The extension plan of IceCube
- The ARA project

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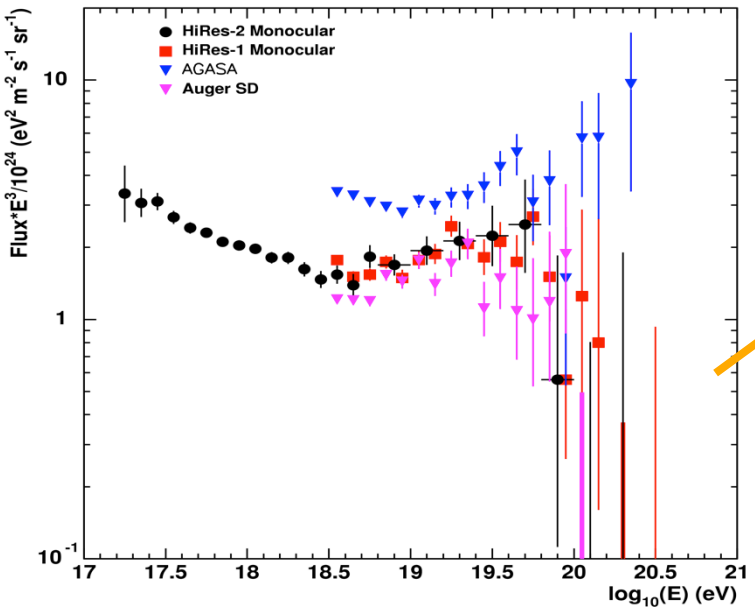
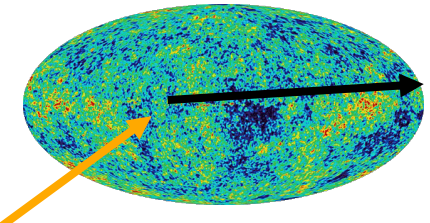
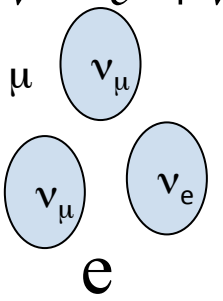
The Extremely High Energy Neutrinos (>10^7 GeV)



$$p\gamma_{2.7K} \rightarrow \pi^{\pm} + X \rightarrow \mu^{\pm} + \nu \rightarrow e^{\pm} + \nu' s$$



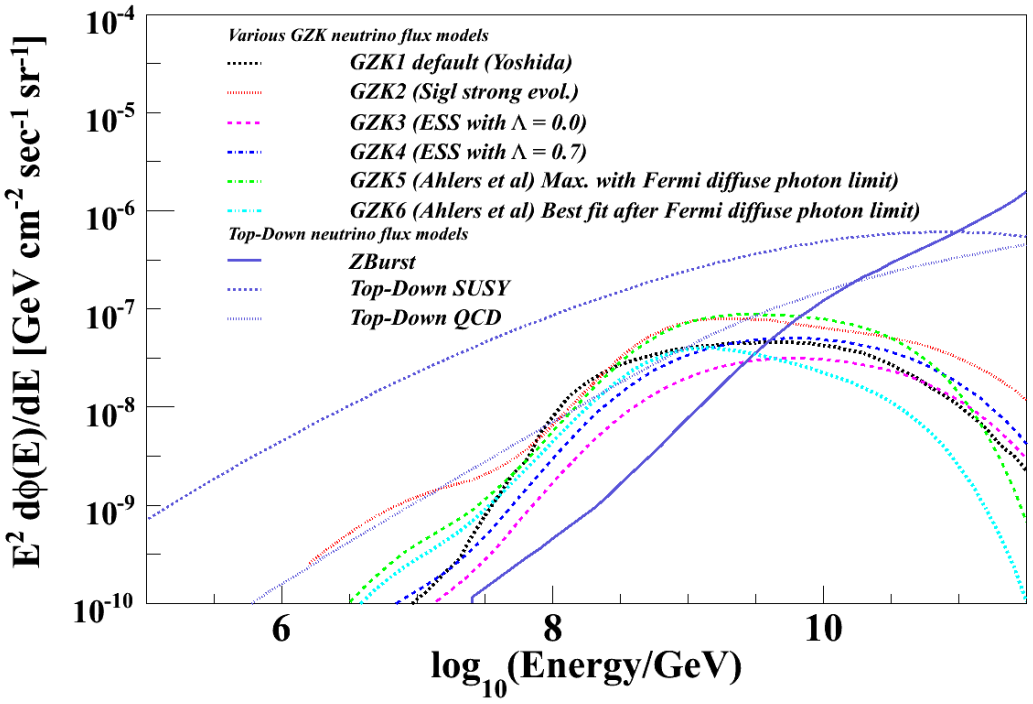


Shed light on the EHECR origin

- ✧ Source position
- ✧ Composition (proton/iron)?
- ✧ Source evolution

IceCube: ~1 event/year expected

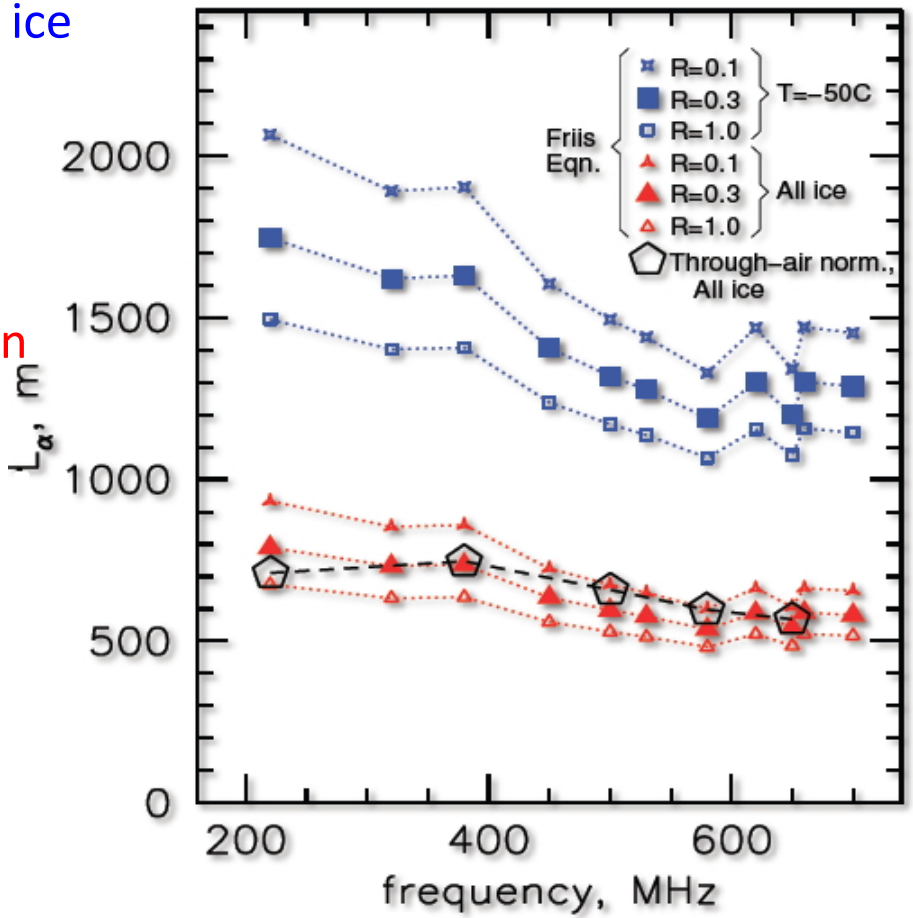
-> MORE waned!



Radio wave

- Attenuation length of the south pole ice
  - Optical: ~100m
  - Radio: ~1km
- Easier to make a bigger detector in an economical way
- More information needed for the precise modeling

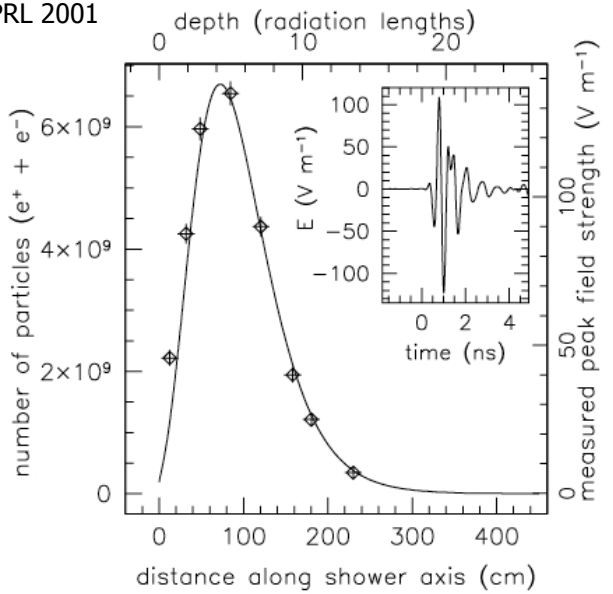
Barwick, Besson, Gorham Saltzberg,
J. Glaciology, Vol 51, 2005, p 231

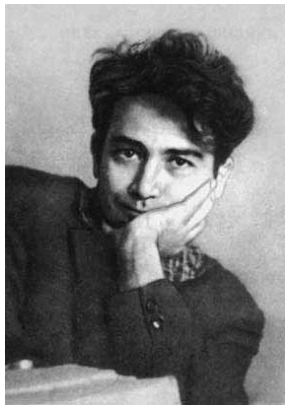


Askaryan effect

- 1962: Askaryan predicted coherent radio emission from excess negative charge in an EM shower (~20% due to mainly Compton scattering and positron annihilation)
  → Askaryan effect
  (power $\propto \Delta q^2$, thus prominent at EHE)
- 2001: firstly confirmed at SLAC with Silica sand (D. Saltzberg et al.)
- 2005: confirmed with salt (P. Gorham et al.)
- 2007: confirmed with ice (P. Gorham et al.)
- The effect started to be well understood.

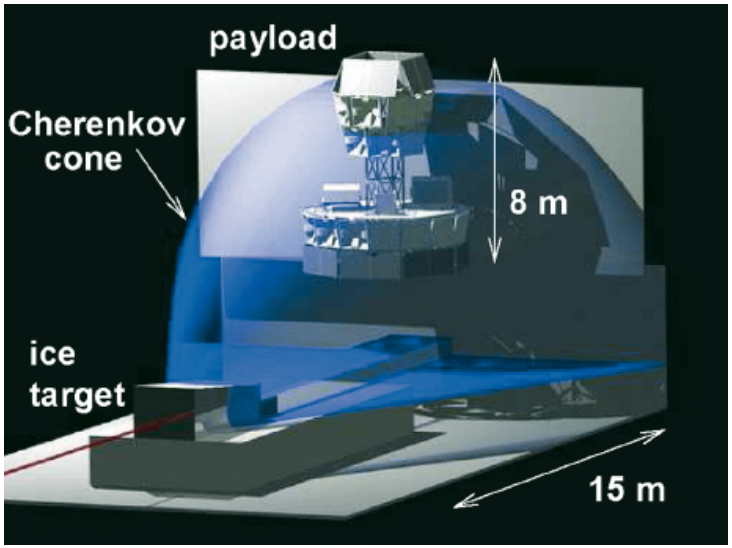
Saltzberg et al. PRL 2001

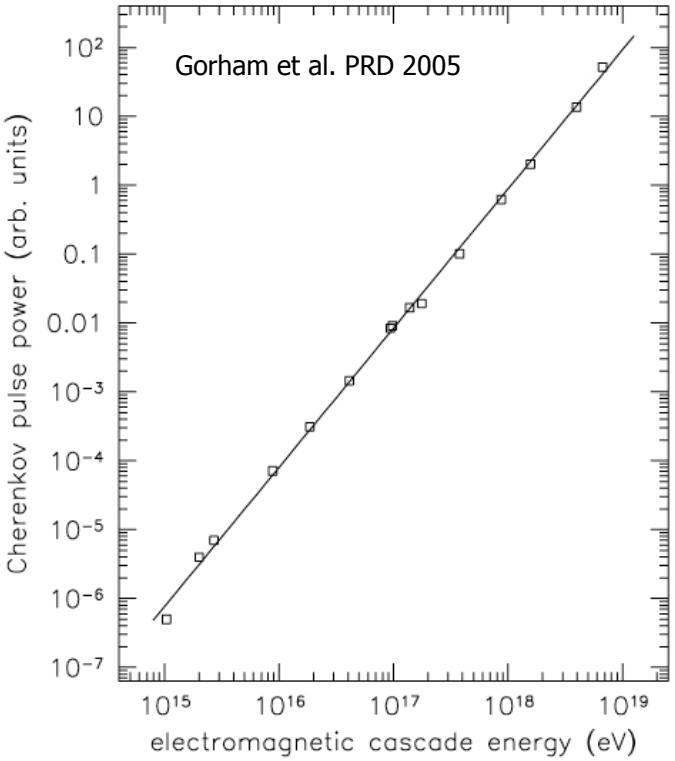




G. Askaryan

Gorham et al. PRL 2007



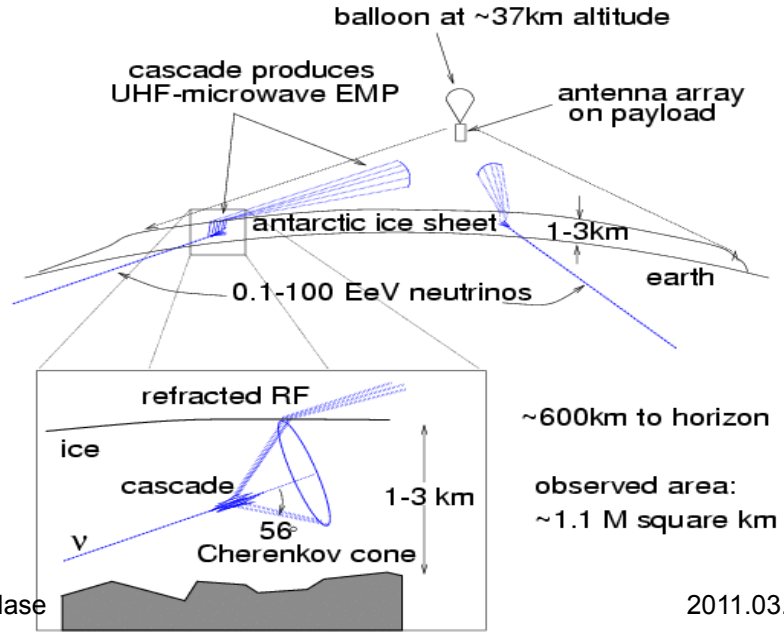


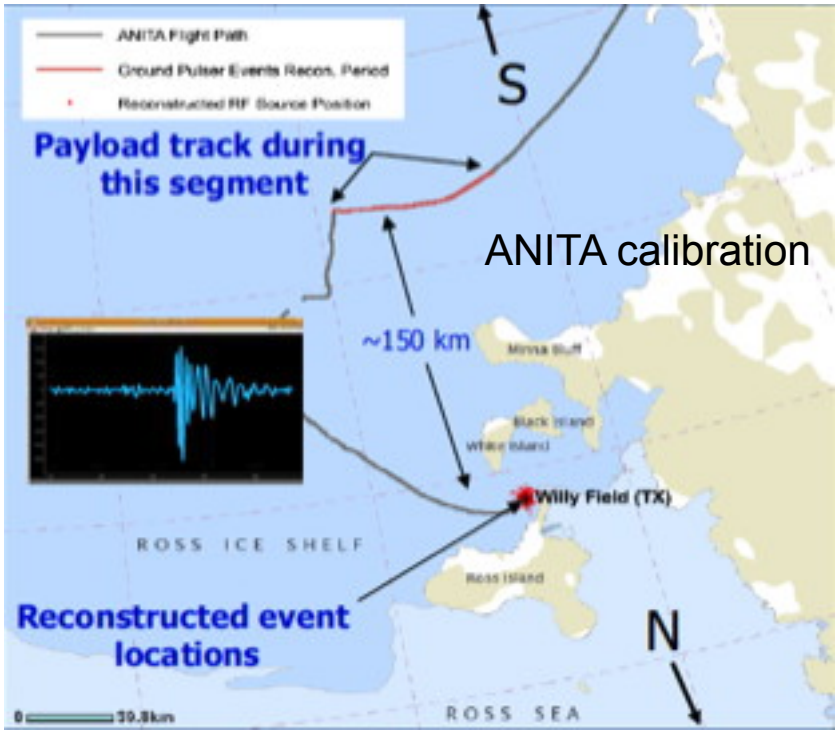
ANITA (Antarctic Impulsive Transient Antenna)

- detects radio wave from showers using Askaryan effect
- view: 1.5 M km^2 ! (Tokyo-Hakata: 880km)
- sensitive: 0.2-1.2 GHz
- 2003-4: ANITA-lite (2 hones)
- 2006-7: full ANITA

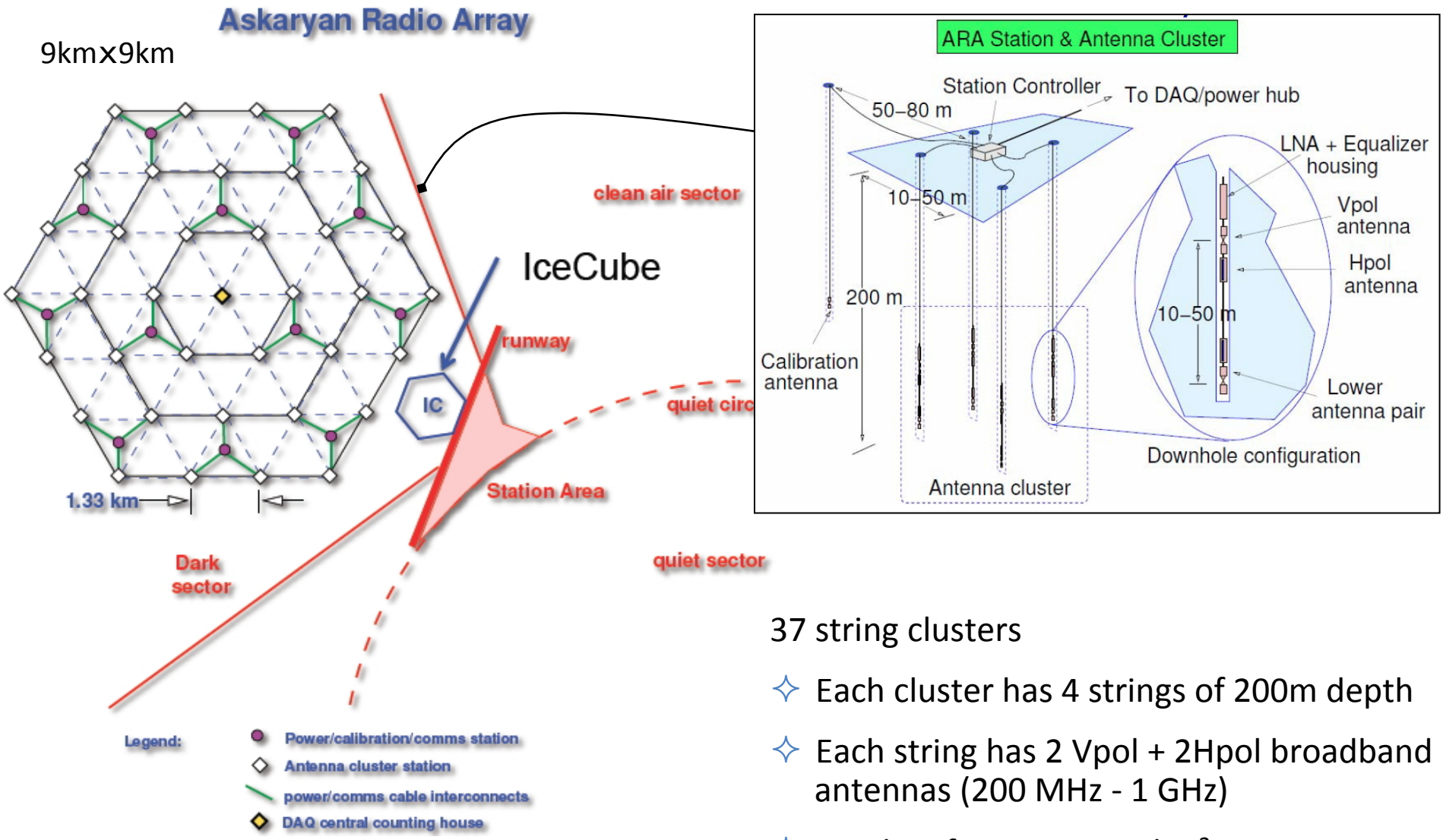
  35 days, 3.5 orbits, good data: ~10 days
- 2008-9: ANITA 2

  live days 28.5 days





Next plan - Askaryan Radio Array (ARA)

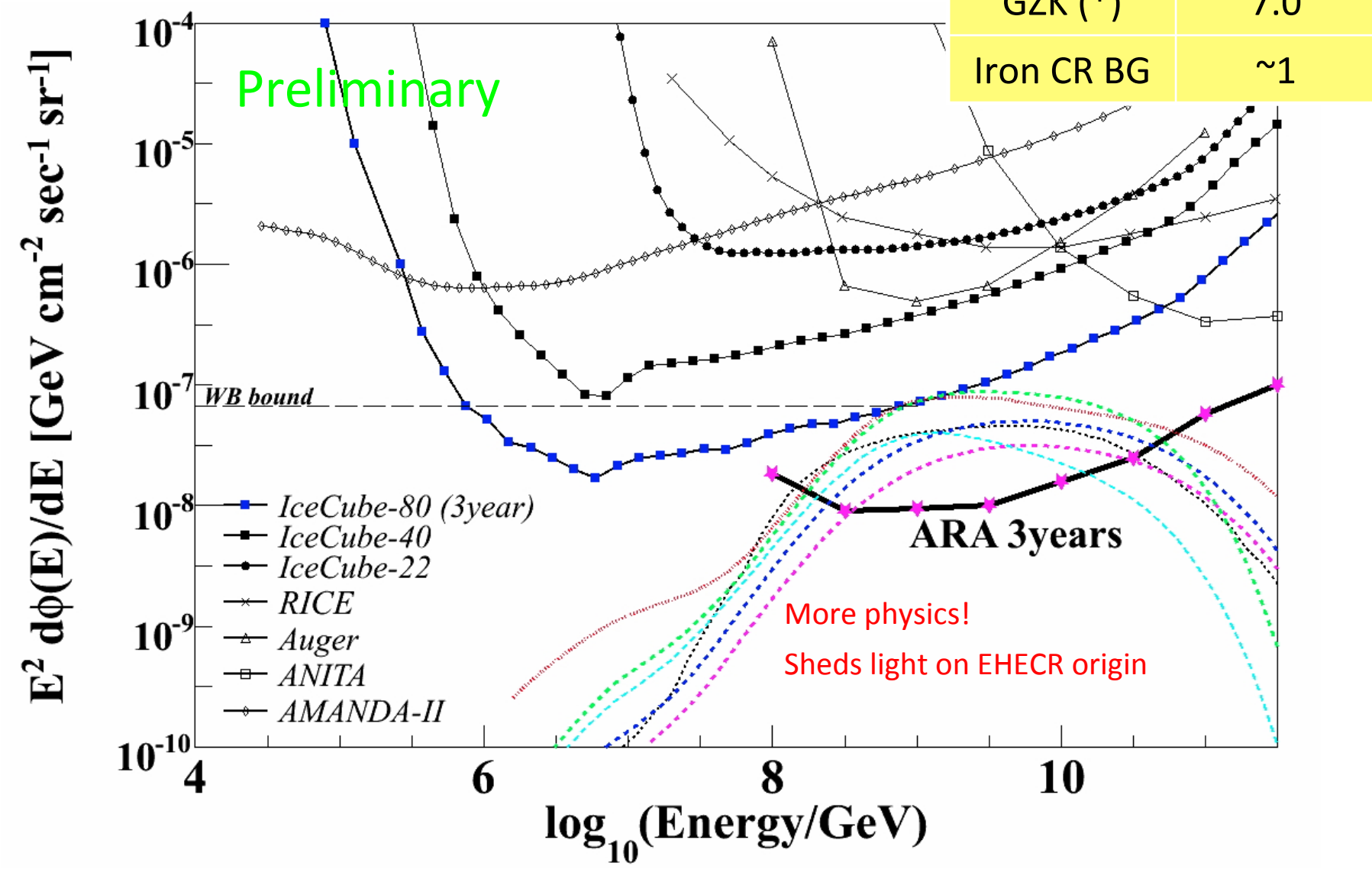


37 string clusters

- Each cluster has 4 strings of 200m depth
- Each string has 2 Vpol + 2Hpol broadband antennas (200 MHz - 1 GHz)
- Total surface area ~80 km^2

The ARA sensitivity

Model	#/year
GZK (*)	7.0
Iron CR BG	~1

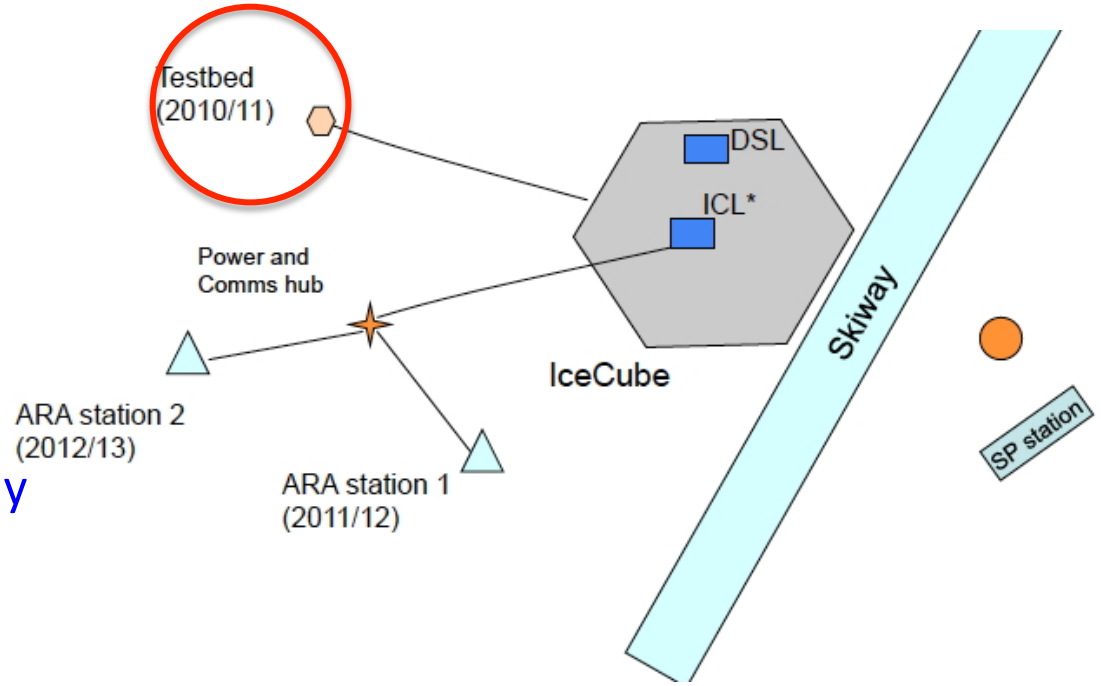


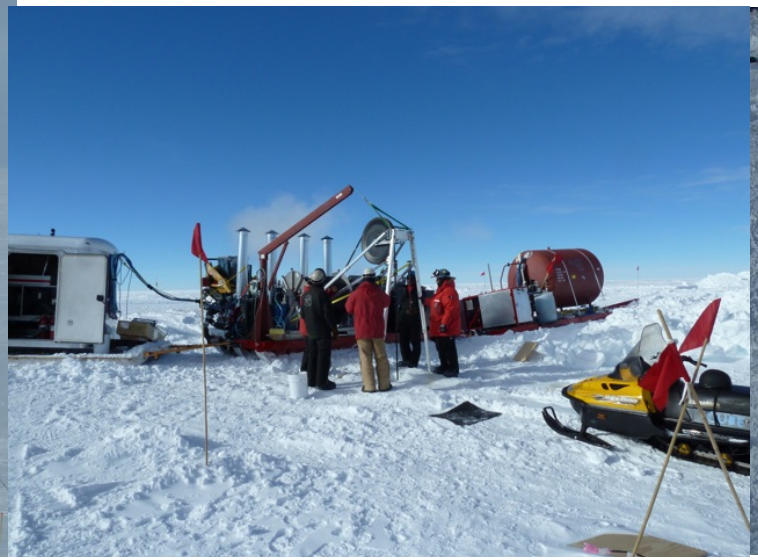
(*) Yoshida et al., ApJ, 1997, m=4, Z_{max}=4

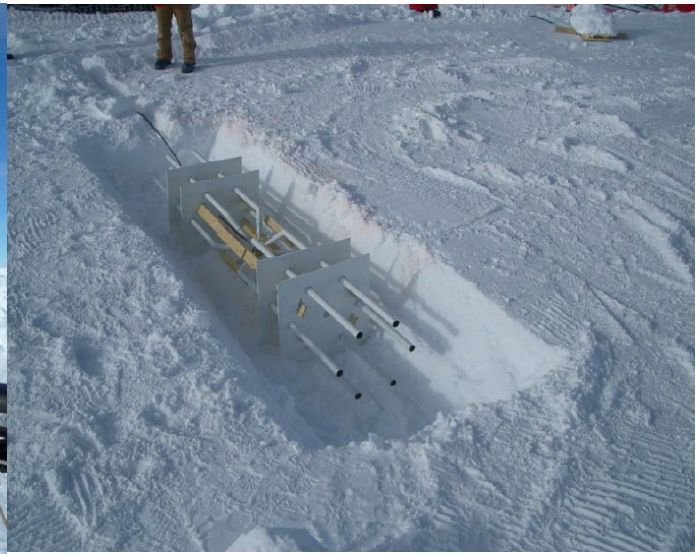
Test at the south pole this year

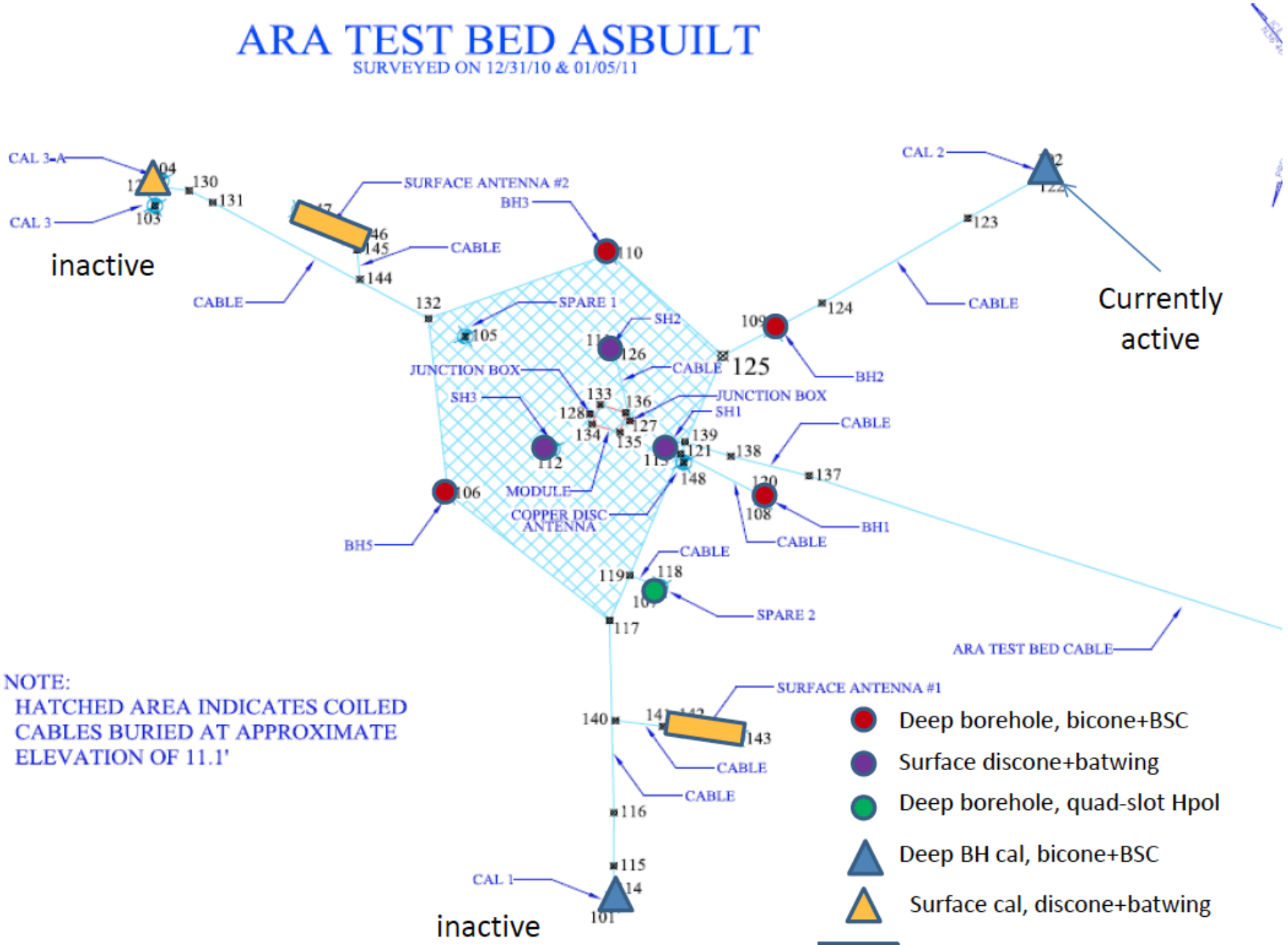
- Test bed
- Pulsar (calibration source)
- Drill test → no problem
- Windmill test

→ one of three is working properly

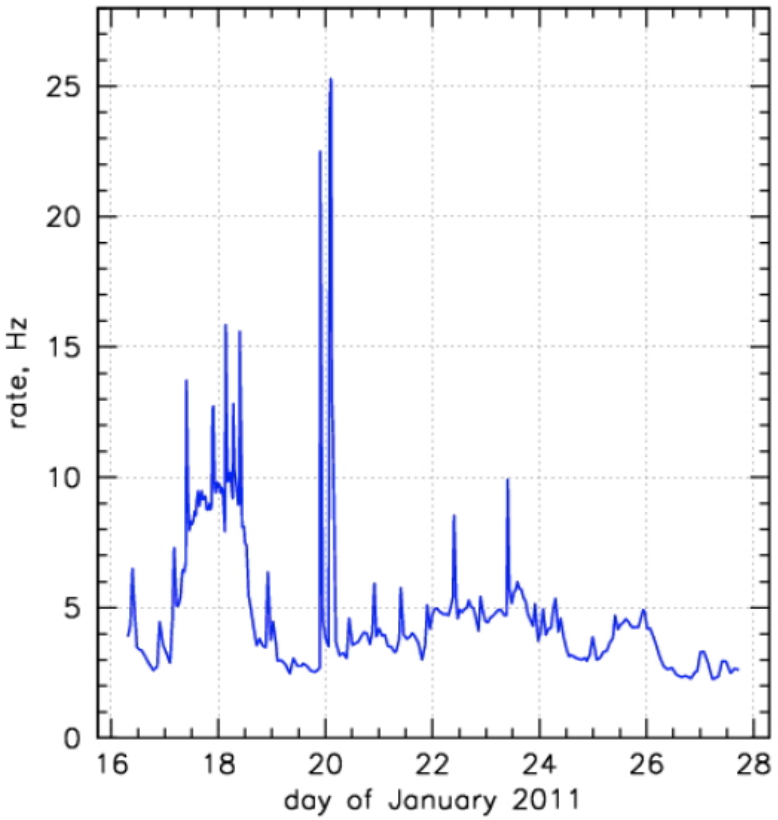






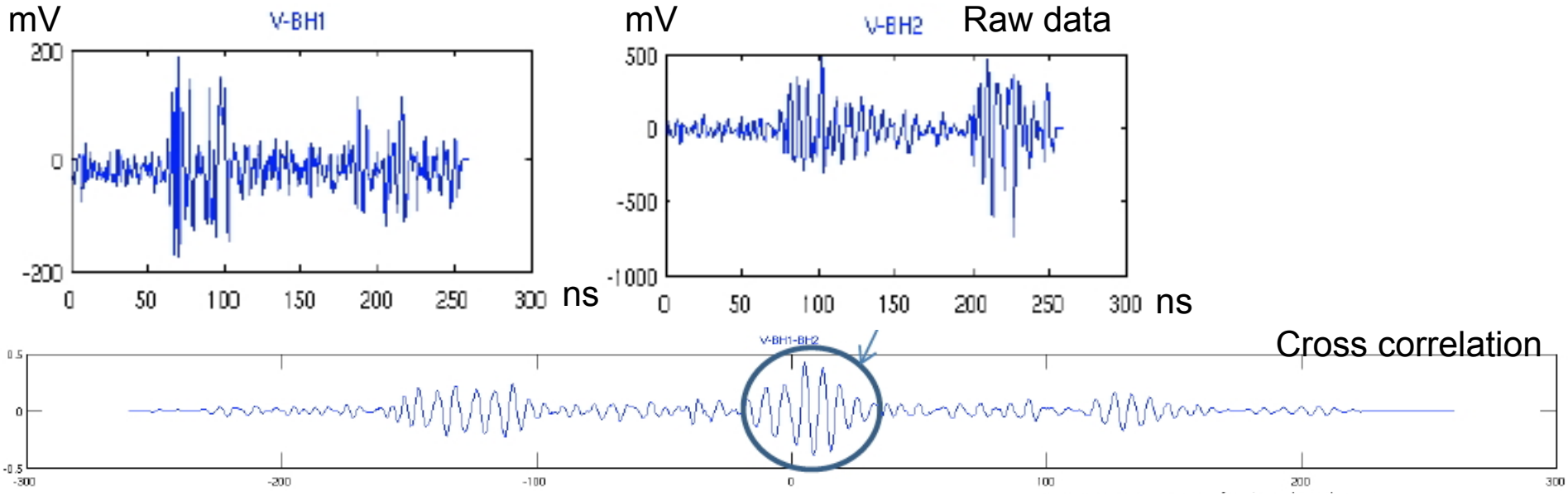

ARA TEST BED ASBUILT
SURVEYED ON 12/31/10 & 01/05/11
CAL 3-A
CAL 3
inactive
SURFACE ANTENNA #2
CABLE
CABLE
BH3
SPARE 1
SH2
JUNCTION BOX
SH3
SH1
JUNCTION BOX
CABLE
MODULE
COPPER DISC
ANTENNA
BH5
CABLE
SPARE 2
CAL 2
CABLE
Currently
active
BH2
CABLE
BH1
CABLE
ARA TEST BED CABLE
SURFACE ANTENNA #1
CABLE
CABLE
CAL 1
inactive
NOTE:
HATCHED AREA INDICATES COILED
CABLES BURIED AT APPROXIMATE
ELEVATION OF 11.1'
Deep borehole, bicone+BSC
Surface discone+batwing
Deep borehole, quad-slot Hpol
Deep BH cal, bicone+BSC
Surface cal, discone+batwing
Surface low-freq. antenna

The event rate



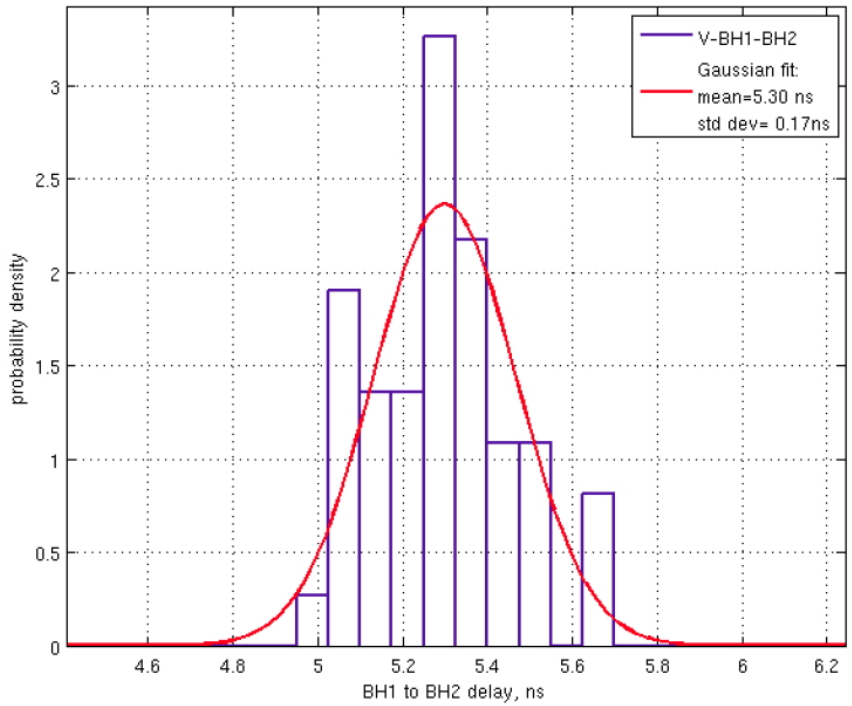
- Very quite!
- Trigger rate: 2-3 Hz
  - 1 Hz: calibration source
  - 0.5 Hz: unbiased data (forced trigger)
  - Remaining: thermal noise
- Live time > 95%

Time resolution by using a calibration source

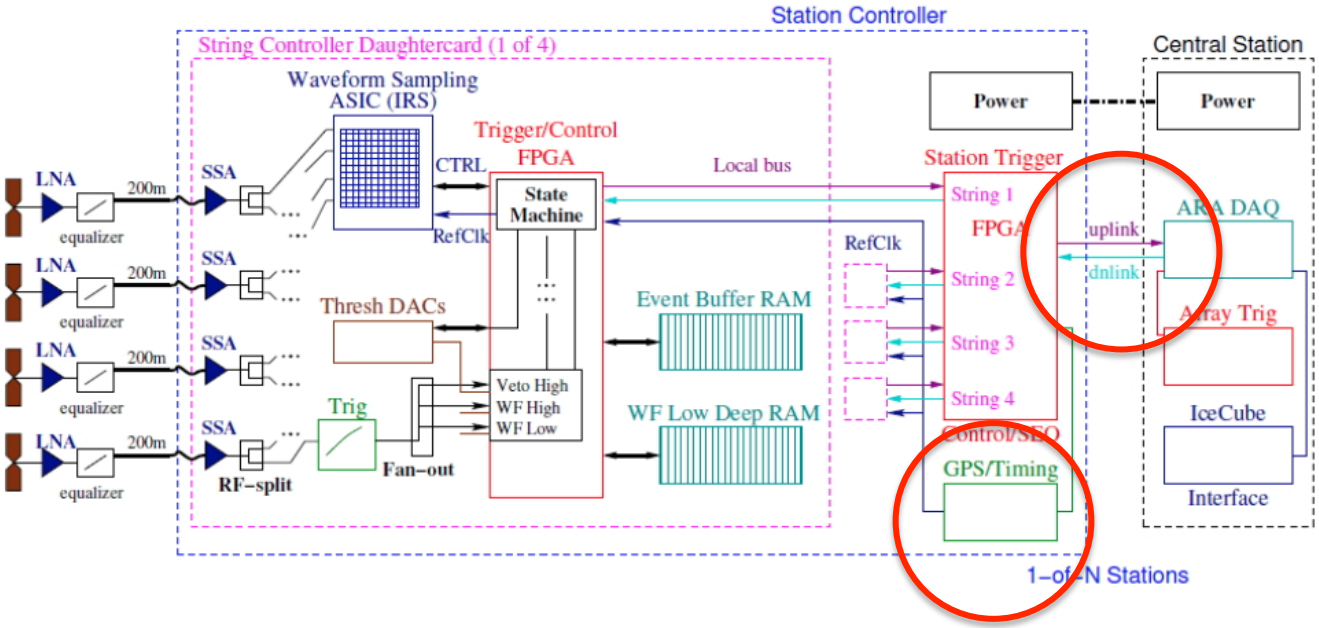


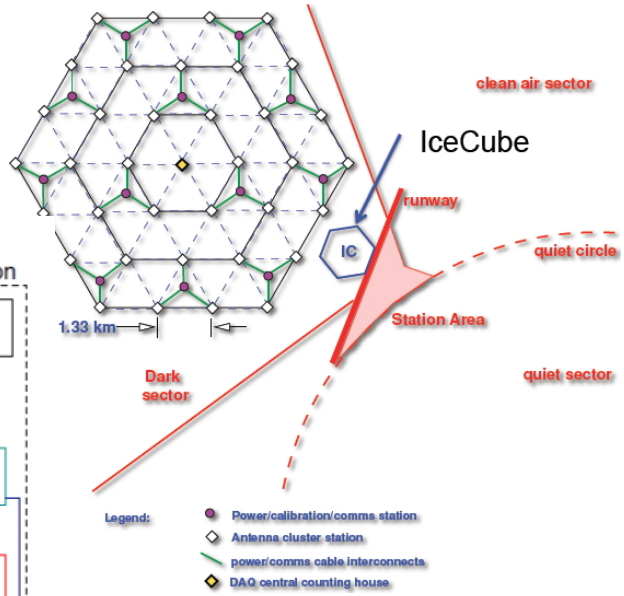
- Resolution of ~170ps
- Uncalibrated data used

  → should be better
- ~3cm resolution
- ~0.3° angular resolution with 10m antenna separation

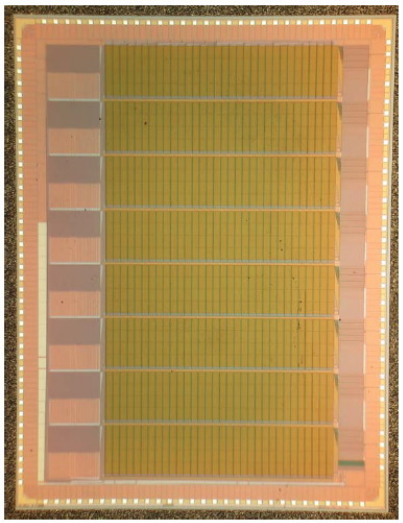


The DAQ system





Ice Radio Sampler (IRS)



- 2GSa/s
- GPS will be used for the absolute timing (~10ns)
- Rubidium clock will be used for the better stability (~500ps@1s required)
- Wireless will be used for the communication between stations (~1Mbps required)

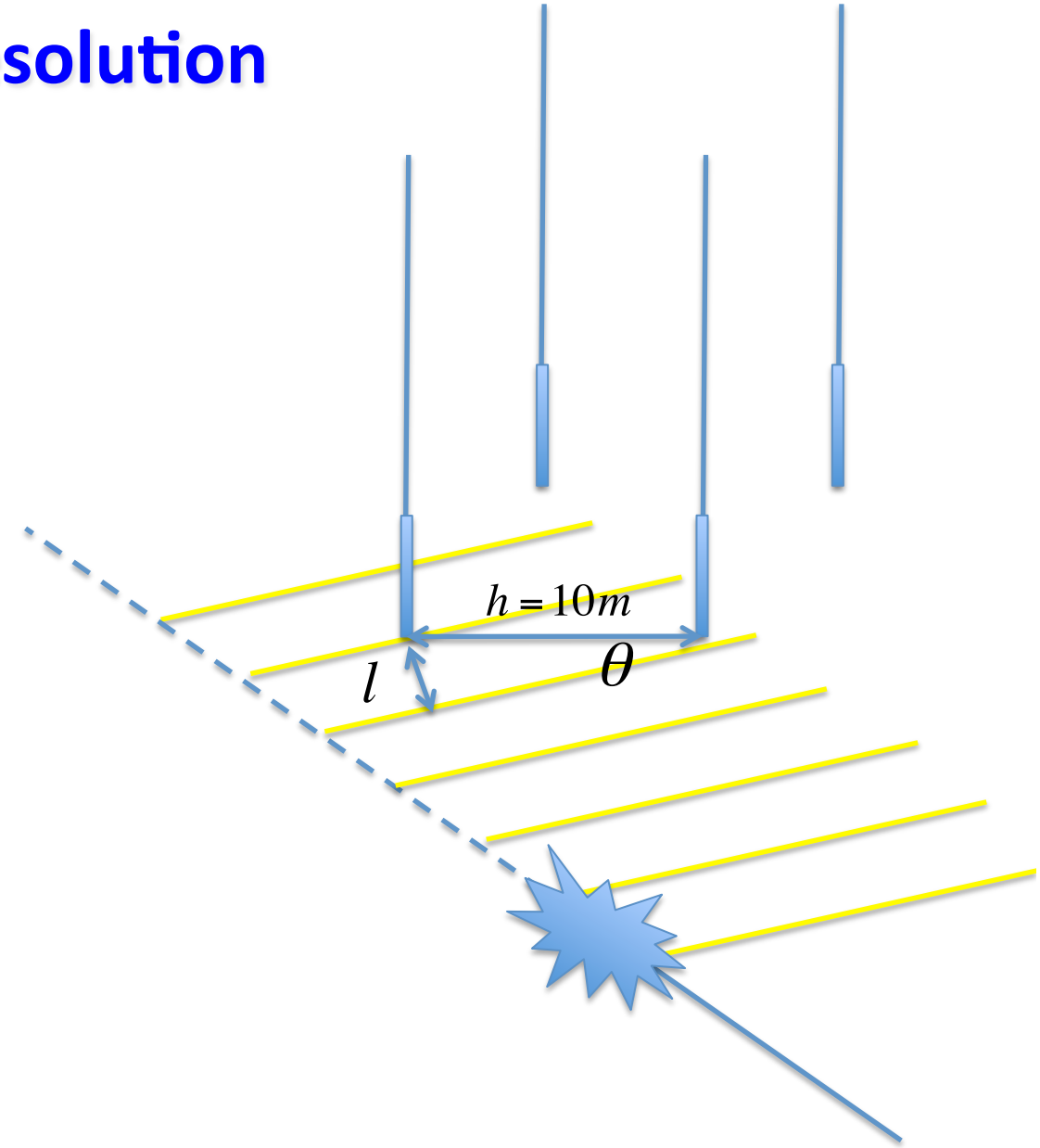
Required time resolution

Simple assumption

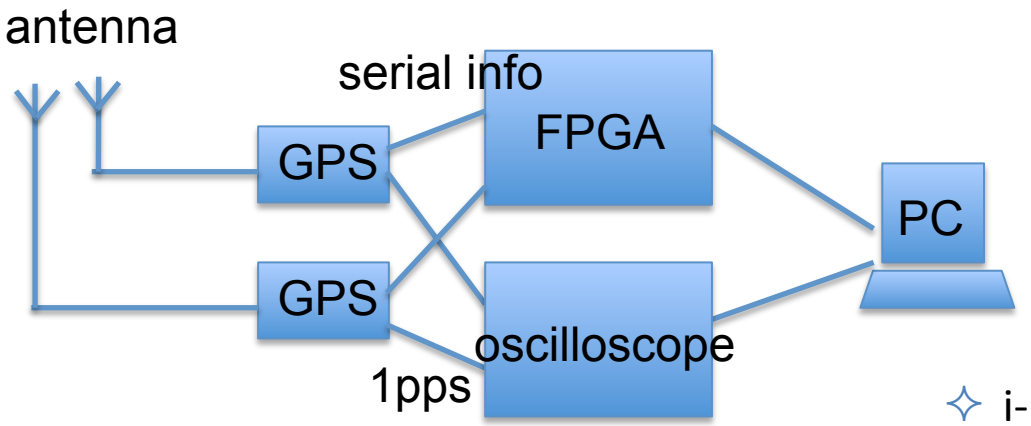
$$t = \frac{l}{c/n} = \frac{h\sin\theta}{c/n}$$

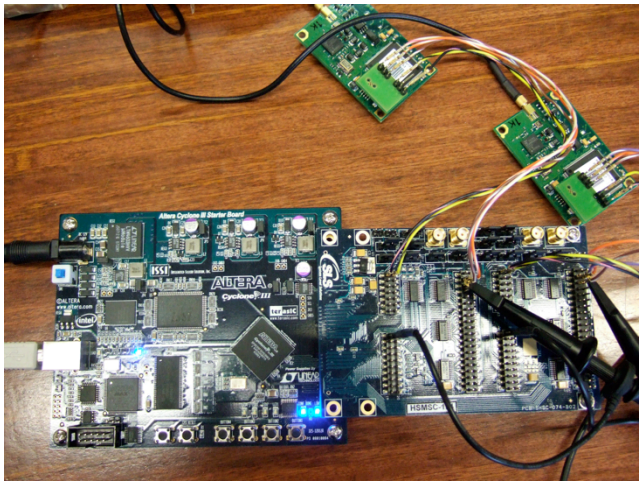
$$\Delta t = \frac{h\cos\theta}{c/n}\Delta\theta \cong 600\,ps$$

$$(\Delta\theta = 1^o,\ h = 10m,\ \theta = 45^o)$$

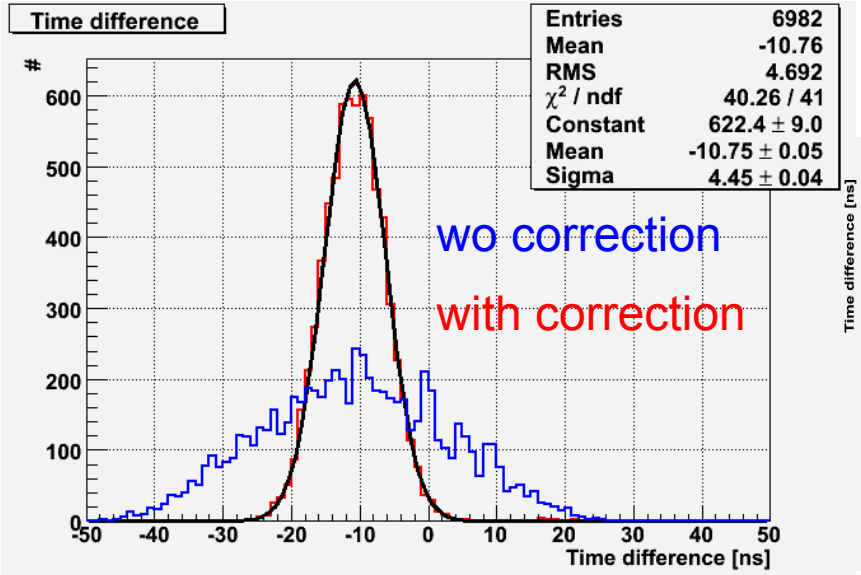


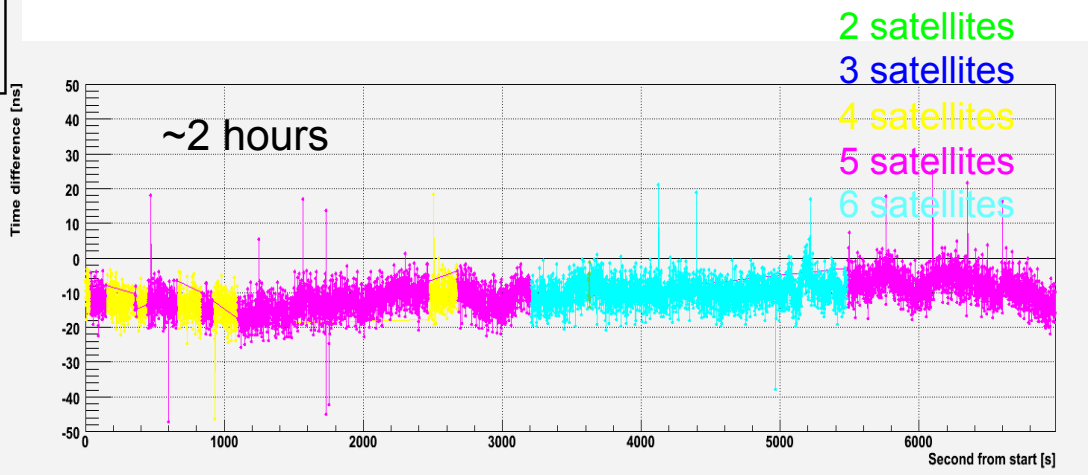
GPS test





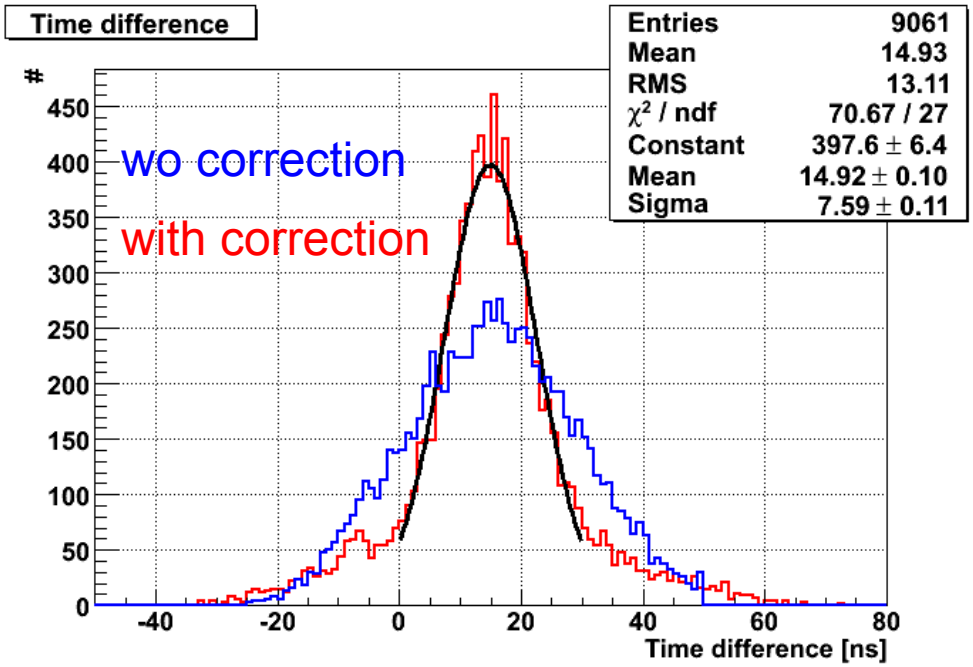
- i-LOTUS M12M (successor of Motorola)
  - Resolution (wo correction): 9.2 ns
  - Resolution (with correction): 3.1 ns
- No degrade seen by satellite number

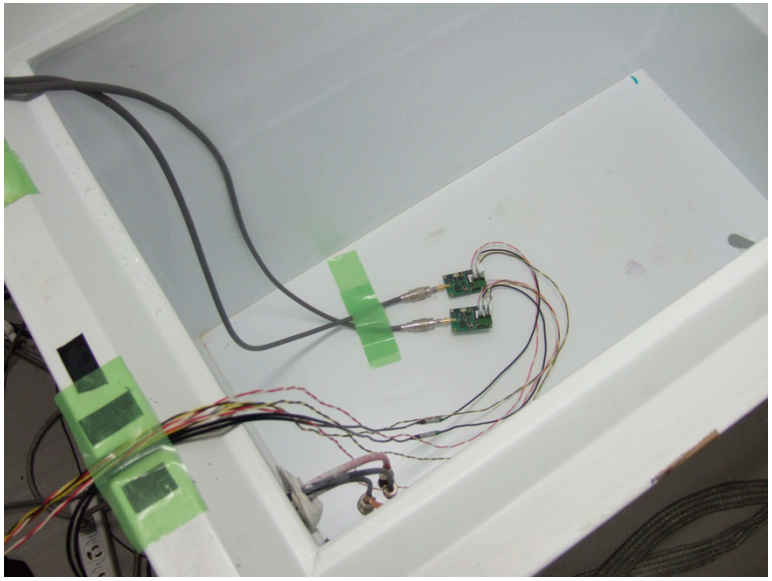




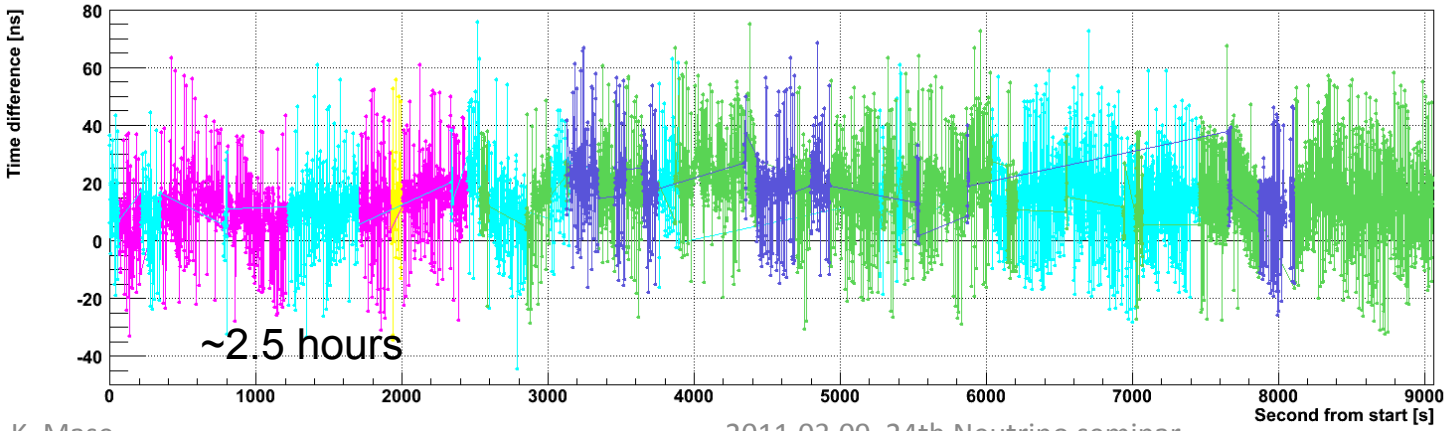
GPS test in a freezer

-40℃



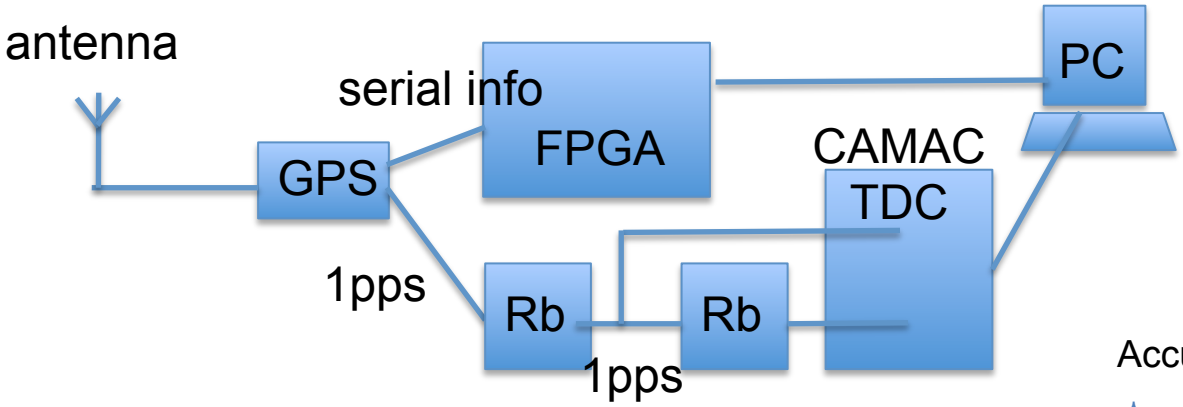


- Resolution (wo correction): 10.0 ns
- Resolution (with correction): 5.4 ns
- Only a little degrade at -40 deg.



1 satellite
2 satellites
3 satellites
4 satellites
5 satellites
6 satellites
7 satellites
8 satellites
9 satellites

Rb clock test

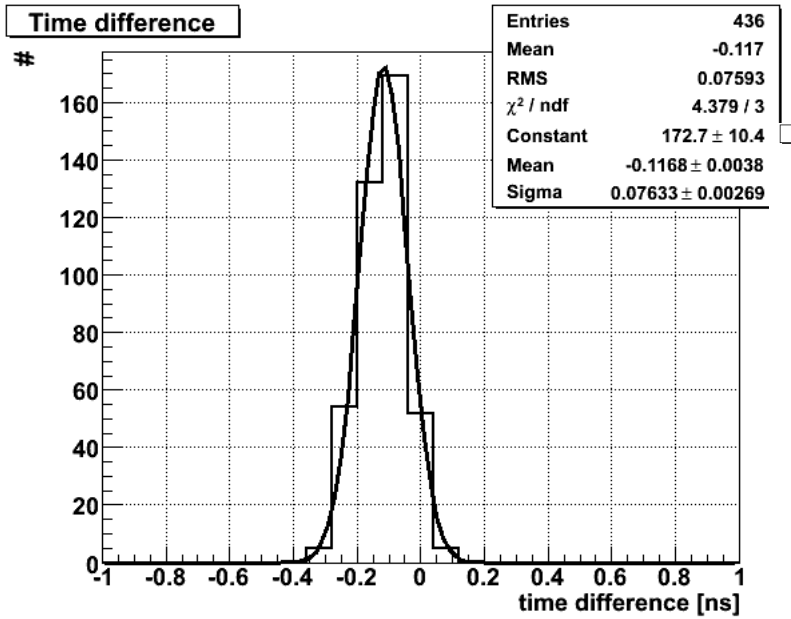


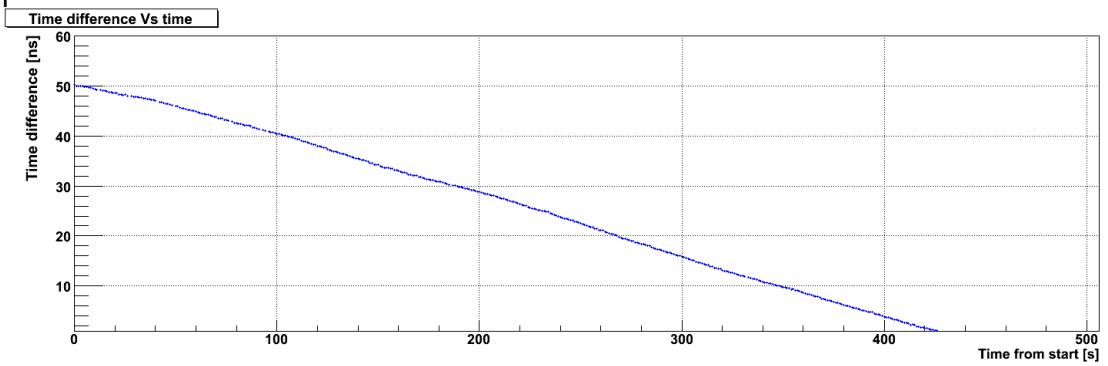
Accubeat AR133A

- 1 second Allan deviation: 3 x 10^{-11} (30 ps)
- 1 PPS input possible
- 1 PPS and 10 MHz clock output

Time difference between events

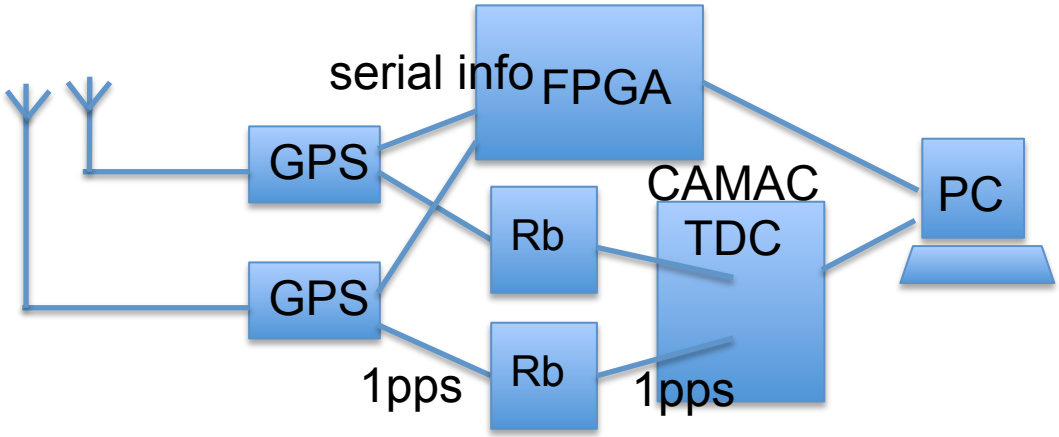
1pps



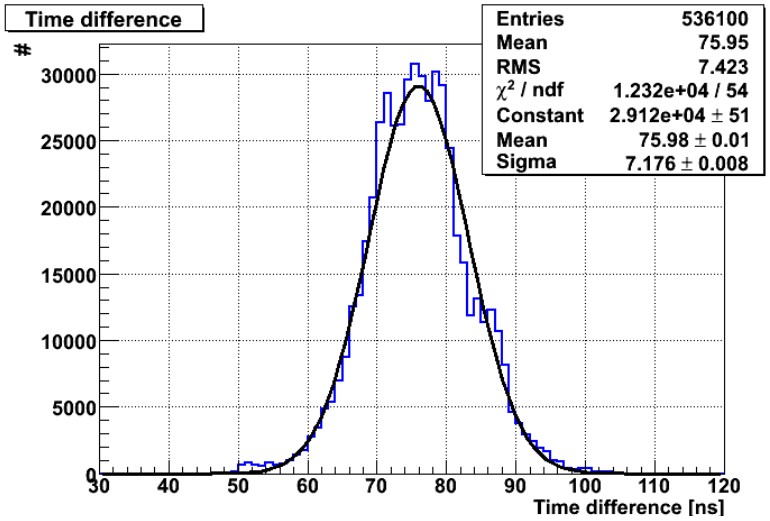


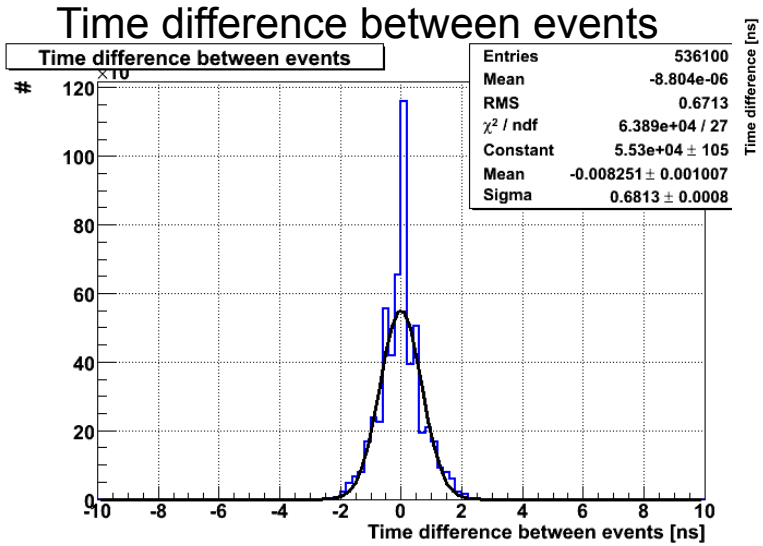
1 second Allan deviation of 3.8 x 10^{-11} (38 ps)

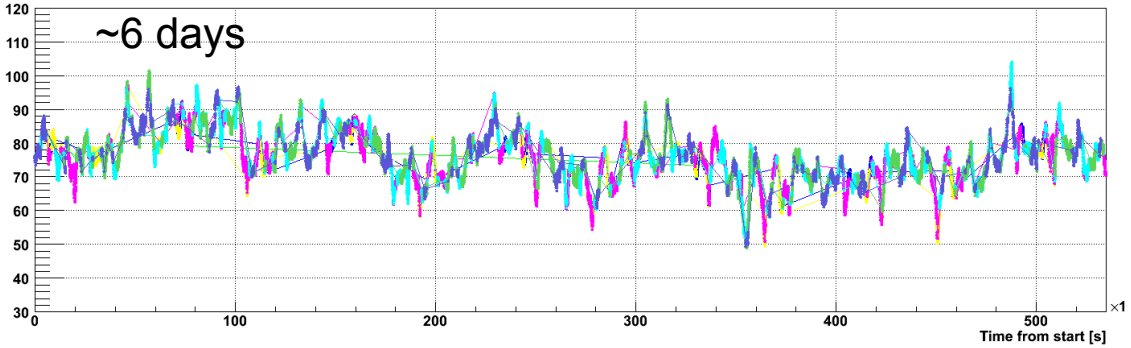
Rb clock test with GPS input



Total spread: ~5ns





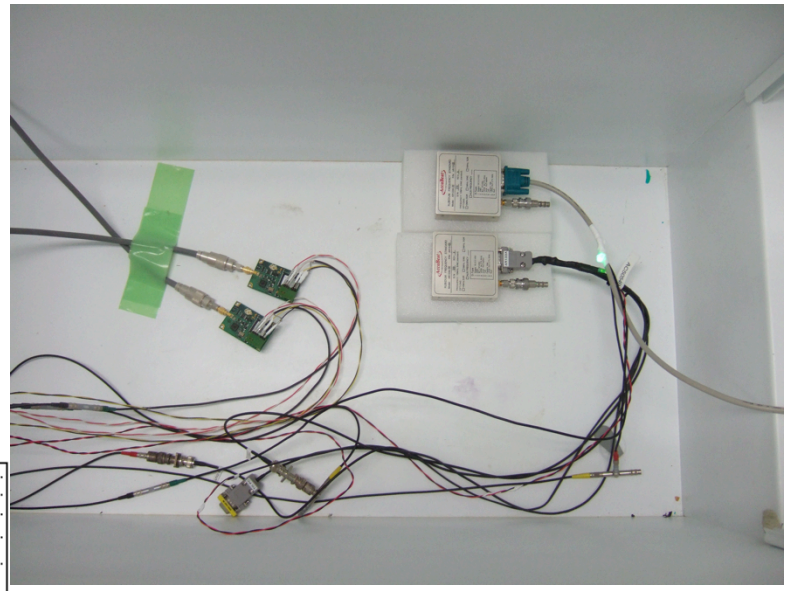


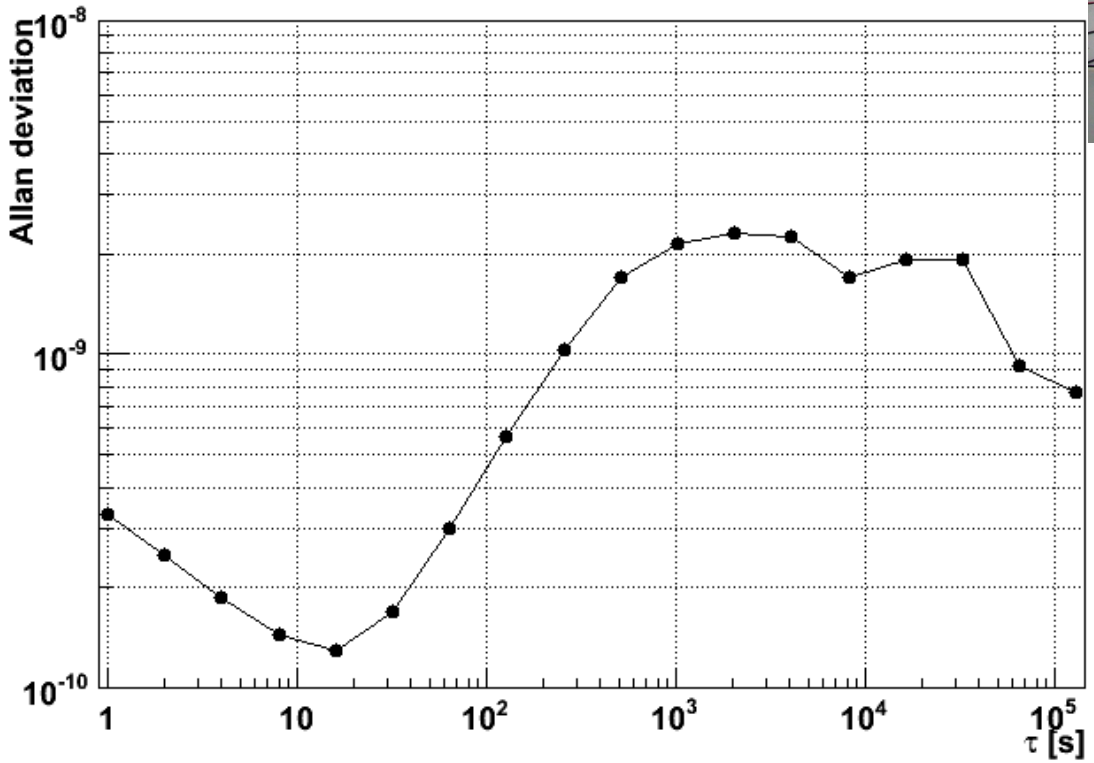
1 second Allan deviation: 3.4 x 10^{-10} (340 ps)

By fitting only the peak: 6.7 x 10^{-11} (67 ps)

Rb clock test with GPS input at low temperature

- The Rubidium clocks and GPS were tested in a freezer (-40 deg.).
- The results did not change.





Allan deviation:

$$\sigma_y^2(\tau) = \frac{1}{2(m-1)} \sum_{i=1}^{m-1} (\bar{y}_{i+1} - \bar{y}_i)^2$$

Indicates the deviation for the time scale

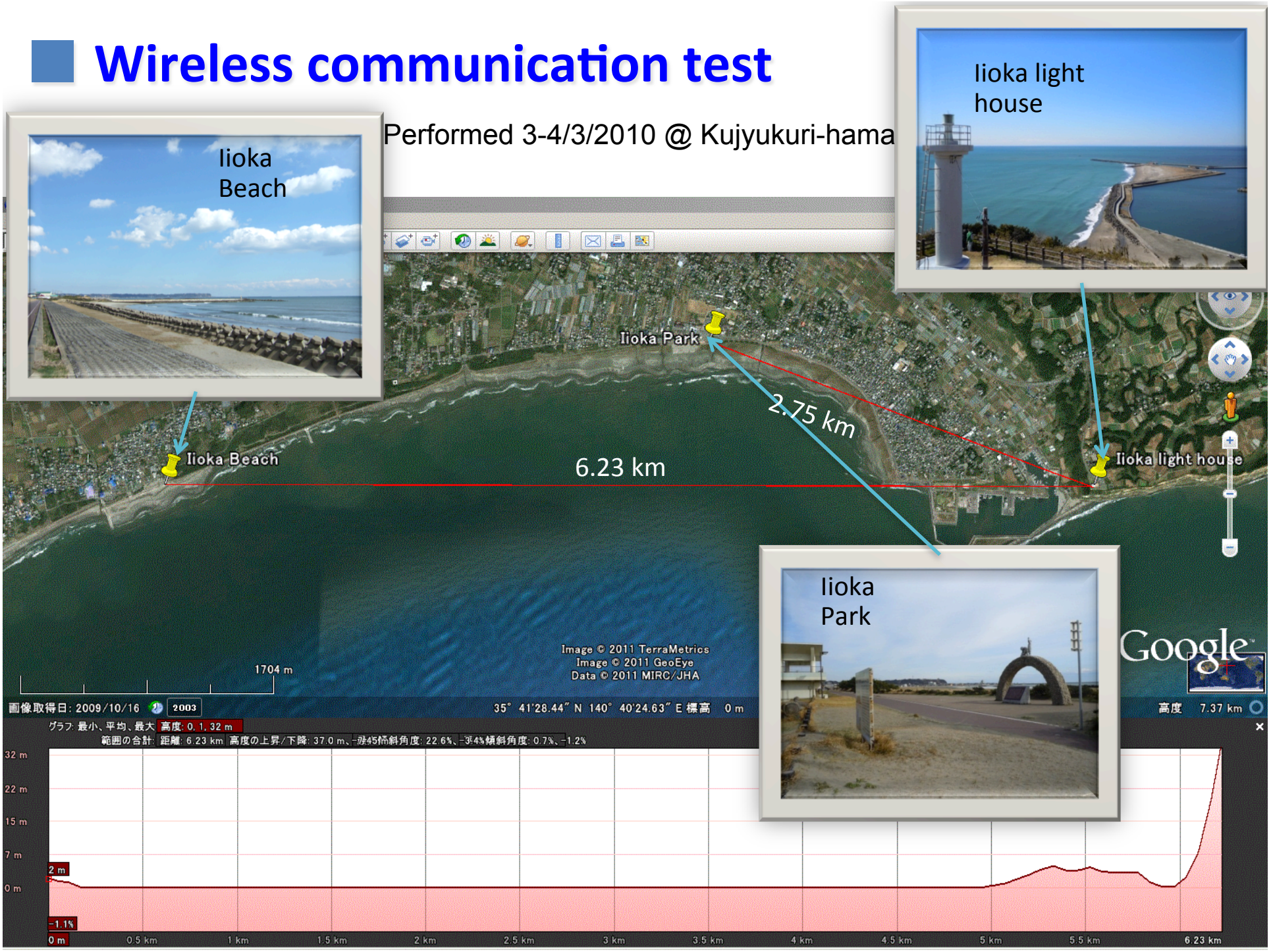
1 sec Allan deviation: ~3 x 10^{-10}

(better taking out the outliers)

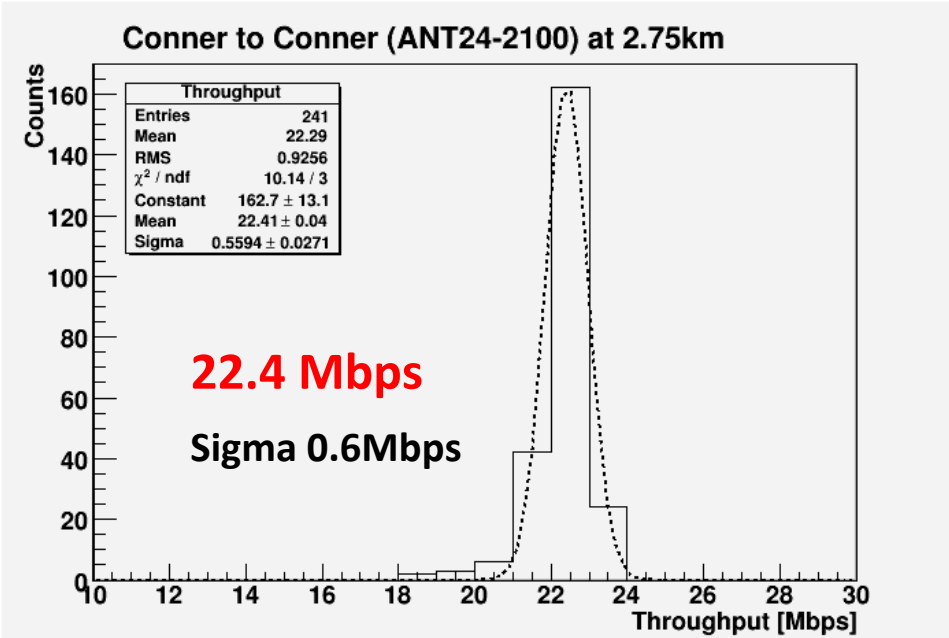
Maximum Allan deviation: ~2 x 10^{-9}

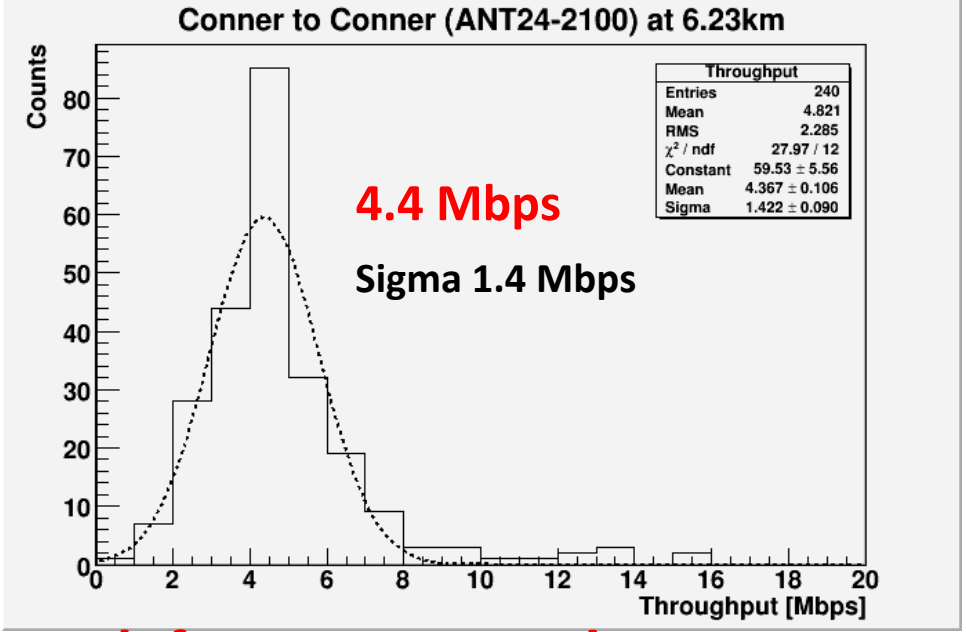
Wireless communication test

Performed 3-4/3/2010 @ Kujyukuri-hama



Throughput

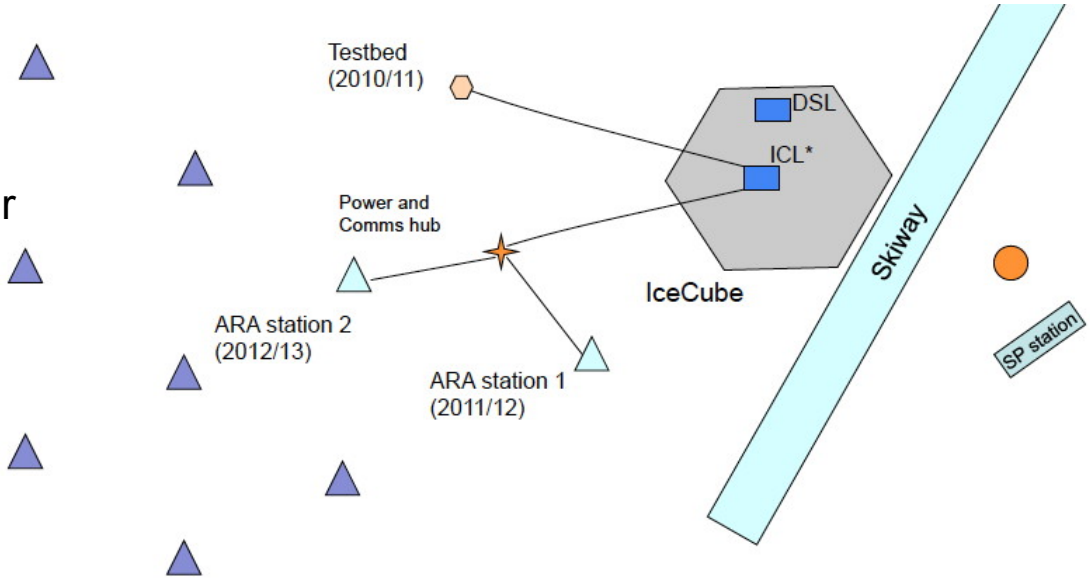




- **The throughput is enough for our purpose!**
- Tests at low temperature will be performed.

Further plan

- 2011/12
  - ARA station 1
  - Performance demonstration
  - Test wireless and remote power
- 2012/13
  - ARA station2
  - Performance demonstration
  - Deploy 7 more stations?



- Total 9 stations are funded.
- Need more fund to realize the full arrays (37).
- Hope your cooperation!

Summary

- The ARA project has just started in order to reveal long standing mystery of the EHECR origin.
- The first equipment was deployed at the south pole.
- The first data indicates the excellent performance. (0.3° angular resolution)
- Tests for GPS, Rubidium clock and wireless was performed. The performances satisfy the requirements.

Backups

Station Data Reduction (self-trigger)