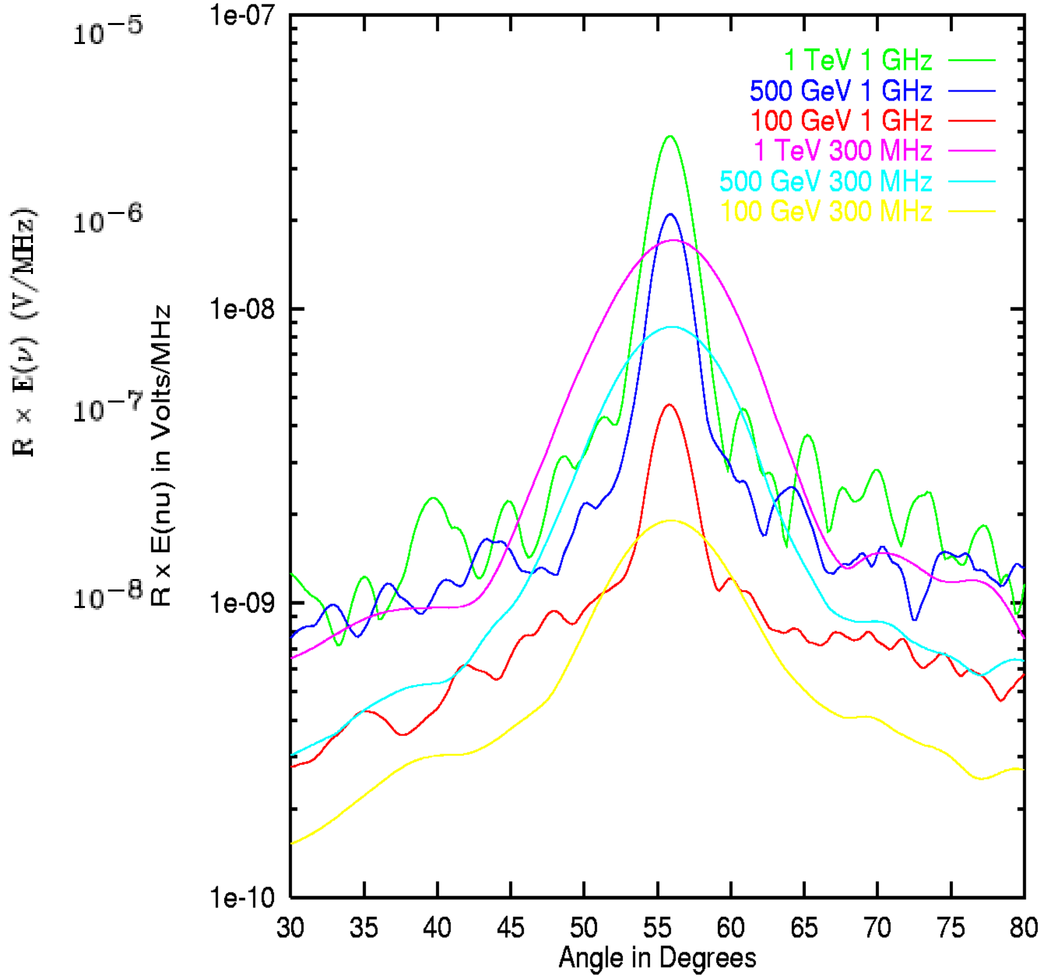
- Track down number of different detector options based on above results (earlier?)

- Write „Proposal“ for submission to FA‘s end 2010 (realistic ?)

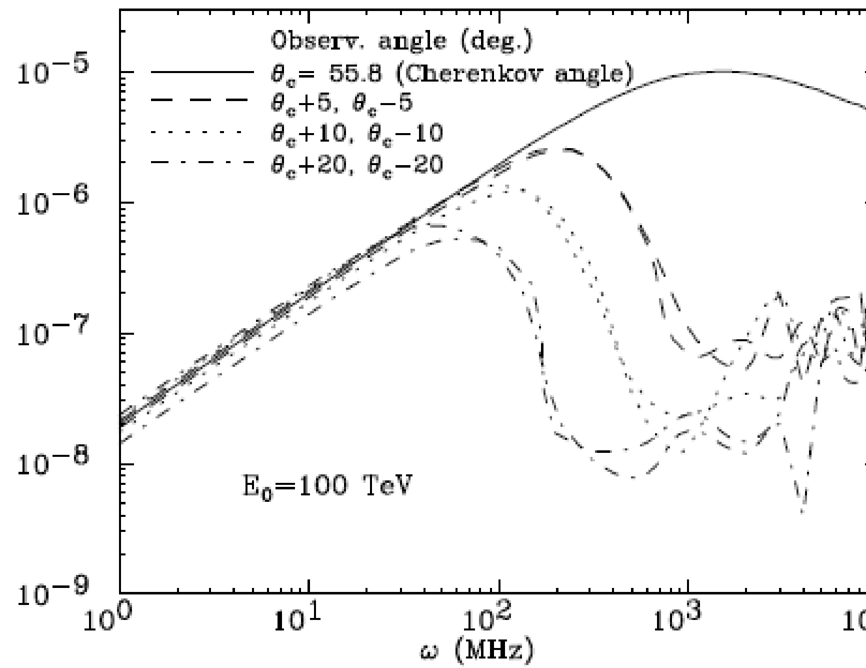
expand letter of intent to give detailed information
based on extensive MC and hardware studies
still goes with flexible design plan and 2 phase structure
works out realistic budget plan

Askaryan Signal

Electric Field angular distribution

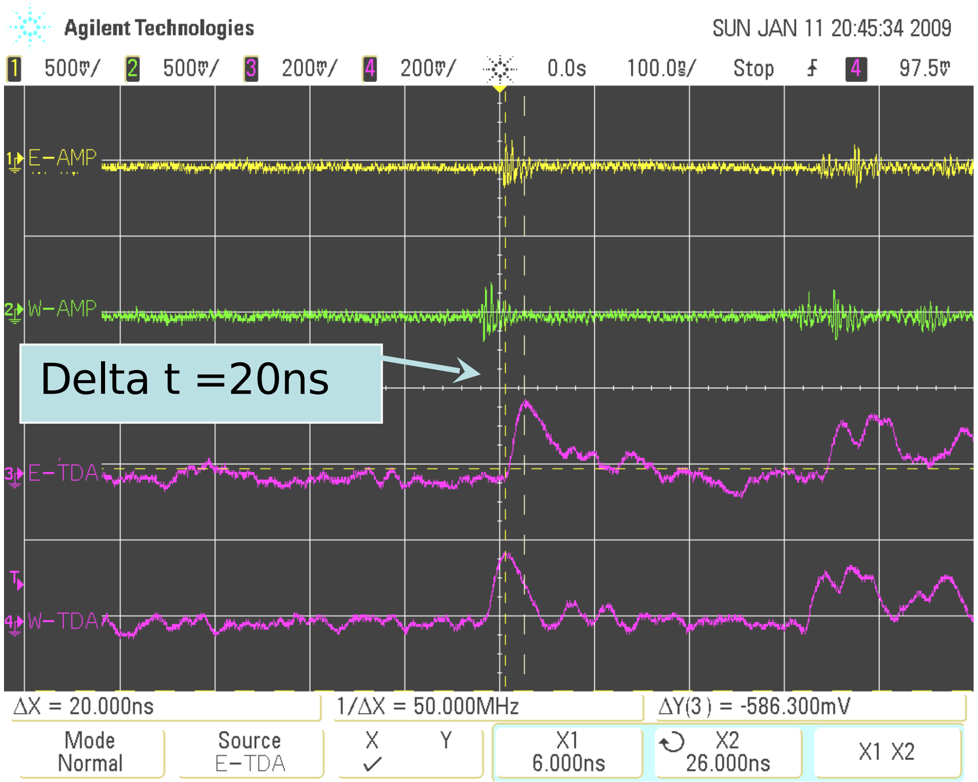


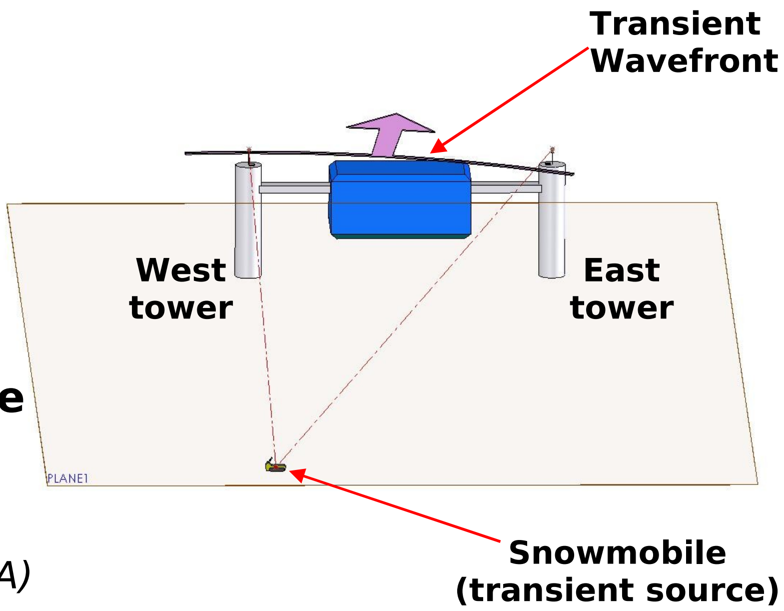
Electric Field frequency spectrum



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

Example Transient (from snowmobile ignition)



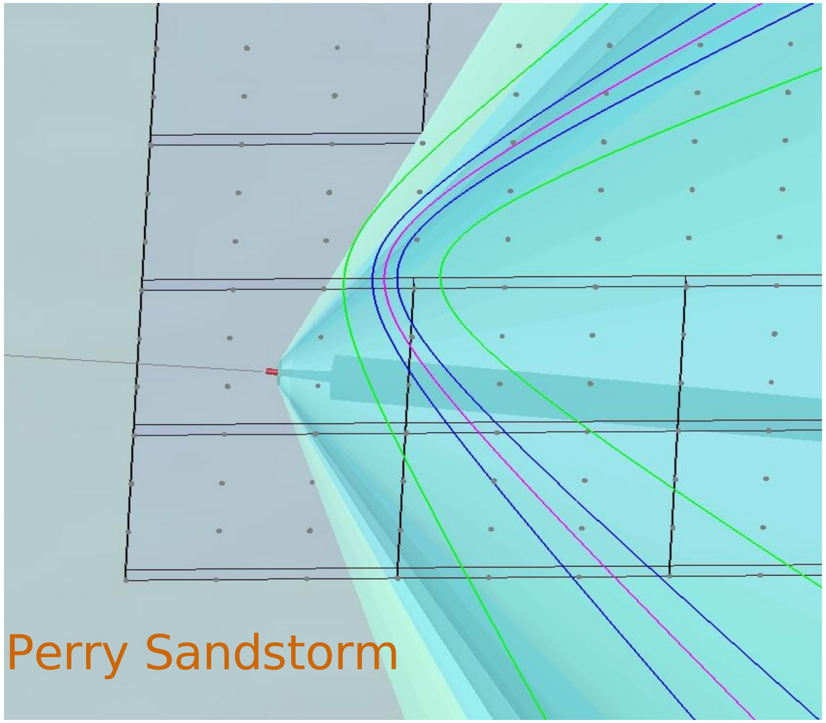


Ignition noise transients from idling snowmobile

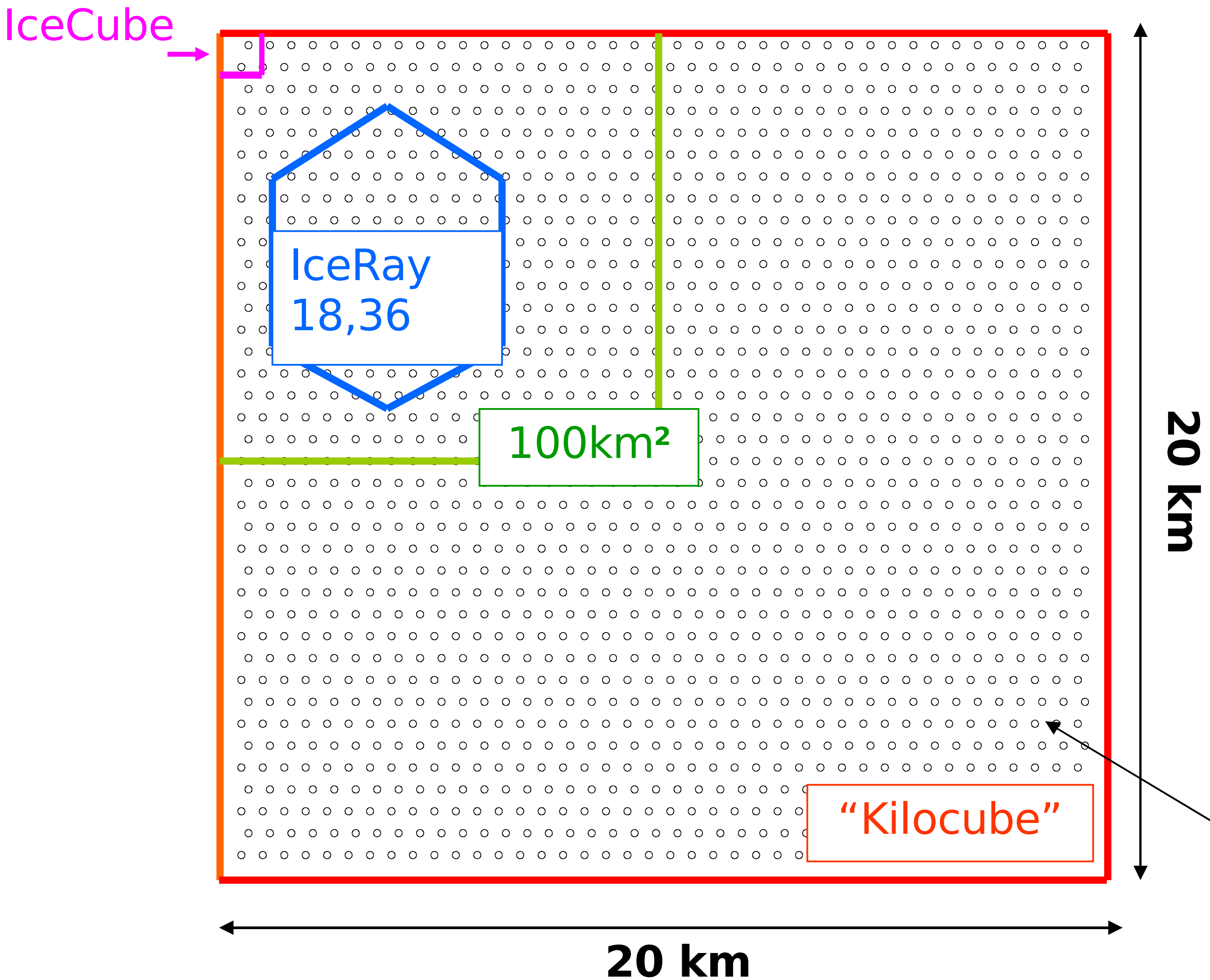
Snowmobile was approximately 100m distance from ICL.
Snowmobile was perpendicular with West tower.
Signals as acquired by ic-scope-ag1
Time Delay=20ns W-E, consistent with Angle-of-Arrival (AOA)

Transient sensor array

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



Case study: Transient Detector Footprints



500m x 500m sensor spacing shown

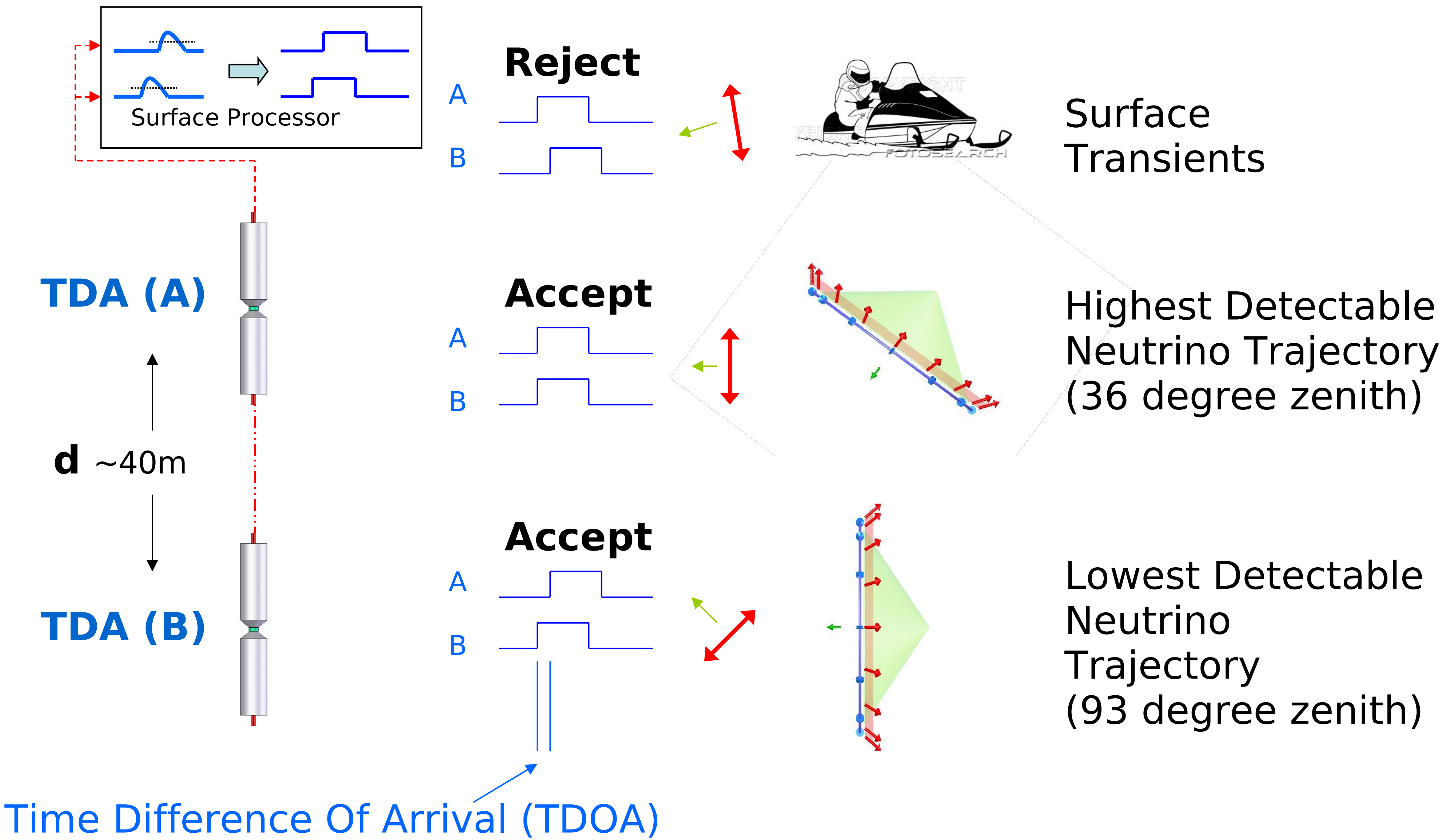
"Kilocube"
# of Sensors vs. Density:

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

Downward Rejection

via Priority, Coincidence

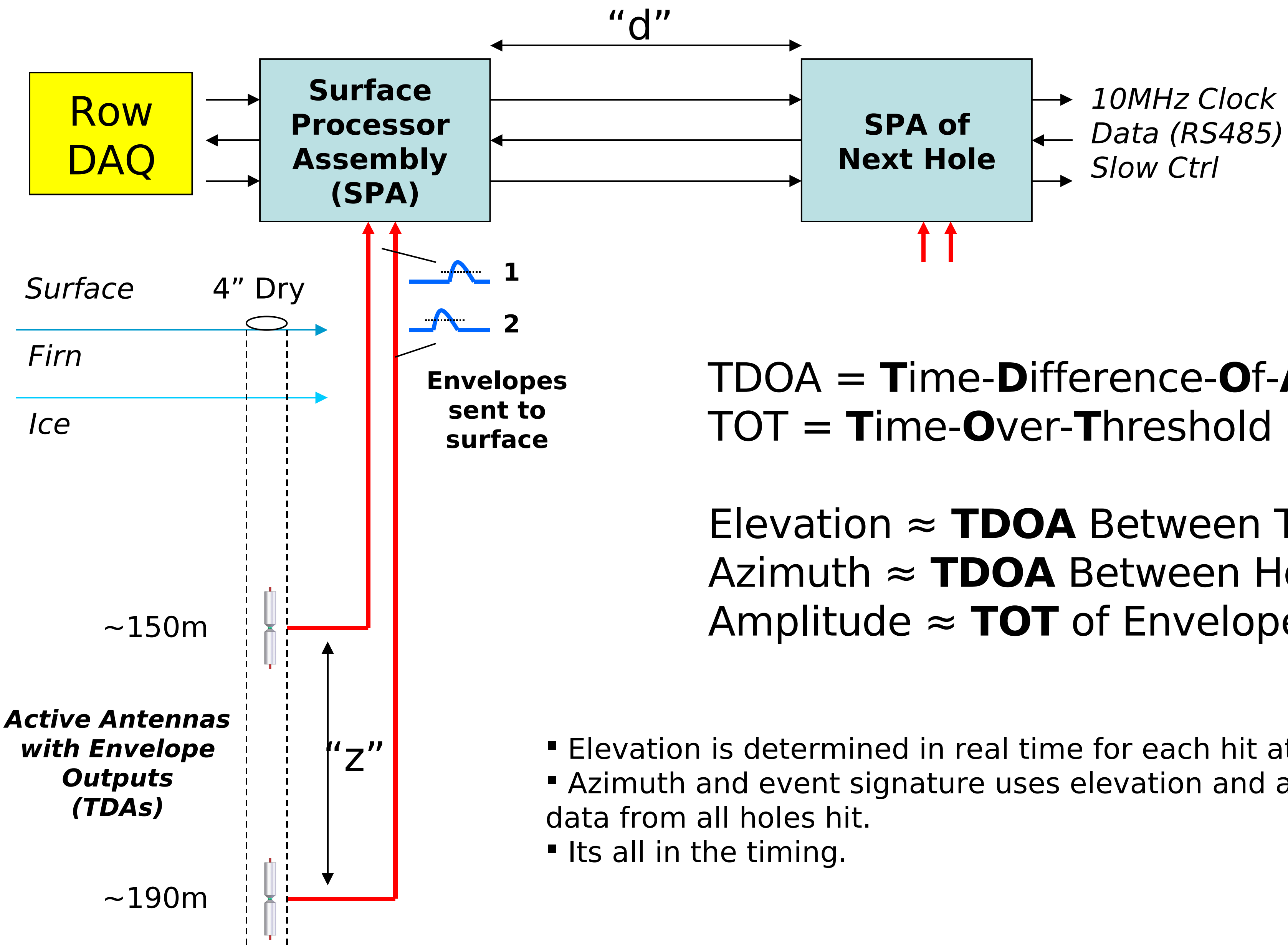
Real-Time, Simplest “Elevation Gating”



SATRA Functional Blocks

(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

Compare TOAs for
Elevation Angle

Compare TOT
(amplitudes)
for
“hit quality”

8bits	14bits	14bits	8bits	14bits	8bits	**TDA 3,4, etc**
		TDA1 Rise	**TDA1 TOT**	**TDA2 Rise**	**TDA2 TOT**	

Hole Address

Course Time

From Masterclock

LSB= 10ns

Range=100us

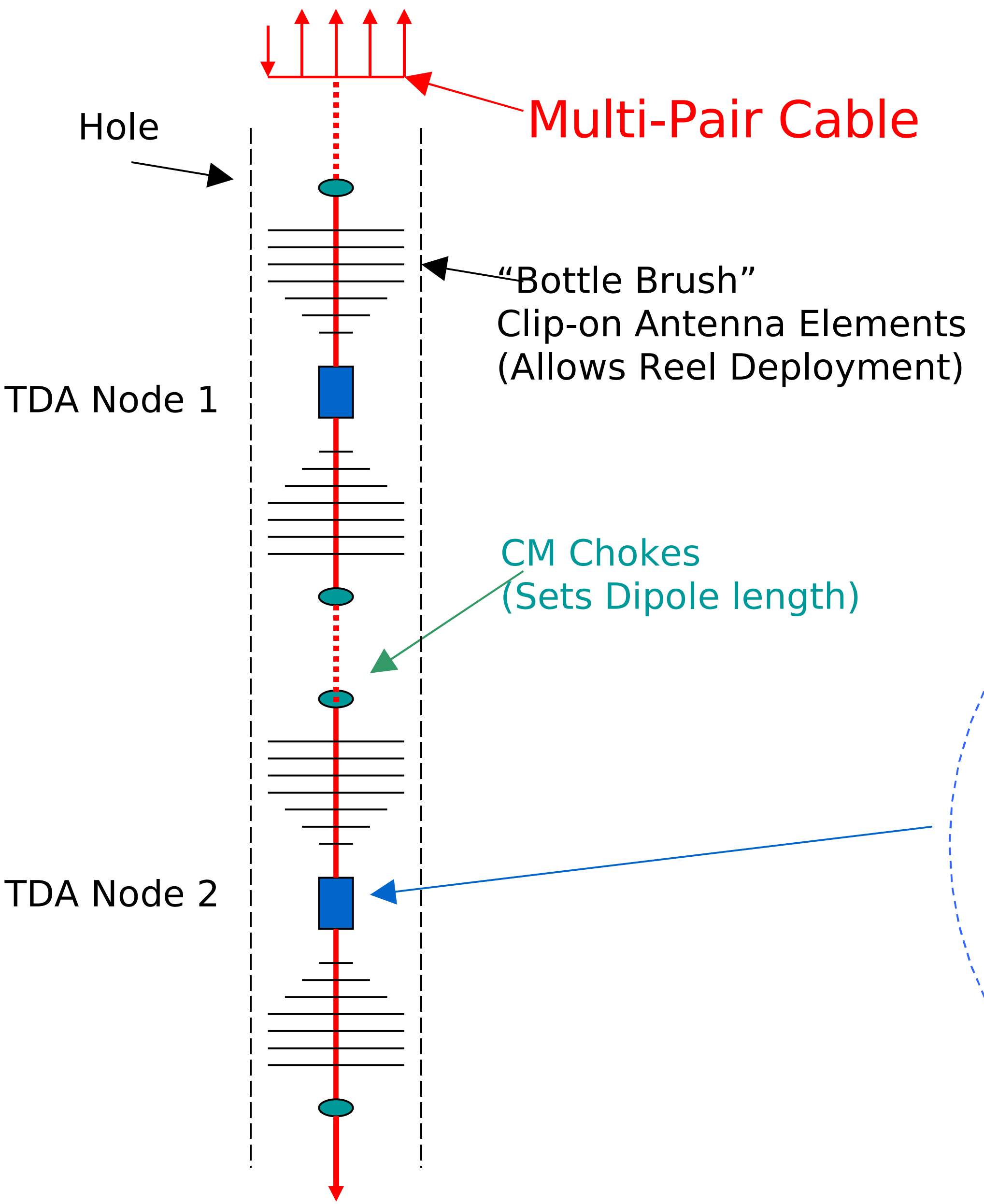
Fine Times

From Time-Digital-Converter (TDC)

LSB=250ps

Range=500ns

Sensor String Baseline Configuration

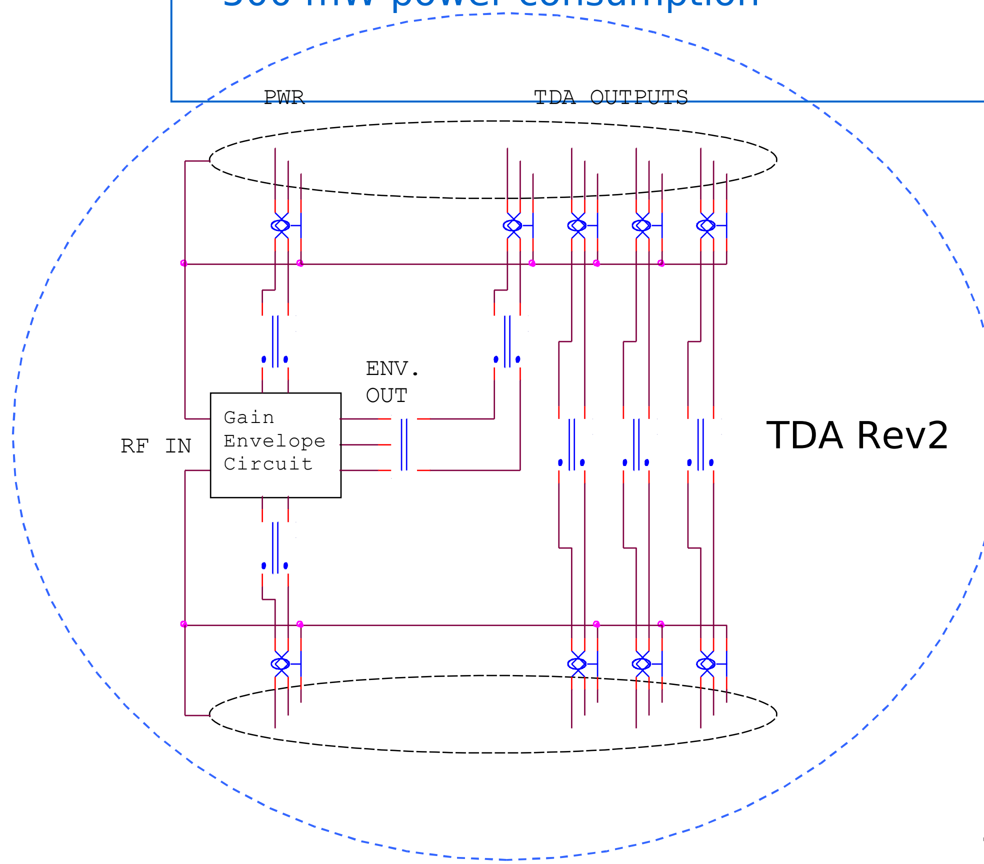


“Common Mode” TDA Node:

- 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

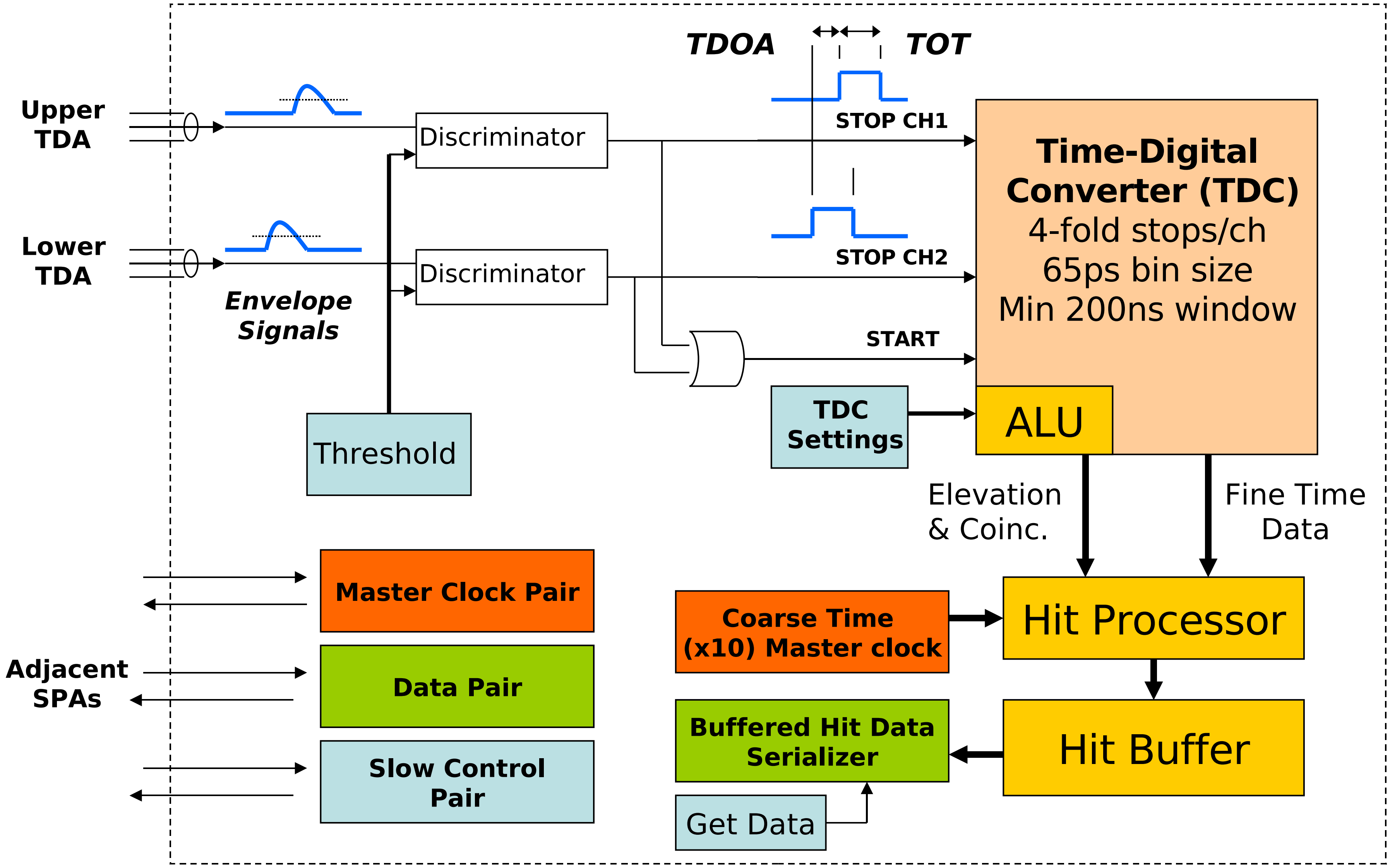


Sensor String Development
separable activities/disciplines by color

- 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

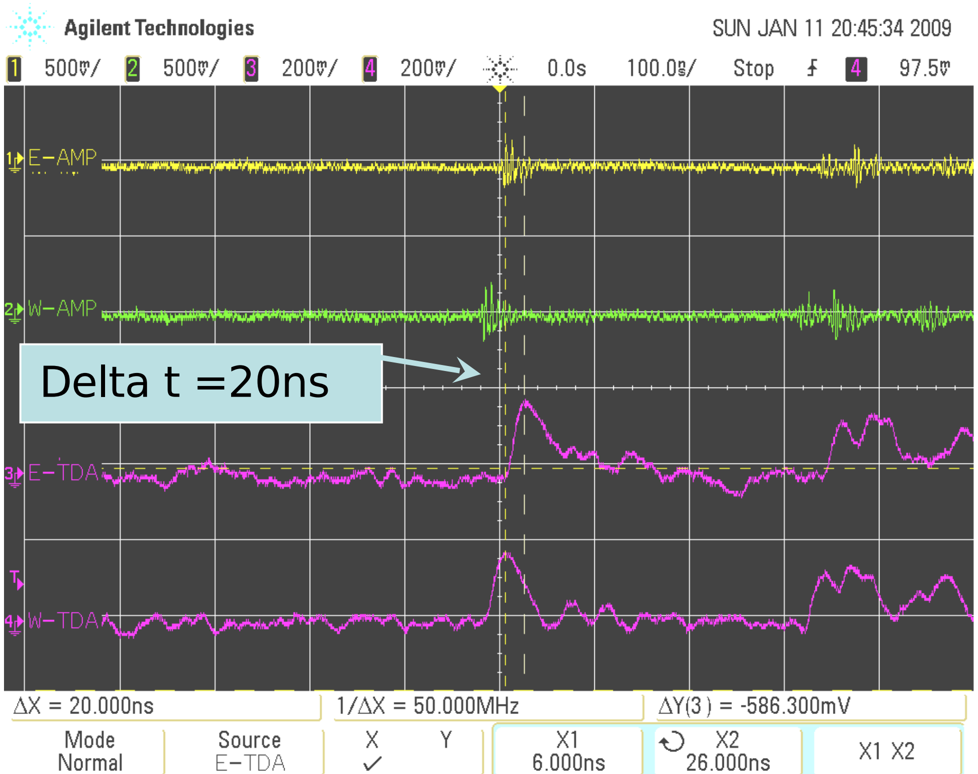
separable activities/disciplines by color

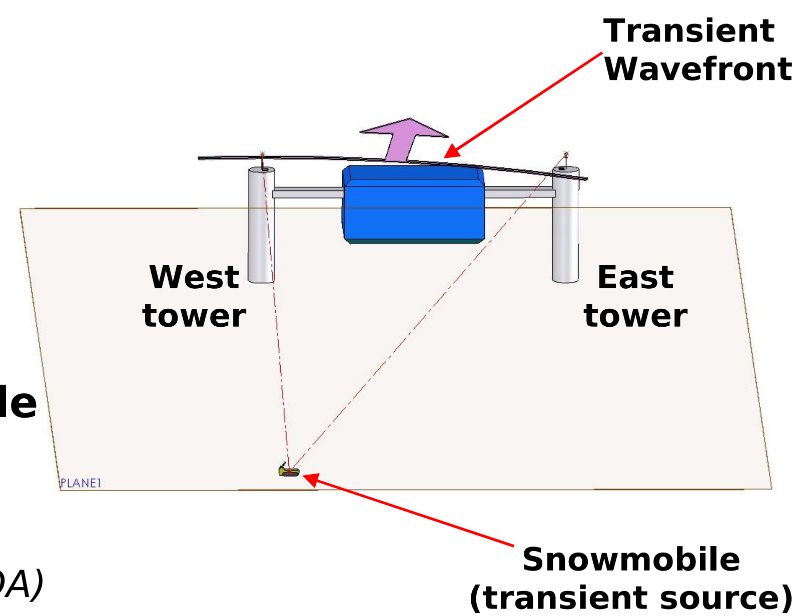
- Surface Cable and Interface
- Discriminator
- TDC (or simple elevation gate for ’09-’10 expmt)
- Hit Processor (µProcessor or FPGA)
- PLL & Course-Time Counter
- Data Format and Buffer
- DC-DC Converter/ Head-end PSU requirements
- Enclosure and Integration

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.

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





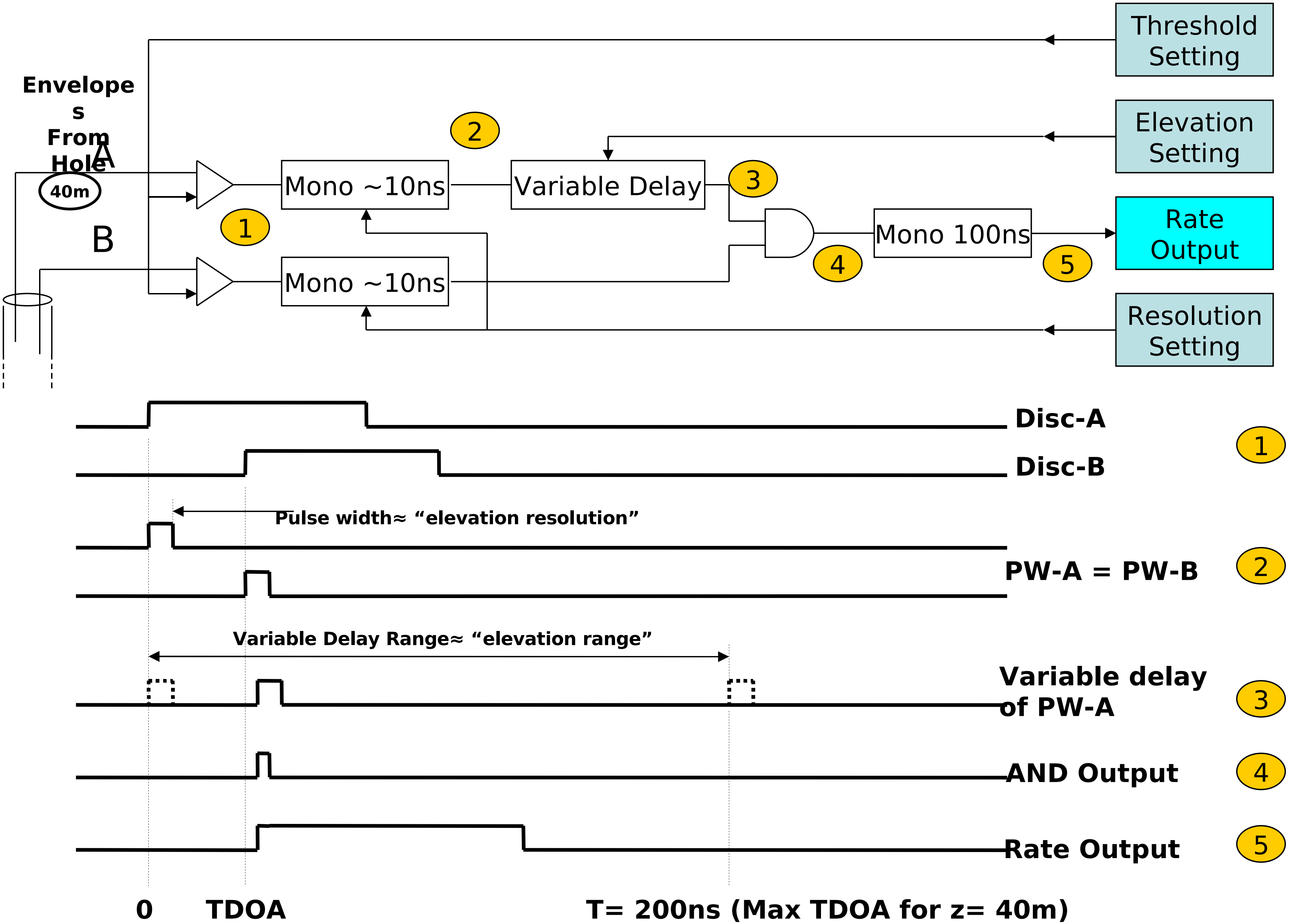
Ignition noise transients from idling snowmobile

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)

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