Neutrino Experiments at Antarctica

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LeCosPA,
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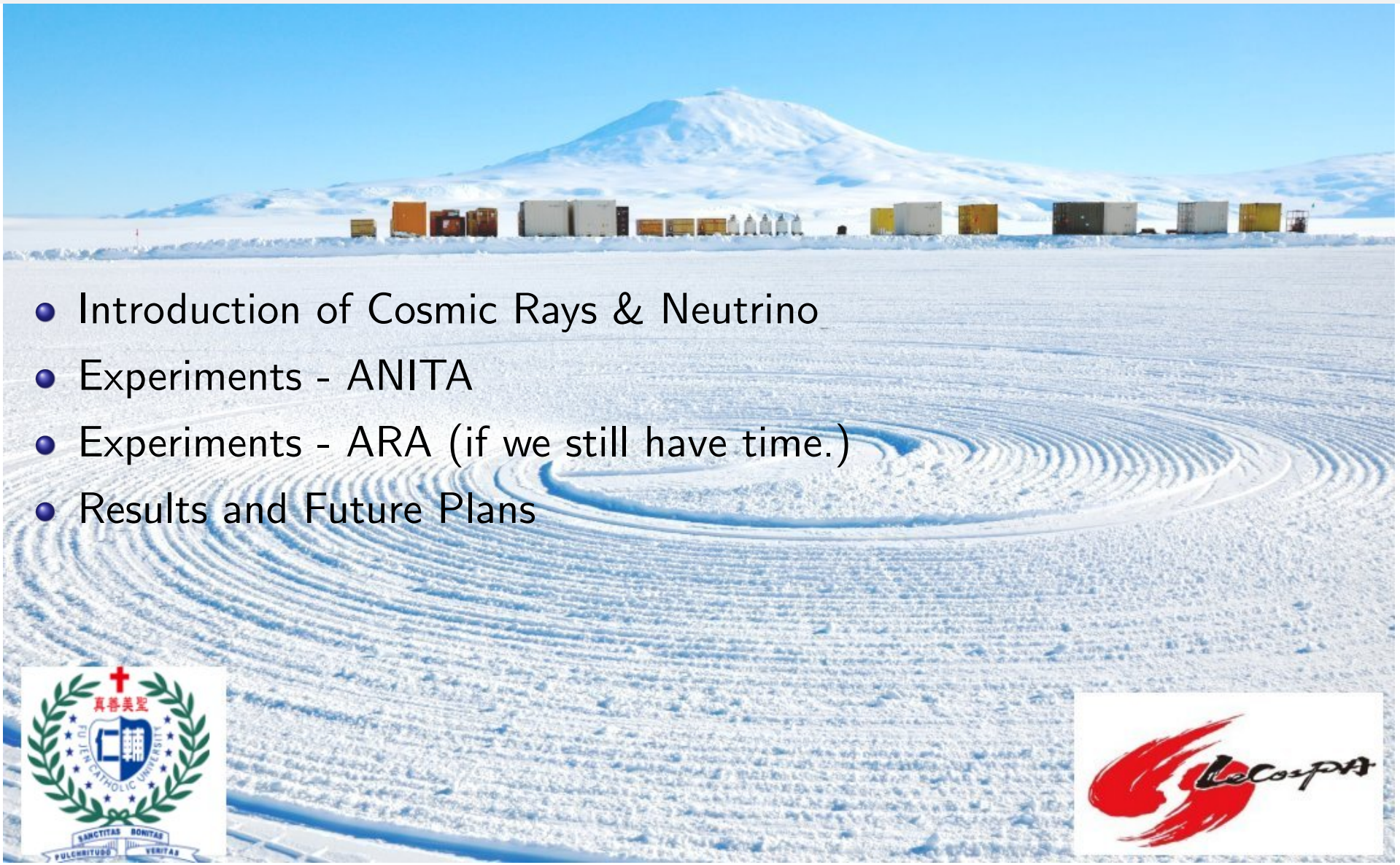
May 21, 2015

Outline:



- Introduction of Cosmic Rays & Neutrino
- Experiments - ANITA
- Experiments - ARA (if we still have time.)
- Results and Future Plans

Discovery of Neutrino

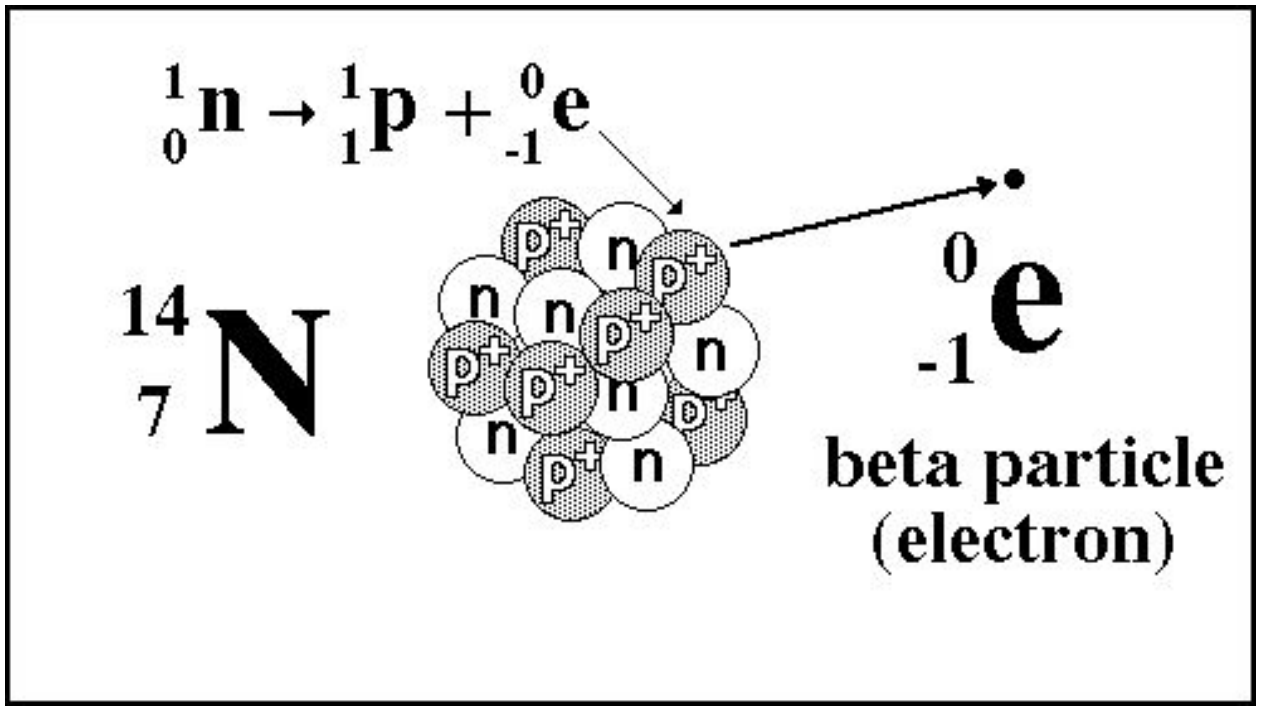


Figure : beta decay could conserve energy, momentum, and angular momentum in 1930.

“Neu-trino”

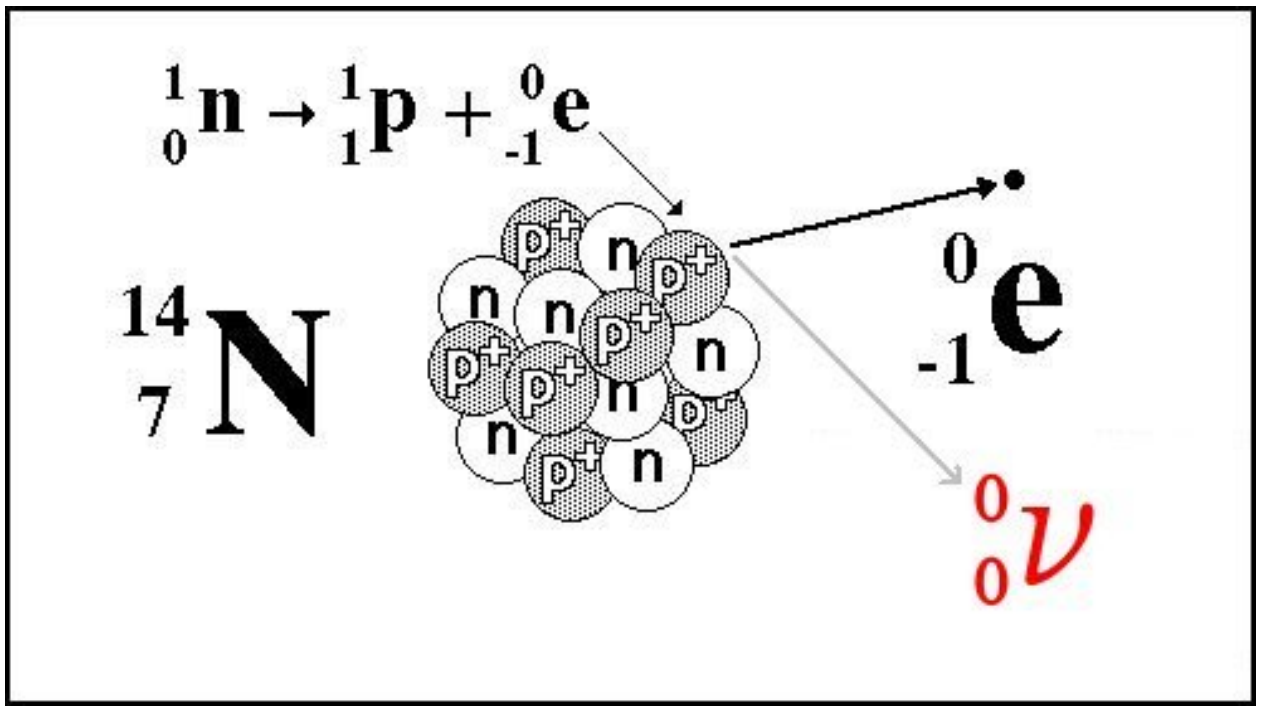
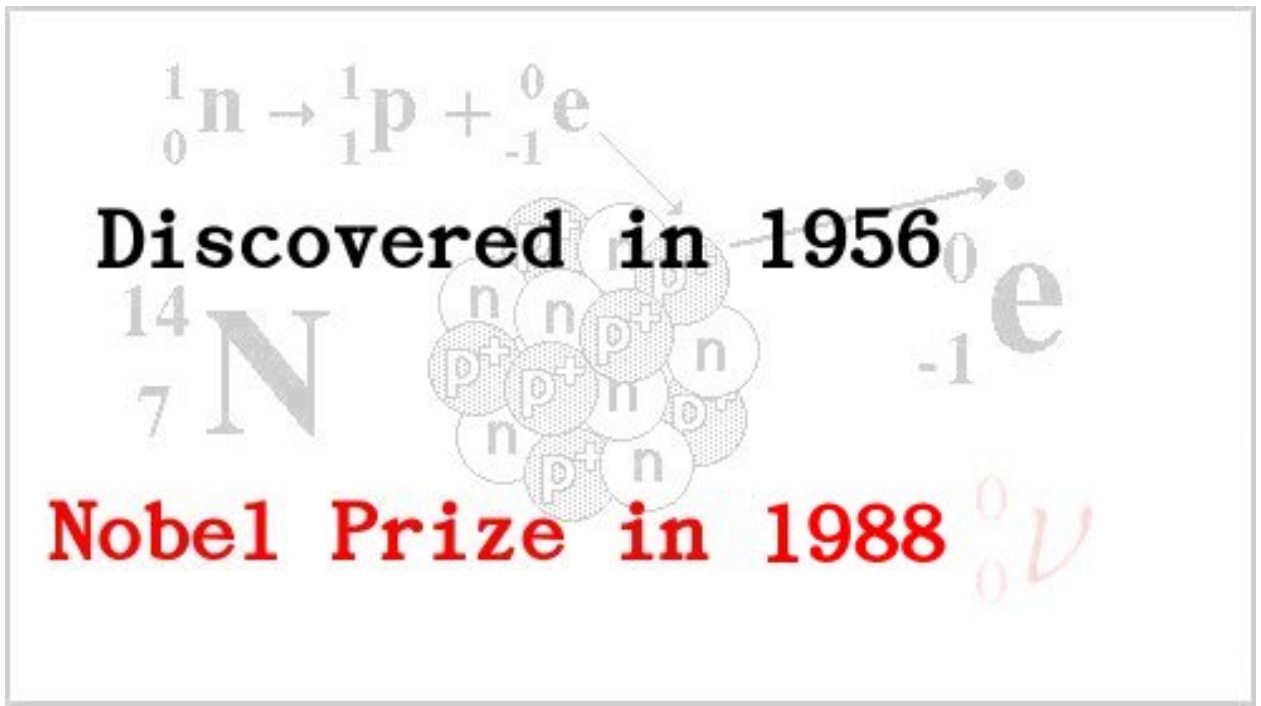


Figure : Pauli hypothesized an undetected particle that he called a ”neutron” in keeping with convention.

Discovery of Neutrino



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How Many Generations?

Figure : When the third type of lepton, the tau, was discovered in 1975 at the SLAC, it was expected to have an associated neutrino (the tau neutrino).

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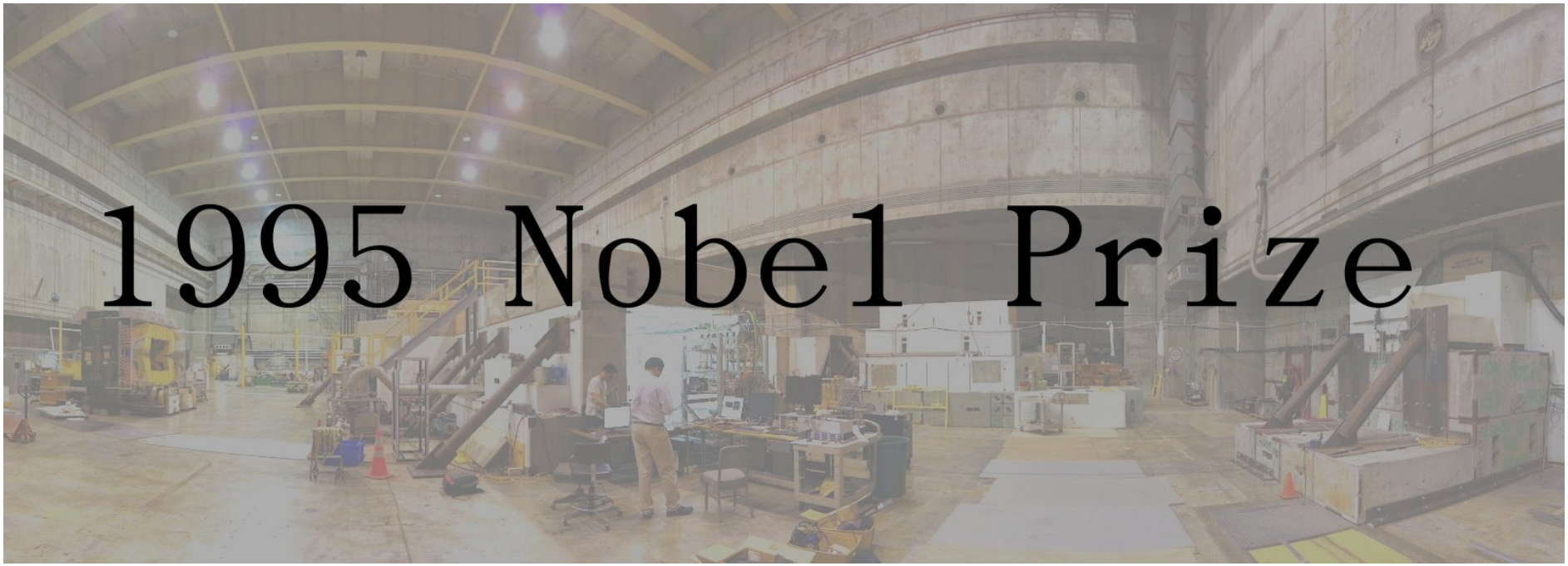

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Neutrino Flux is not Conserved ?!

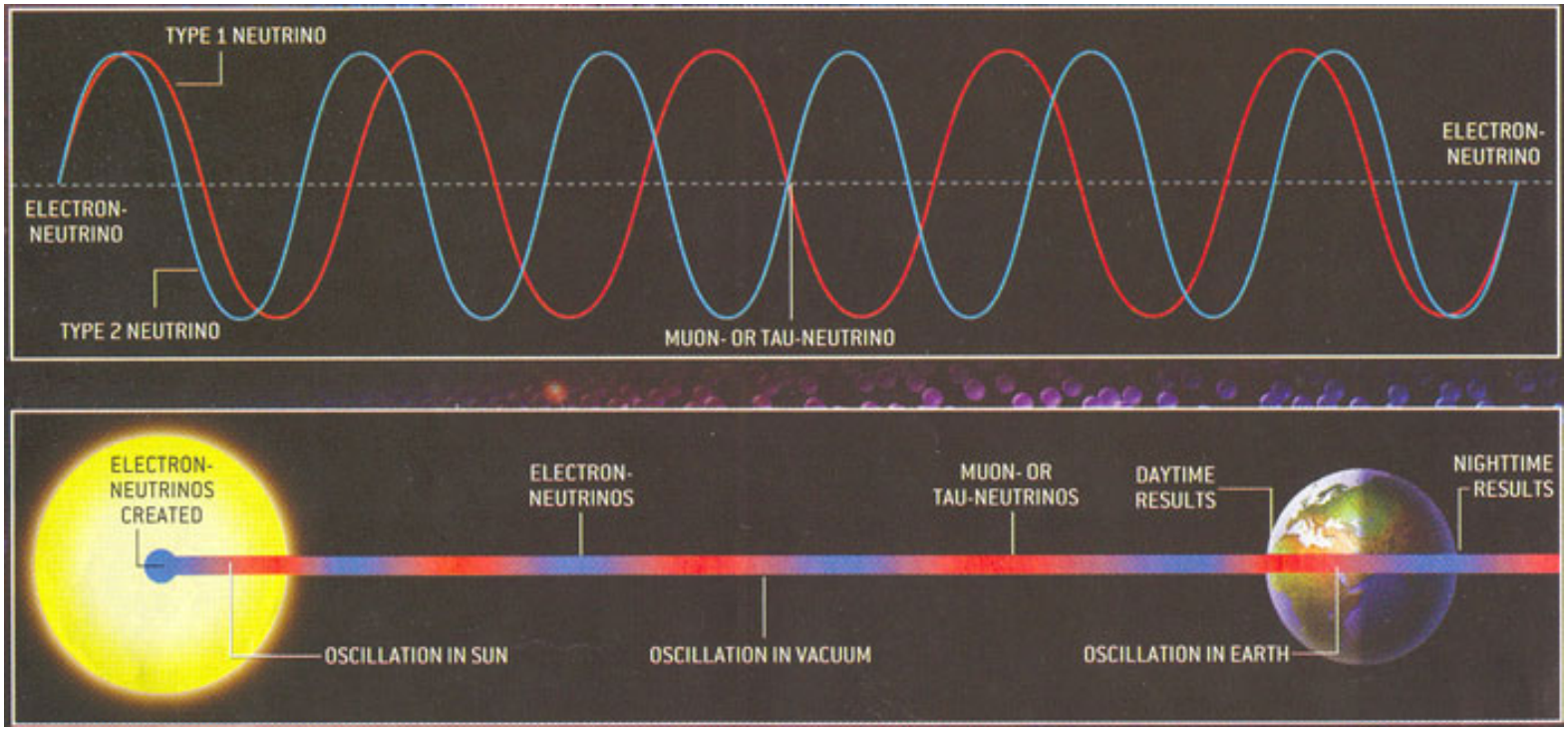

Figure : Measurements of solar neutrino types were not consistent with models of the Sun's interior

Neutrino Flux is not Conserved ?!

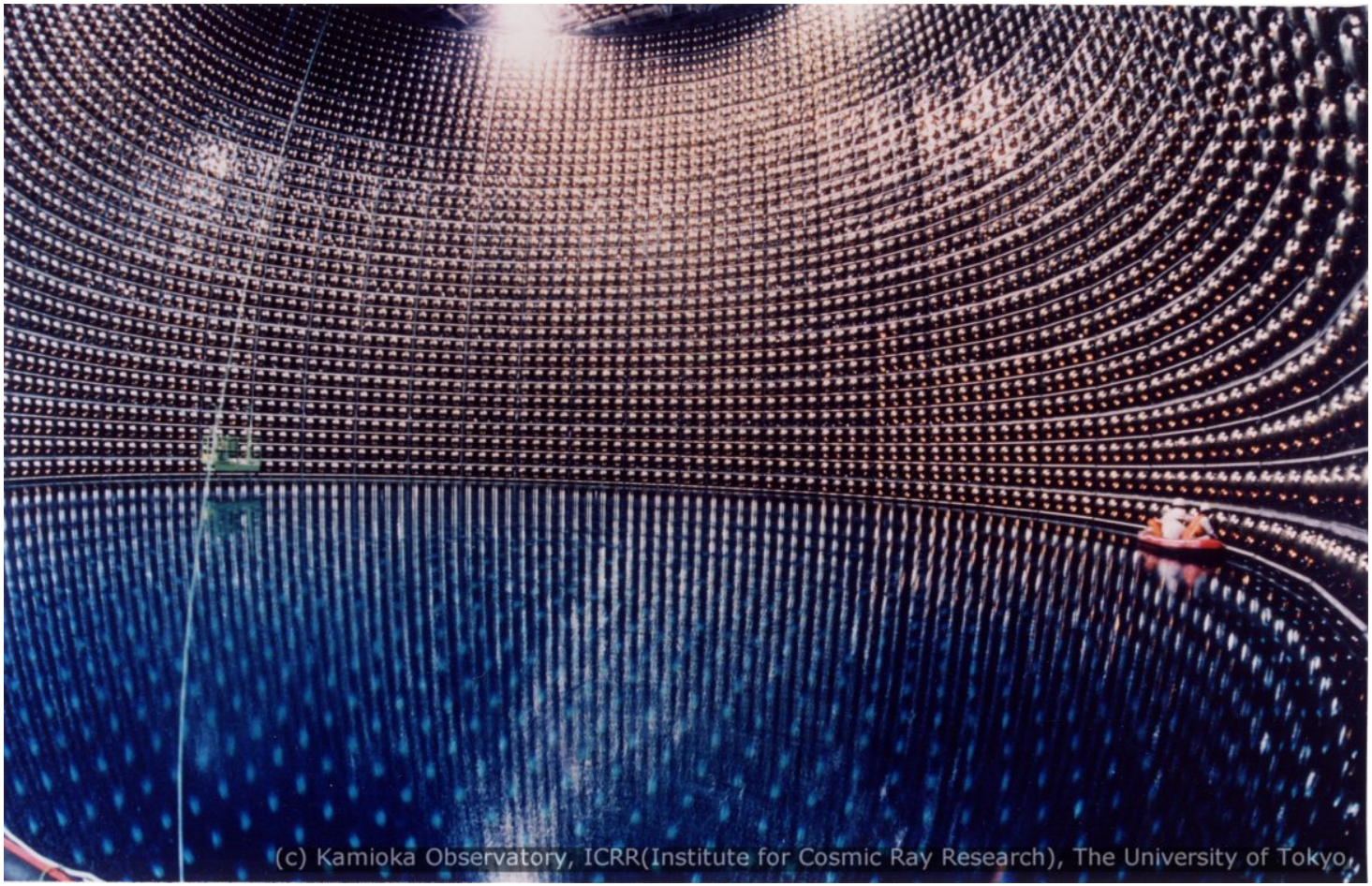

Figure : Super-Kamiokande observed super nova neutrino and confirm the Neutrino oscillation mechanism.

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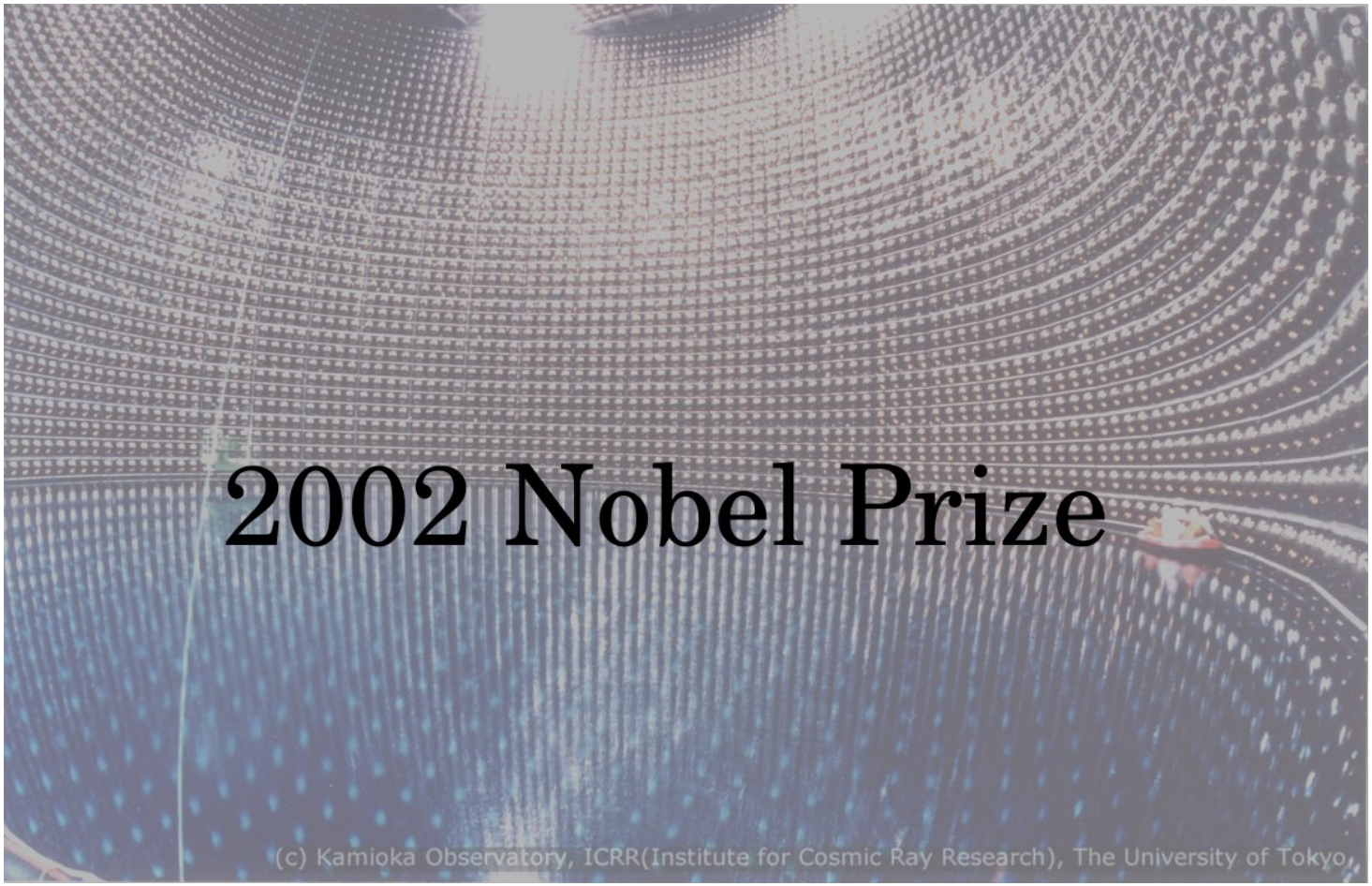
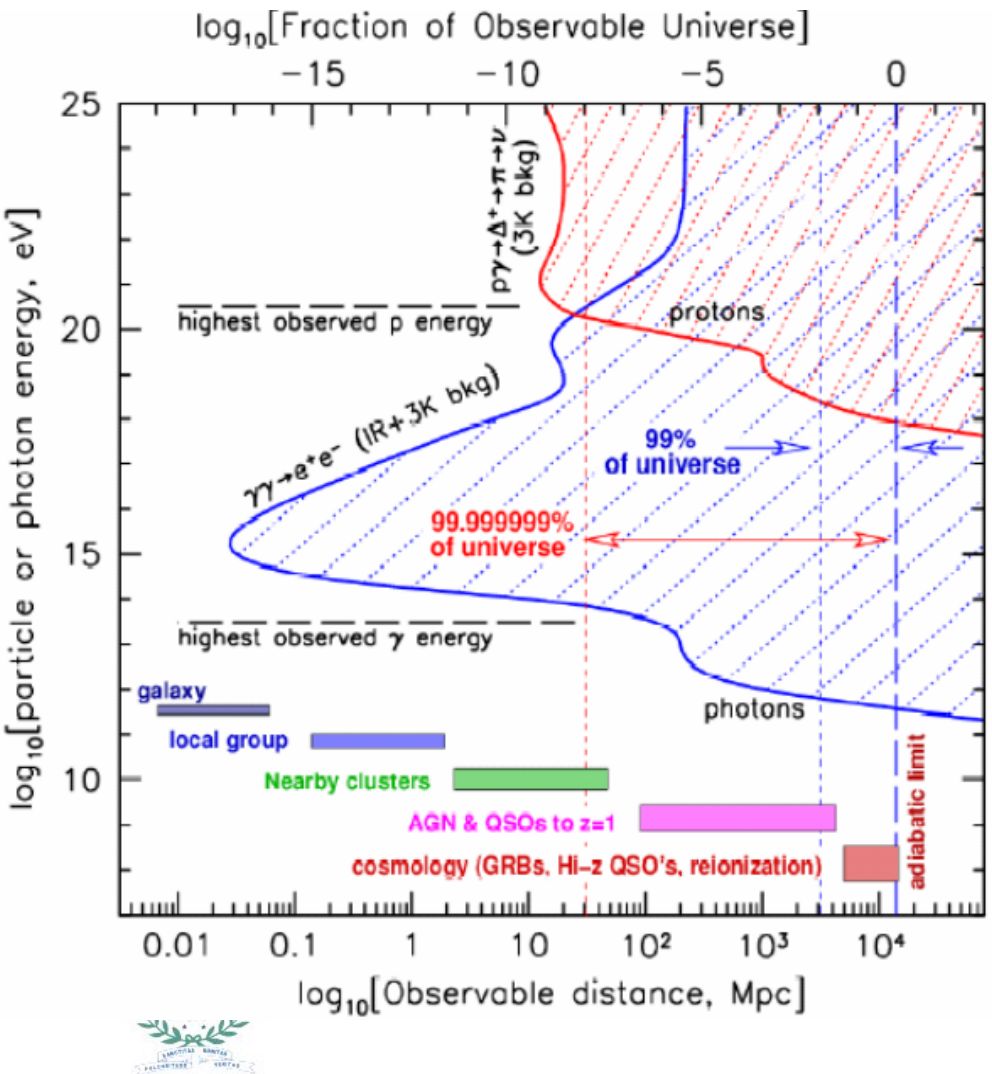


Figure : Super-Kamiokande observed super nova neutrino and confirm the Neutrino oscillation mechanism.

Short Summary I: Unsolved Problems

- Absolute mass of the neutrinos.
- Neutrino decay.
- Neutrino hierarchy.
- How many generations?
- Sterile neutrino. (right-handed neutrinos)
- Dark matter, WIMP.
- Mixing Angles.
- .....

What I Want? The Ideal UHE Messenger



- Photons lost above 100 TeV (pair production on CMB & IR)
- Protons and Nuclei suffer curvature induced by B fields
- But: we know there are sources up to 10^{20} eV!!

UHE Neutrino Detectors Study:

- Highest energy observation of extragalactic sources
- Very distant sources
- Deep into opaque sources

from A. G. Vieregg

Neutrinos

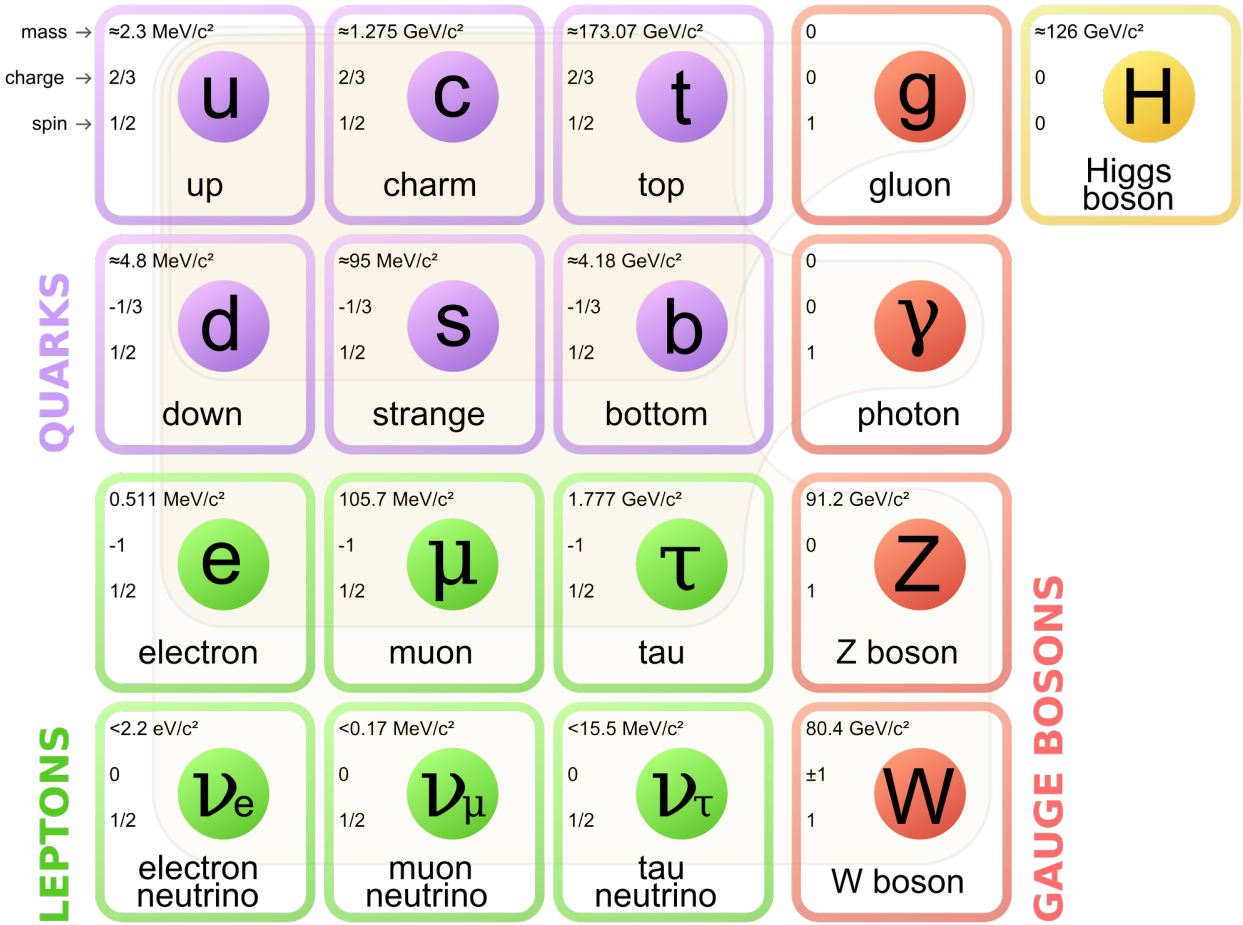


Figure : Neutrino only involves in weak interactions.

Fundamental Forces

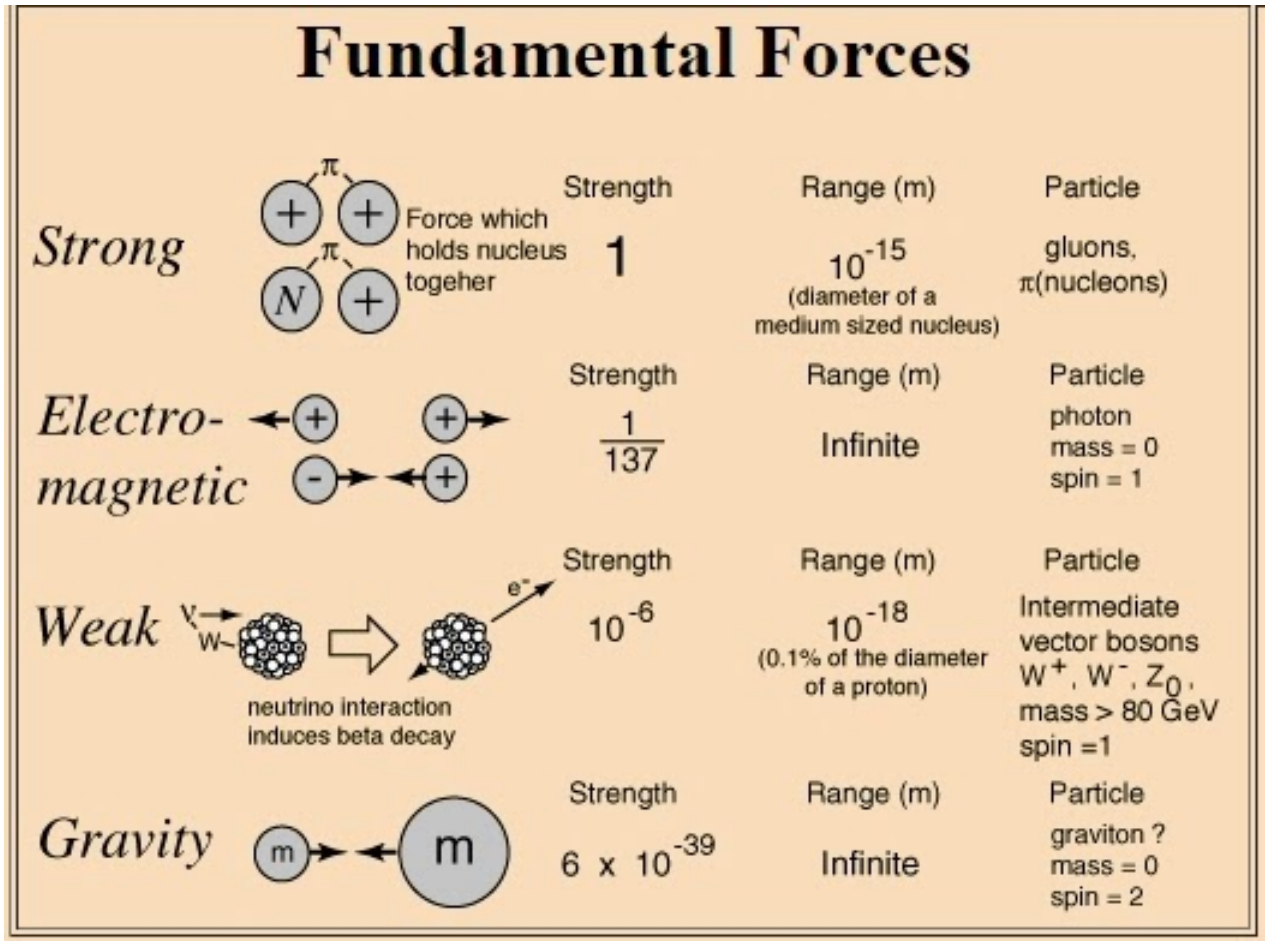


Figure : Fundamental Forces.

Cross Section of Neutrino

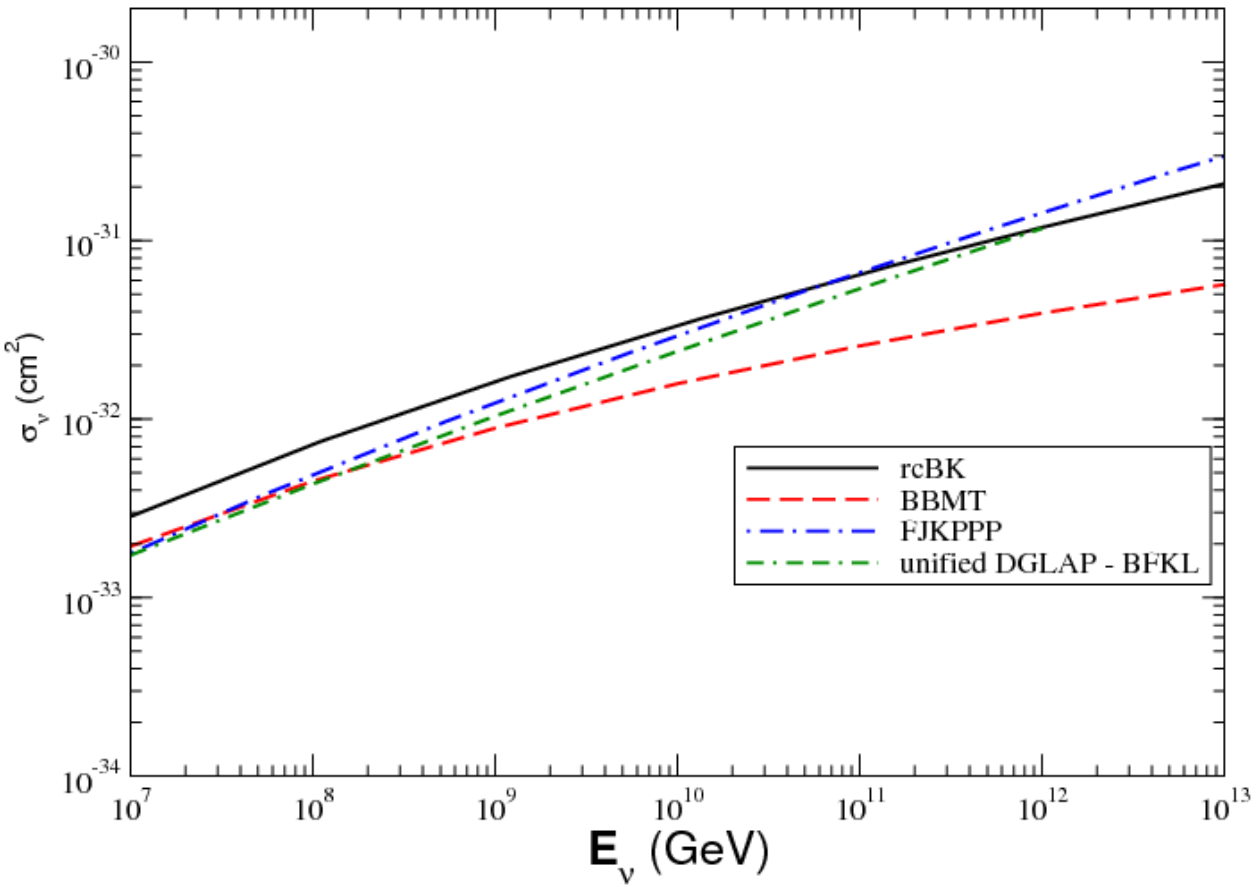


Figure : Neutrino cross section. 1 barn $=10^{-24}$cm^2. [Phys.Rev. D83 (2011) 014014]

Interaction Length of Neutrinos

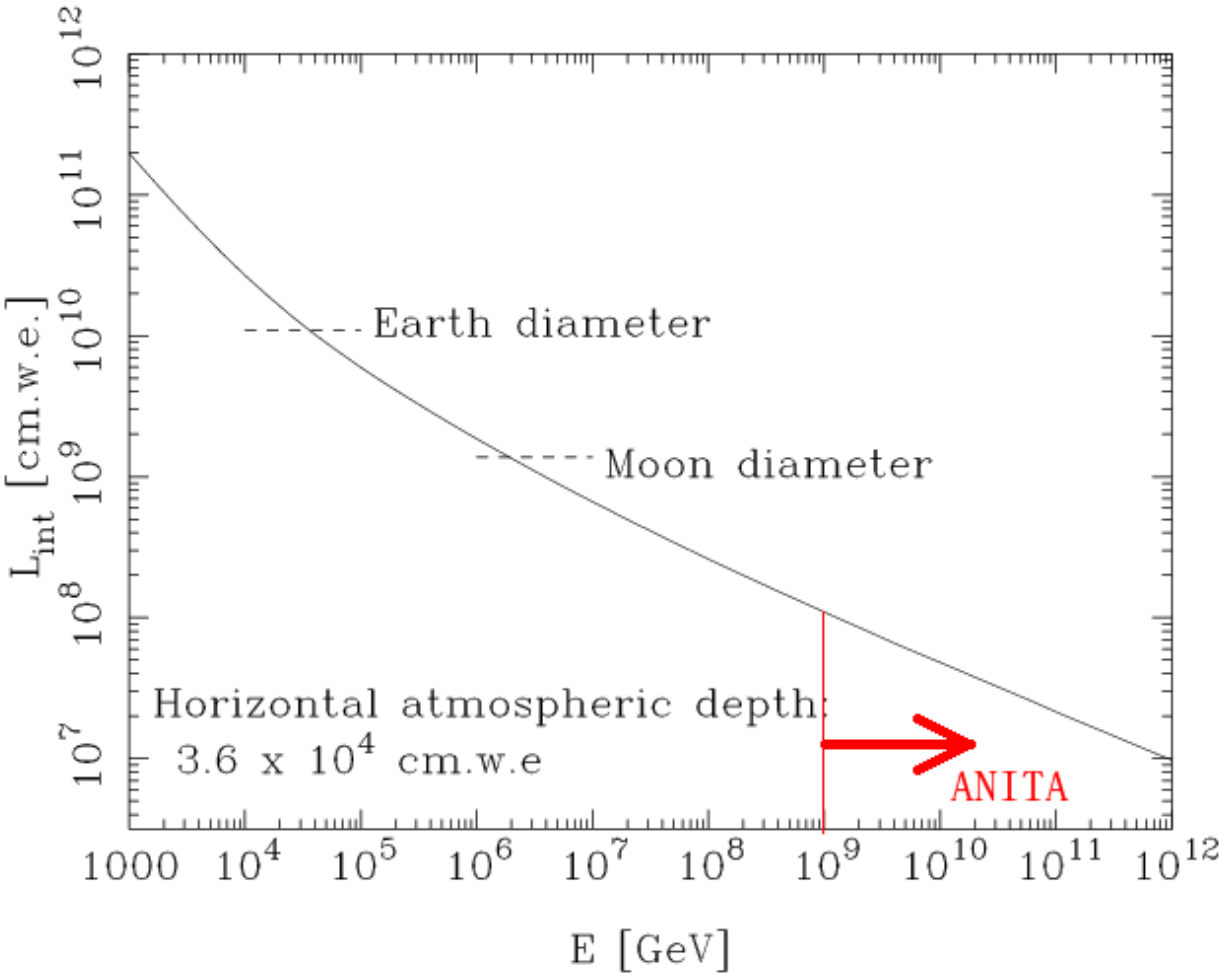
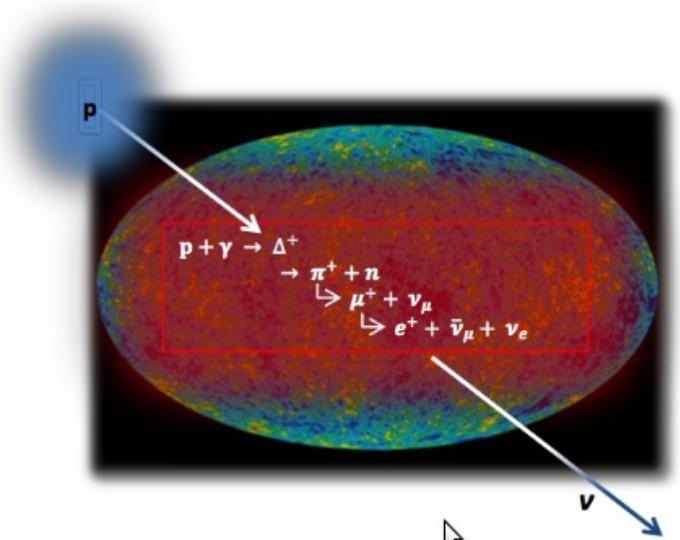


Figure : The neutrino interaction length (in centimeters water equivalent distance) [Astropart.Phys. 35 (2012) 383-395]

UHE Neutrino & GZK Effect



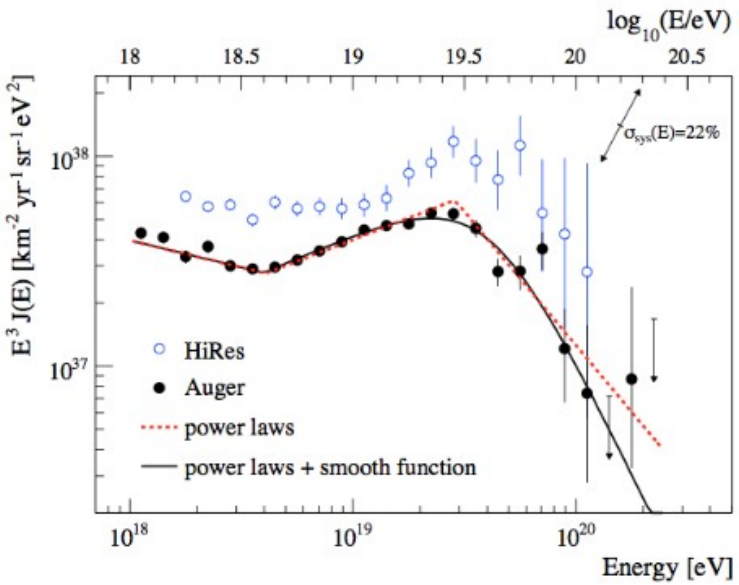
Auger and HiRes measurements of UHE cosmic rays consistent with GZK cut-off

Guaranteed GZK neutrino flux, but how large?

copy from Jonathan's slides

At energies above ~$10^{19.5}$eV cosmic rays will interact with CMB photons producing neutrinos

Process is known as the GZK effect



The Pierre Auger Collaboration (2010): Phys. Lett. B 685 (4–5): 239–246. HiRes Collaboration, Astropart. Phys. 32 (2009) 53.

GZK Radius

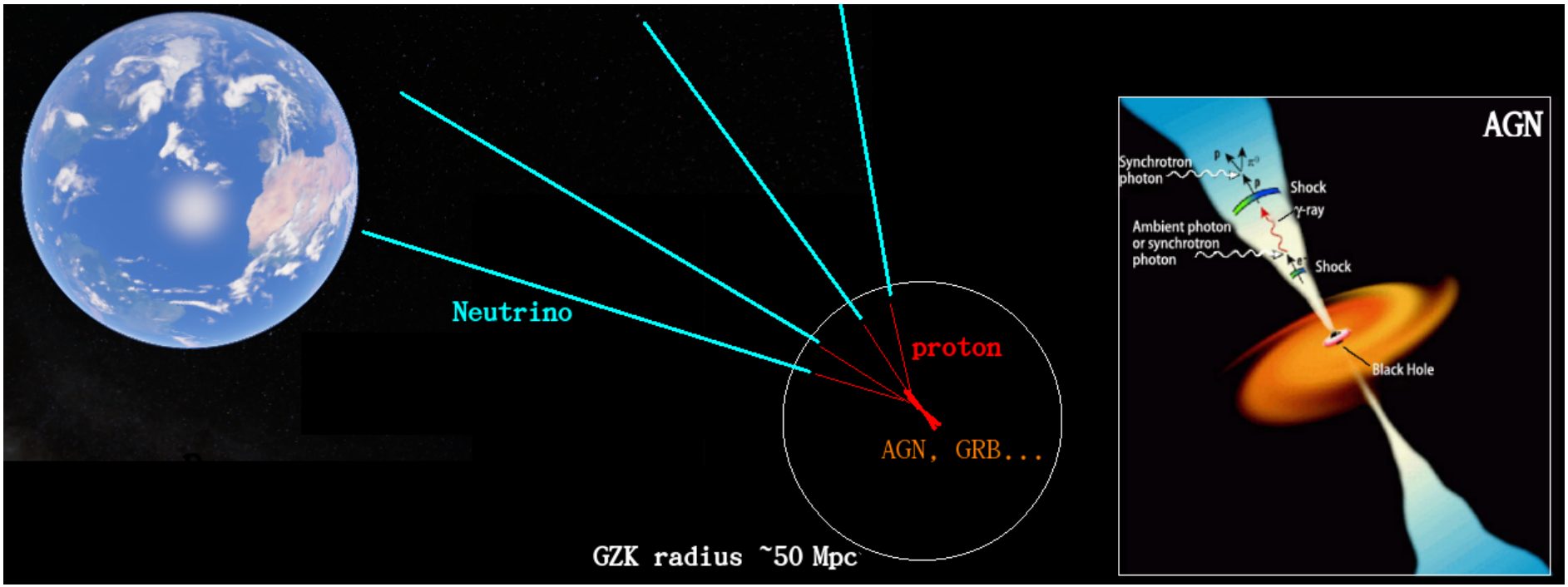


Figure : The UHE neutrinos can point back to the original UHE source without bending of B field.

Short Summary II: The UHE Neutrinos

- Trace particle UHECR hyper-accelerators to very early epochs

  Even at z˜10 or more, GZK neutrino energies peak at 10-100 PeV they all point back directly to the UHECR sources

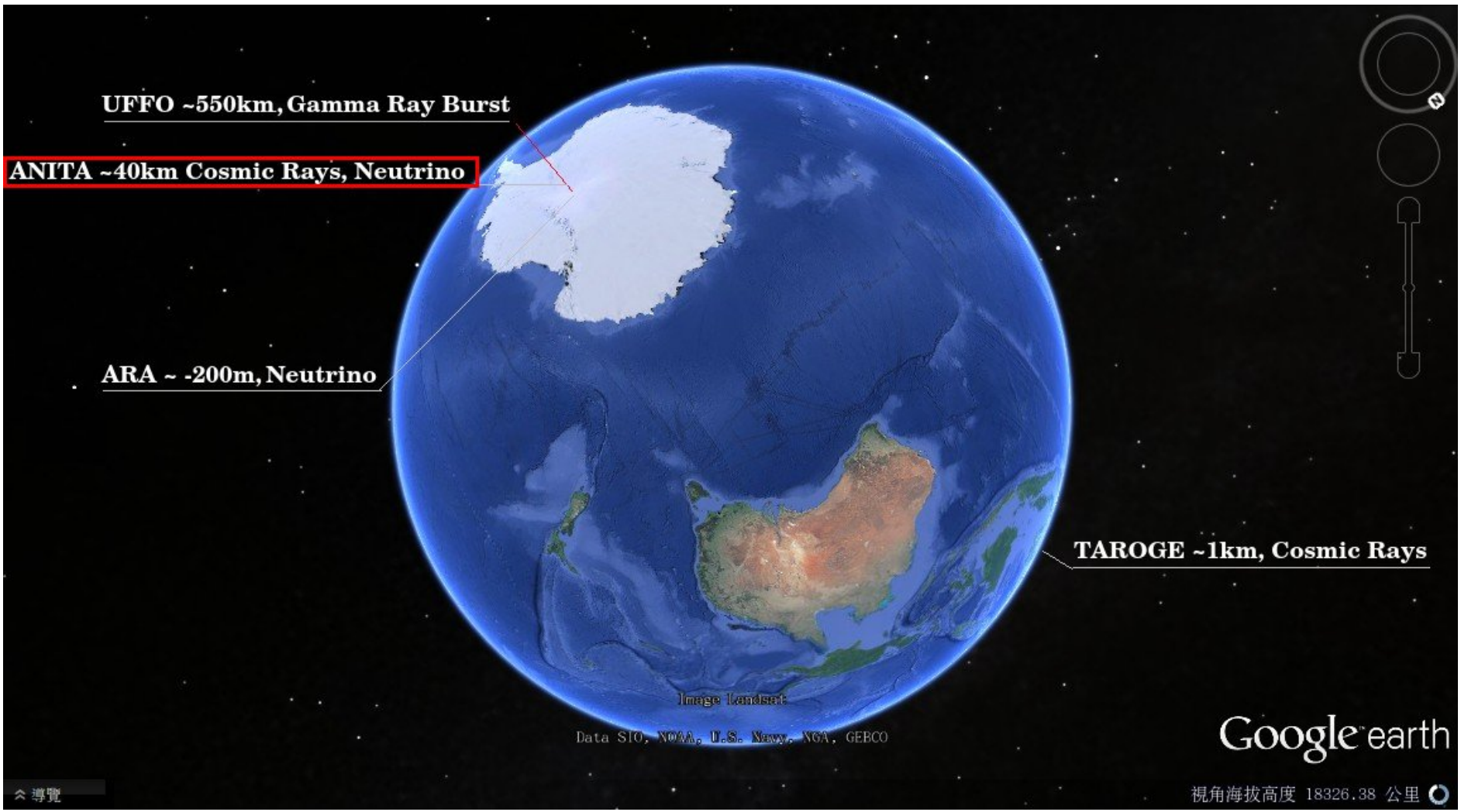
- Their flux is constrained by UHECR sources, once determined

  Can become a quasi-isotropic "test beam" of UHE neutrinos

- Neutrino Flavor physics

  Can encode source information by flavor ratio, even new physics (neutrino decay?)

The ANtarctic Impulsive Transient Antenna (ANITA)



UHE Neutrino Interact with Earth

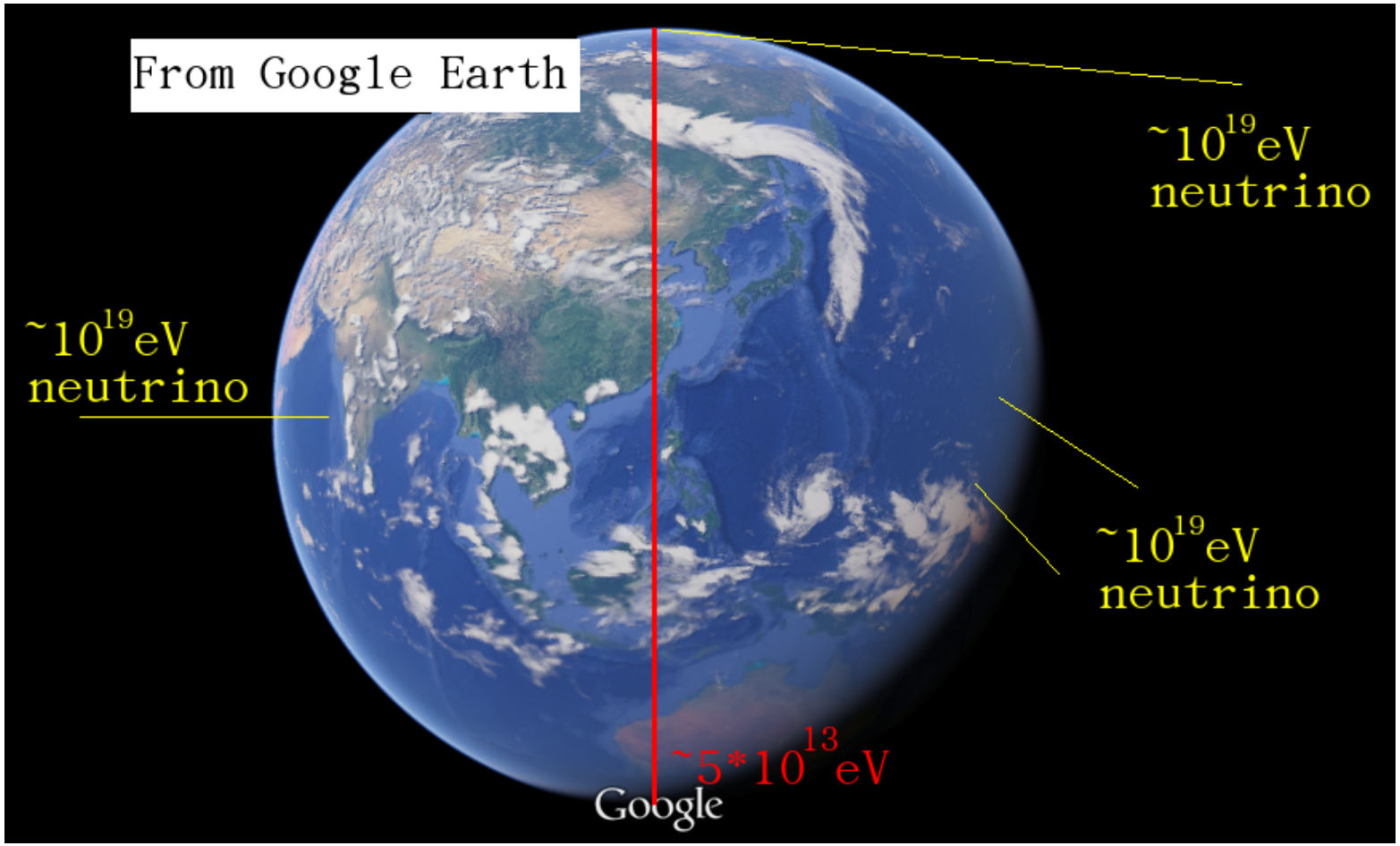


Figure : The interaction length of neutrino with $5 * 10^{13}$ eV is close to diameter of Earth. The interaction length for 10^{19} eV neutrino is $6 * 10^7$ g/cm^2

Take a Break

The ANITA Concept

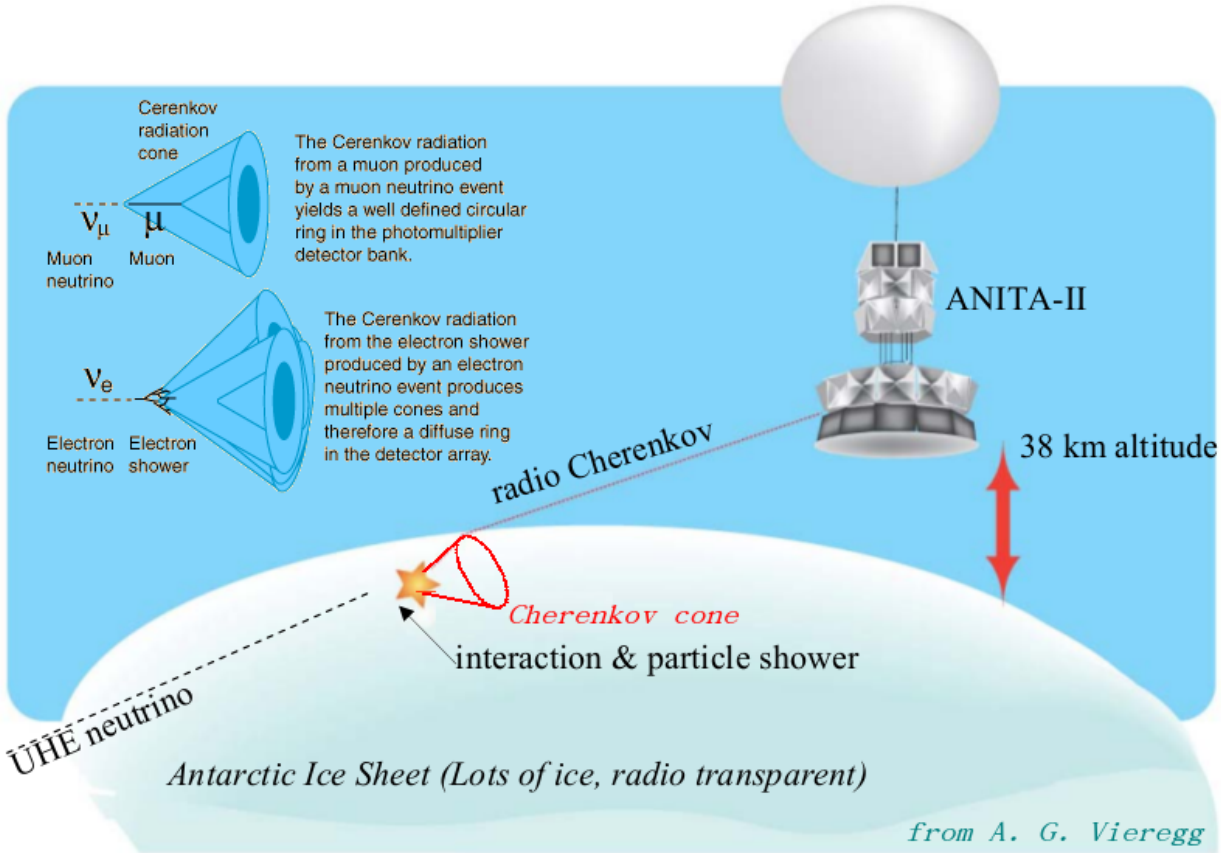


Figure : Cherenkov radiation is electromagnetic radiation emitted when a charged particle passes through a dielectric medium at a speed greater than the velocity of light in that medium.

Coherent Radio Emission (Askaryan Radiation)

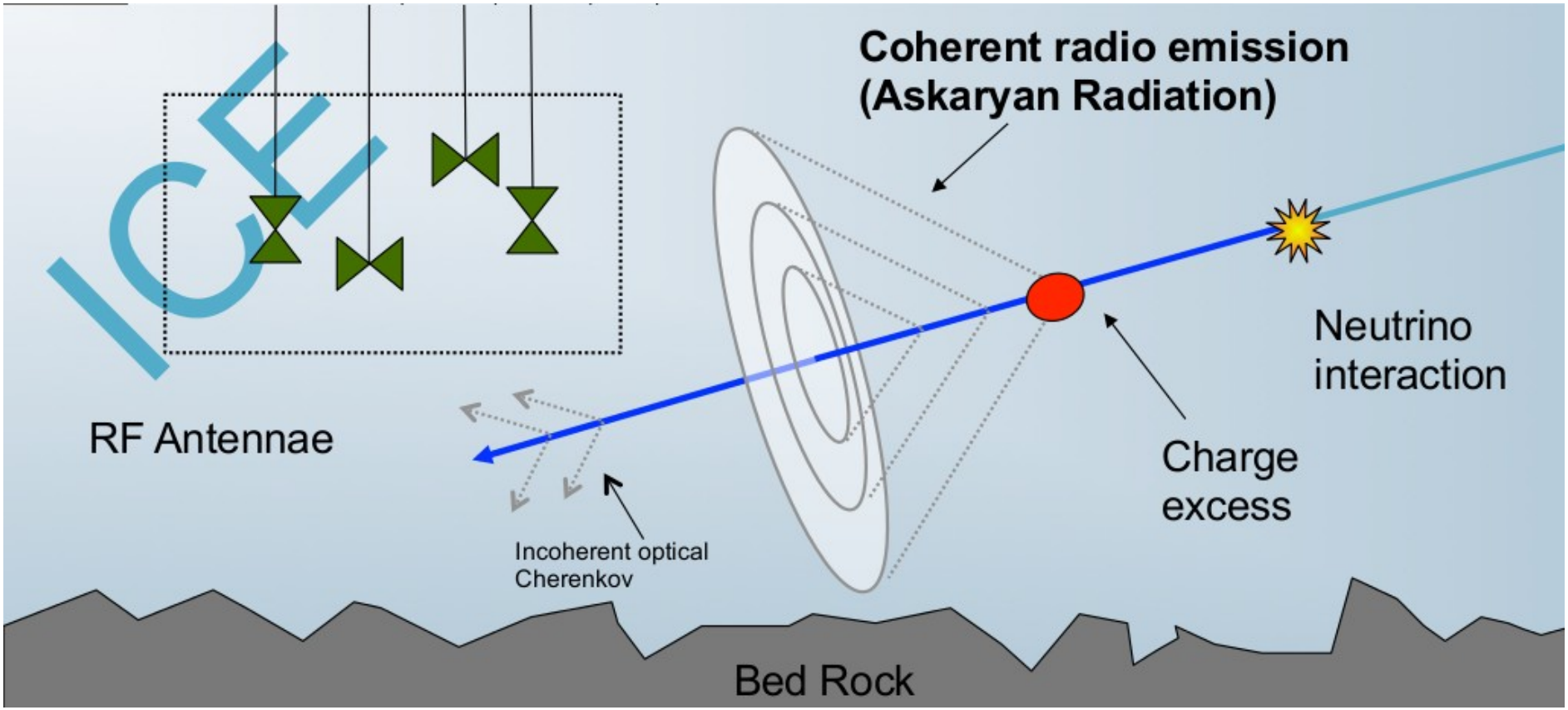
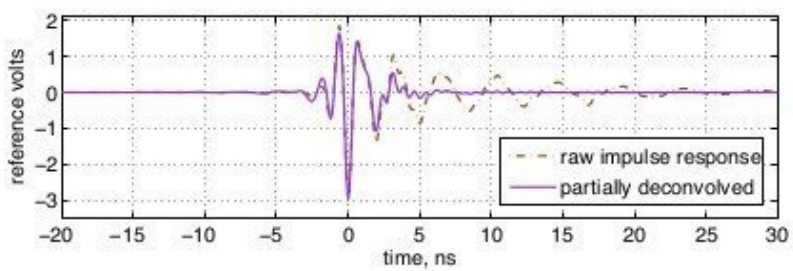


Figure: Detect radio emission from neutrino induced particle cascades in ice

Askaryan Radiation Experiment in SLAC

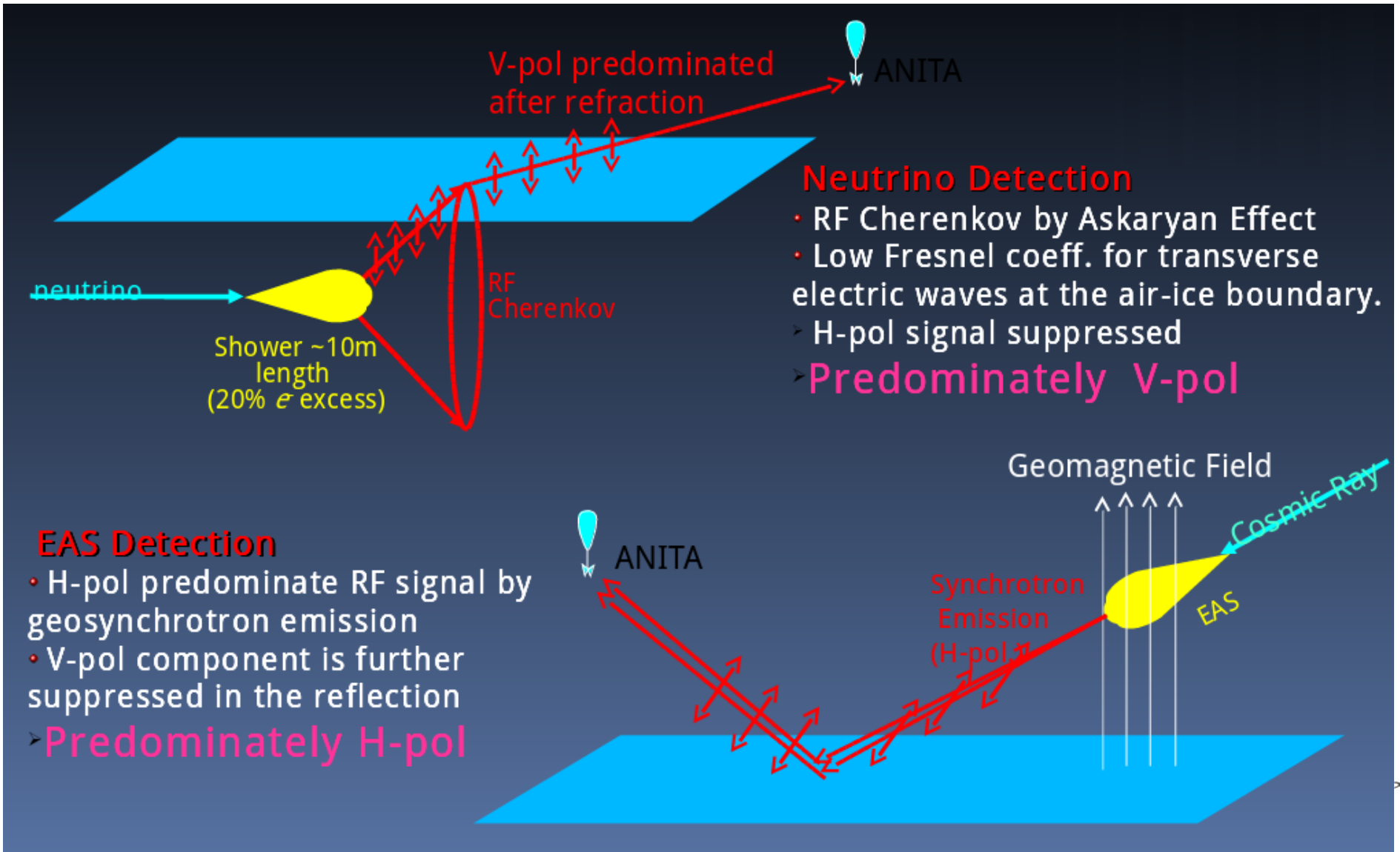
Askaryan effect in
sand(2000)
rock salt(2003)
and ice(2006)



PRL 99, 171101 (2007)
see also:
PRE 62, 8590 (2000),
PRL 86, 2802 (2001),
PRD 72, 023002 (2005)
PRD 74, 043002 (2006)

copy from Ryan's slides

Signal Type (neutrino VS. EAS)



Setup of T-510 (Geo-Synchrotron Radiation)

Figure : Electron beam creates secondary cascades in a 4 m long high-density polyethylene(HDPE) target placed in a magnetic field(up to 1000G).

ANITAs

ANITA - lite
2003
LDB,Texas

ANITA
2006-2007
Antarctica

ANITA-II
2008-2009
Antarctica

Figure : Before 2010, we already launched 2 balloons in Antarctica.

Flight Path of ANITA & ANITA-II

- Over 65 days of flight over Antarctica
- Over 35 million triggered (noise) events

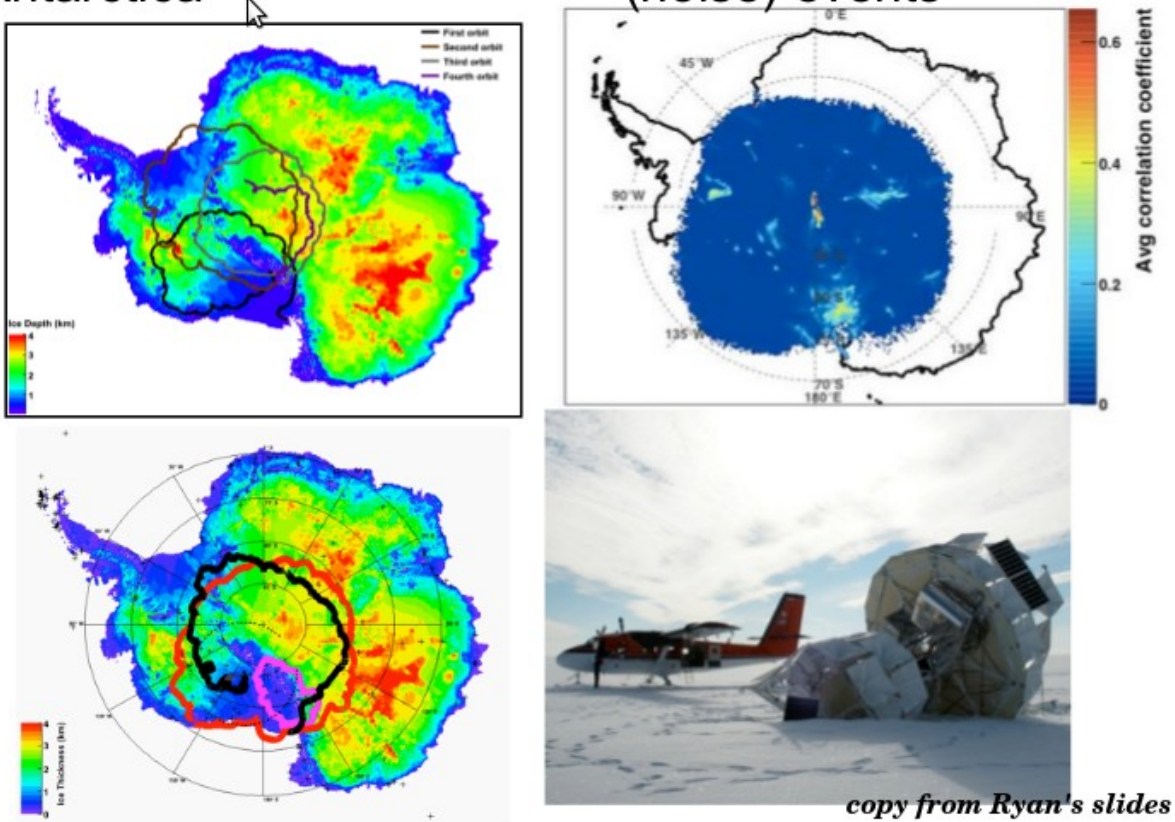


Figure : flight path of ANITA & ANITA- II.

FoV of ANITA

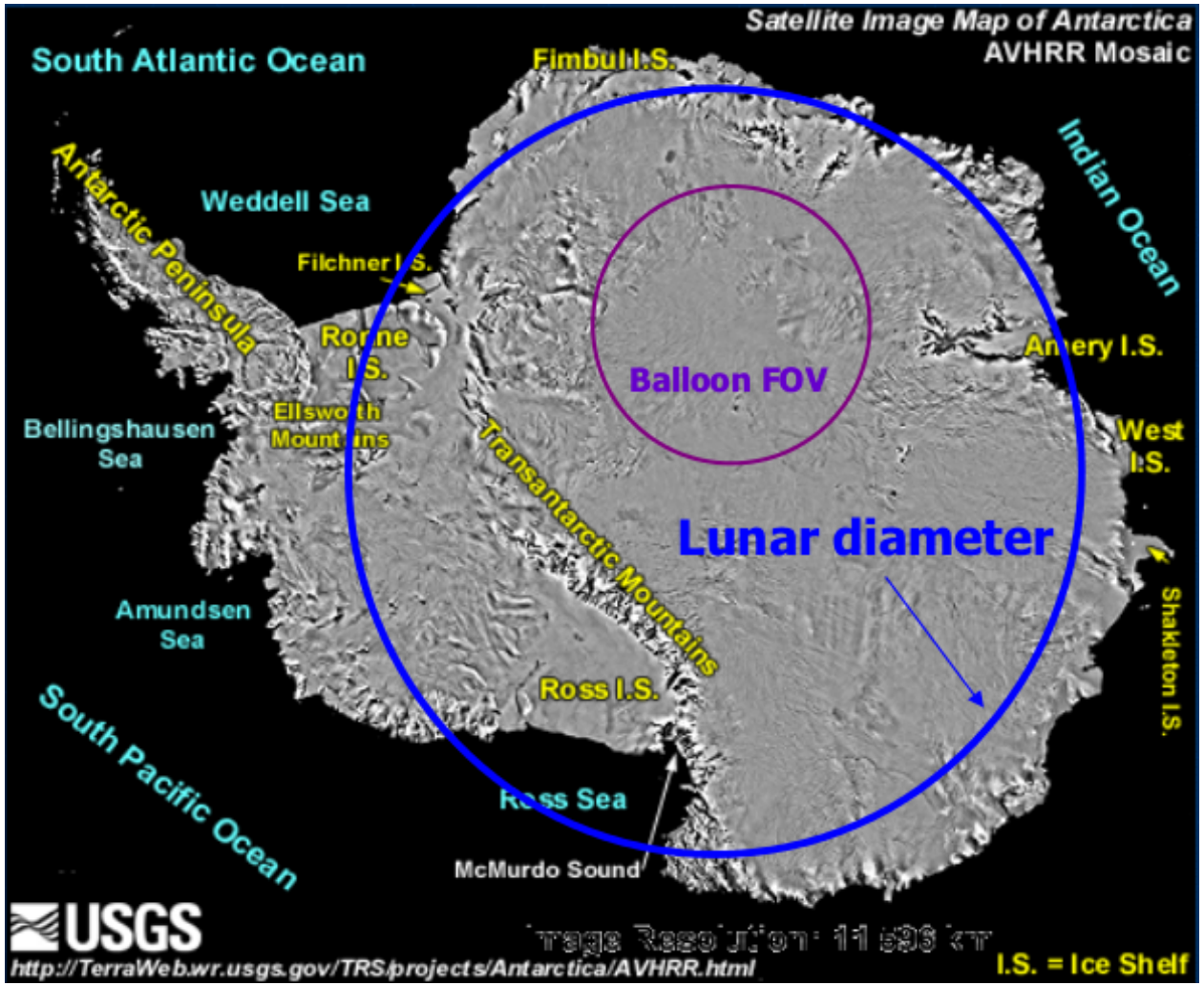
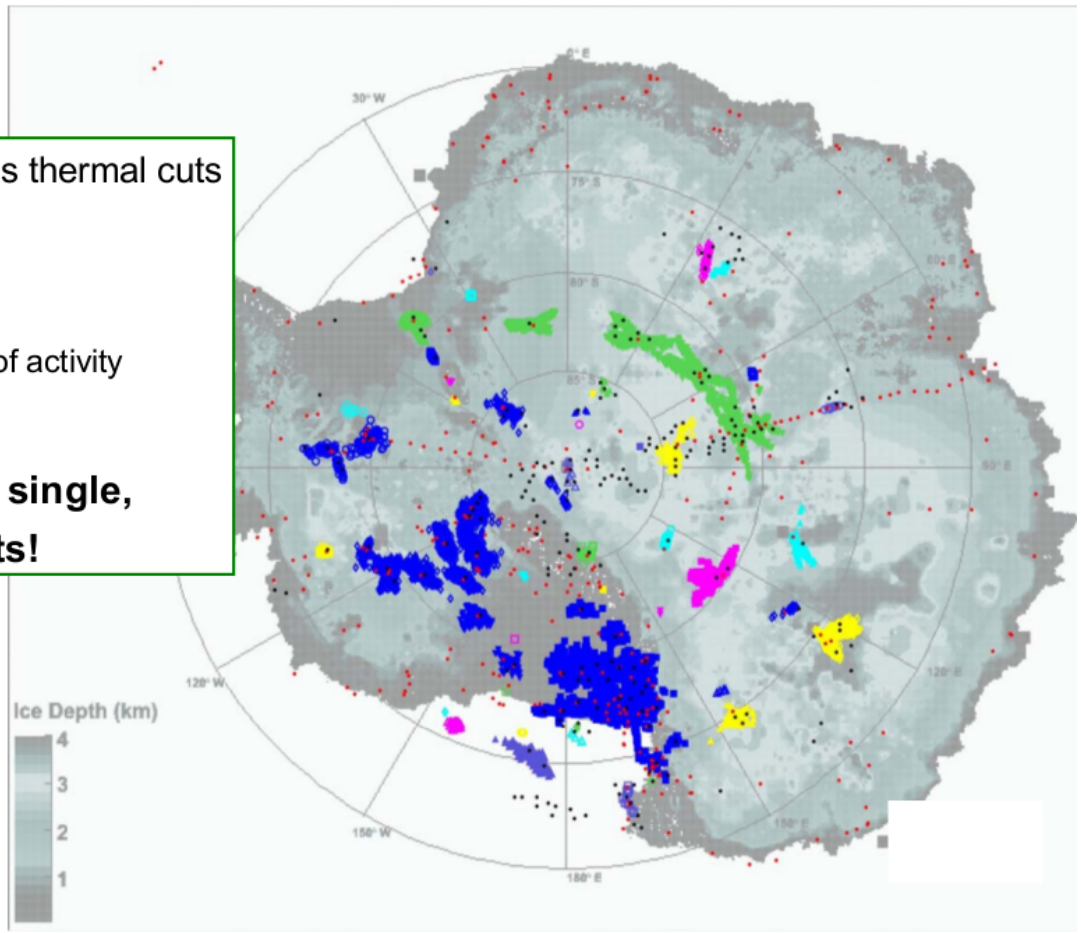


Figure : The radius of FoV is about 500km.

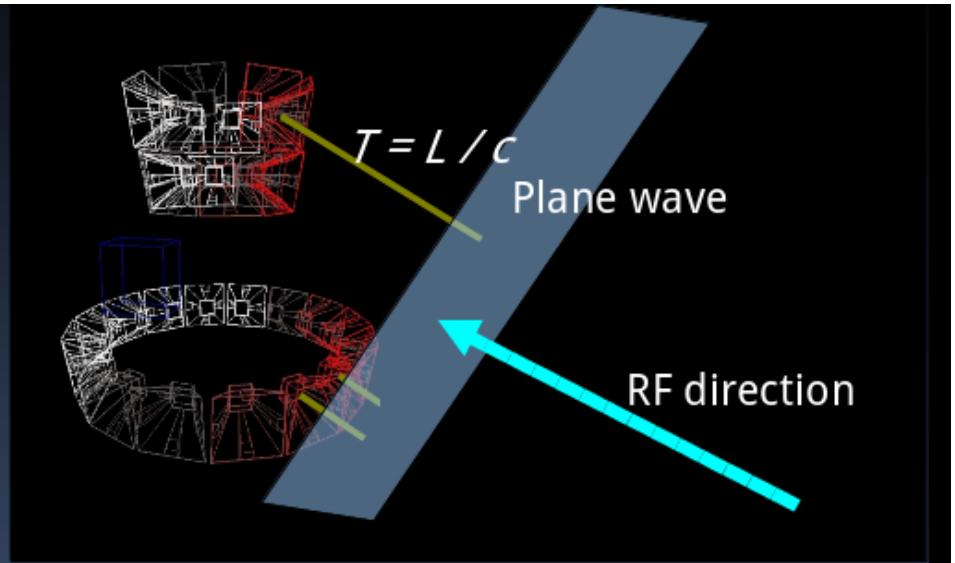
Man-Made EVENTs of ANITA

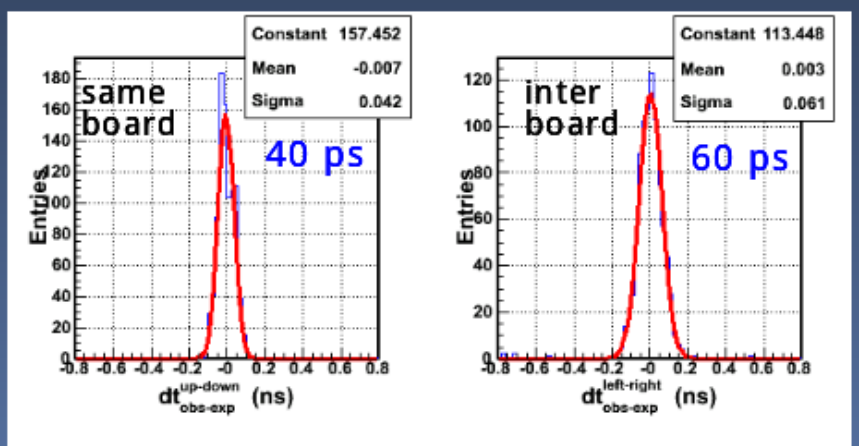
- 300k events pass thermal cuts
- Cluster with:
  - Other events
  - Known bases of activity
  - "Hot-Spots"
- **Neutrinos are single, isolated events!**



Event Reconstruction

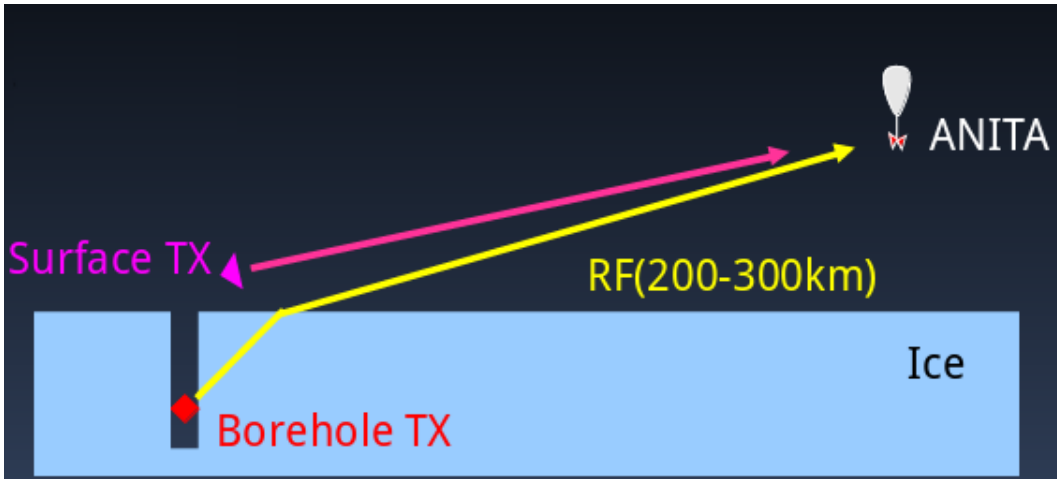
- Angular reconstruction is a crucial part in the ANITA data analysis.
- Powerful background rejection
  - incoherent thermal events (99% of data set)
  - anthropogenic RF events from existing bases
  - air shower RF events.
- Neutrino reconstruction
  - neutrino direction information
  - provides R and refraction angle for energy measurement.
- Angular reconstruction using timing.
- time resolution; 40-60 ps
  - (time difference between channels)
- Achieved angular resolution;
  - 0.2° (zenith) and 0.8° (azimuth.)

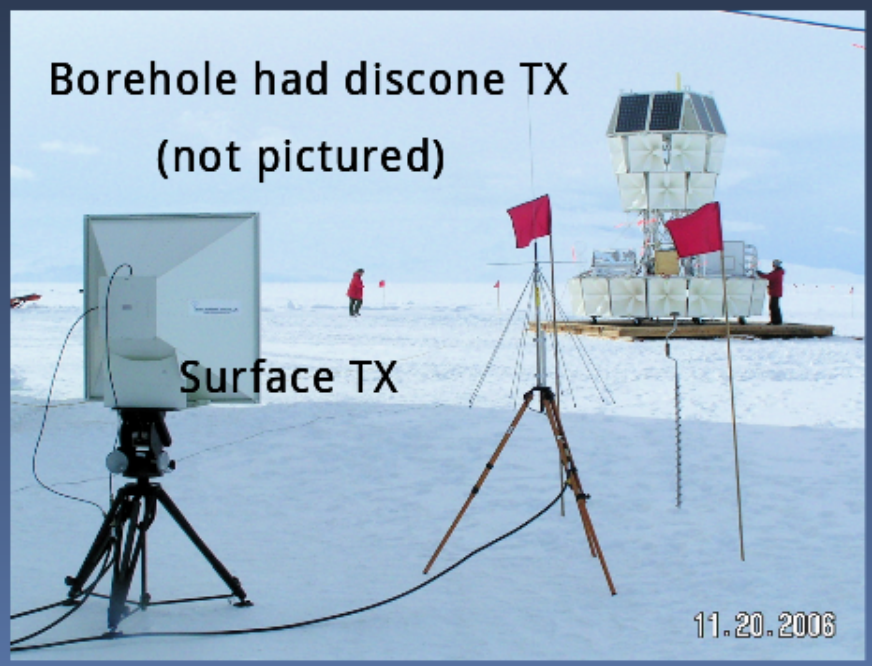


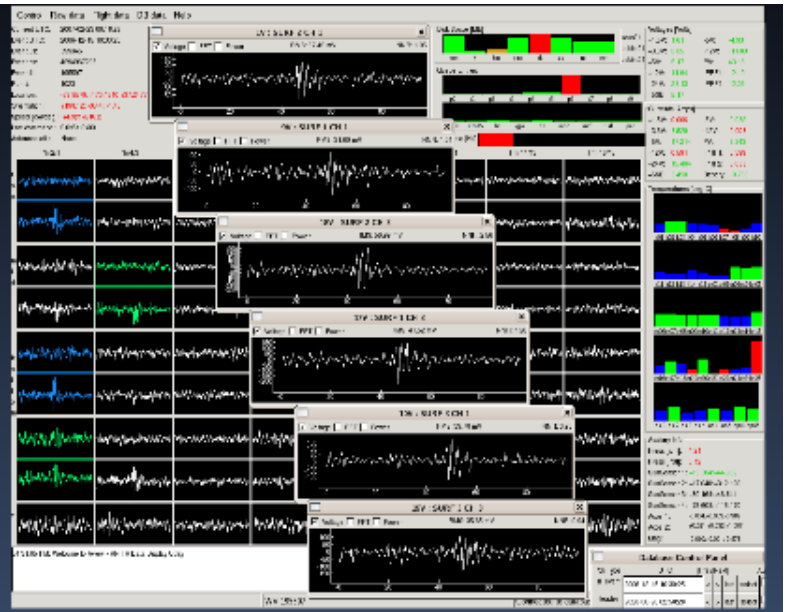


from Jiwoo Nam

Ground Pluser System



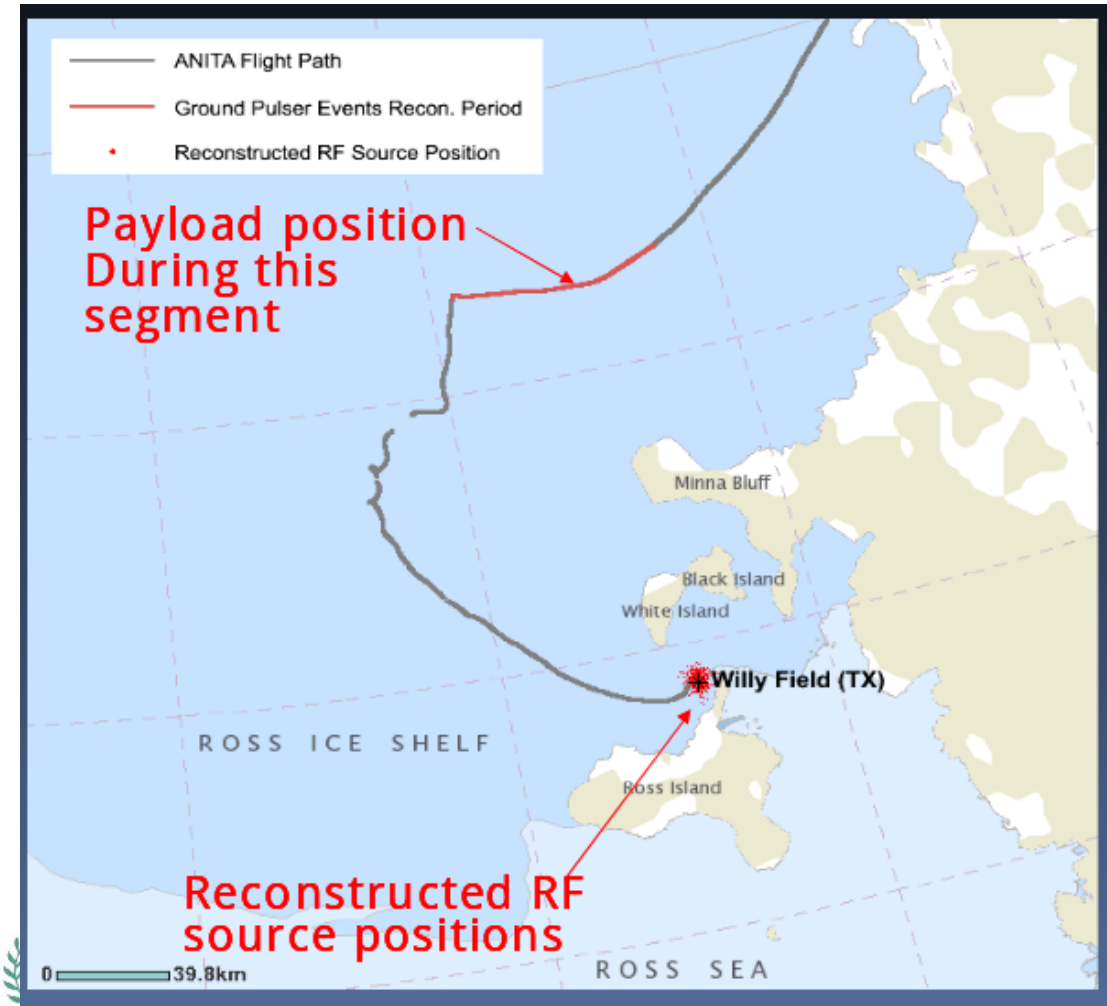


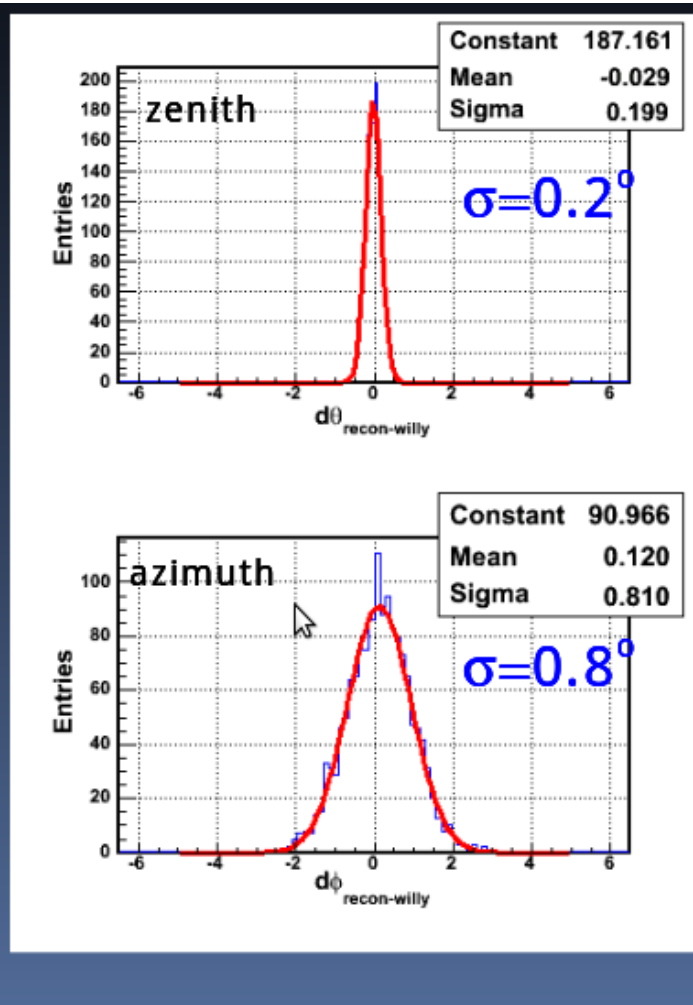


borehole pulse event

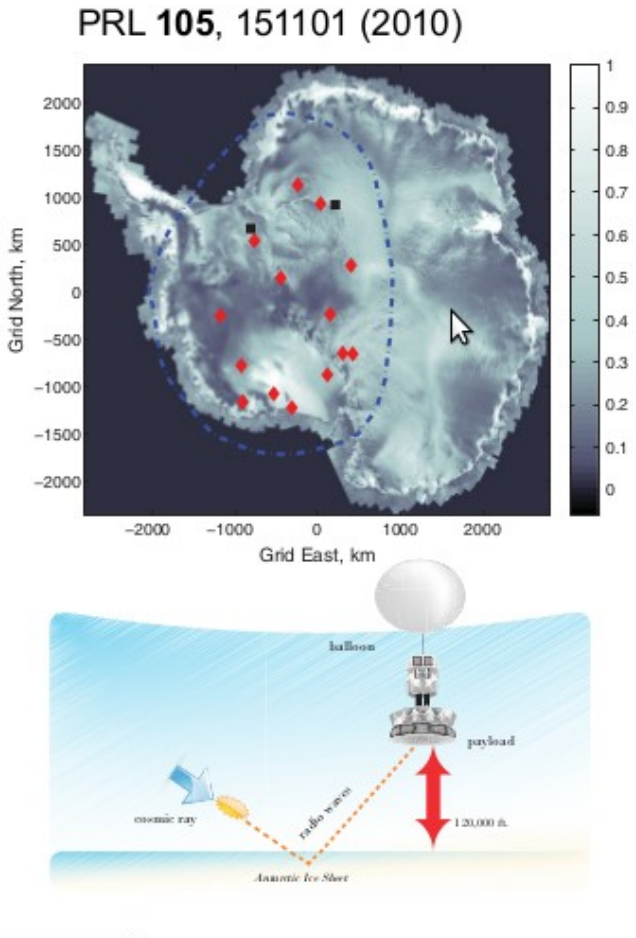
- Two Ground Pulser Systems @Williams Field and Taylor Dome
- System Verification
- Trigger Test
- Propagation and Surface
- Timing / Angular Resolution

Angular Resolution





Results of ANITA I & II (cosmic rays)



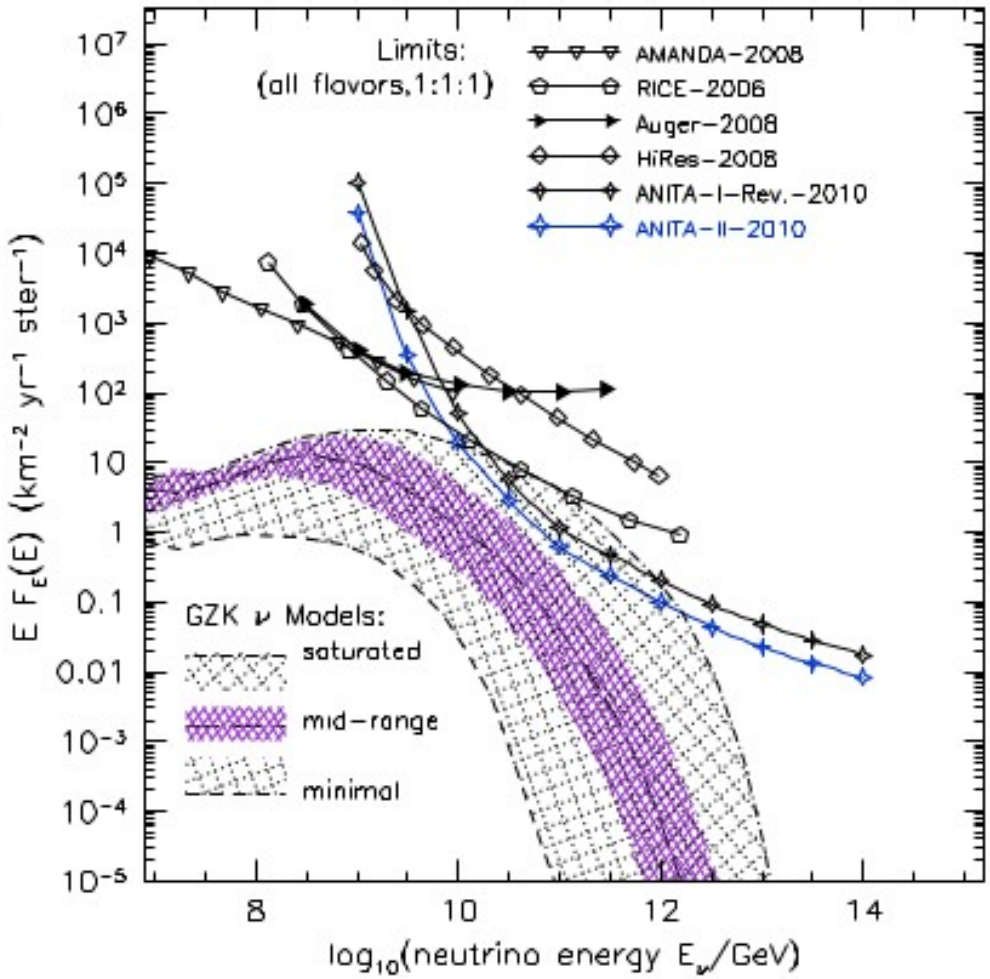
- A combination of **vxB** and Fresnel coefficients result in air shower emission being horizontally polarised at the payload
- ANITA-I detected 16 isolated H-pol candidate UHECR events
- ANITA-II did not trigger on the H-pol channels
  – Doh!!
- Still detected 5 UHECR candidate events

Results of ANITA I & II (Neutrino)

- ANITA-II Results

Isolated v-pol events	1
Expected background events	0.97 ± 0.42

- Combine with efficiency to extract world's best limit on UHE neutrino flux above 10^{19}eV



The ANtarctic Impulsive Transient Antenna (ANITA-III)

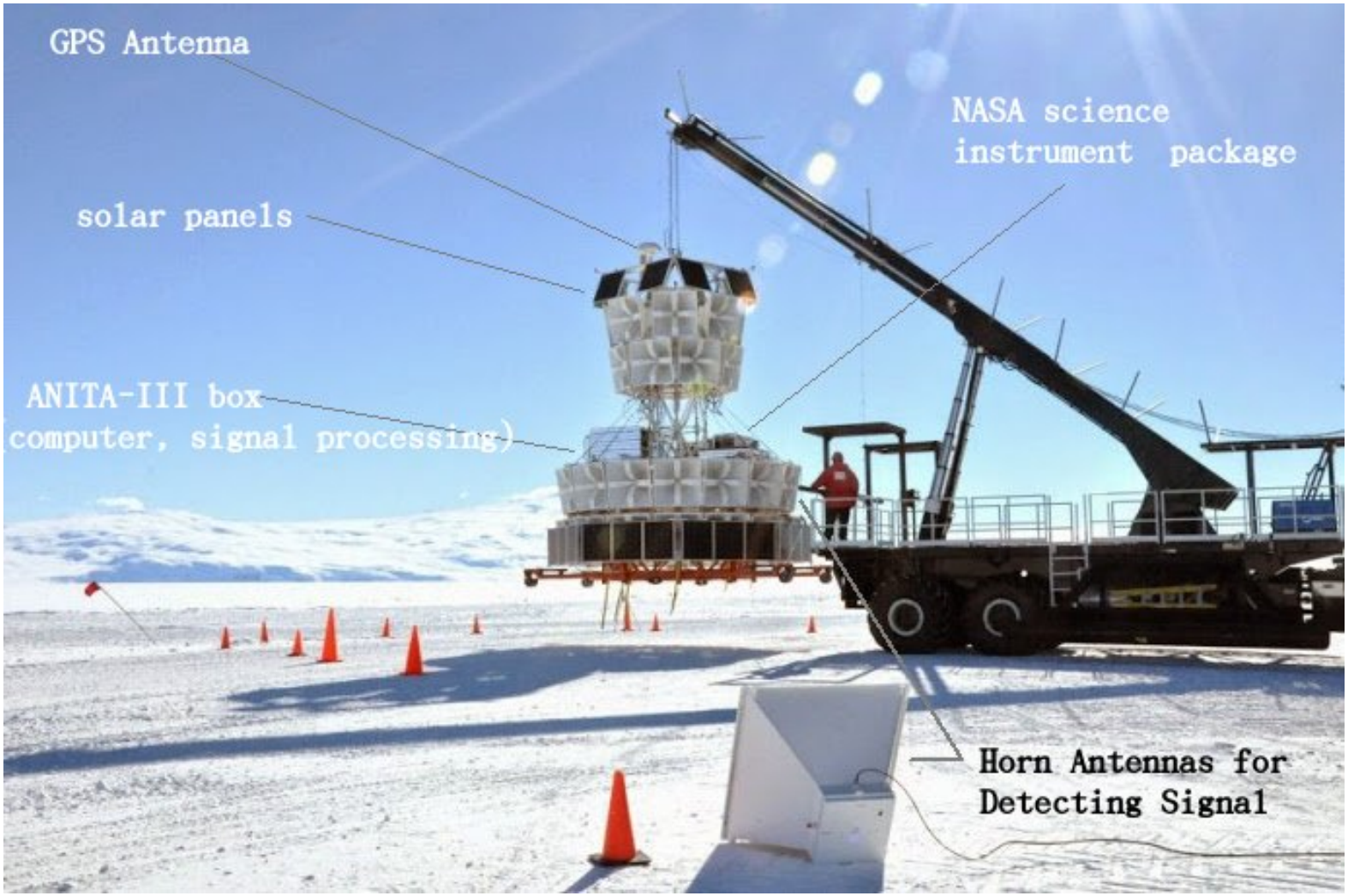


Figure : ANITA-III instrument, 2014-1015.

Flight Path of ANITA-III 2014-2015

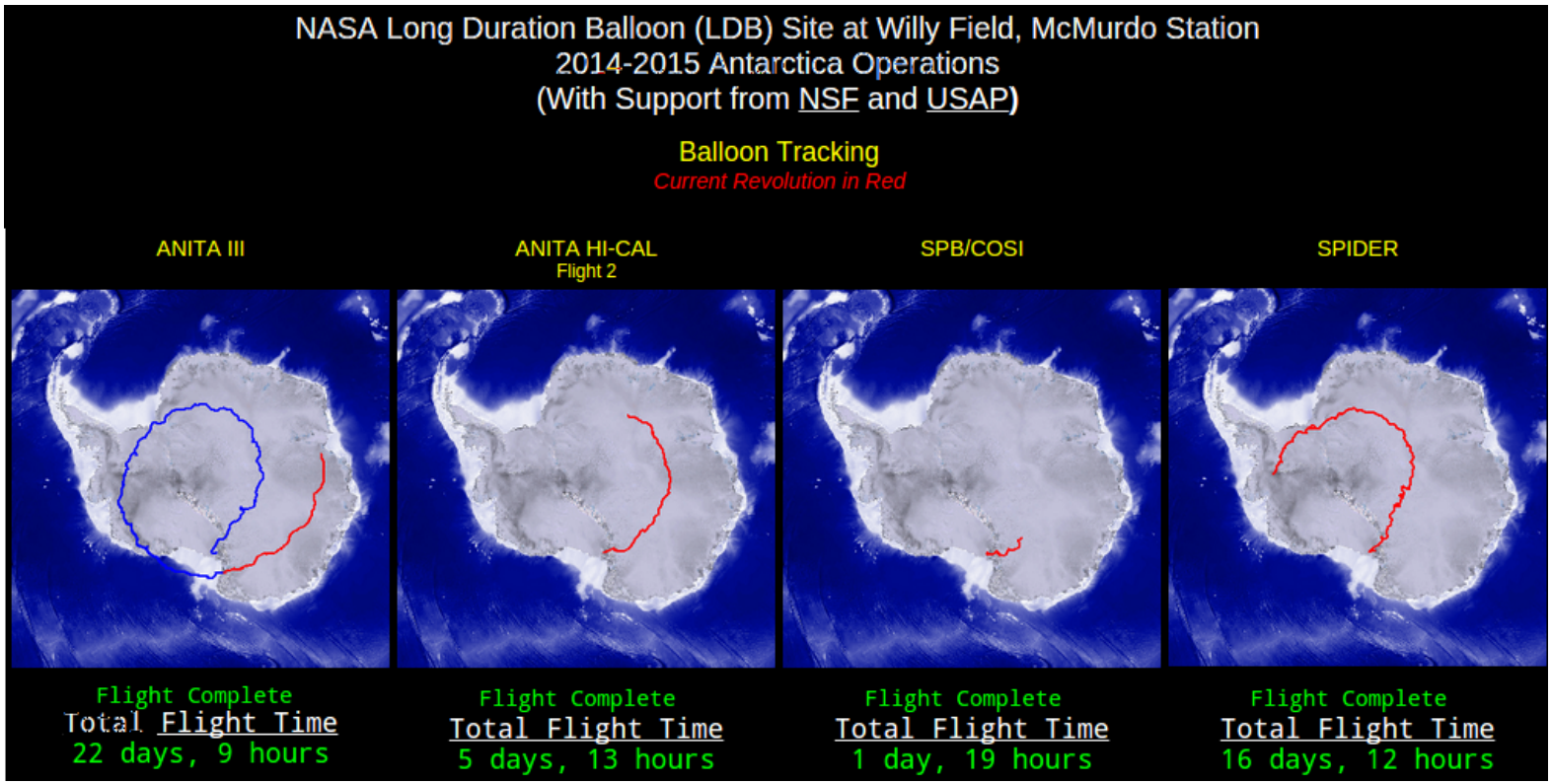
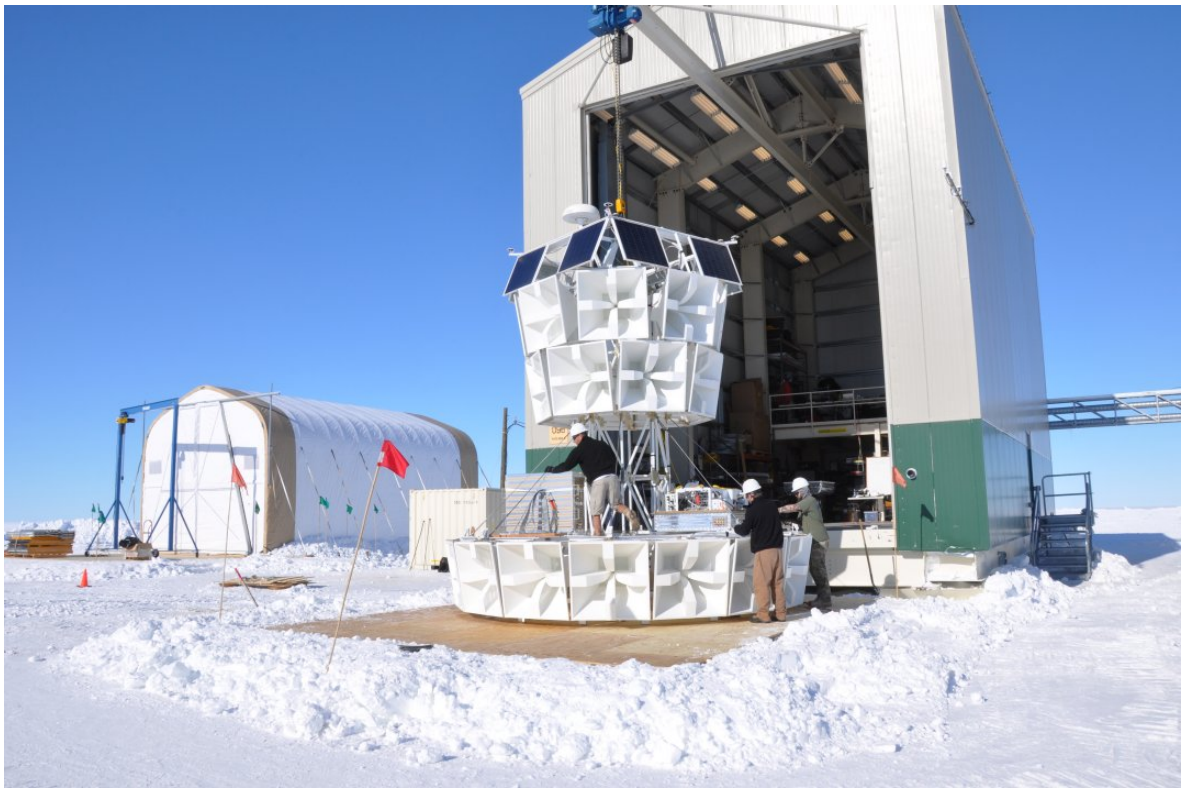


Figure : Flight path of ANITA III.

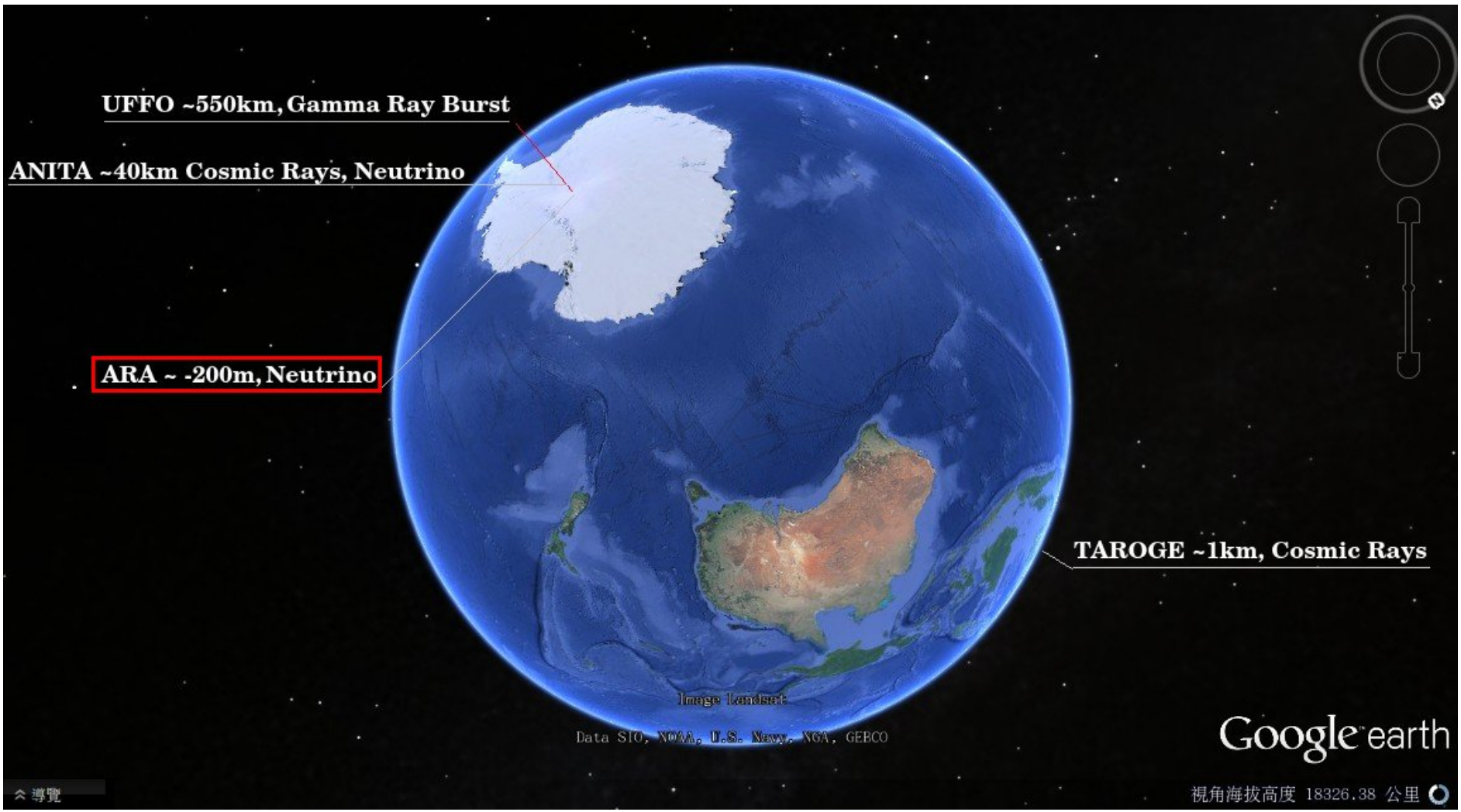
http://www.csbf.nasa.gov/antarctica/payloads.htm

Time for video

Time for Video !!!



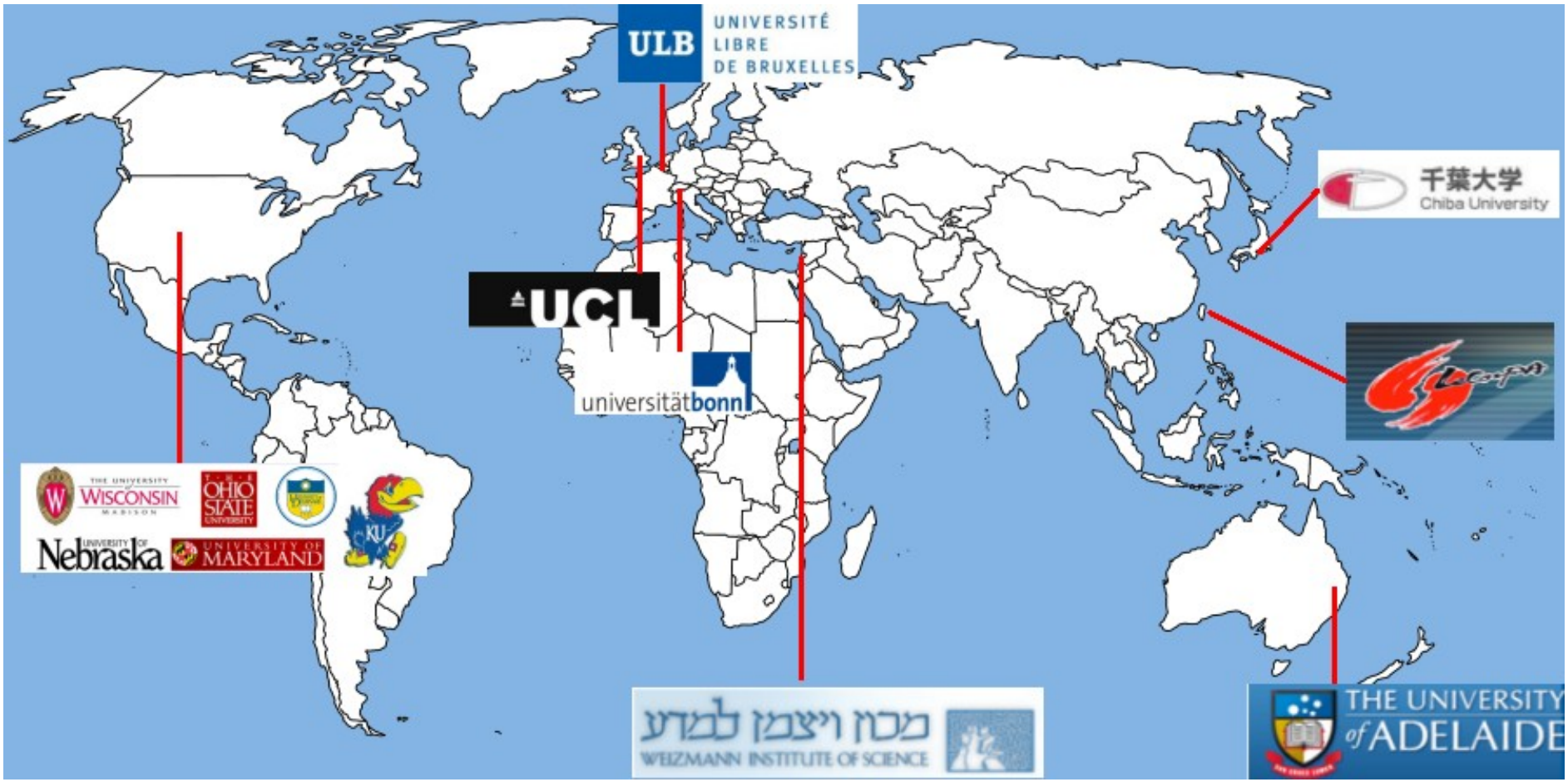
ARA at -200m


UFFO ~550km, Gamma Ray Burst
ANITA ~40km Cosmic Rays, Neutrino
ARA ~ -200m, Neutrino
TAROGE ~1km, Cosmic Rays
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth
導覽
視角海拔高度 18326.38 公里

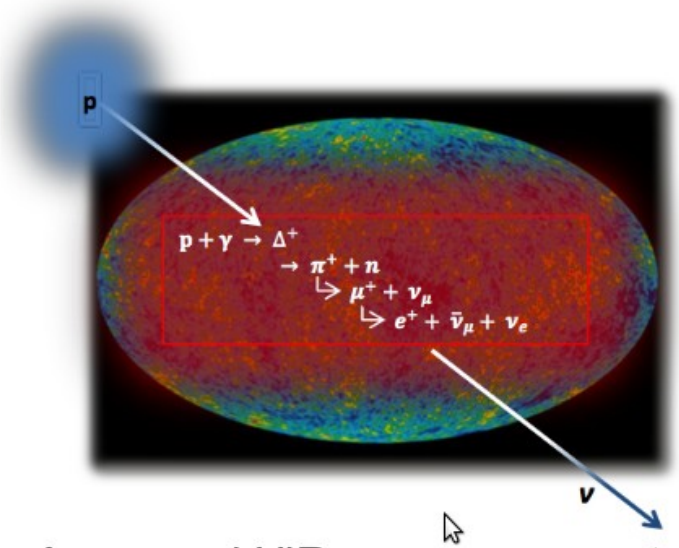
ARA at -200m


The Askaryan Radio Array (ARA)
Detecting Neutrinos in Antarctica
NTU
NTU

The ARA Collaboration



The Askaryan Radio Array (ARA) is an Ultra High Energy (UHE) Neutrino Detector at the South Pole



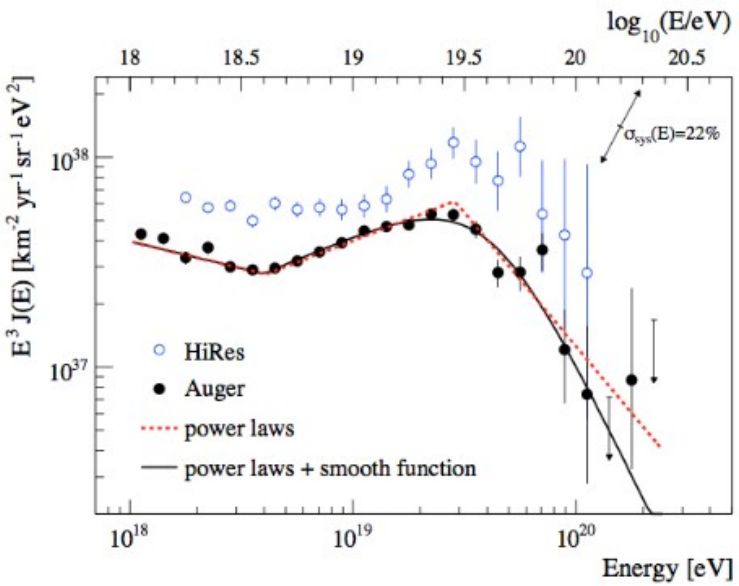
Auger and HiRes measurements of UHE cosmic rays consistent with GZK cut-off

Guaranteed GZK neutrino flux, but how large?

copy from Jonathan's slides

At energies above ~$10^{19.5}$eV cosmic rays will interact with CMB photons producing neutrinos

Process is known as the GZK effect



The Pierre Auger Collaboration (2010): Phys. Lett. B 685 (4–5): 239–246. HiRes Collaboration, Astropart. Phys. 32 (2009) 53.

ARA-37

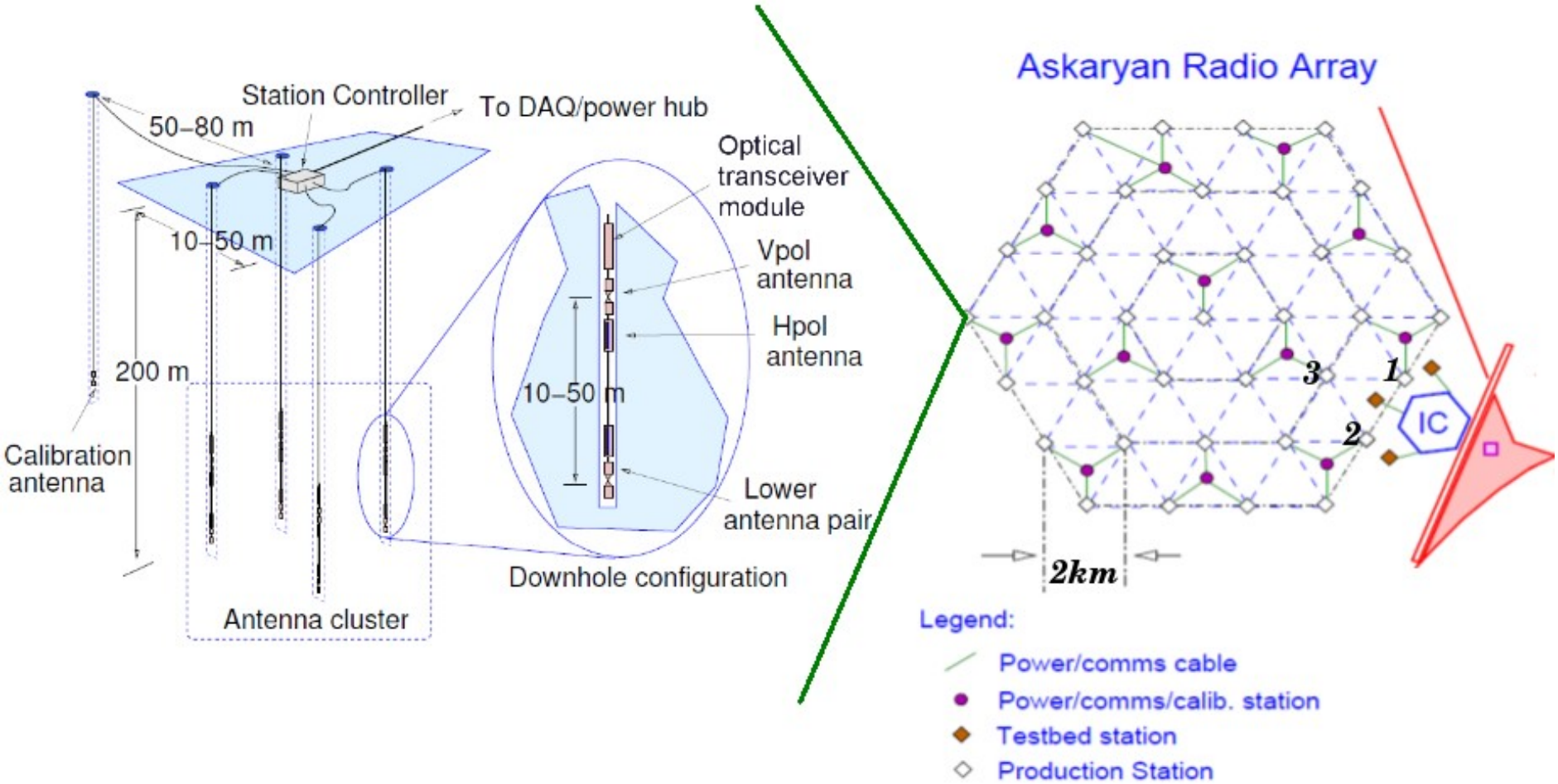


Figure : ARA 37 Layout, 37 Stations 200m below the surface$\sim$200km^2 coverage

DAQ System and Antenna Cluster

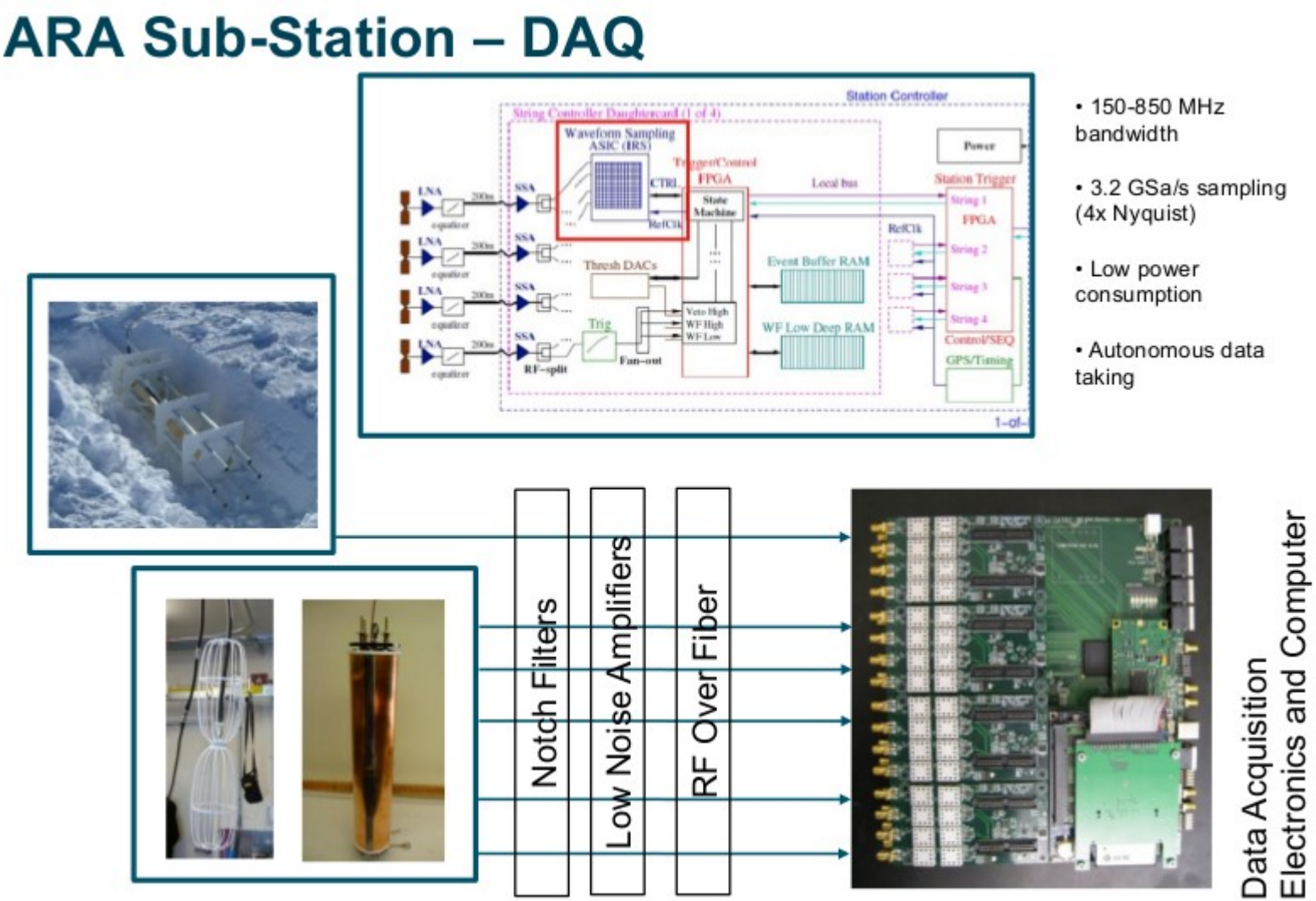
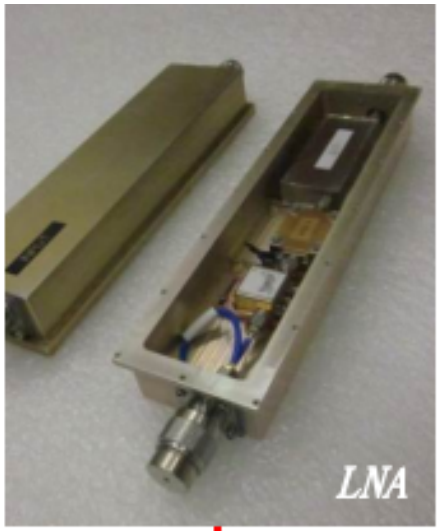


Figure : Each station has 4 string with 16 channels

DAQ System and Antenna Cluster



Build & Test in Taiwan

Figure : Building ARA2 & ARA3 last year

Delivery

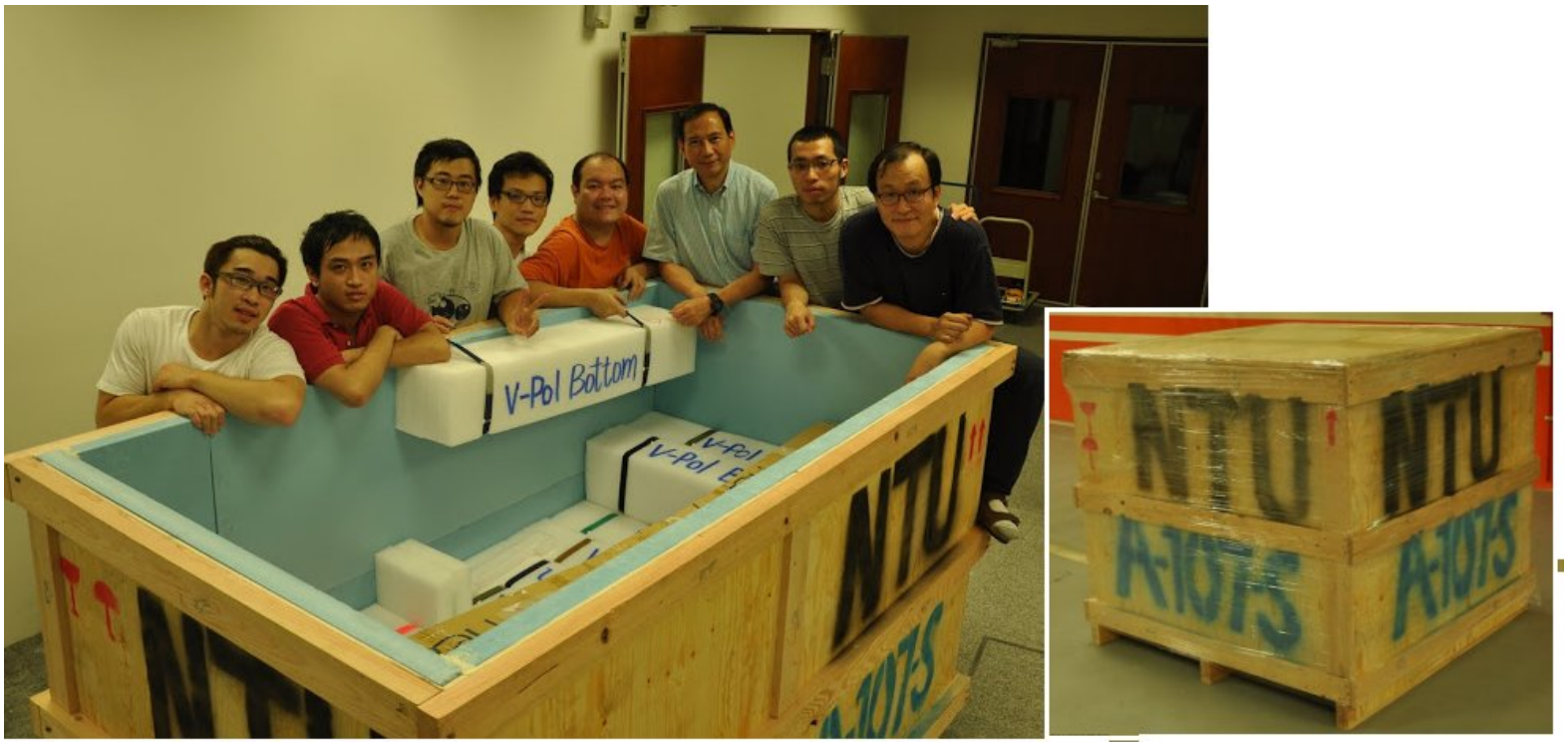
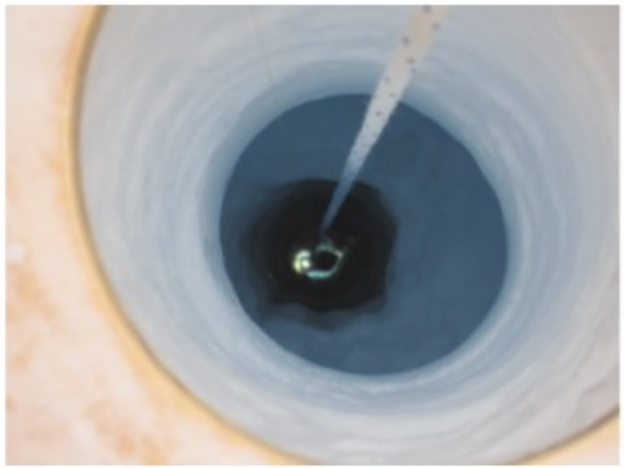


Figure : delivery for 2 stations

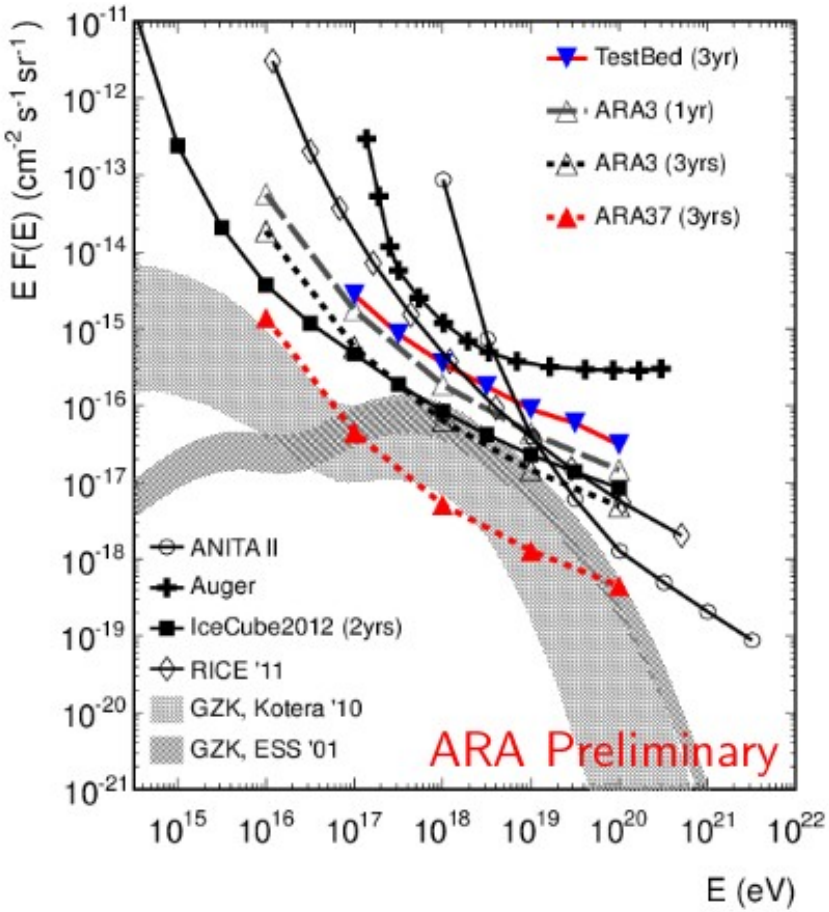
Drilling and Deployment

- Hot water drill creates 6" wide holes
- Holes are pumped dry
- Approaching $\sim$ 8 hr $\times$ $\sim$ 1 drill crew per 200 m hole
- Instrumentation deployed from greenhouse sled



Simulation & Expected Sensitivity

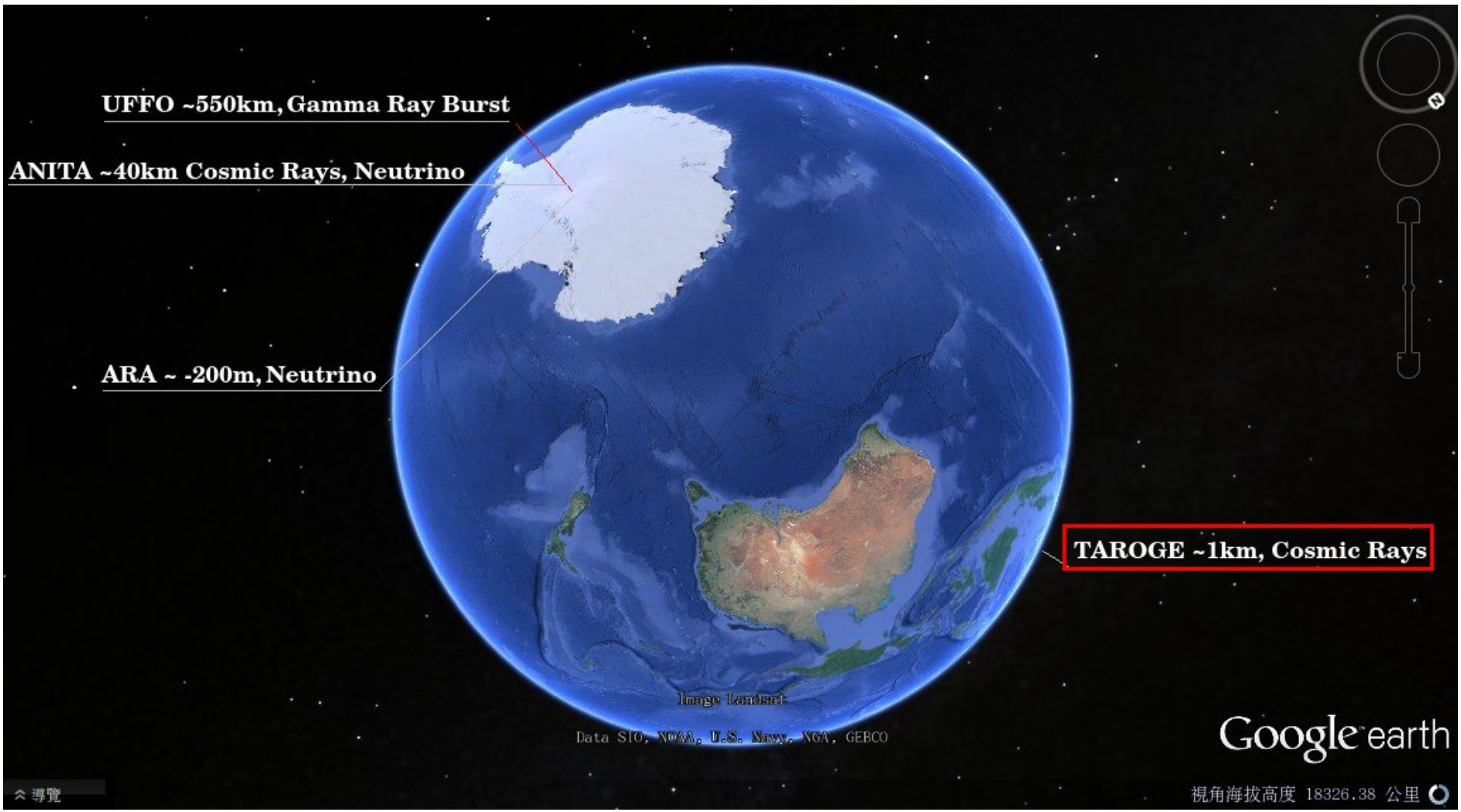
- In-house tool called `AraSim`
- Simulates
  - → neutrino interaction
  - → radio emmission
  - → radio propagation
  - → instrument response
  - → thermal, instrument noise
  - → hardware trigger
  - → digitized waveforms
- Has been used to calculate trigger-level neutrino sensitivity



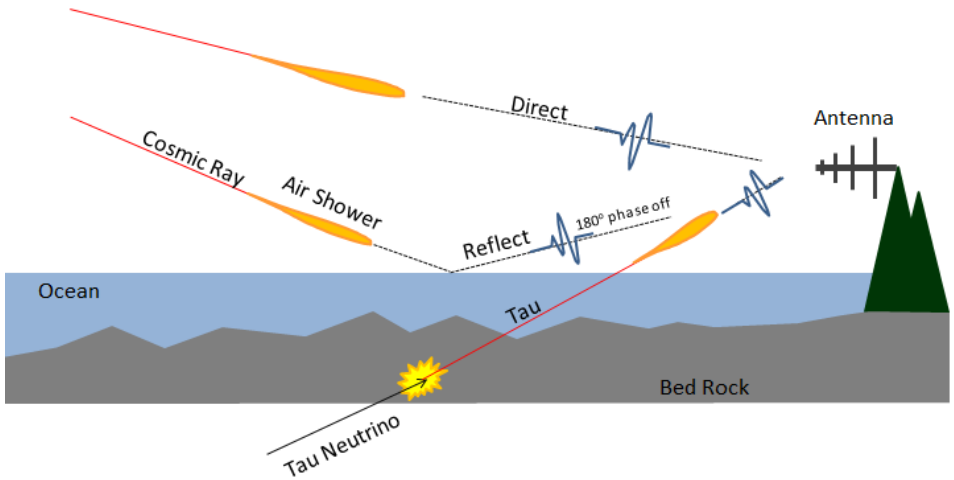
Future Plans

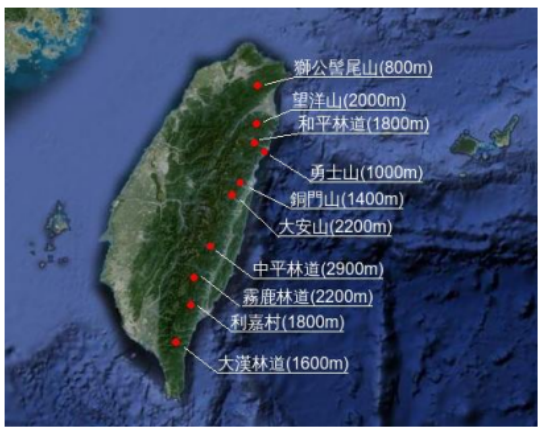
- ANITA-4 (2017): Neutrino & cosmic rays
- SWORD(TBD) :cosmic rays
- ARA37 (within 10 years): Neutrino
- TAROGE-10 (within 4 years): Neutrino & cosmic rays

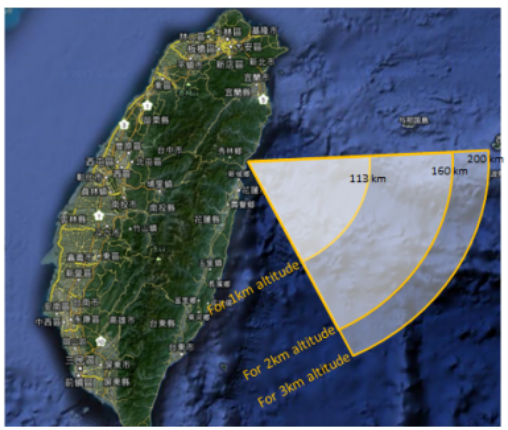
Outline: The Distribution of Experiments



Taiwan Astroparticle Radiowave Observatory for Geo-synchrotron Emission(TAROGE)



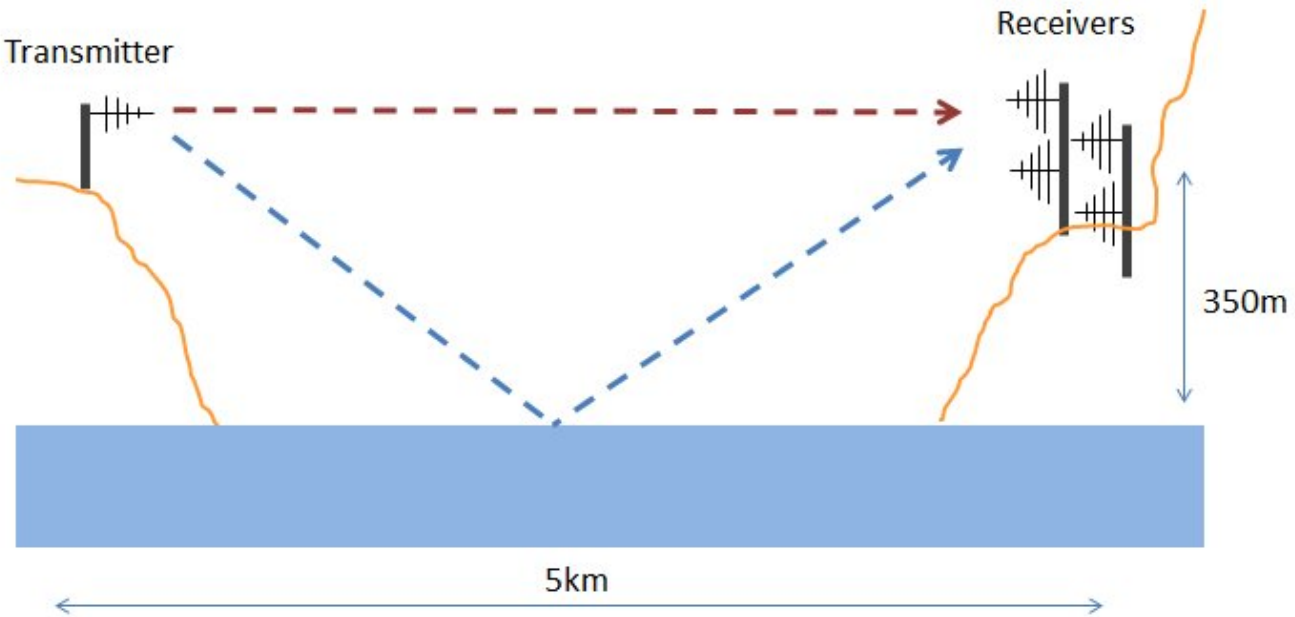


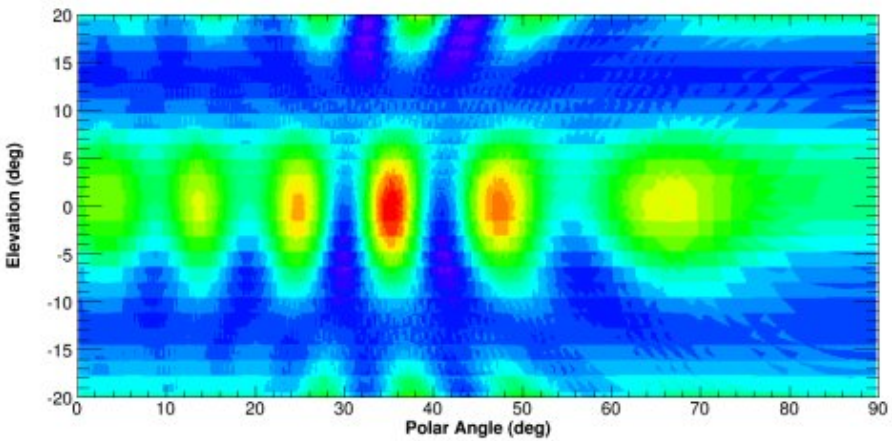


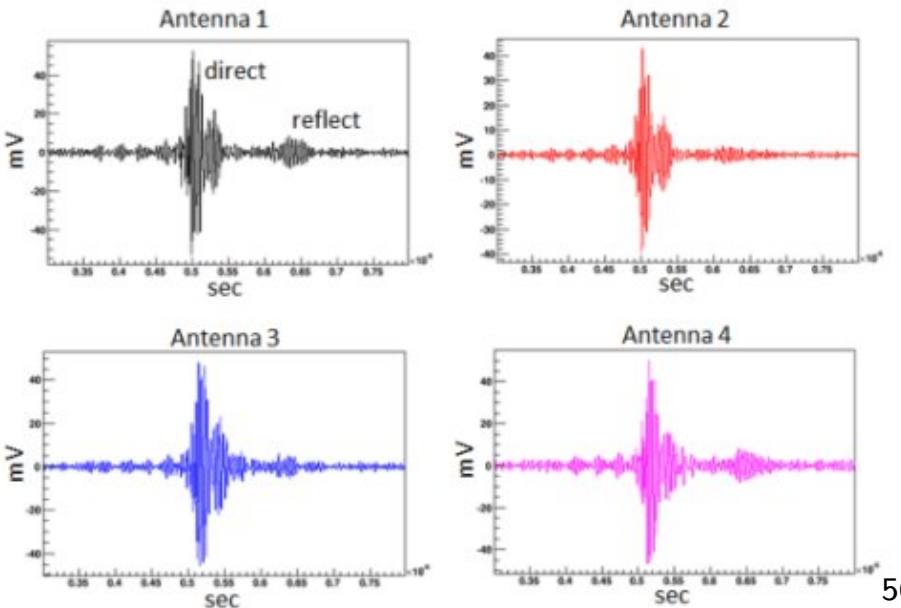
TAROGE I at He-Ping

TAROGE at 1200˜2000m

Reflection Test of TAROGE







The Synoptic Wideband Orbiting Radio Detector (SWORD)

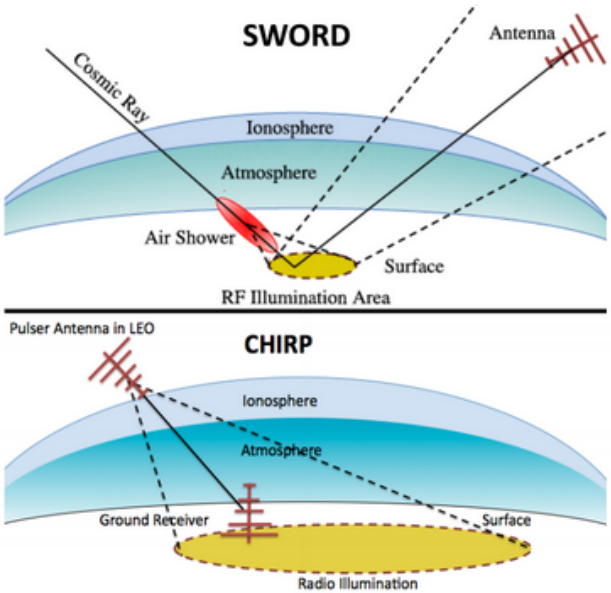


Figure 1: The top figure outlines the SWORD mission concept. The UHECR interacts in the atmosphere to produce an extended air shower. The geo-magnetic field separates the positrons and electrons in the shower to produce a geo-

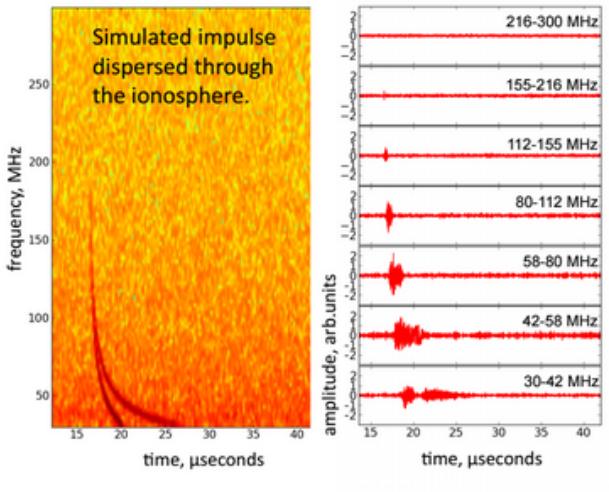


Figure 2: An example of a simulated 2×10^{20} eV cosmic ray induced geo-synchrotron radio impulse after propagation through an ionospheric profile with 14 TECU. The spectrogram of the signal (left) shows the effect of dispersion and birefringence (Equation 1) for a signal detected by a linearly polarized antenna. Waveforms (right) for the bands used in SWORD show the progressively larger amount of

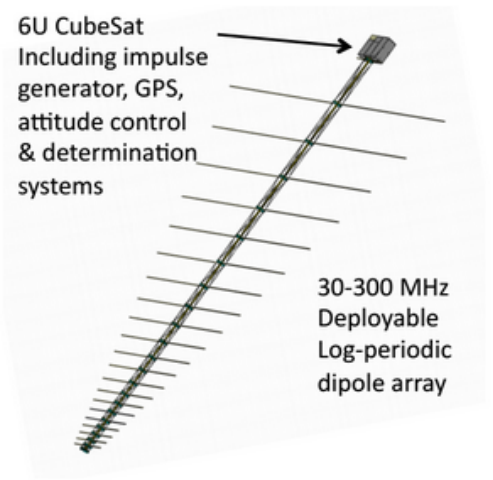


Figure 4: The CHIRP satellite consists of a deployable log-periodic dipole antenna that is 4.7 meters in length with 3.7 meter longest dipole element. The antenna is stowed in a 1.5U volume of the 6U CubeSat bus, which contains all the major subsystems needed for the mission.

Future Plans

- ANITA-4 (2017): Neutrino & cosmic rays
- SWORD(TBD) :cosmic rays
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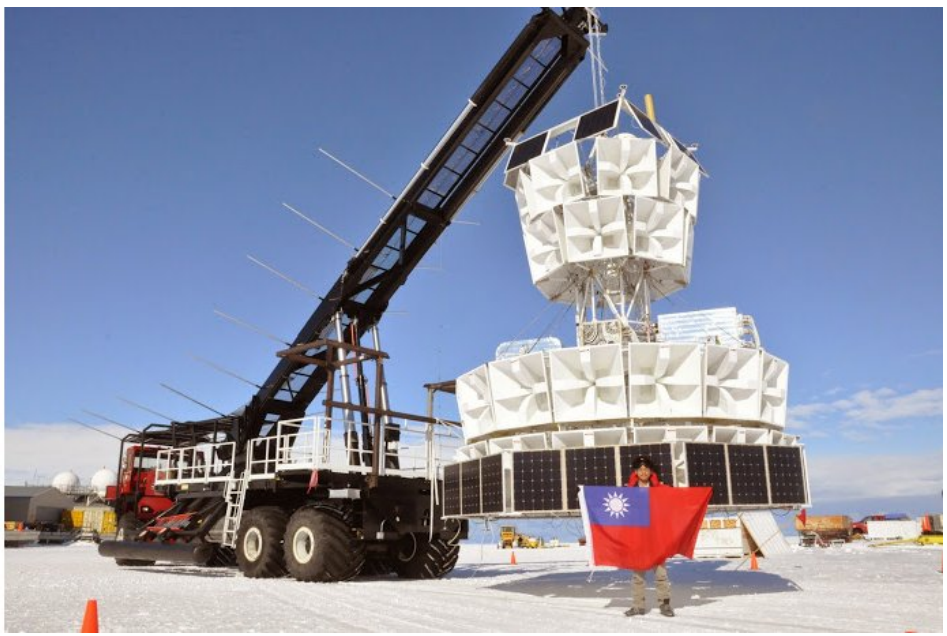
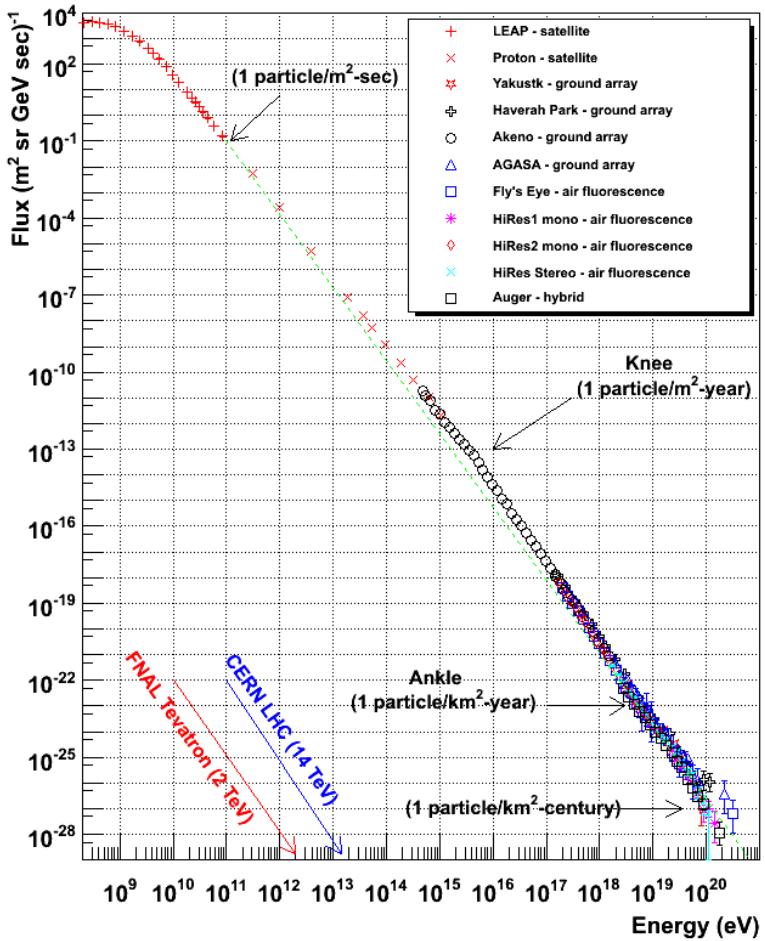
Thank you!

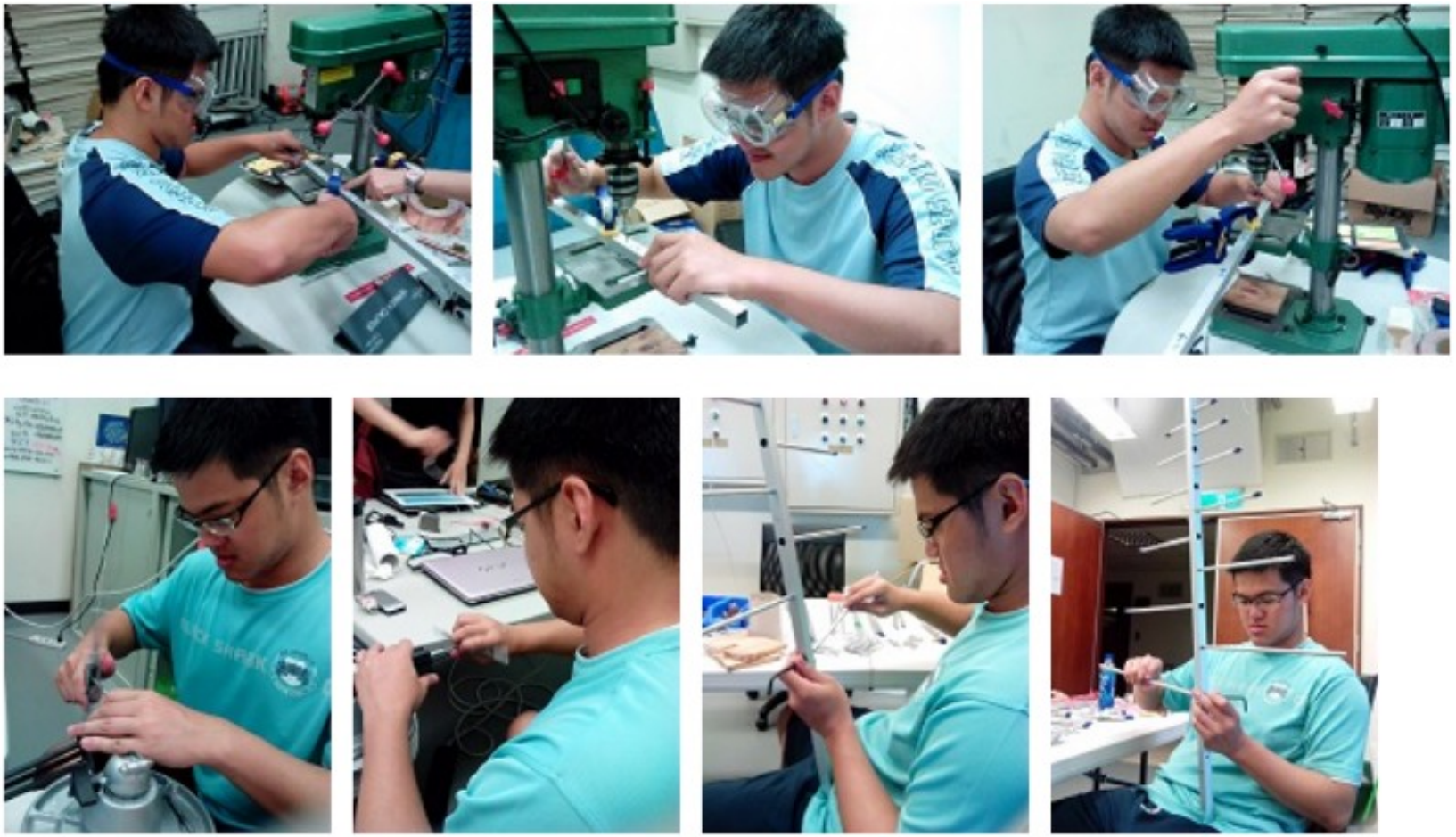


Cosmic Background Flux



Cosmic ray spectra of various experiment

Building Antenna



Summer intern student from FJU and NCTU makeing the antenna.

Testing Antenna

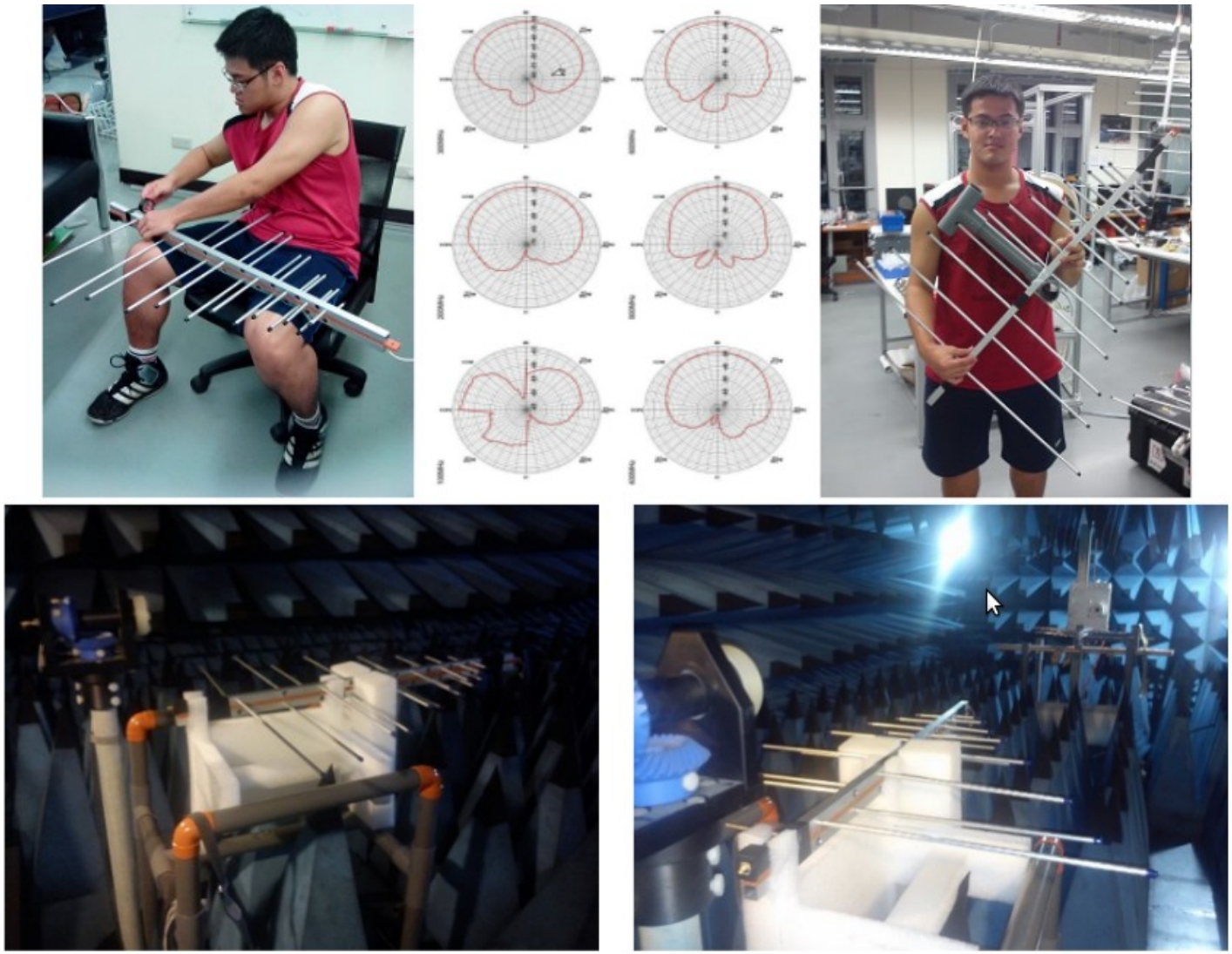
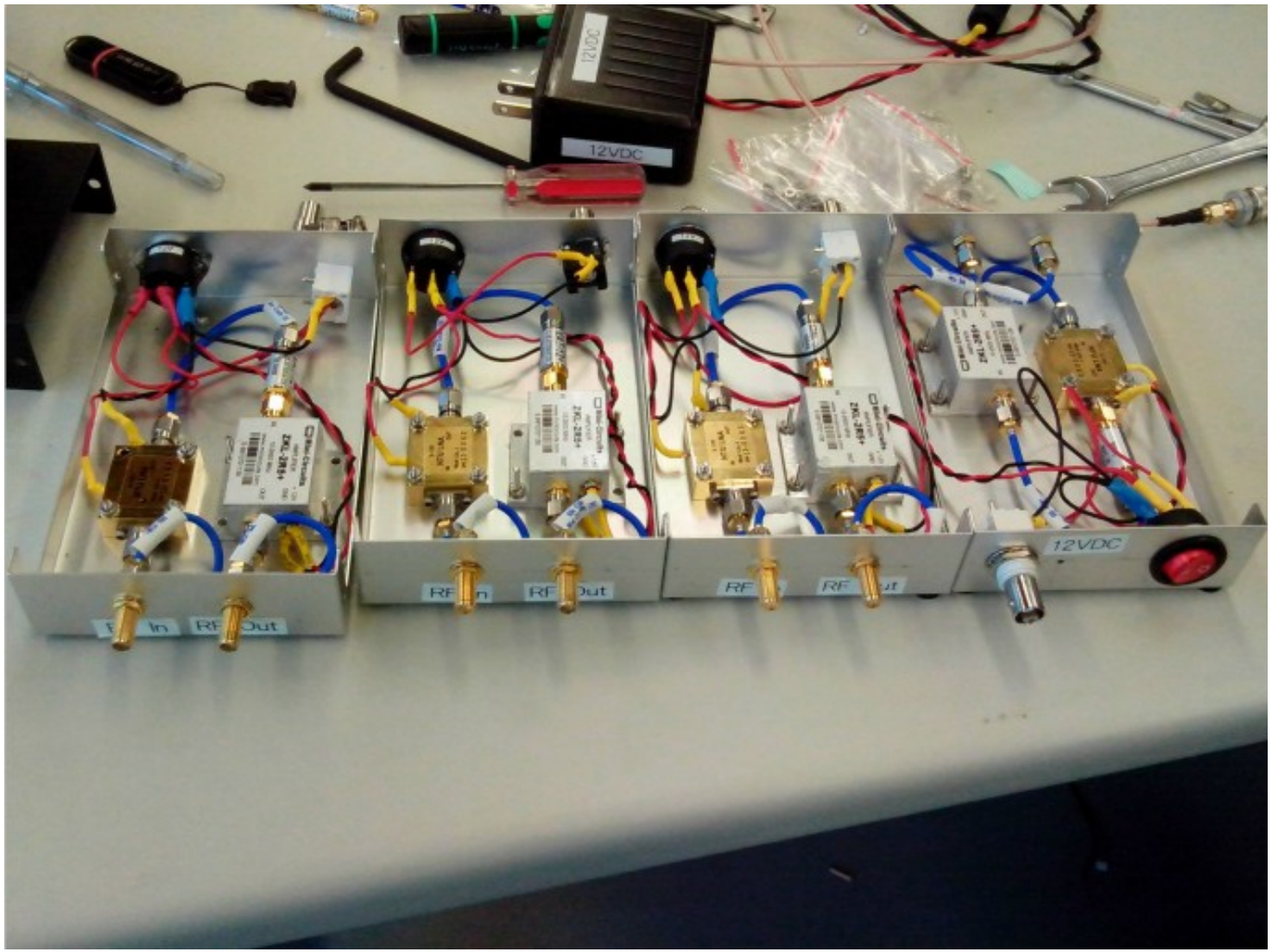
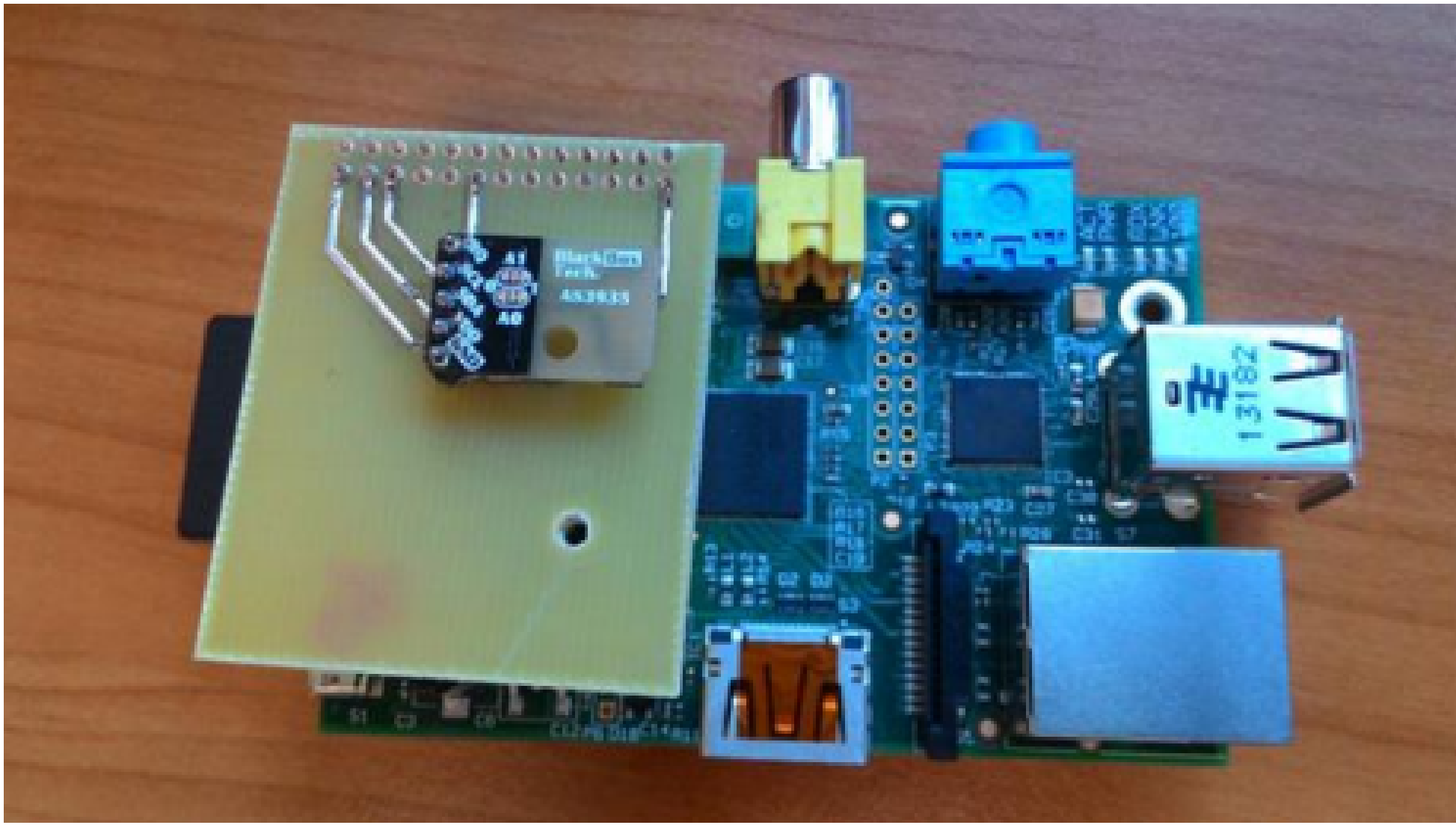


Figure : Summer intern students measure the antenna response.

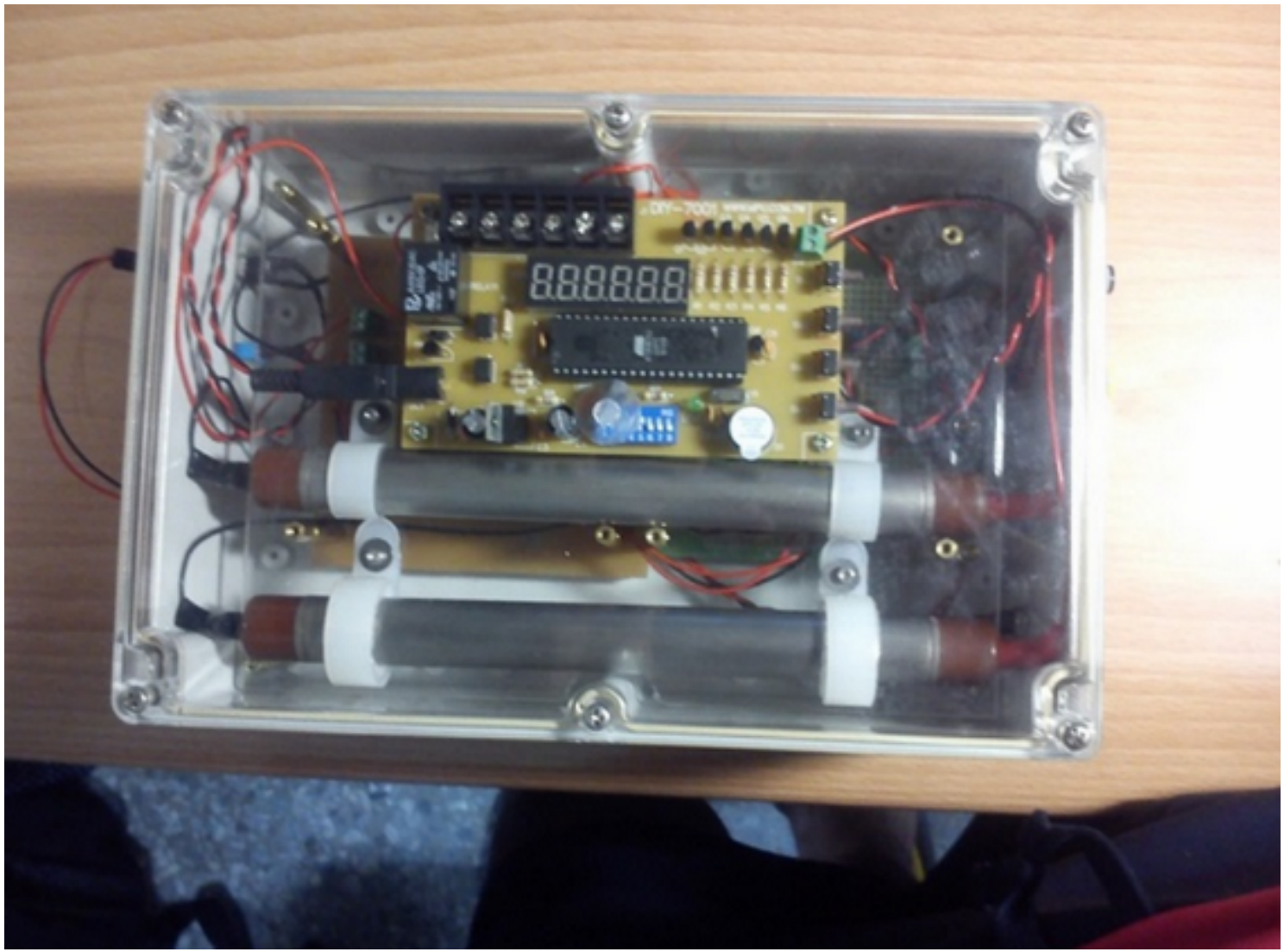
LNAs of TAROGE



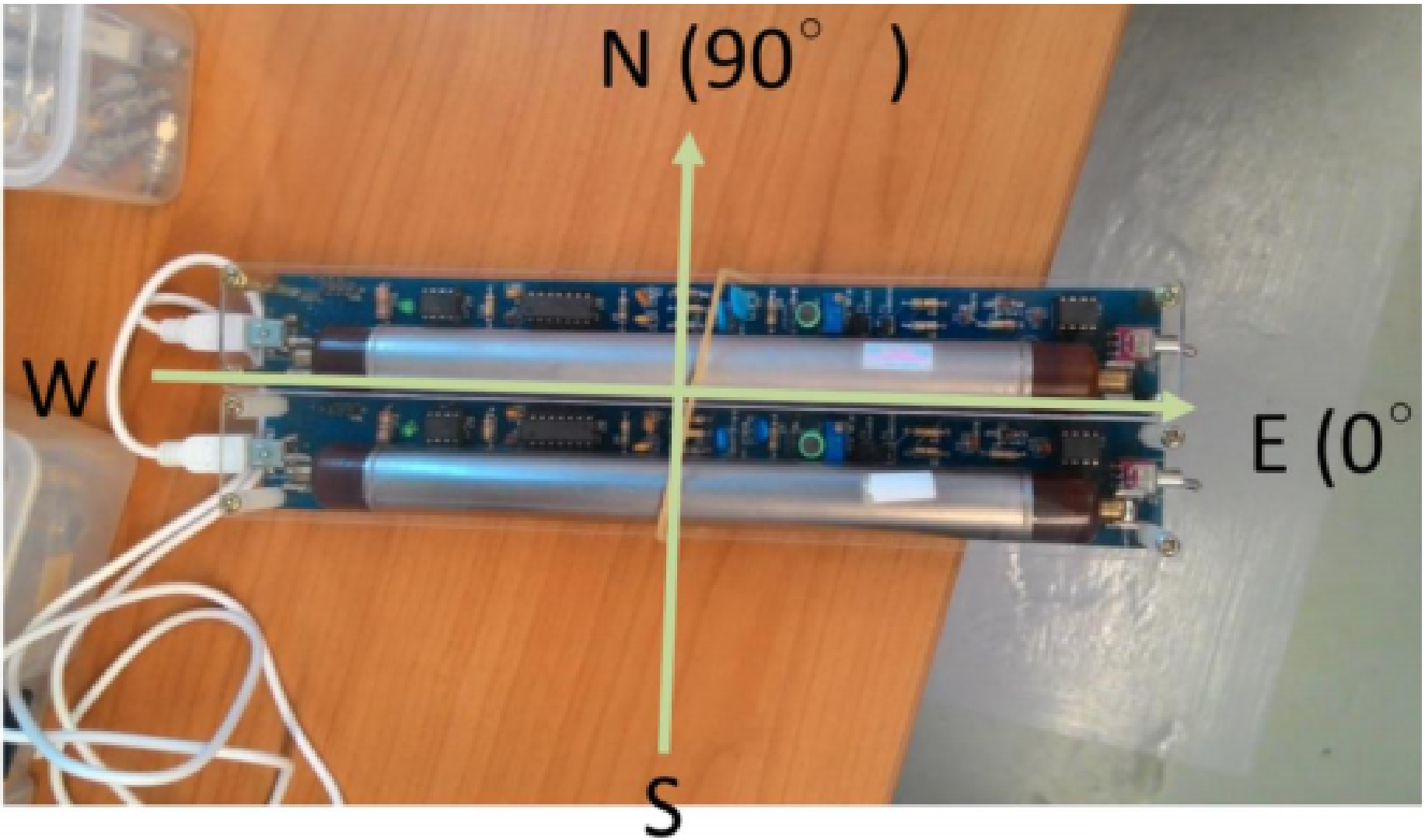
Lightning Detecor of TAROGE



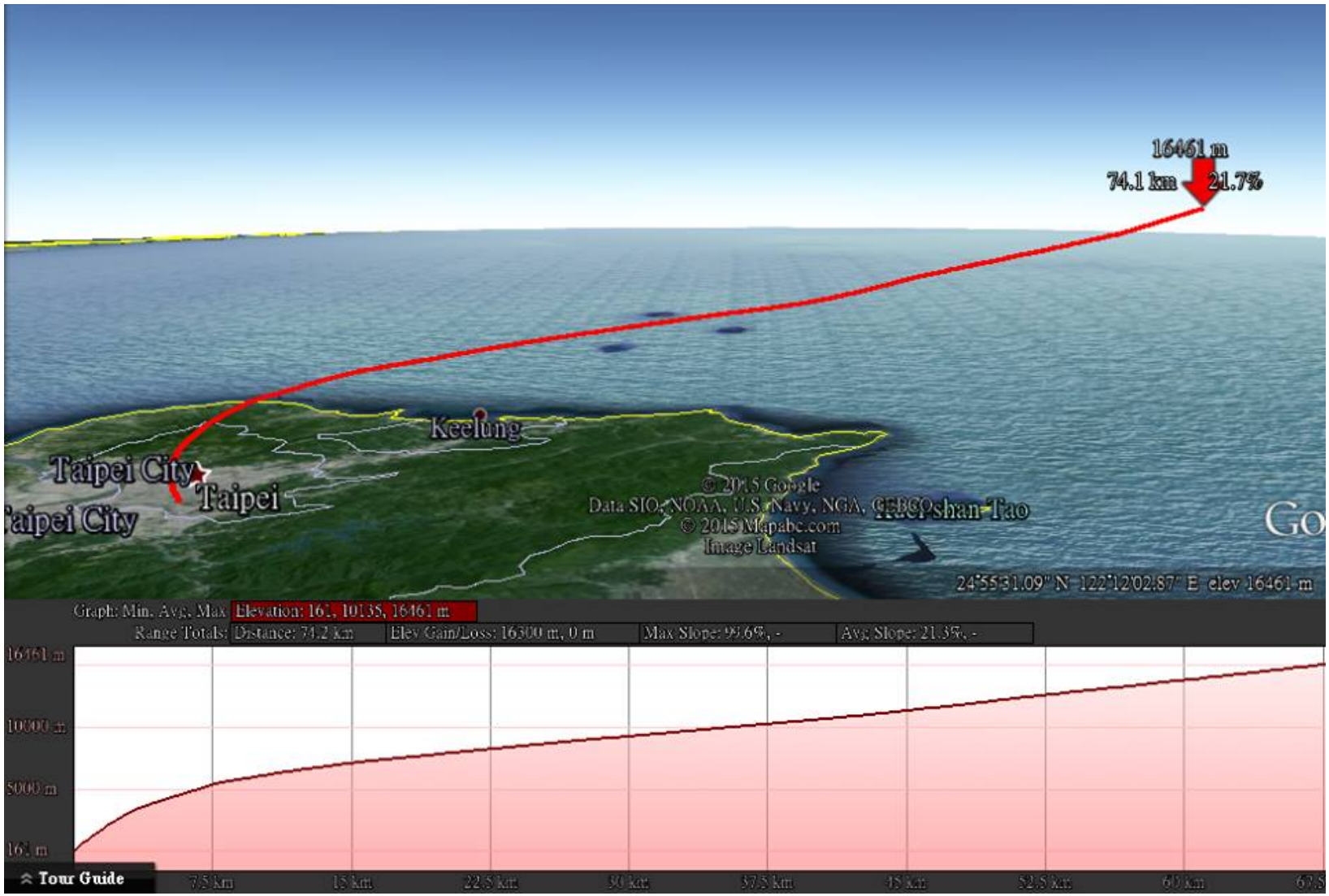
Muon Detecor



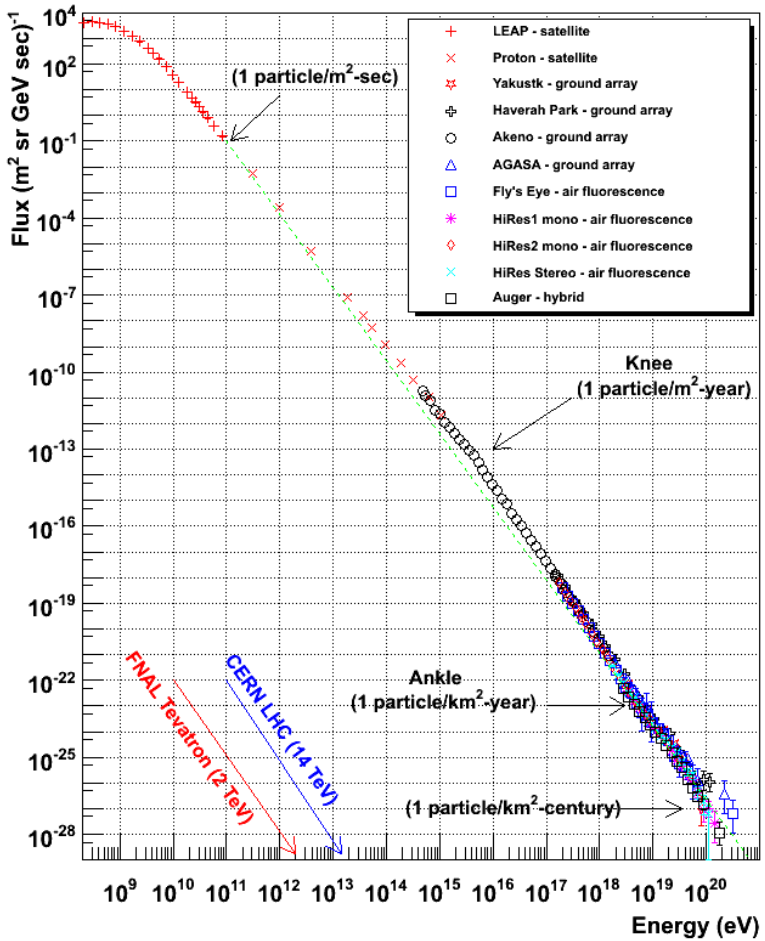
Muon Detecor



Muon Detecor



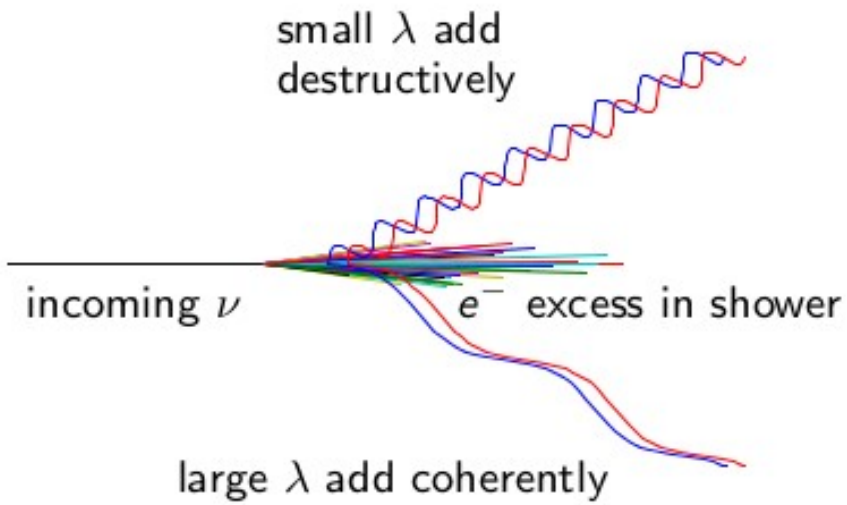
Cosmic Background Flux



Cosmic ray spectra of various experiment

Askaryan Effect

- Askaryan effect: Neutrinos with energy above $\sim 30\,\text{PeV}$ most efficiently detected with radio
- Delta-ray production, Compton scattering and positron annihilation give charge excess
- Compact bunch moves together
- Long wavelengths add coherently



The South Pole has the perfect combination of ice volume, ice RF-transparency, and existing science infrastructure for this experiment.

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