The Askar’yan Radio Array

Thomas Meures for the ARA Collaboration

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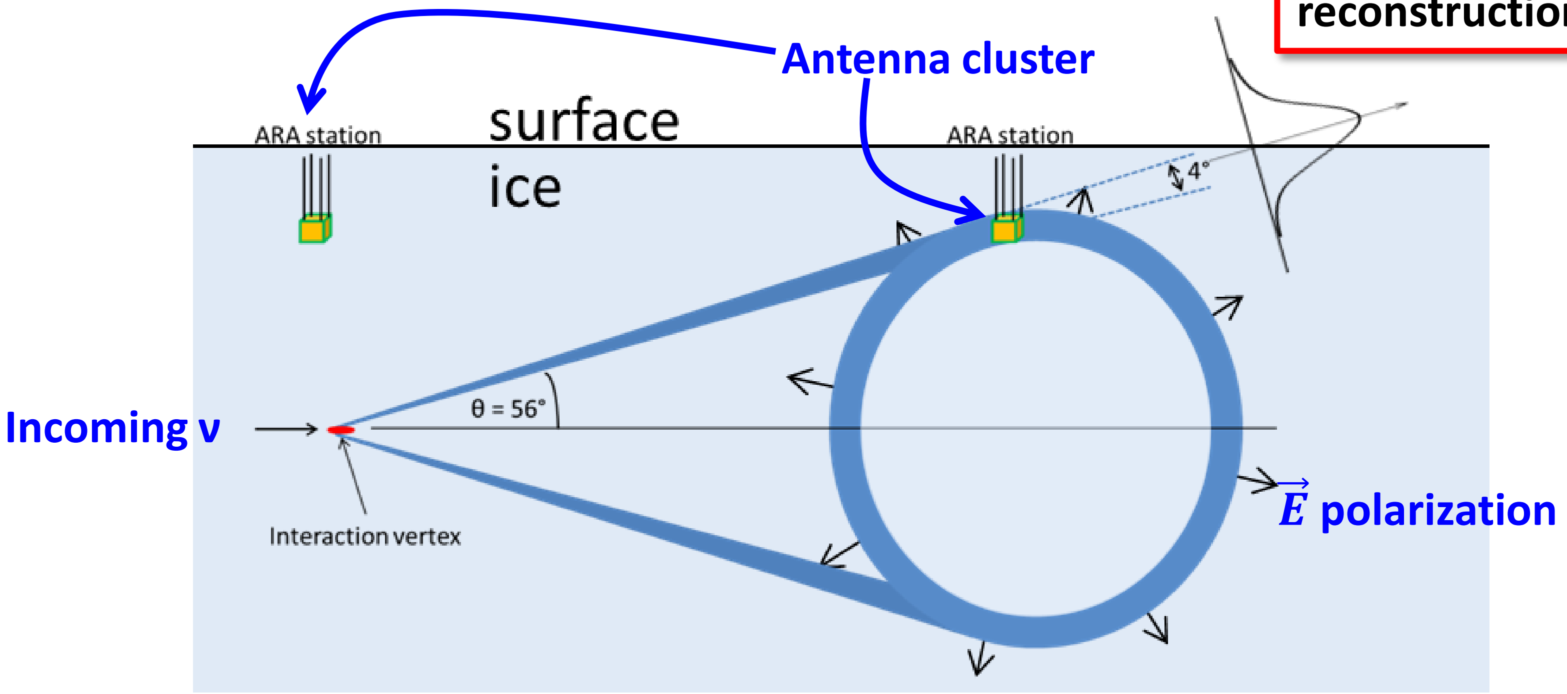
The principal idea of ARA

1) Detection of Radio waves, emitted by neutrino induced cascades in ice

2) Achievement of O(100km³) detection volume using widely spaced antenna clusters, which detect "discrete" Cherenkov cones

3) Use timing + polarization information for neutrino reconstruction

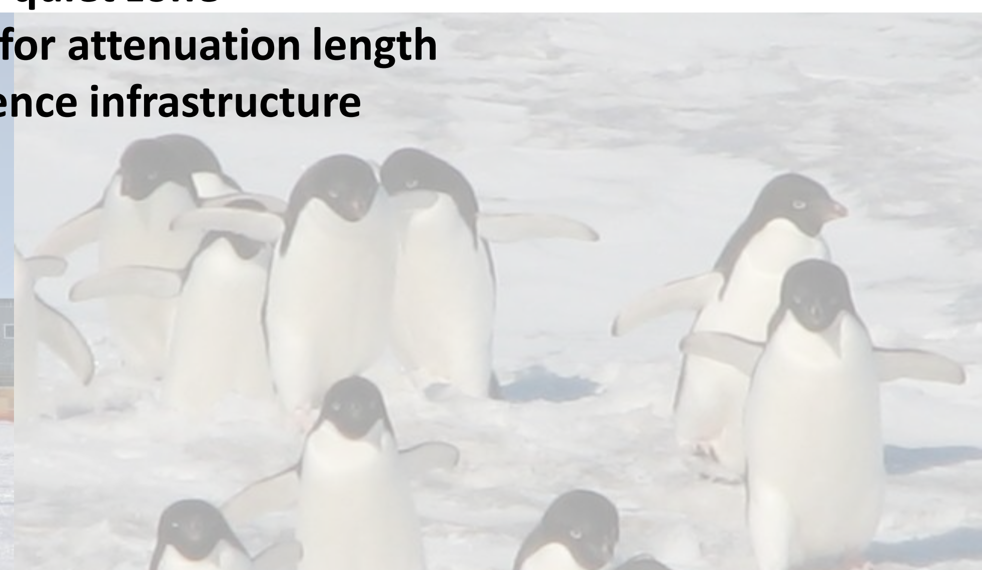



Why exactly at the South Pole?

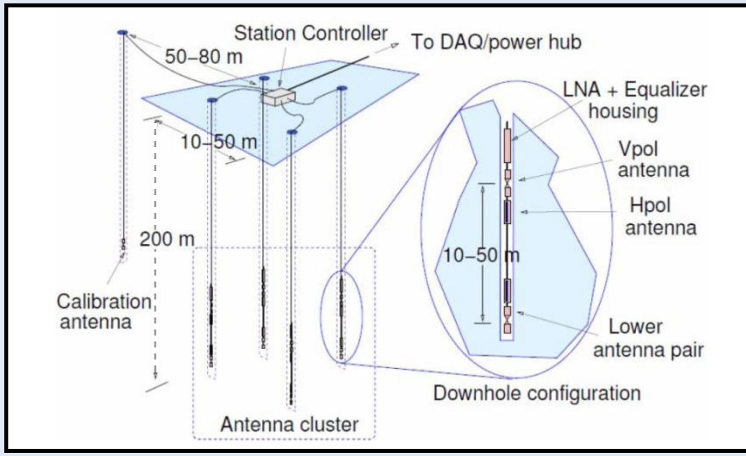


Why exactly at the South Pole?

- **Biggest volume of radio-transparent matter on earth (3 km thick, area virtually unlimited)**
- **Radio-quiet zone**
- **Cold ice → good for attenuation length**
- **Available science infrastructure**

Detector setup



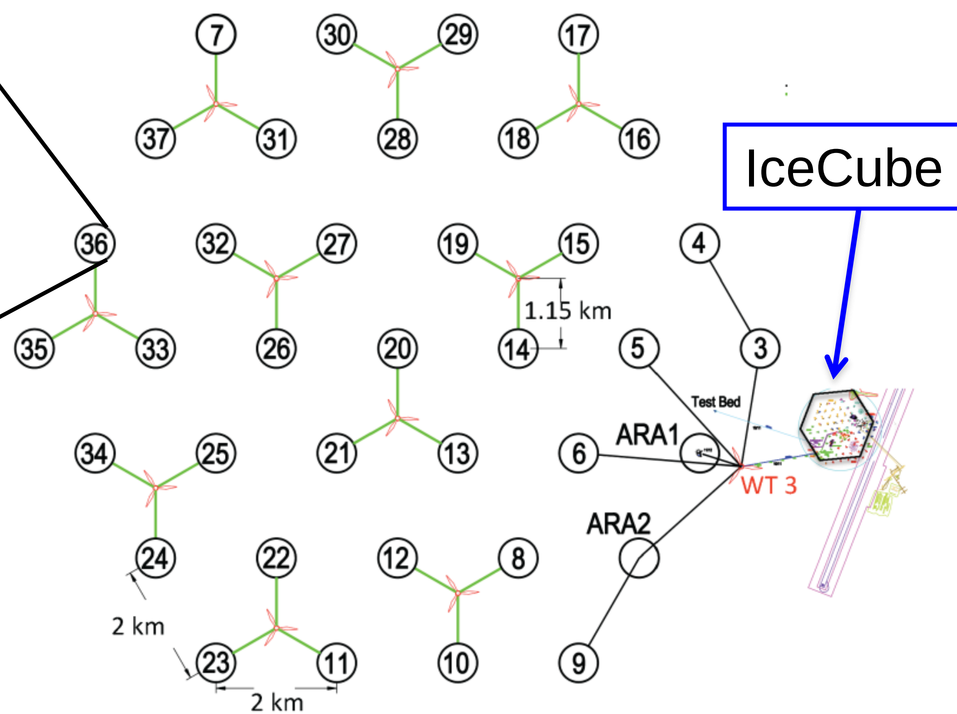
One station:

- **Measurement system:**
  - 4 holes, 20 m spacing
  - 16 antennas, 150 MHz – 800 MHz (8 horizontally polarized., 8 vertically pol.)

- **Calibration system:**
  - 2 holes, ~40 m distant
  - 4 pulsing antennas (2 h-pol., 2 v-pol.)

Each station is an autonomous detector!

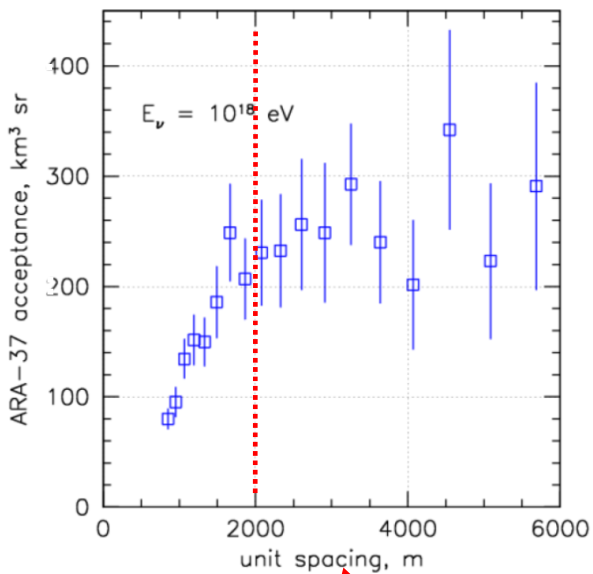
ARA at South Pole



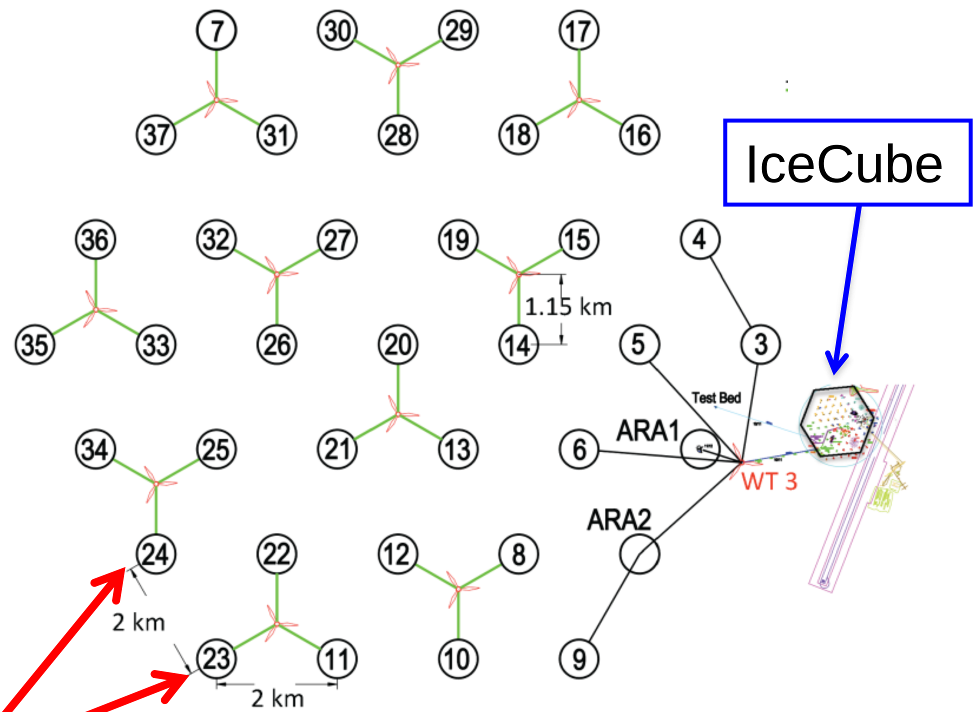
- 37 stations
- 200m below surface
- ~200km^2 coverage

Detector setup

Station spacing



ARA at South Pole



2 km station spacing:

- Attenuation length for radio waves in ice ~800m
- Simulated acceptance saturates at around 2km

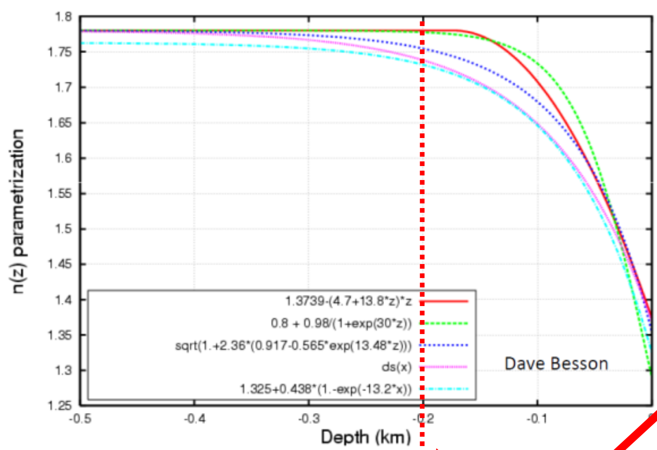
Detector setup

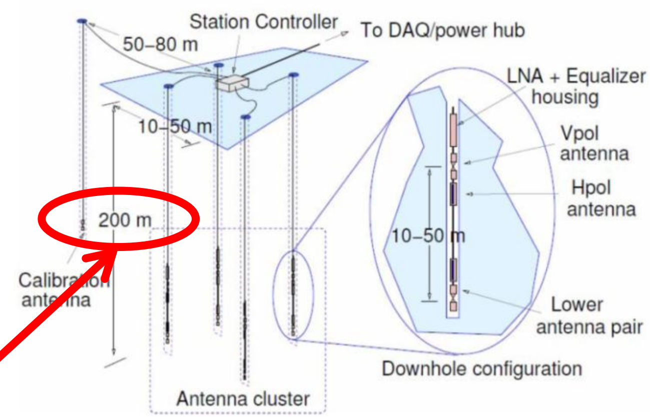
Deployment depth - Ray bending in SP ice

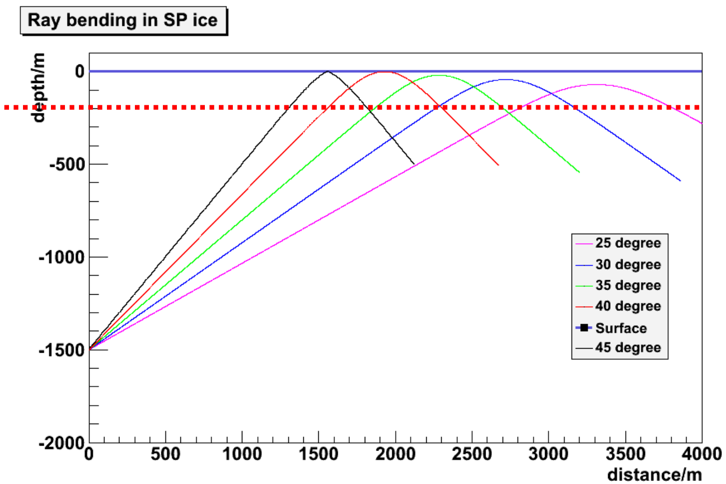
Refraction index n depends on depth

- Main factors: Ice temperature, Density

→ **Ray bending:** Radio rays are bent downwards during propagation



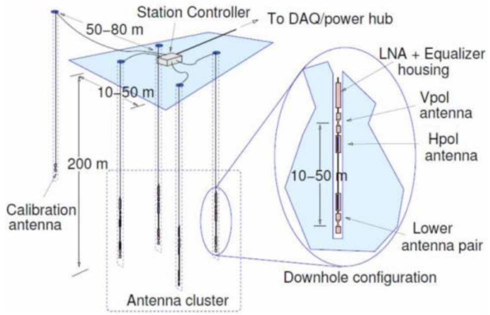




200m deployment depth:

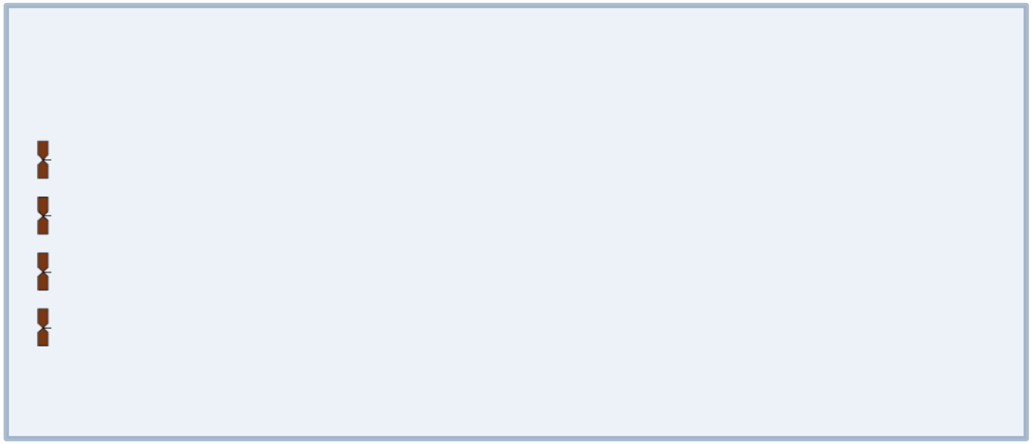
- Going below main “bending zone”
- accounting for drilling cost/time

The ARA station

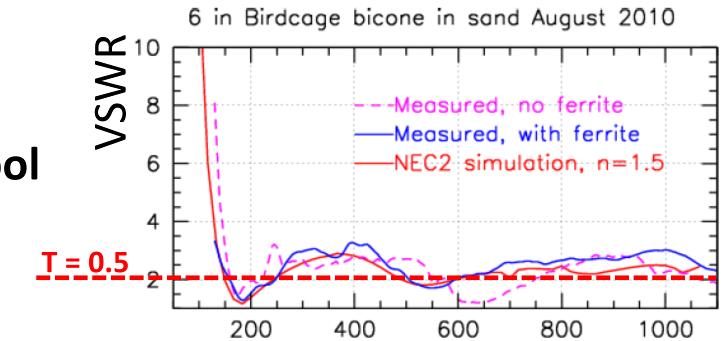


The ARA station

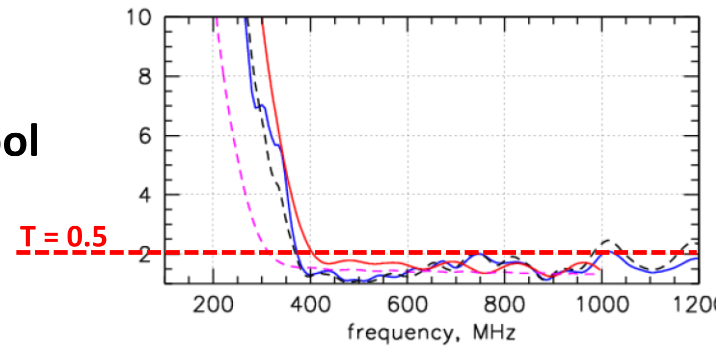
The antennas



V-pol

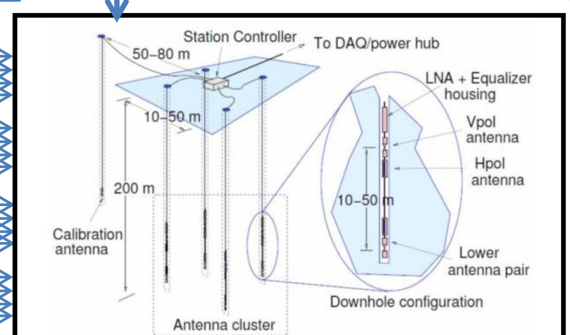


H-pol



Surface antennas

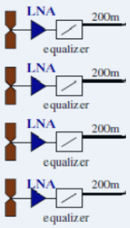
V-pol **H-pol**



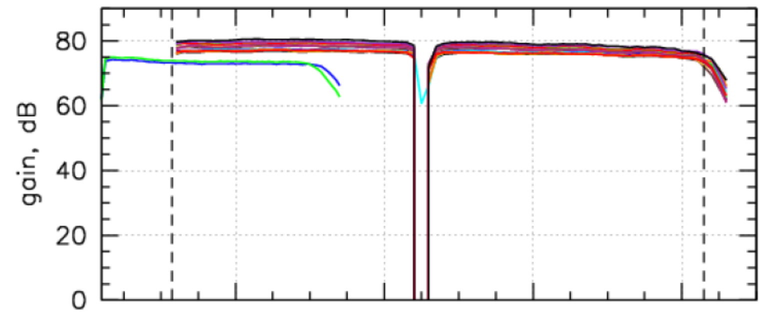
T= Transmission coefficient

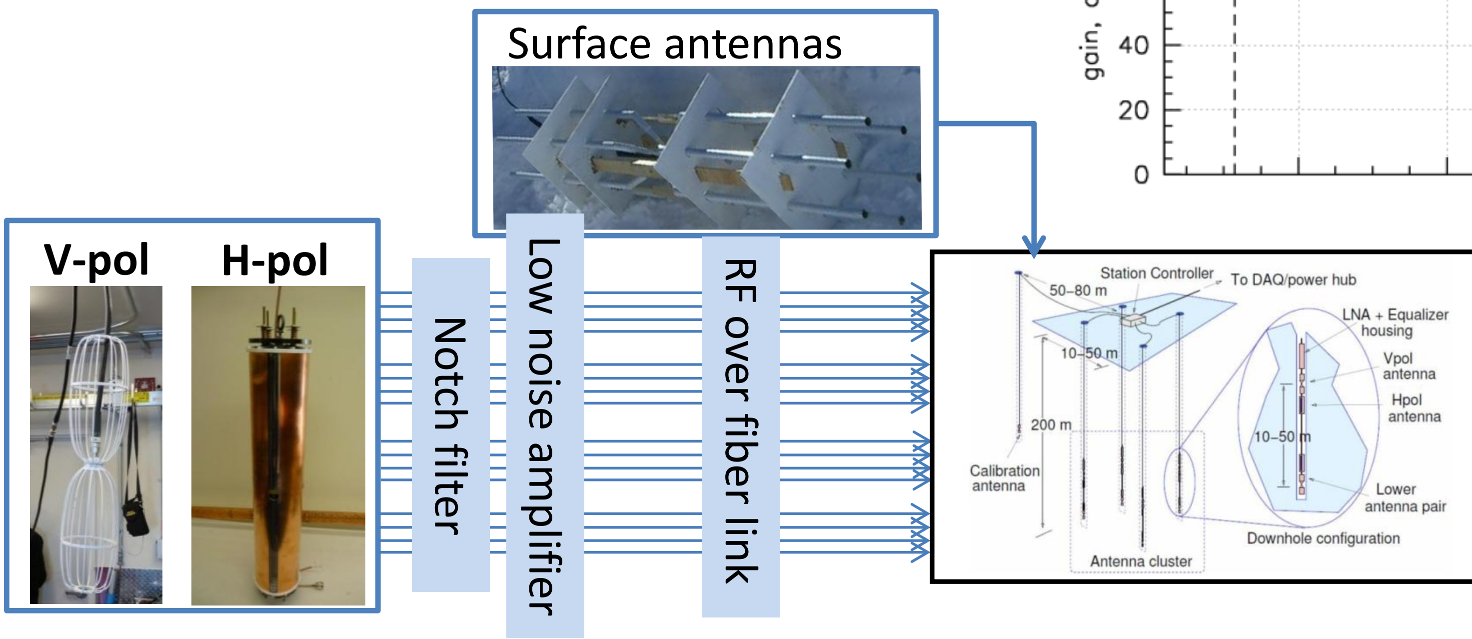
The ARA station

Filters - Amplifiers



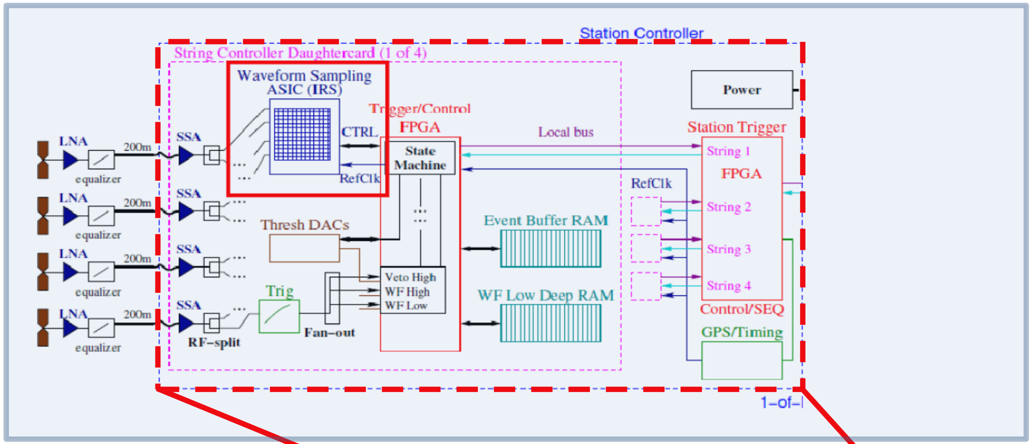
- Band + notch filter, to limit the LNA input to **"our"** signal
- **L**ow **N**oise **A**mplifier to enhance the signal for the data acquisition system

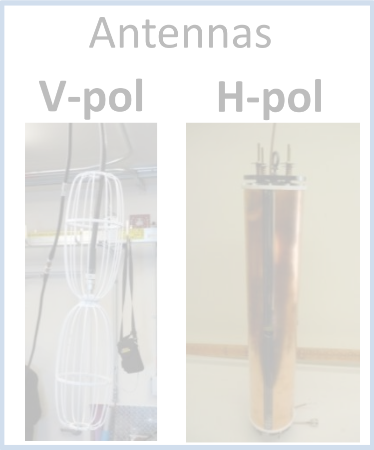


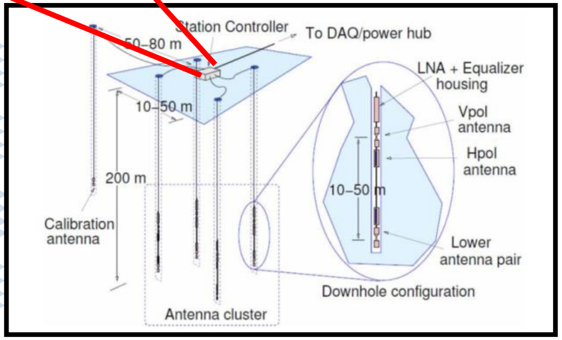


The ARA station

The DAQ system

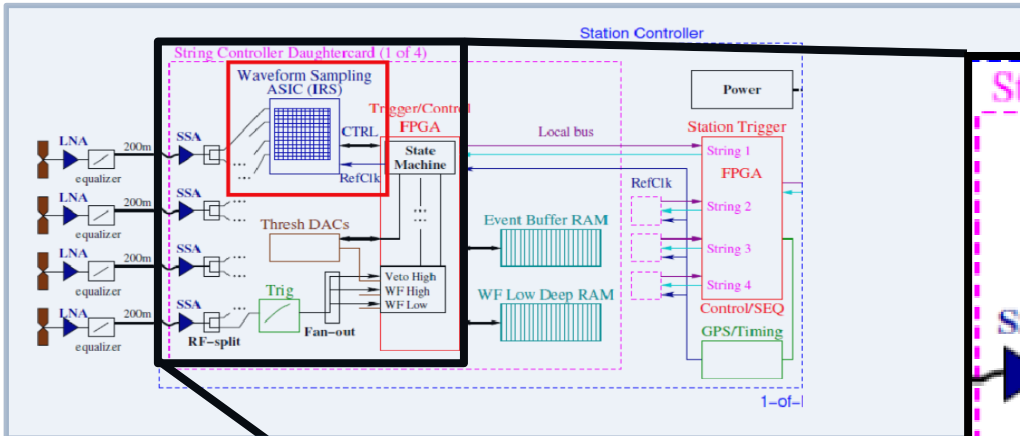


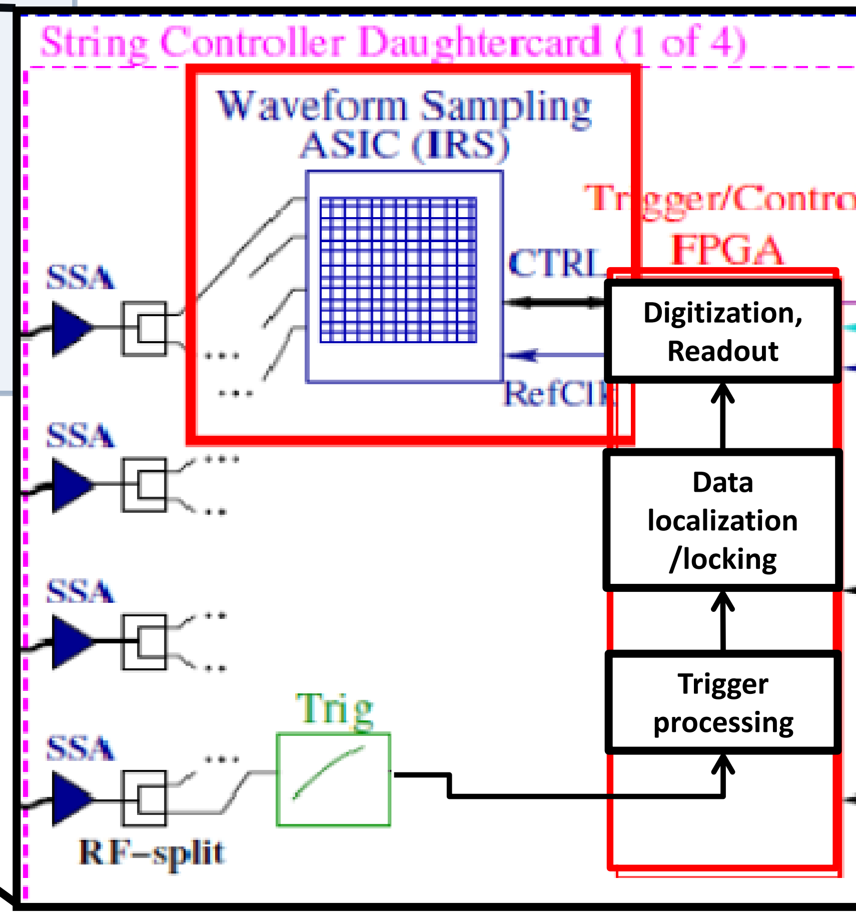




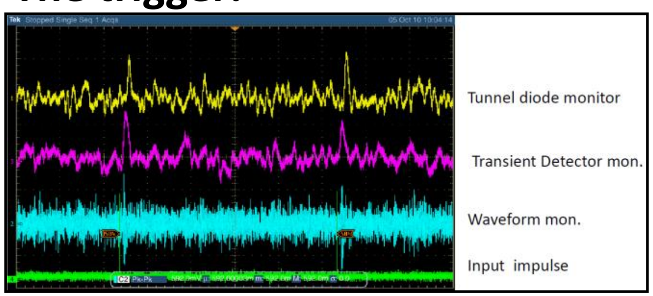
The ARA station

The DAQ system





The trigger:



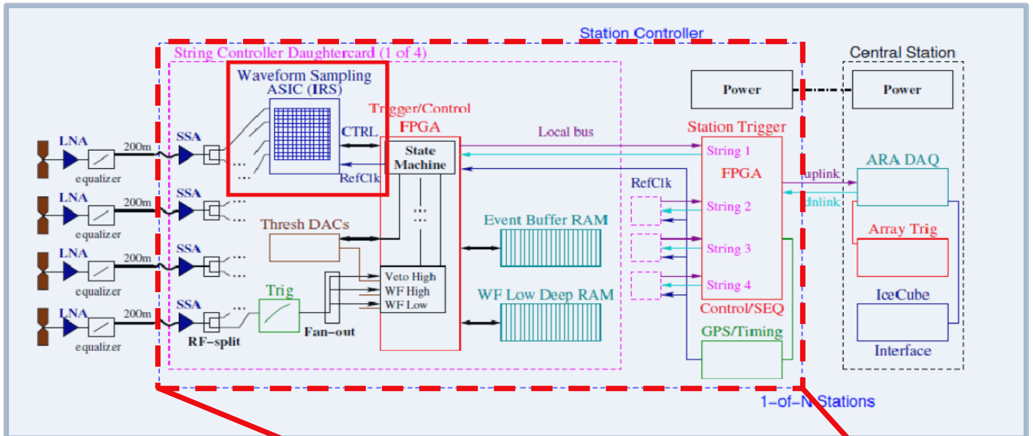
The DAQ-Chip:

- 3.2GS/s, 8 channels
- Data gathered in blocks
- Random access to blocks

→ 1kHz event digitization + readout **without dead time at lowest power consumption**

The ARA station

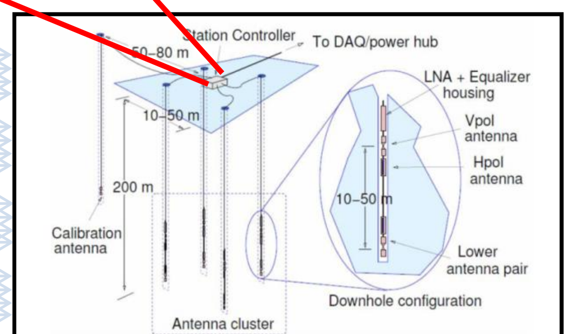
Power - Communication



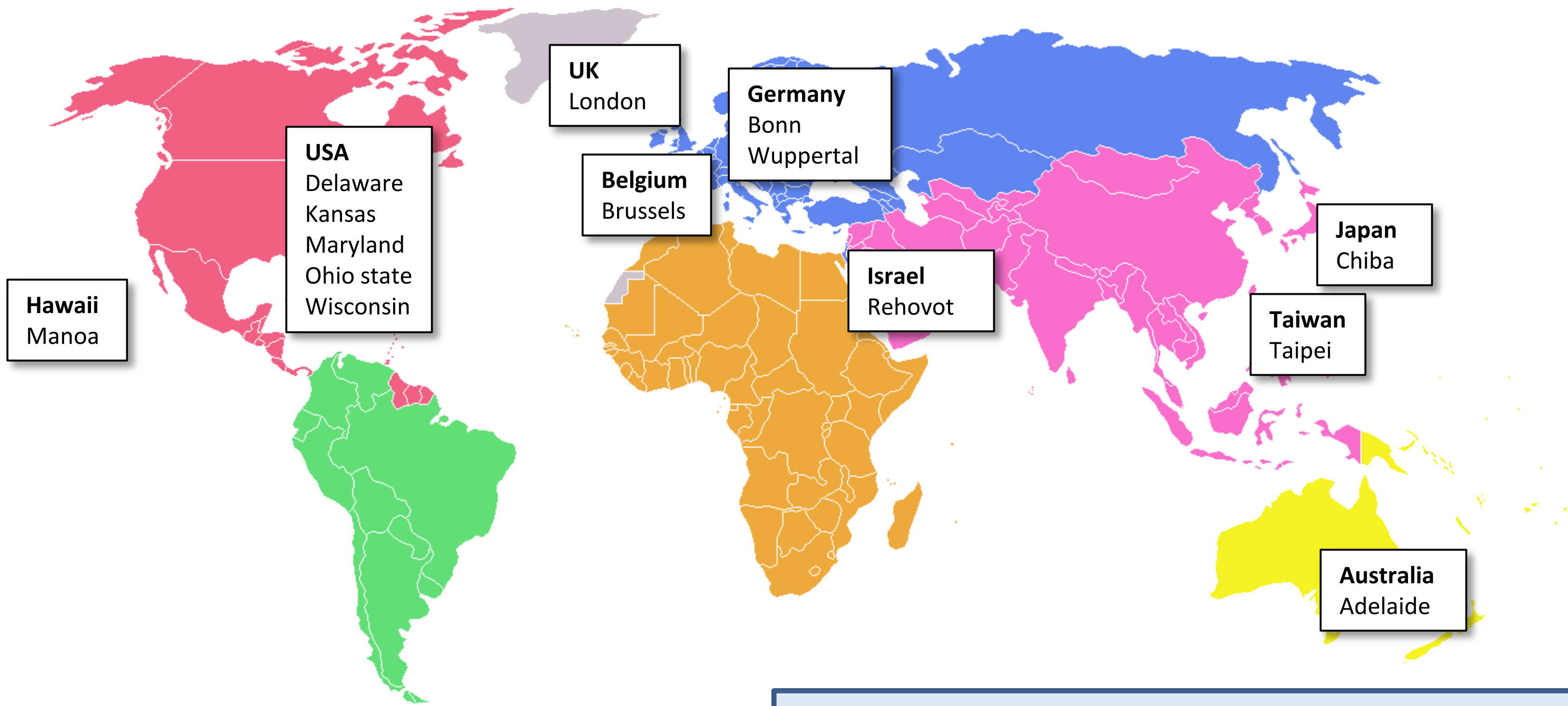
- Stations will be cabled to centralized power source
- Data transmission to IceCube Lab over optical fiber links

Antennas

V-pol H-pol



The ARA collaboration



The ARA collaboration:

AUSTRALIA, BELGIUM, GERMANY, ISRAEL, JAPAN, TAIWAN, UK, USA

Proposal: arXiv:1105.2854v2

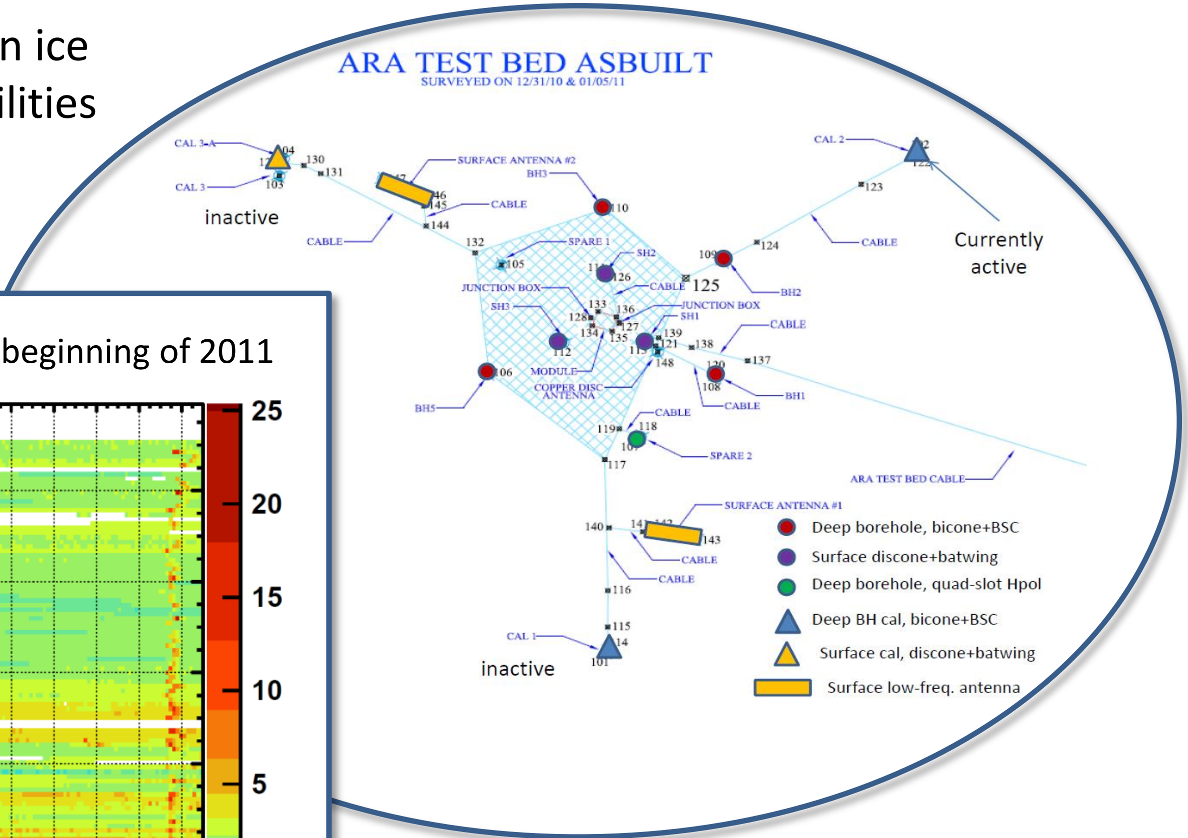
Time line:

2010/2011: **ARA prototype: "testbed", to measure: attenuation length, noise, timing precision**
2011/2012: **deployment: ARA station 1**
2012/2013: station 2 - 4
2013/2014: station 5 - 13
2014/2015: station 14 - 25
2015/2016: station 26 – 37, detector finished

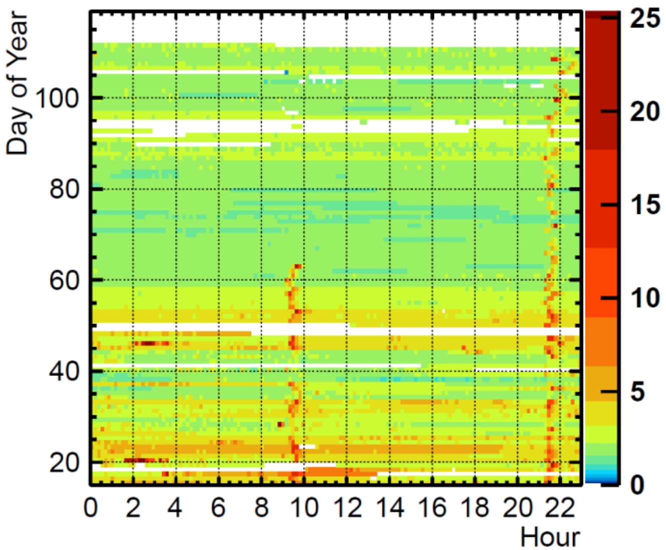
First measurements/The testbed

Different goals:

- Study background noise
- Measure radio attenuation in ice
- Study reconstruction possibilities



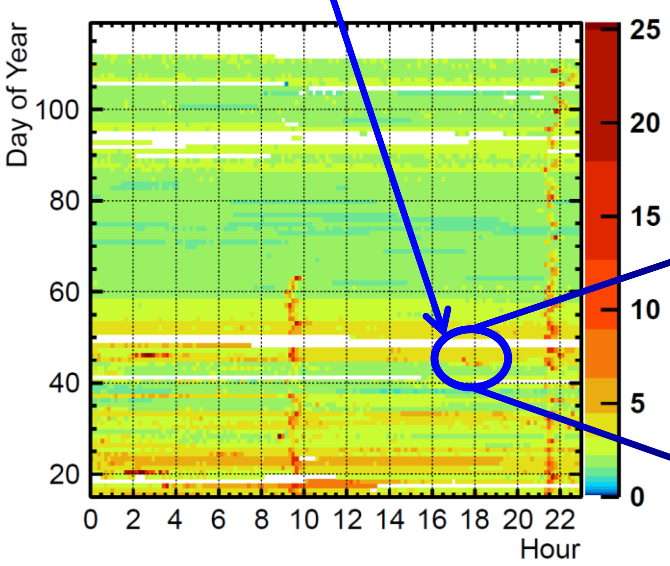
Trigger rates during the beginning of 2011



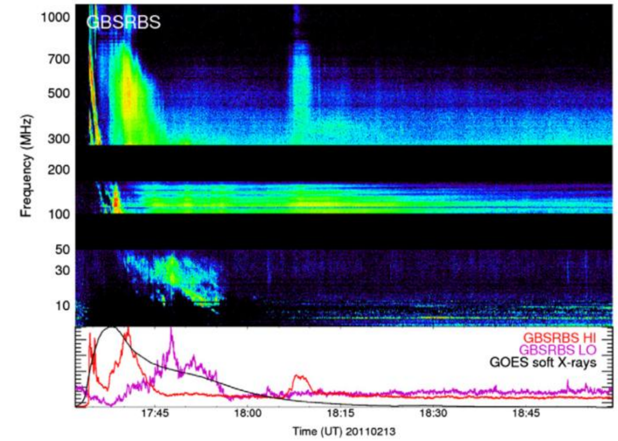
First measurements/The testbed

Solar Flare on Feb. 11 triggers the ARA testbed
Scientific interpretation is in progress

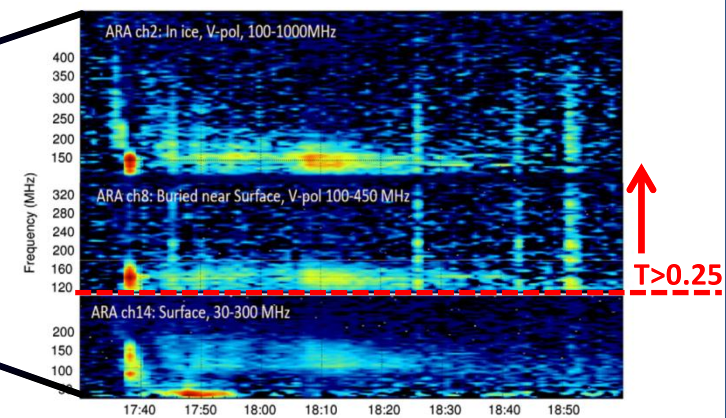
Trigger rates during the beginning of 2011



Solar flare, as observed by the
Green Bank Solar Radio Burst Spectrometer

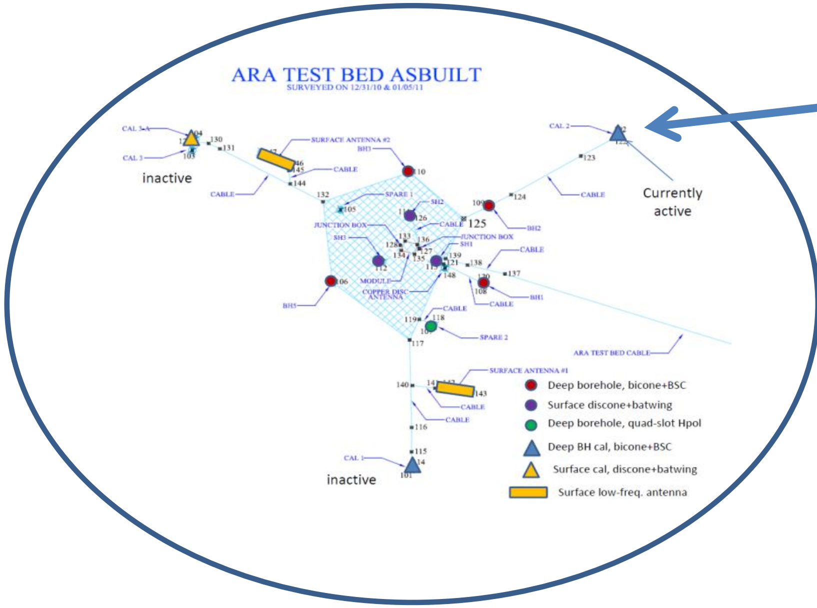


As observed by **ARA**

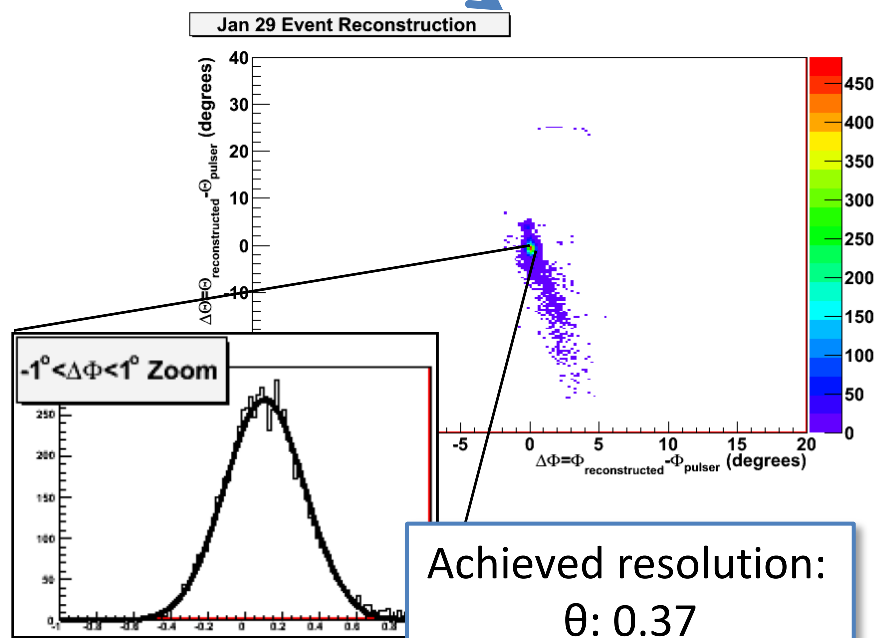


First measurements/The testbed

Reconstruction

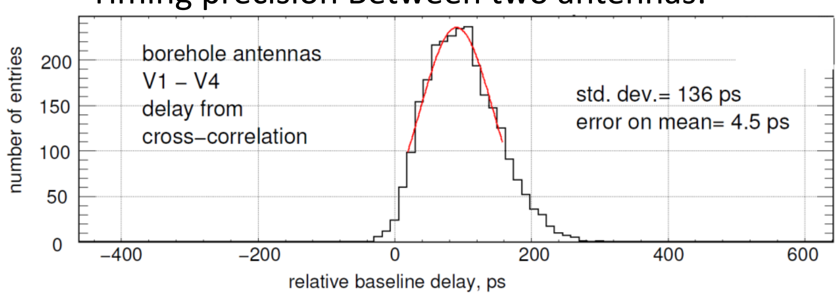


Example: Cal. Pulser reconstruction



Achieved resolution:
θ: 0.37
ϕ: 0.17

Timing precision Between two antennas:



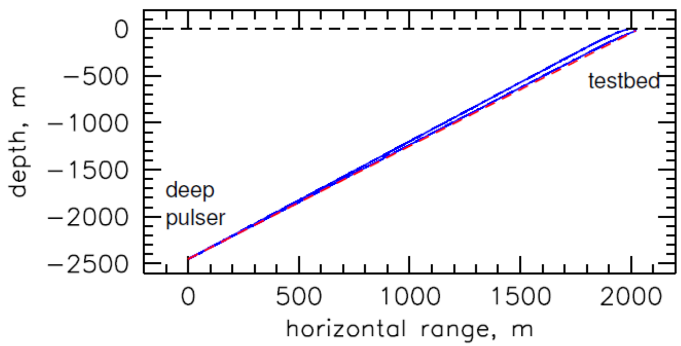
136 ps, baseline of ~20m → ang. reco. precision: ~0.1°

First measurements/The testbed

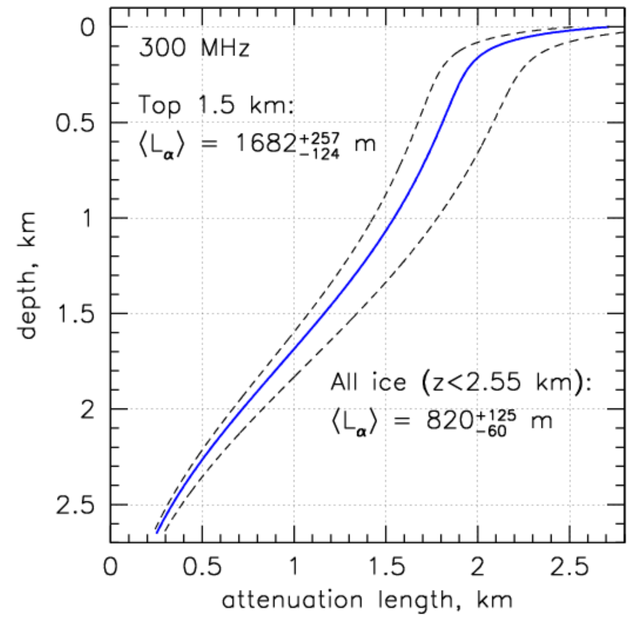
Attenuation length

Pulsers installed with last IceCube strings:

- Depth: 1500m, 2500m
- **Taken risk:** Upper pulsers saturate the testbed →useful for stations at higher distances
- Lower pulsers could already be used for measurement

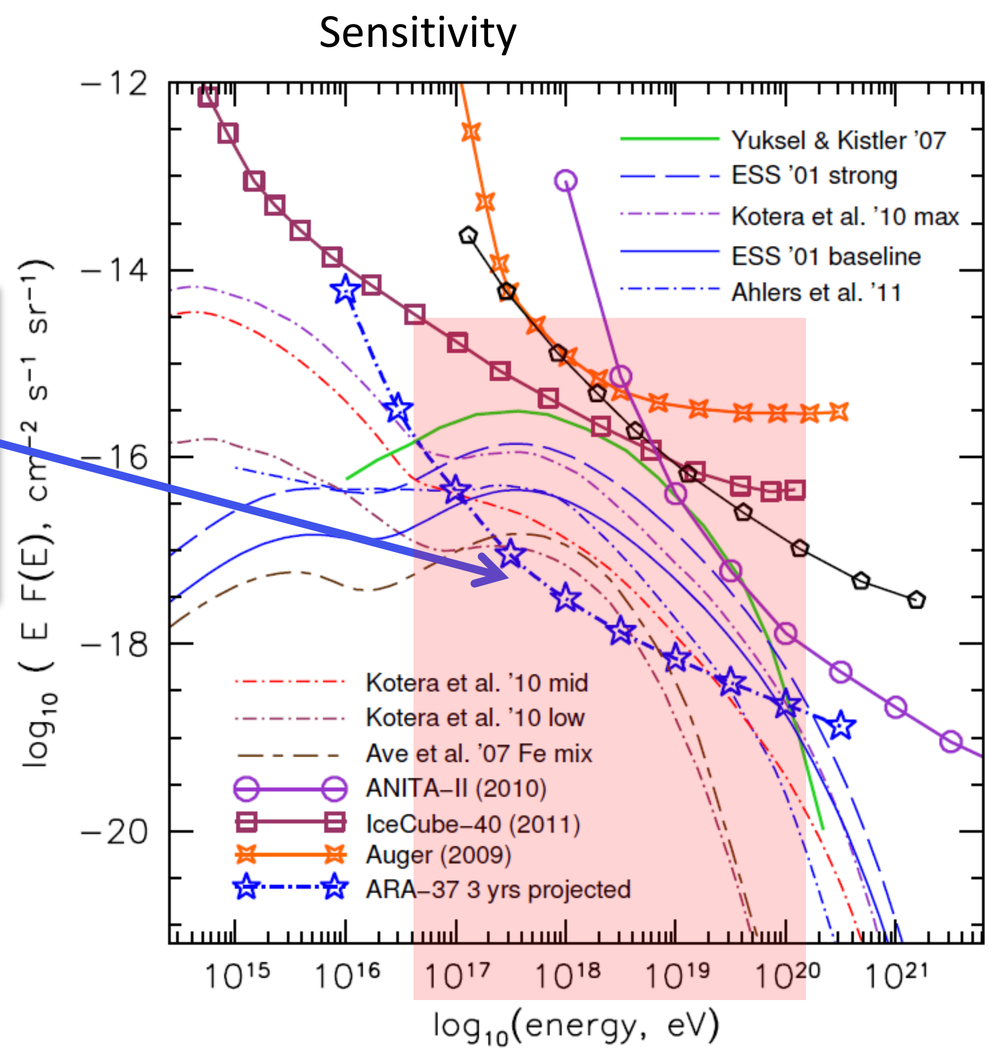


Extrapolation according to the **temperature + density profile** of the ice



Expected sensitivity

1) GZK detection threshold: ~5*10^{16}eV,
2) Sensitivity improving by >factor 10 compared to existing experiments,
3) Even in worst case expected to see neutrinos.



Future plans – work in progress

Present achievements in the ARA collaboration:

- First results from ARA prototype
- **First station deployment in winter 2011/2012**

Future plans:

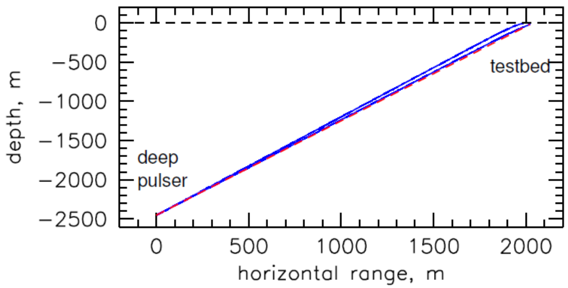
- Data are currently being analyzed to produce first neutrino limit
- Deployment of two more stations in winter 2012/2013
- **Start neutrino search!**

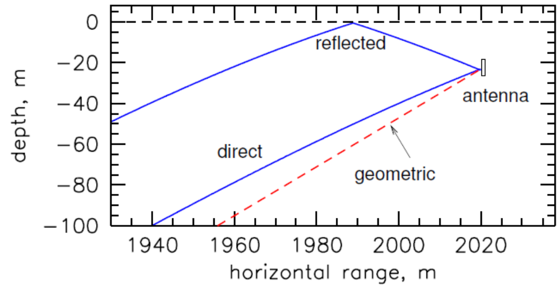
BACKUP

Measuring the refraction index?

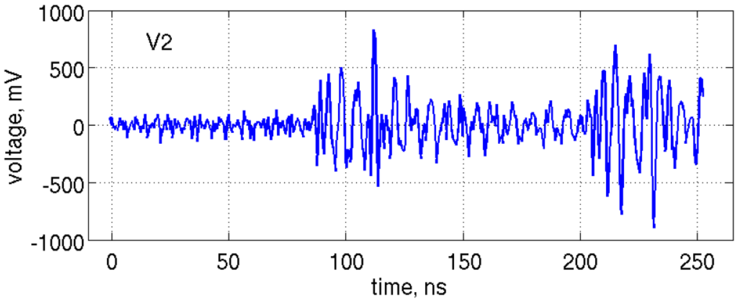
Using deep pulsers in IceCube:

- Depth: 2500m
- Calculating arrival times: direct, reflected wave
- Taking ray bending into account

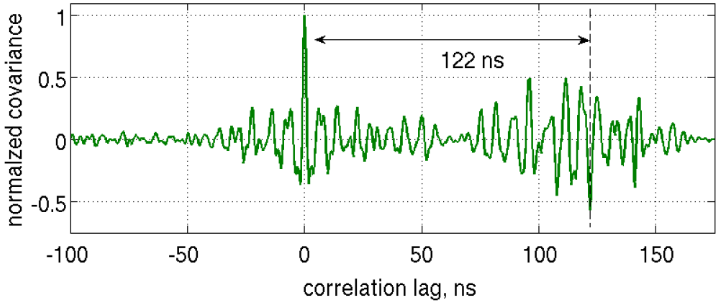




Measurement results fit within 1% error → good model of the refraction index



Expected delay: 122 ns

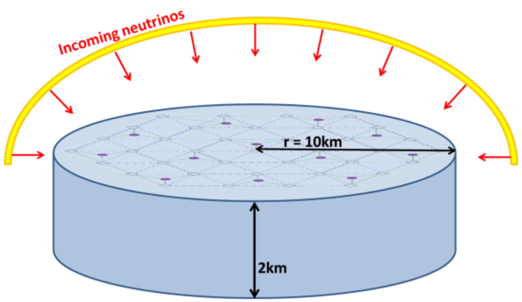


Detector simulation

Calculation of Volumetric acceptance in km³sr

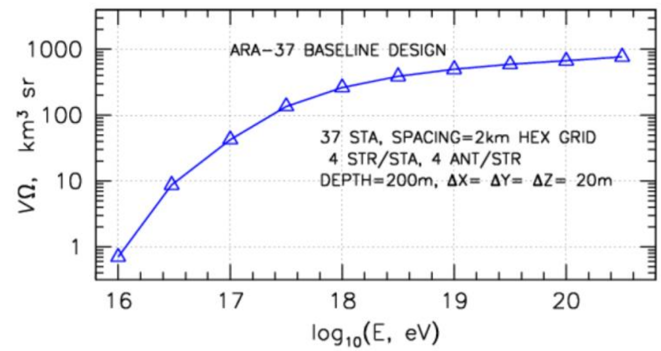
- Assuming cylinder: r=10km, h=2km
- Neutrinos from below are shielded by the earth

  → 4000 km³sr



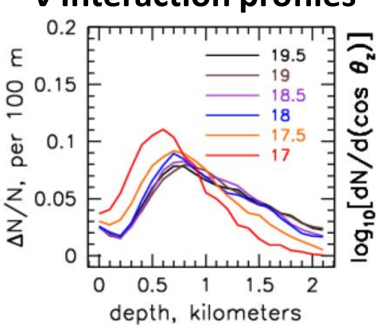
Taking into account:

- Antenna sensitivity
- Attenuation length
- Cross section
- …

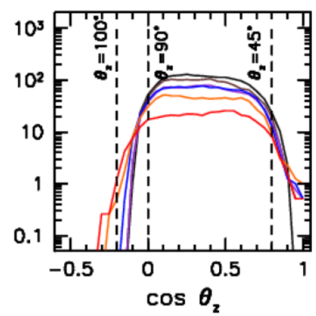


Other interesting values:

ν Interaction profiles



Zenith distr. of detected ν

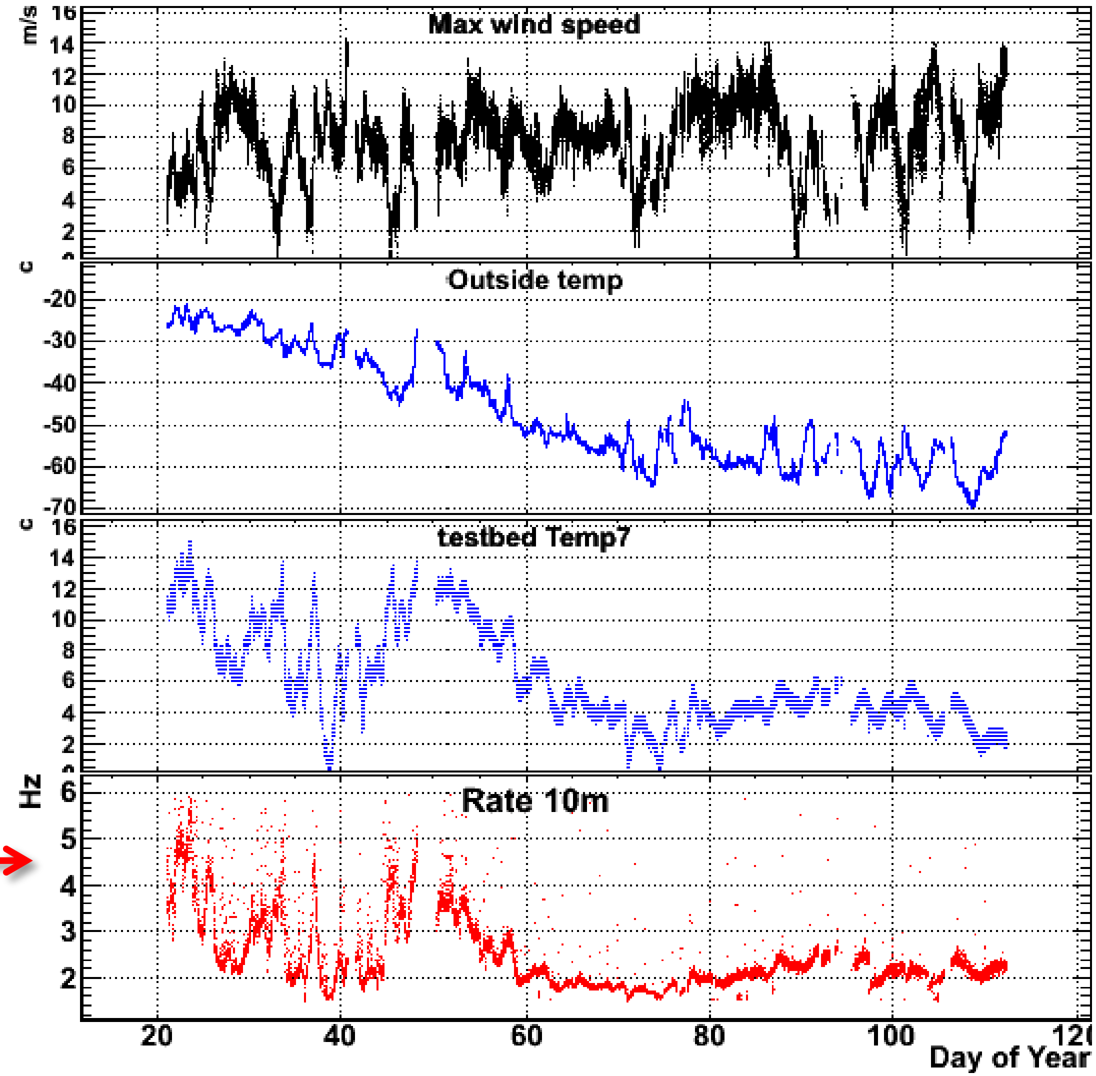


Non signal influences

Wind:
Causes snow blowing across the surface
→ Spontaneous el. discharges at the surface

Outside temperature:
Testbed is relatively shallow
→ Strong temperature changes together with air temperature

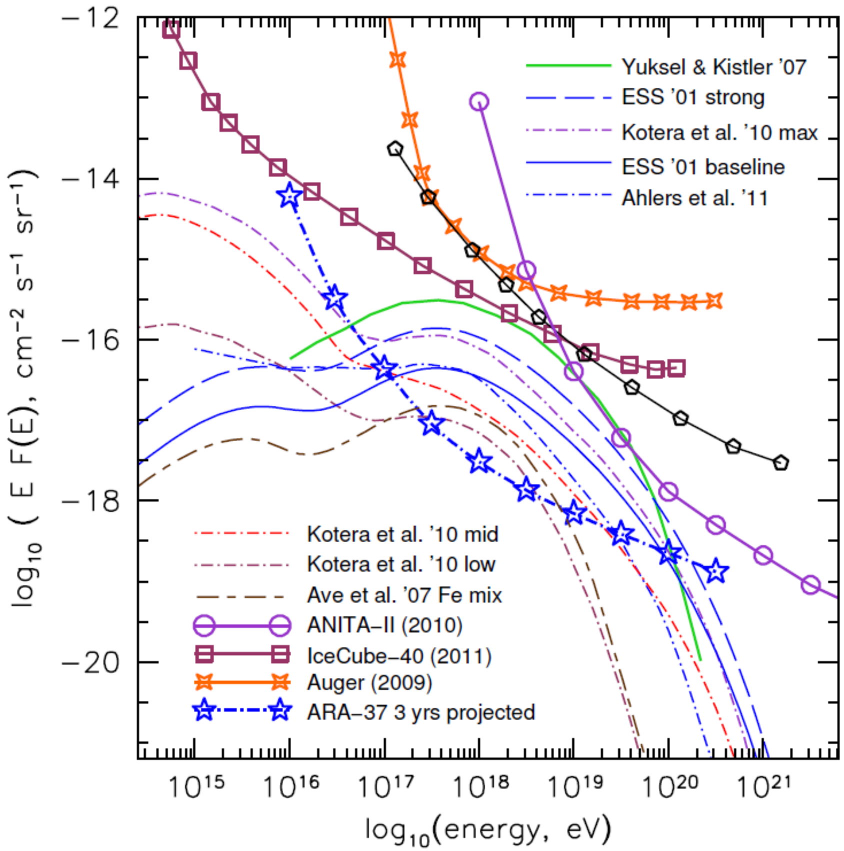
Testbed trigger rate:
- Not correlated to wind speed
- Strong dependence on temperature



The performance

In real numbers

Model & references N_ν:	ANITA-II, (2008 flight)	ARA, 3 years
Baseline cosmogenic models:		
Protheroe & Johnson 1996 [27]	0.6	59
Engel, Seckel, Stanev 2001 [28]	0.33	47
Kotera,Allard, & Olinto 2010 [29]	0.5	59
Strong source evolution models:		
Engel, Seckel, Stanev 2001 [28]	1.0	148
Kalashev *et al.* 2002 [30]	5.8	146
Barger, Huber, & Marfatia 2006 [32]	3.5	154
Yuksel & Kistler 2007 [33]	1.7	221
Mixed-Iron-Composition:		
Ave *et al.* 2005 [34]	0.01	6.6
Stanev 2008 [35]	0.0002	1.5
Kotera, Allard, & Olinto 2010 [29] upper	0.08	11.3
Kotera, Allard, & Olinto 2010 [29] lower	0.005	4.1
Models constrained by Fermi cascade bound:		
Ahlers *et al.* 2010 [36]	0.09	20.7
Waxman-Bahcall (WB) fluxes:		
WB 1999, evolved sources [37]	1.5	76
WB 1999, standard [37]	0.5	27



Event reconstruction

- **After Fraunhofer interference:**
  - Signal is Gaussian distributed over angle $\Delta\theta$ around opening angle of the cone

$$E(\omega,R,\theta) = E(\omega,R,\theta_C)e^{-\ln 2\left[\frac{\theta-\theta_C}{\Delta\theta}\right]^2}$$

$$\Delta\theta \simeq \begin{cases} 2.7^o \, \frac{\nu_0}{\nu} \, \mathrm{E}_0^{-0.03} & \text{for } \mathrm{E}_0 < 1 \ PeV \\ 2.7^o \, \frac{\nu_0}{\nu} \, \left[\frac{E_{LPM}}{0.14 \ \mathrm{E}_0 + E_{LPM}}\right]^{0.3} & \text{otherwise} \end{cases}$$

$$E(\omega,R,\theta_C) \propto \frac{E_0}{R}$$

Values to be reconstructed:

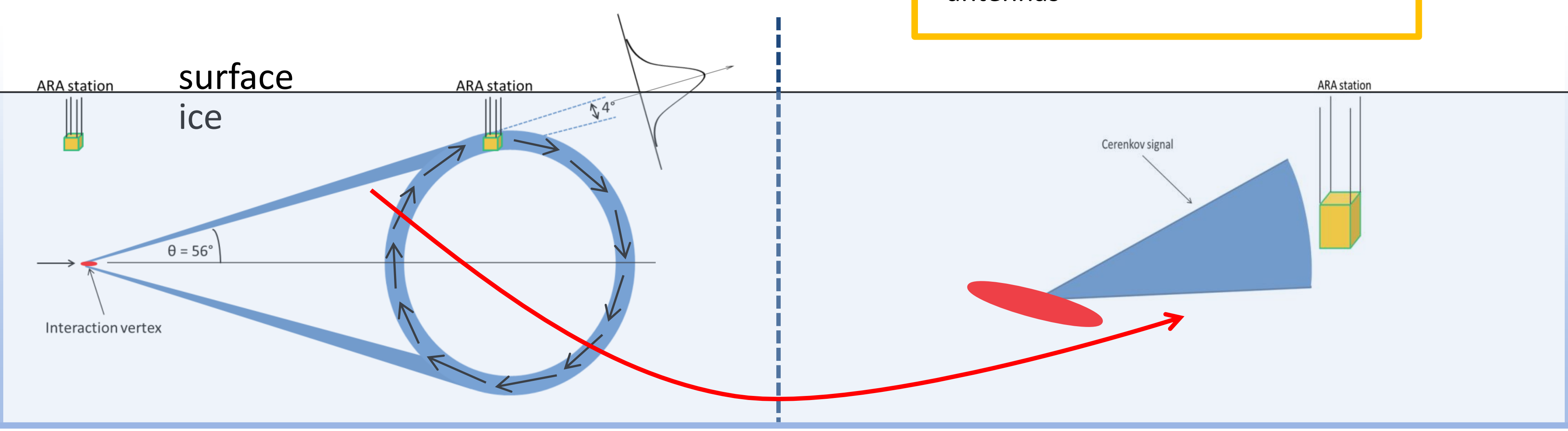
1) Direction
2) Distance to vertex
3) Polarization

1), 2): Reconstruction via grid search:

$$\chi^2 = \sum_i \frac{[\Delta t_i^{obs} - \Delta t_i^{hyp}(x_{sh}^{hyp})]^2}{\sigma_t^2}$$

Δt = time difference between antenna triggers

3): with differently polarized antennas



Reconstruction precision