Askaryan Radio Array (ARA)

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PHYSICS

Cosmic Rays and Neutrino Sources

Cosmic rays exist at highest energies:

The puzzle

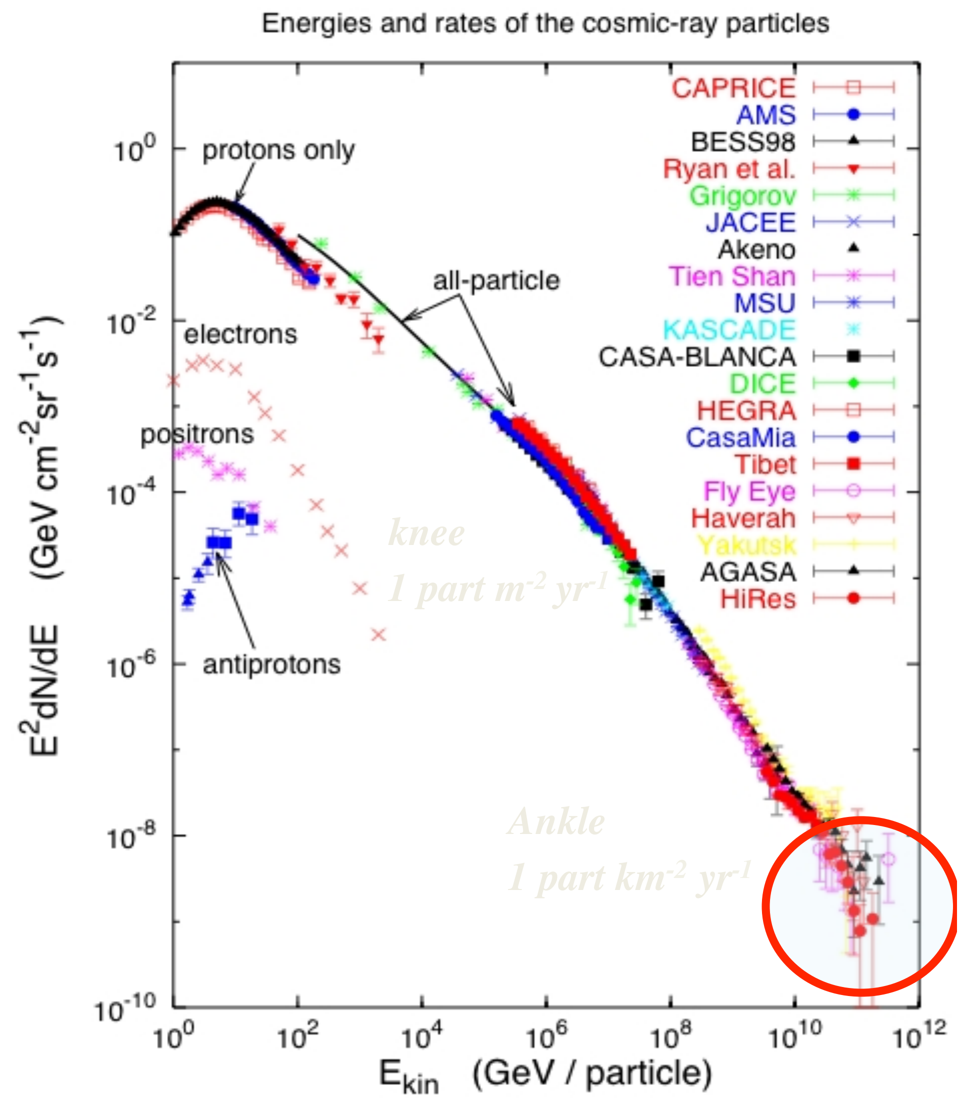
No nearby (<50Mpc) sources observed.
More distant sources are not observable in cosmic rays due to collisions with microwave background.

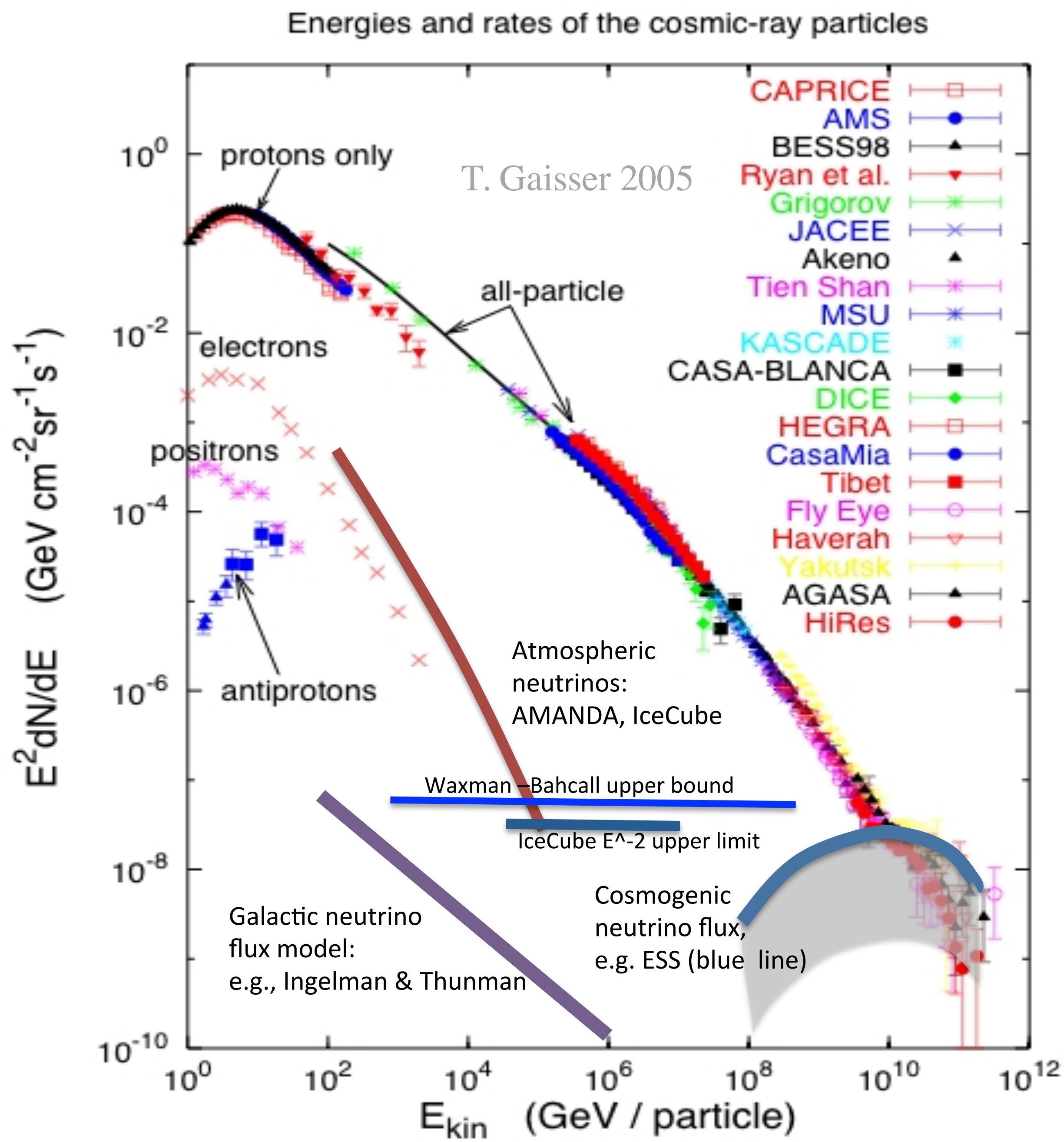
Neutrinos above $10^{17\text{-}19}$ eV, GZK or cosmogenic neutrinos are at some level guarantueed.

However, fluxes will be small, requires very large detectors

$$p + \gamma_{\mathrm{CMB}} \rightarrow \Delta^+ \rightarrow p + \pi^0$$
$$\rightarrow n + \pi^+$$

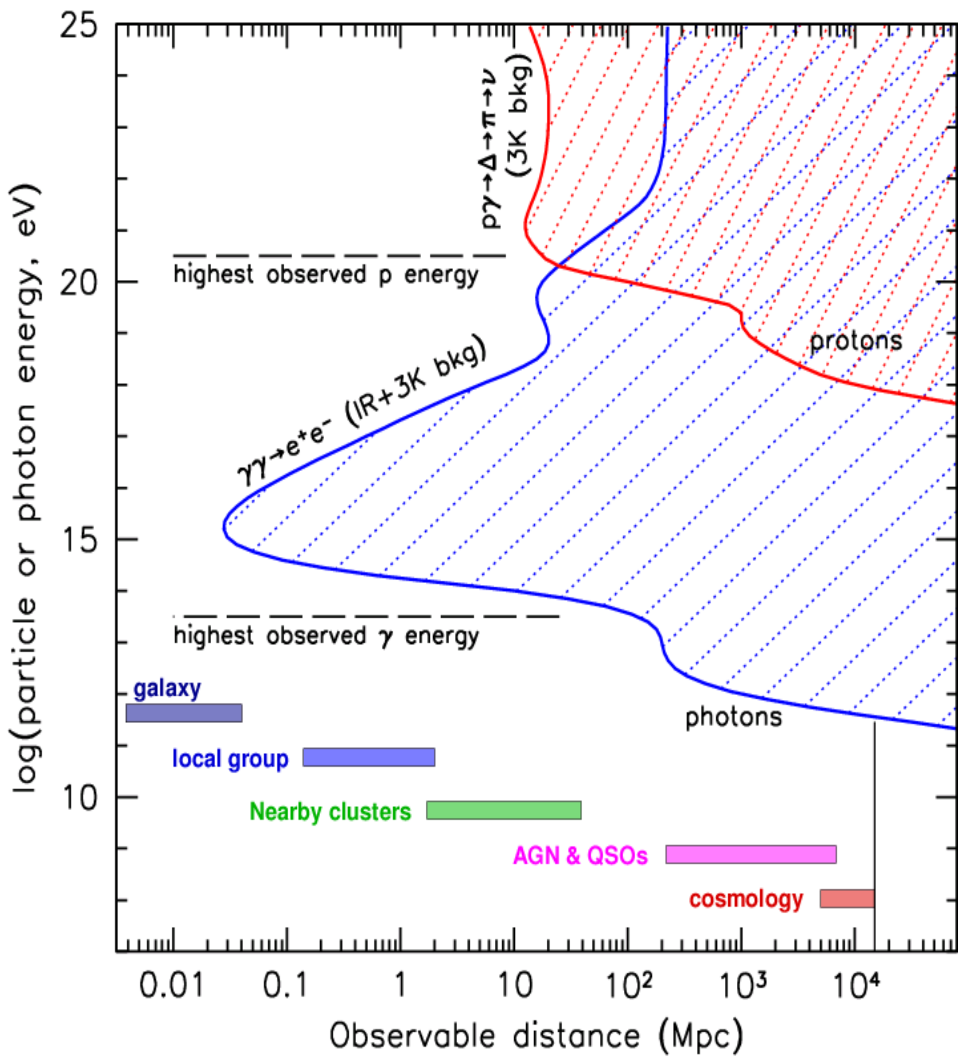
Gaisser 2005





Energies and rates of the cosmic-ray particles
T. Gaisser 2005
protons only
all-particle
electrons
positrons
antiprotons
CAPRICE
AMS
BESS98
Ryan et al.
Grigorov
JACEE
Akeno
Tien Shan
MSU
KASCADE
CASA-BLANCA
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
Yakutsk
AGASA
HiRes
Atmospheric
neutrinos:
AMANDA, IceCube
Waxman –Bahcall upper bound
IceCube E^-2 upper limit
Galactic neutrino
flux model:
e.g., Ingelman & Thunman
Cosmogenic
neutrino flux,
e.g. ESS (blue line)
E^2dN/dE (GeV $cm^{-2}sr^{-1}s^{-1}$)
E_{kin} (GeV / particle)

Neutrinos as messengers



Study of the highest energy processes and particles throughout the universe requires PeV-ZeV neutrino detectors

To "**guarantee"**EeV neutrino detection, **design for the GZK neutrino flux**

Existence of extragalactic neutrinos inferred from CR spectrum, up to 10^{20} eV, and similarly, Galactic up to 10^{18} eV

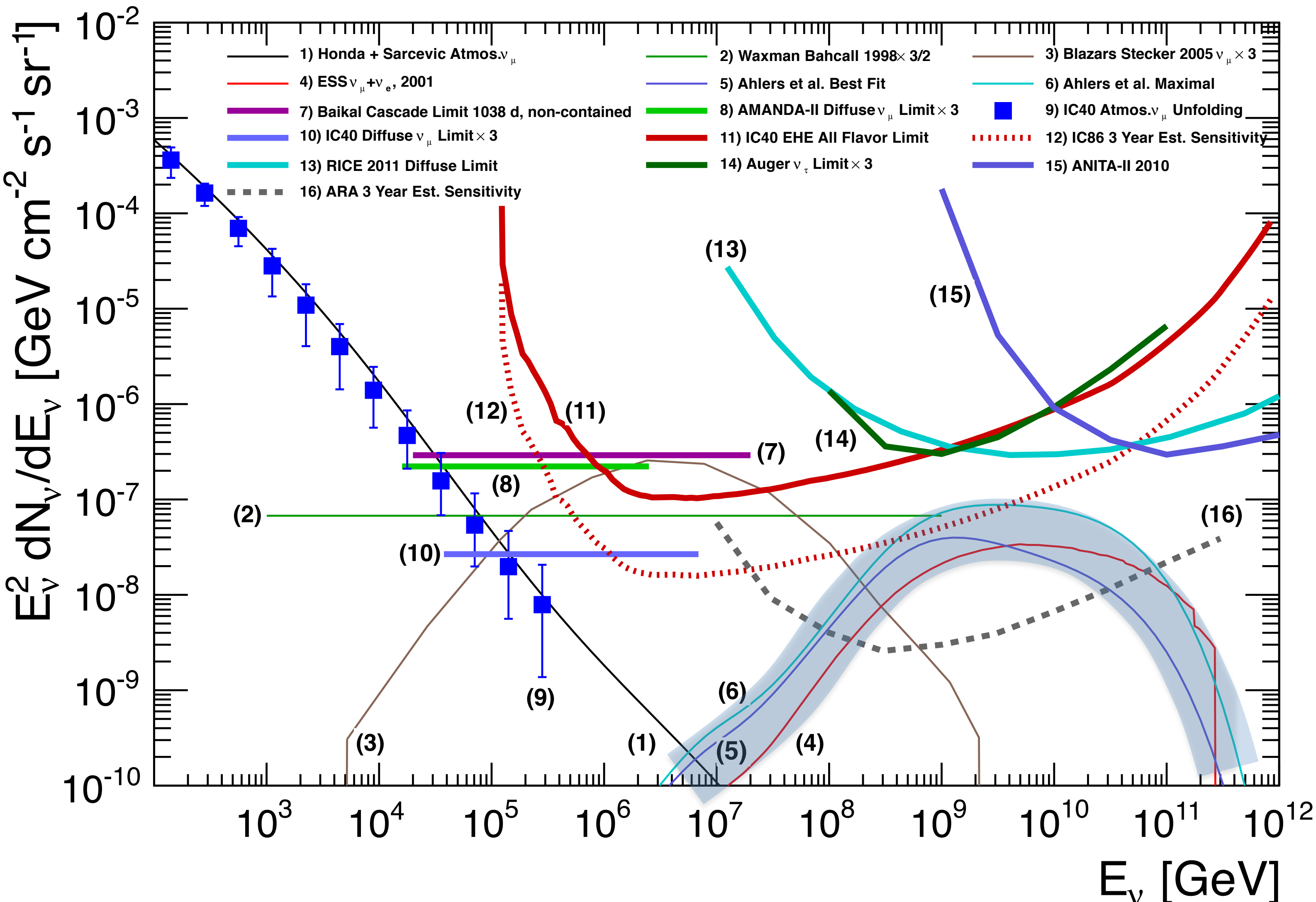
Need gigaton (km^3) mass (volume) for TeV to PeV detection, and teraton at 10^{19} eV

Neutrino detection associated with EM sources will ID the UHECR sources

"EM Hidden" sources may exist, visible only in neutrinos.

Neutrino eyes see farther (z>1), and deeper (into compact objects), than gamma-photons, and straighter than UHECRs,with no absorption at (almost) any energy

The cosmic energy frontier, 10^7 to 10^{11} GeV
Cosmogenic or *GZK* neutrinos



The cosmic energy frontier, 10^7 to 10^{11} GeV
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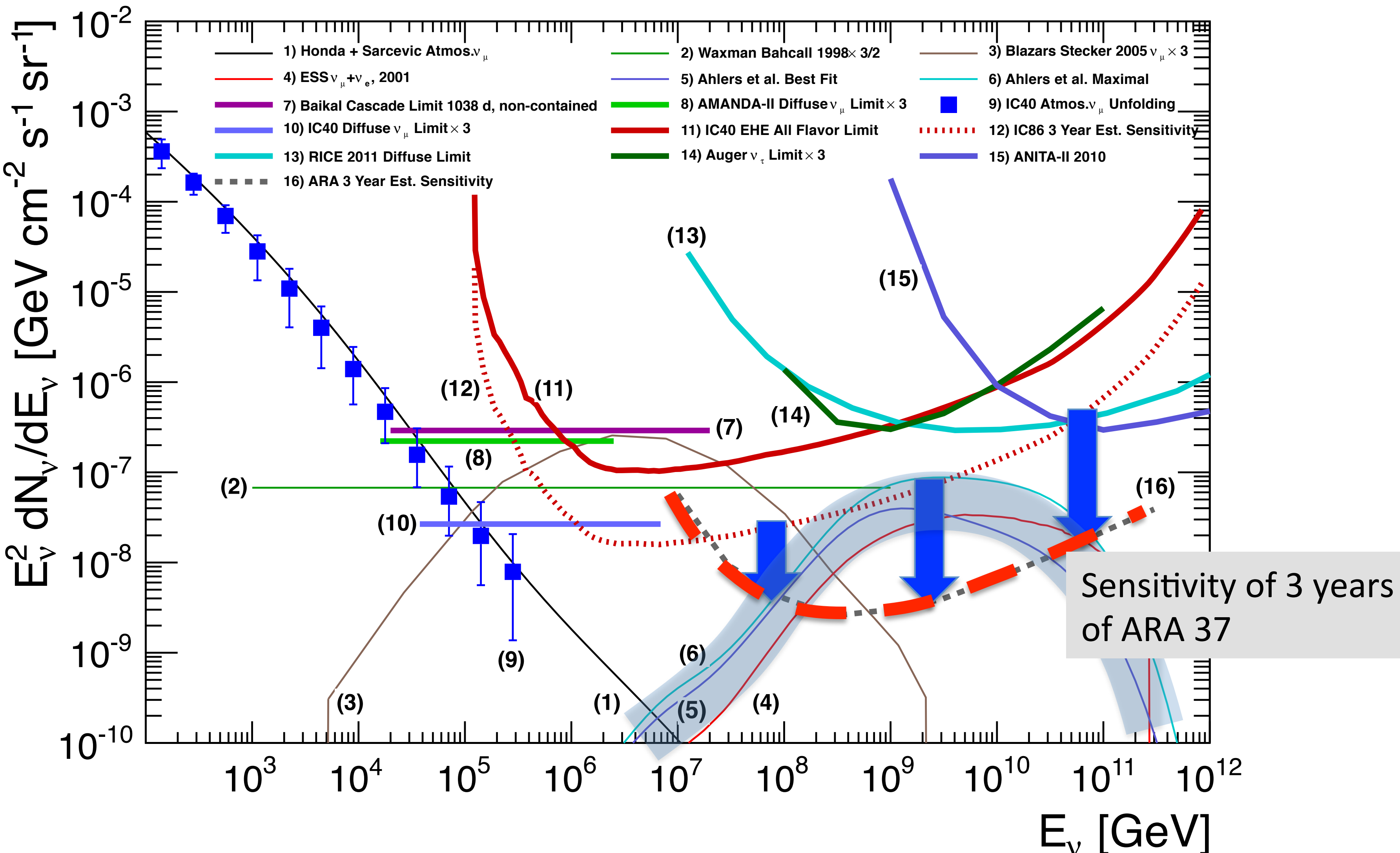
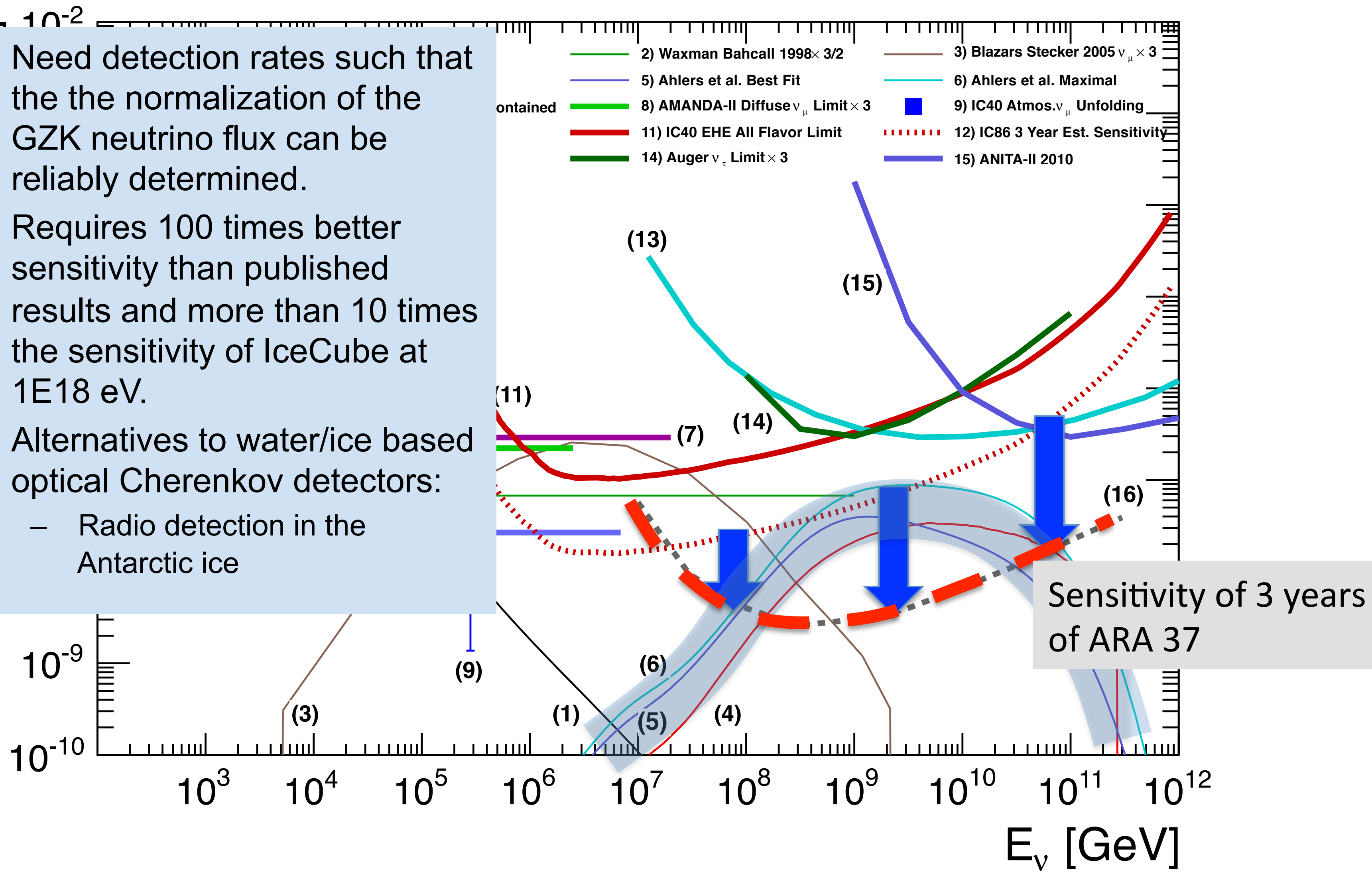


10^16 – 10^20 eV energy scale

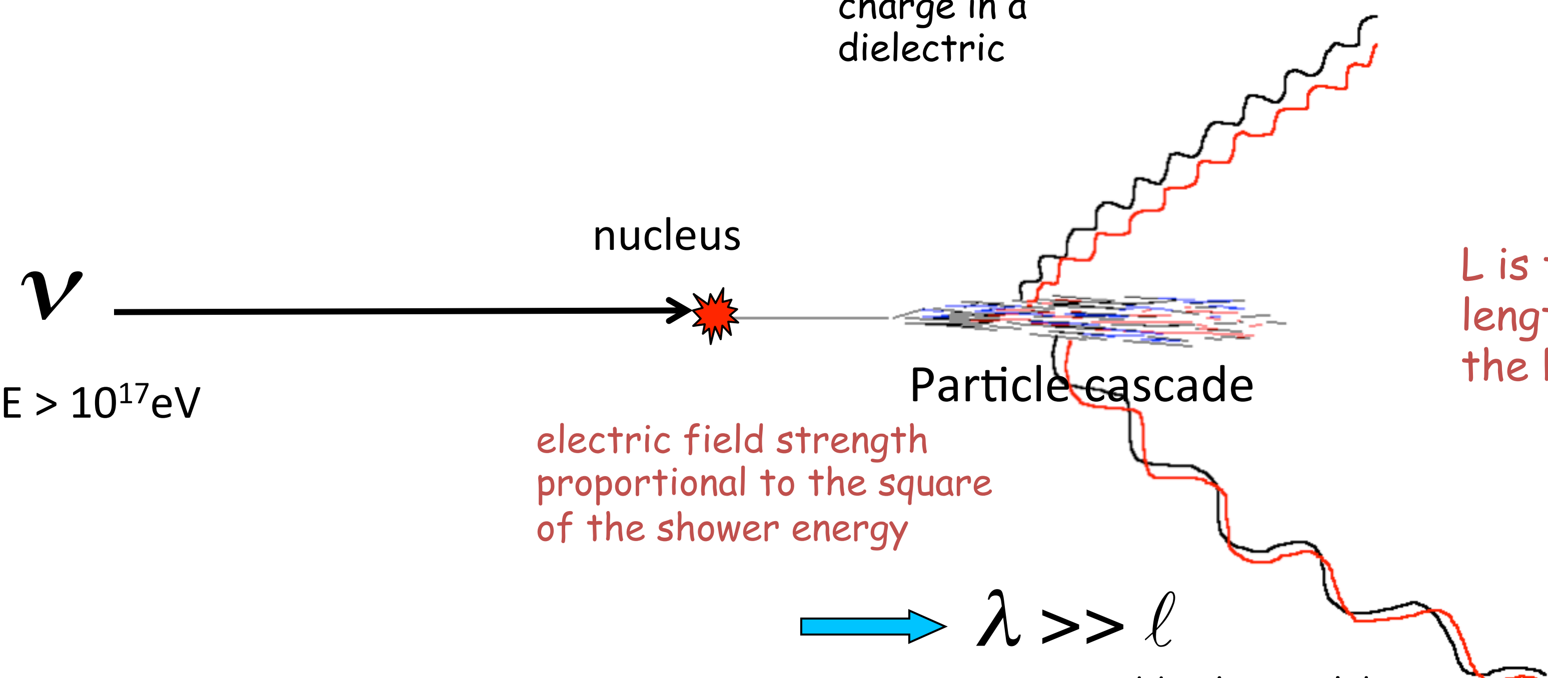
- Need detection rates such that the the normalization of the GZK neutrino flux can be reliably determined.
- Requires 100 times better sensitivity than published results and more than 10 times the sensitivity of IceCube at 1E18 eV.
- Alternatives to water/ice based optical Cherenkov detectors:
  - Radio detection in the Antarctic ice



ASKARYAN EFFECT

Detection mechanism proposed by G. Askaryan (1962):
Measure the coherent RF signal generated by neutrino interaction in dielectric media (such as ice)

charge asymmetry in particle shower development results in a 20% excess of electrons over positrons in a particle shower → moves as a compact bunch, a few cm wide and ~1cm thick → Moving net charge in a dielectric → wavelengths shorter than the bunch length suffer from destructive interference



Askaryan Effect

In electron-gamma shower in matter, there will be ~20% more electrons than positrons.

Compton scattering: $\gamma + e^-_{(at\ rest)} \rightarrow \gamma + e^-$

Positron annihilation: $e^+ + e^-_{(at\ rest)} \rightarrow \gamma + \gamma$

In dense material $R_{Moliere}$~ 10cm.

$\lambda << R_{Moliere}$ (optical case), random phases $\Rightarrow$ **$P \propto N$**

$\lambda >> R_{Moliere}$ (microwaves), coherent $\Rightarrow$ **$P \propto N^2$**

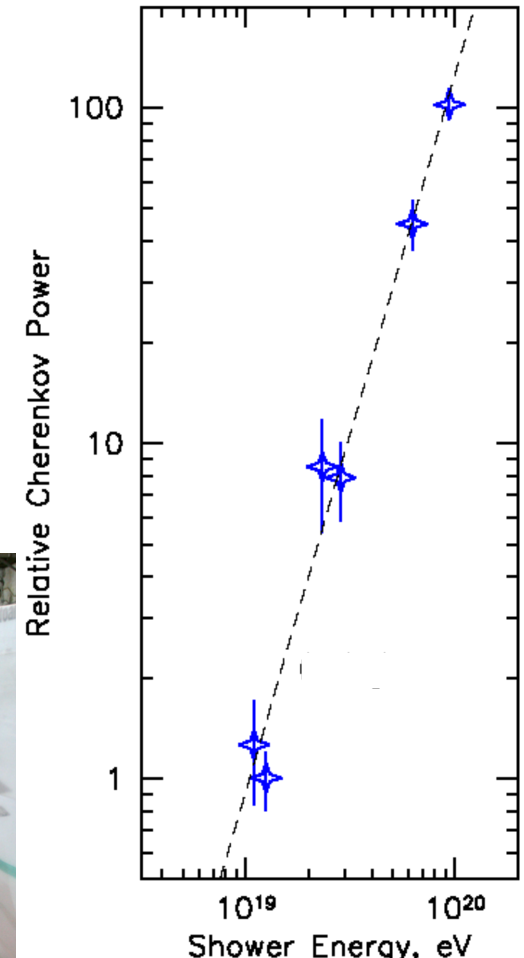
$$\frac{dP_{CR}}{d\nu} \propto \nu d\nu$$

Validation at SLAC

ANITA I beamtest at SLAC (June06): proof of Askaryan effect in ice

- Coherent (Power ~ E^2)
- Linearly Polarized

"Little Antarctica"



Natural target material?

- Lunar regolith (20m attenuation length)
  Parkes Telescope; GLUE; WSRT; …
- Ice (100-1500m attenuation lengths)
  Forte (satellensaltedite); ANITA (balloon); ARA
- Salt (100-500m attenuation lengths)
  SalSA (proposed,)
- Air is too thin
- Water is RF lossy, natural, outdoor, sand (as opposed to pure silica) is also lossy

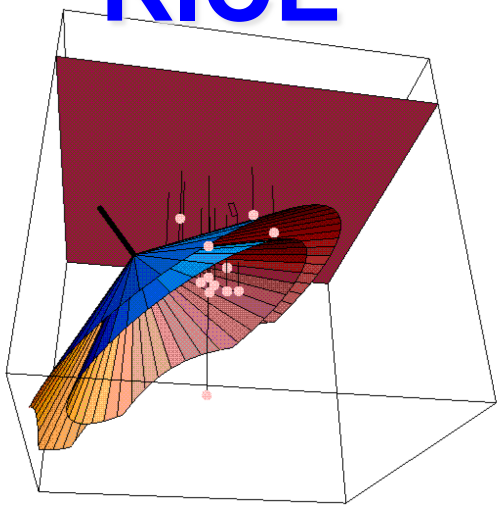
INSTRUMENTATION

10^7 to 10^{11} GeV: Radio ice Cherenkov detection

Askaryan Radio Array (ARA) heritage:
Existing and previous instruments using radio in Polar ice

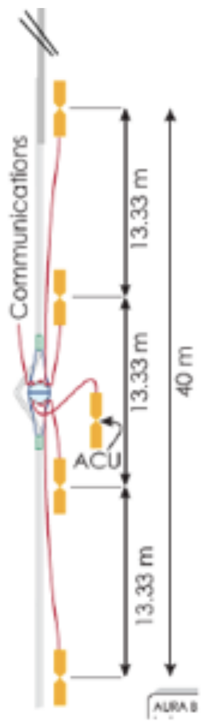
Members of all three efforts are currently involved with ARA

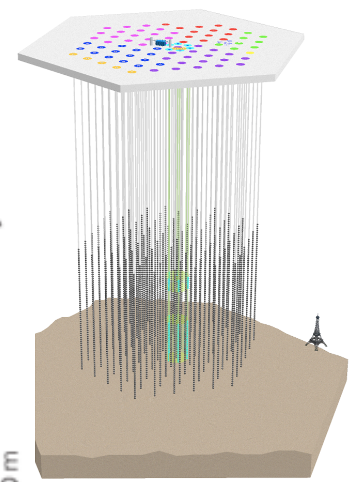
RICE



- array of single dipole antennas deployed between 100 and 300m near the Pole
- much of the instrumentation was deployed in AMANDA holes
- Pioneered technique in the ice

Special radio detectors and pulsers in IceCube





ANITA

- balloon payload of horn antennas
- surveys the ice cap from high altitude for RF refracted out of the ice
- → high fidelity data acquisition system >Gs/sec waveform capture

ARA- Collaboration

- ARA is an international Collaboration
  - 14 institutions
  - ~50 authors

Design and Initial Performance of the Askaryan Radio Array Prototype EeV Neutrino Detector at the South Pole

P. Allison,[1] J. Auffenberg,[2] R. Bard,[3] J. J. Beatty,[1] D. Z. Besson,[4] S. Böser,[5] C. Chen,[6] P. Chen,[6] A. Connolly,[1] J. Davies,[7] M. DuVernois,[2] B. Fox,[8] P. W. Gorham,[8] E. W. Grashorn,[1] K. Hanson,[9] J. Haugen,[2] K. Helbing,[10] B. Hill,[8] K. D. Hoffman,[3] M. Huang,[6] M. H. A. Huang,[6] A. Ishihara,[11] A. Karle,[12] D. Kennedy,[4] H. Landsman,[2] A. Laundrie,[2] T. C. Liu,[6] L. Macchiarulo,[8] K. Mase,[11] T. Meures,[9] R. Meyhandan,[8] C. Miki,[8] R. Morse,[8] M. Newcomb,[2] R. J. Nichol,[7] K. Ratzlaff,[13] M. Richman,[3] L. Ritter,[8] B. Rotter,[8] P. Sandstrom,[2] D. Seckel,[14] J. Touart,[3] G. S. Varner,[8] M. -Z. Wang,[6] C. Weaver,[12] A. Wendorff,[4] S. Yoshida,[11] and R. Young[13]

(ARA Collaboration)

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[13] *Instrumentation Design Laboratory, Univ. of Kansas, Lawrence, KS 66045, USA.*
[14] *Dept. of Physics, Univ. of Delaware, Newark, DE 19716.*

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WEIZMANN INSTITUTE OF SCIENCE

10^{7} to 10^{11} GeV: Radio ice Cherenkov detection

Askaryan Radio Array (ARA)

- a very large radio neutrino detector at the South Pole

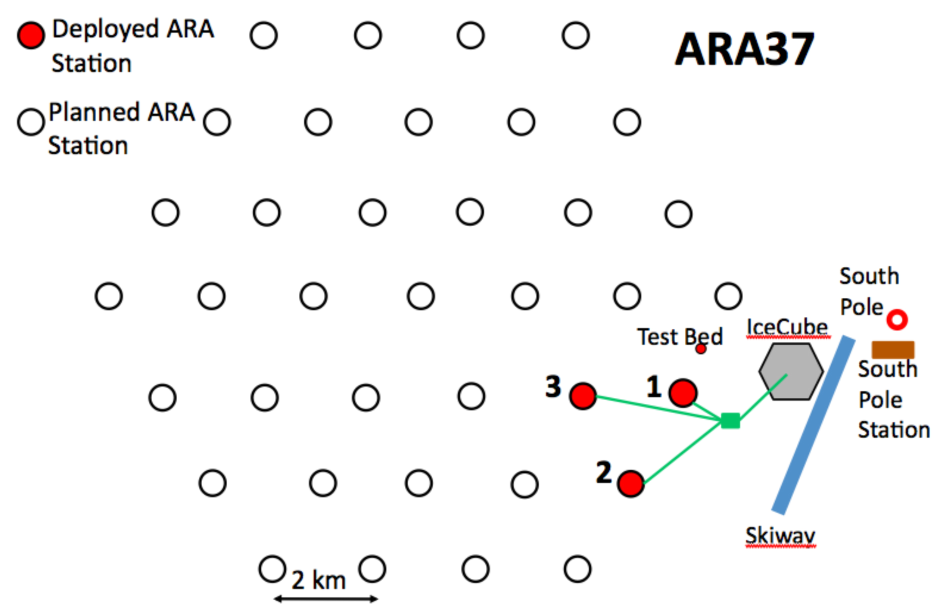
Ref: Allison et al., Astropart.Phys. 35 (2012) 457-477, arXiv:1105.2854 (Design and performance paper)

Scientific Goal:

- Discover and determine the flux of highest energy cosmic neutrinos.
- Understanding of highest energy cosmic rays, other phenomena at highest energies.

Method:

Monitor the ice for radio pulses generated by interactions of cosmic neutrinos with nuclei of the 2.8km thick ice sheet at the South Pole



Areal coverage: ~150km^2

ARA station geometry

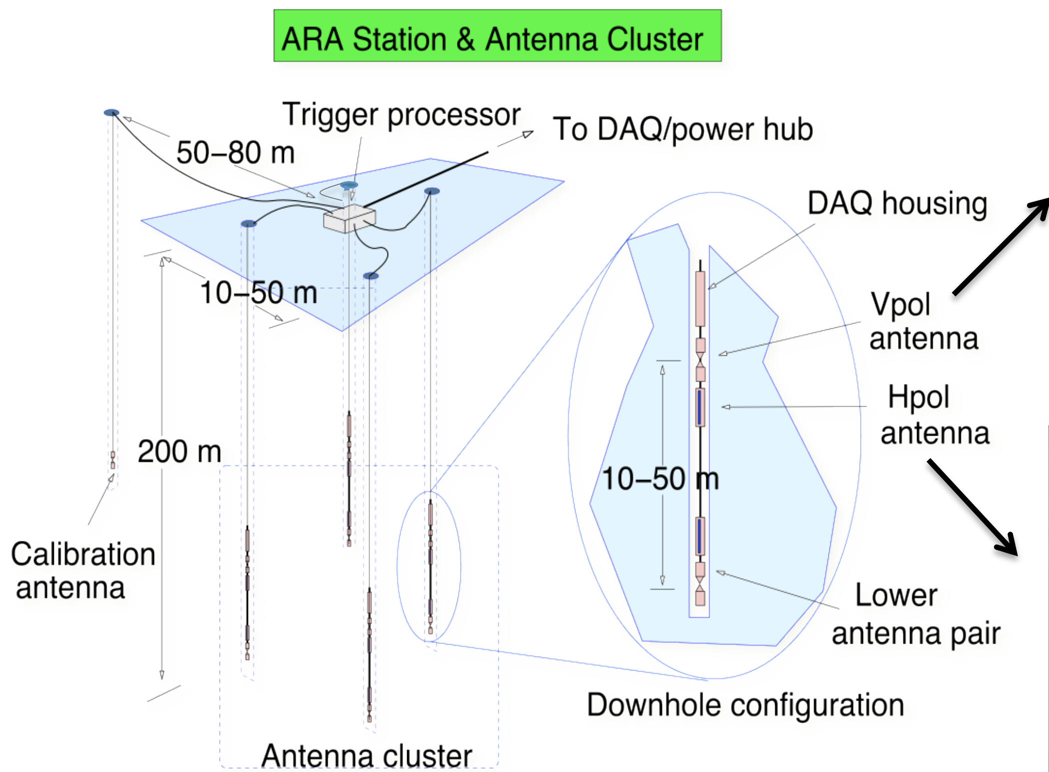
Design goals and choices:

- Every station is a fully functioning detector.

→ Lower energy threshold: nearby events (300m) can be reconstructed.

Background rejection:

→ Embedded strings: Allow good vertex resolution and high vertical resolution for background rejection

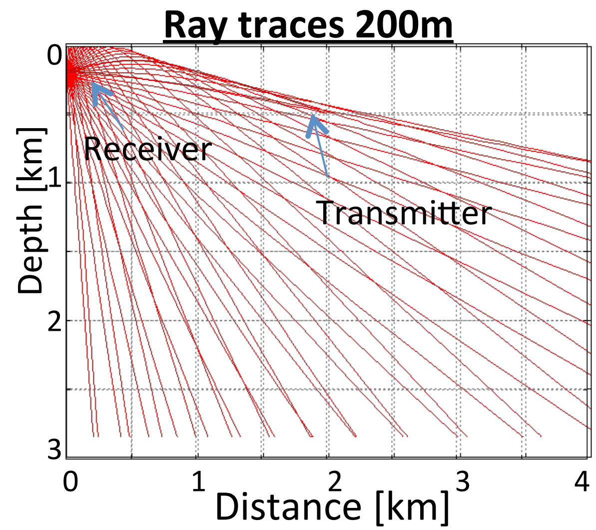


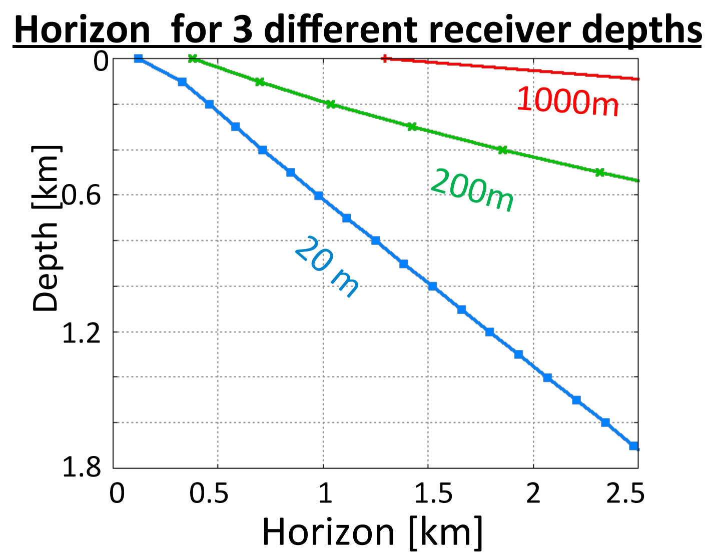
Why strings?

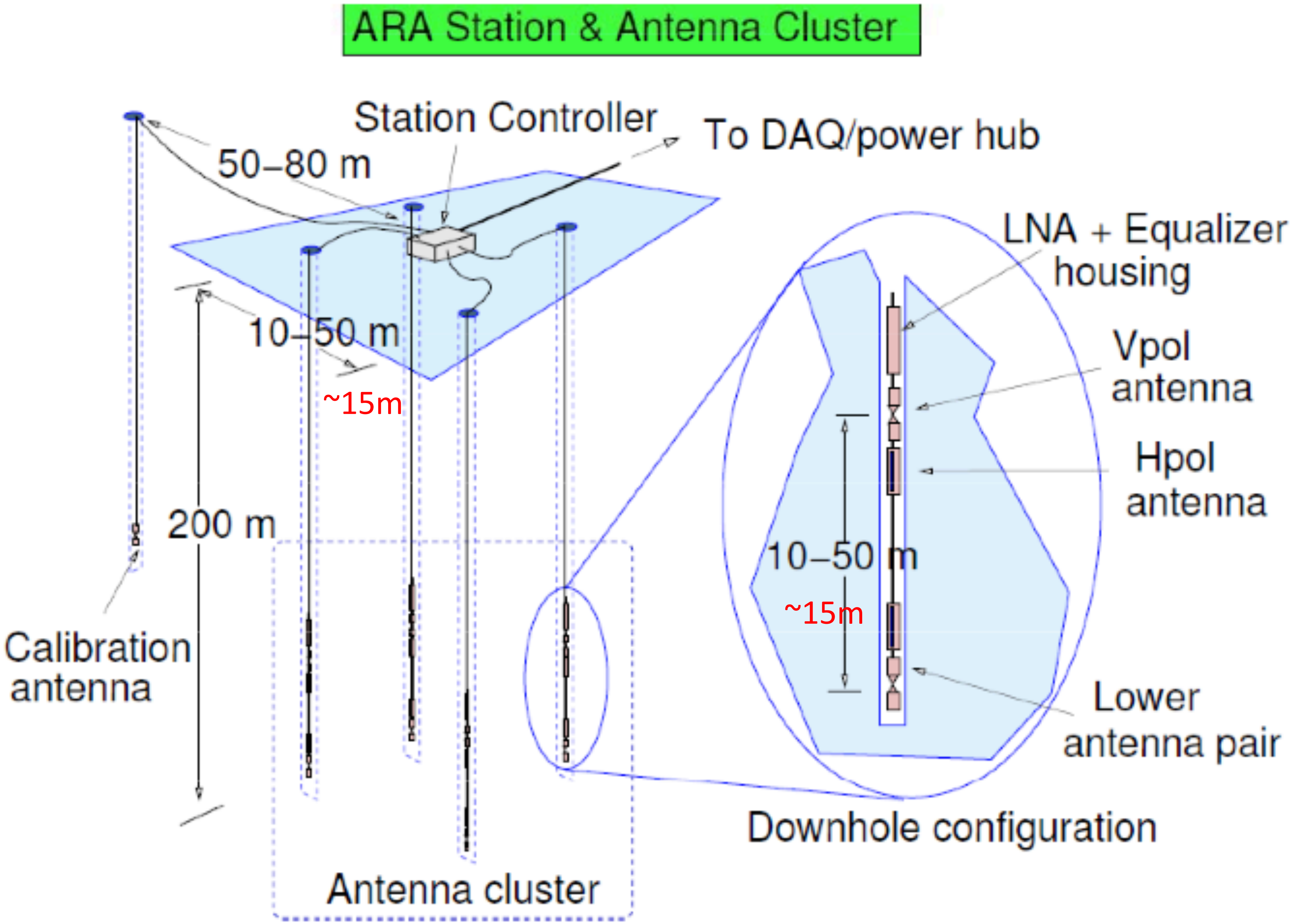
(rather than surface antennas)

- Acceptance: x2
  - Embedded detectors have larger acceptance due to shadowing caused by gradual change of index of refraction in the upper 200m of ice.
  - Gain at 200m depth compared to surface: > x2 event rate

- Background rejection:
  - Transient backgrounds, man made and natural come from surface!
  - Neutrino events generate vertex in the ice and the signal can be uniquely separated by basic event reconstruction.



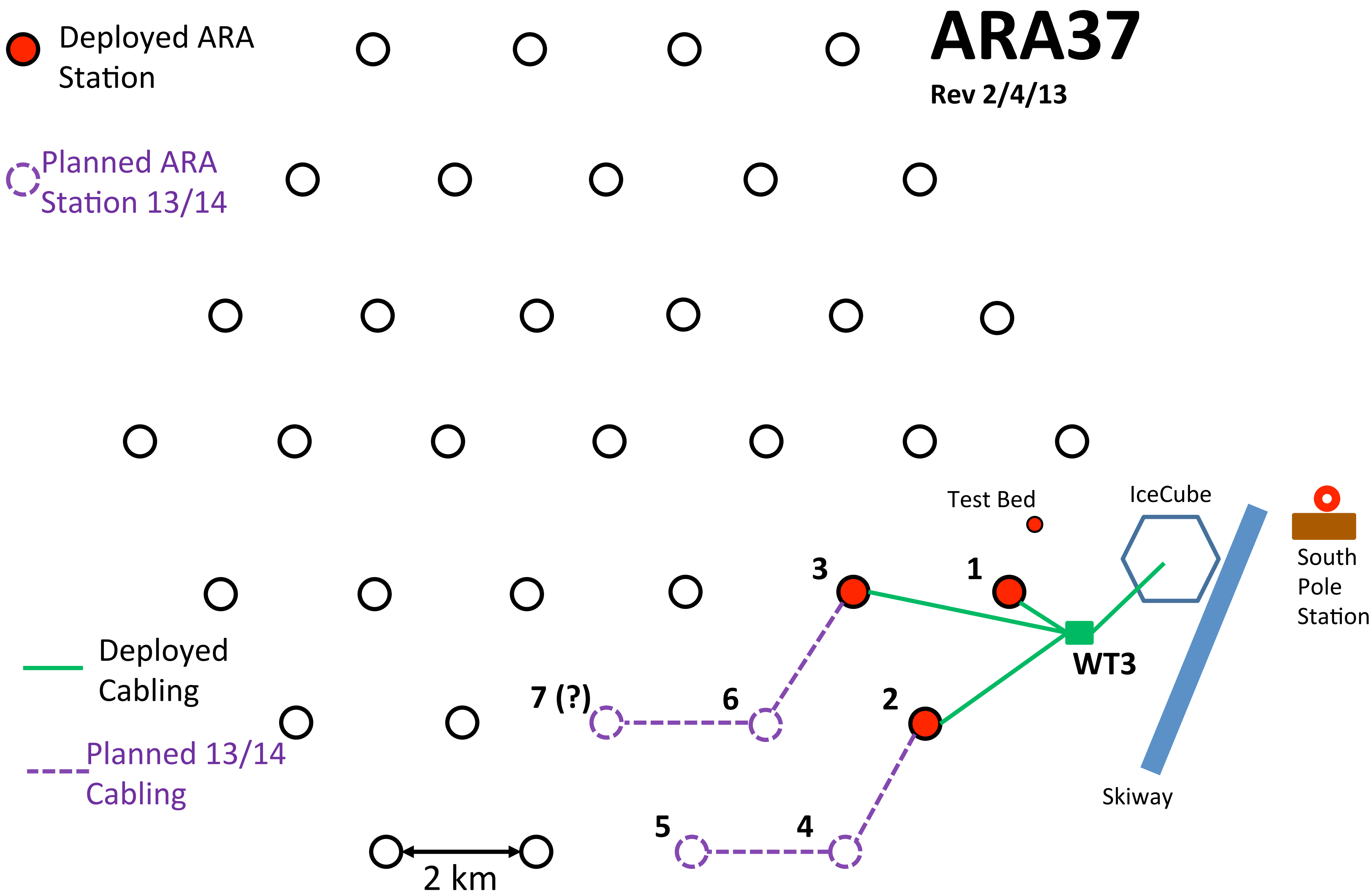


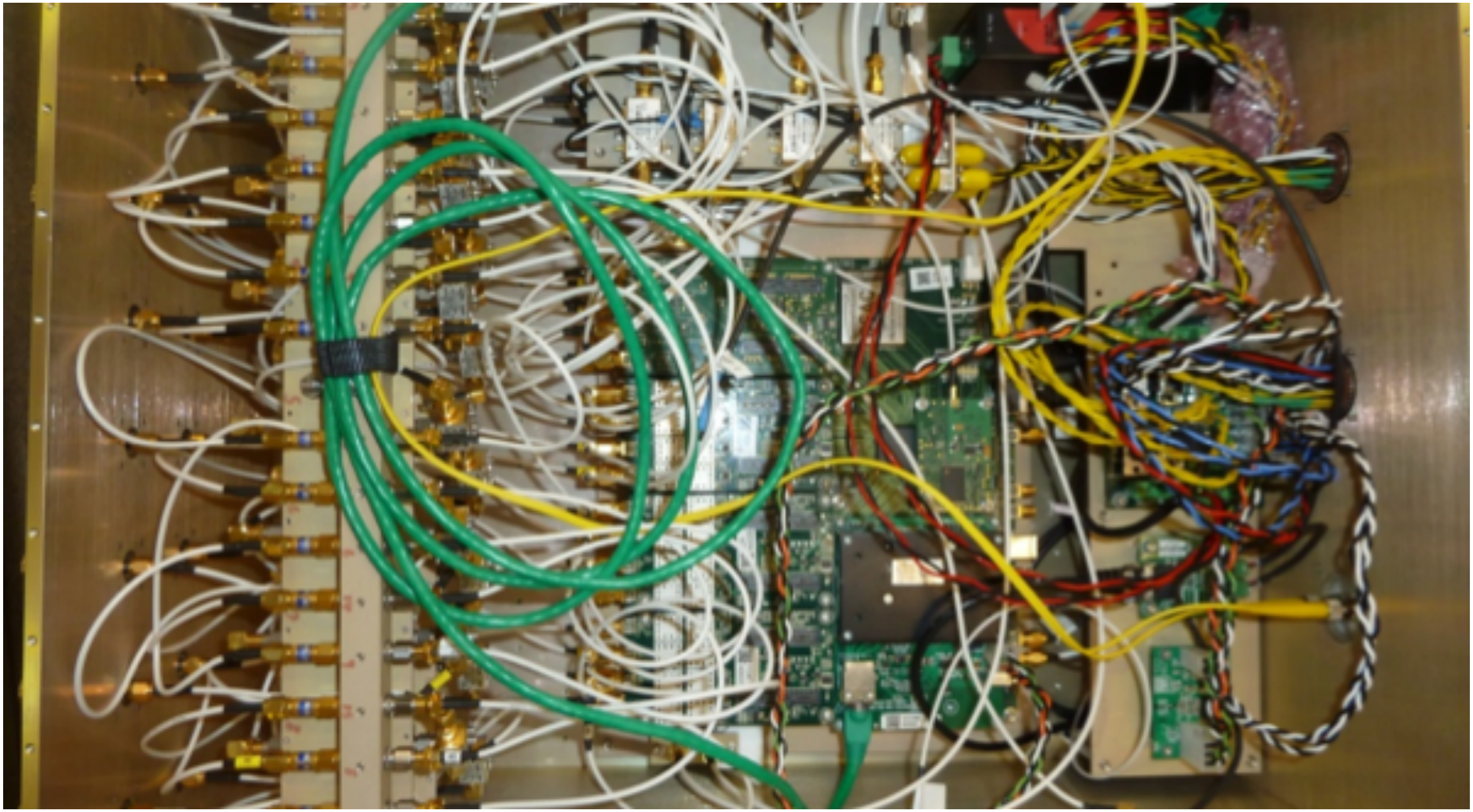

ARA Station & Antenna Cluster
Station Controller
To DAQ/power hub
50–80 m
10–50 m
~15m
200 m
Calibration antenna
Antenna cluster
LNA + Equalizer housing
Vpol antenna
Hpol antenna
10–50 m
~15m
Lower antenna pair
Downhole configuration

Signal Chain

- Physics: Neutrino interacts in the ice, charged particles generate shower, Askaryan radio pulse
- Antennas: Radio pulse wave-front arrives, superimposed on thermal (background) noise
- LNA: Amplify the delicate signal with minimum additional noise, close to the antenna
- RFoF (transmitter & receiver): Transmit signal to the surface without cable distortions, and then return optical to electrical signal
- Trigger: Diode detectors ("square law") followed by combinatorial logic (e.g., 5/16 or in the future something more complex)
- Readout: Analog capacitor storage, triggered readout, digitization, transfer to station computer, fiber to IceCube Lab building, hard drive storage, & satellite to North

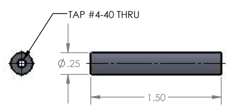
2012-13 SEASON & RECENT WORK


ARA37
Rev 2/4/13
Deployed ARA Station
Planned ARA Station 13/14
Deployed Cabling
Planned 13/14 Cabling
Test Bed
IceCube
South Pole Station
WT3
Skiway
1
2
3
4
5
6
7 (?)
2 km

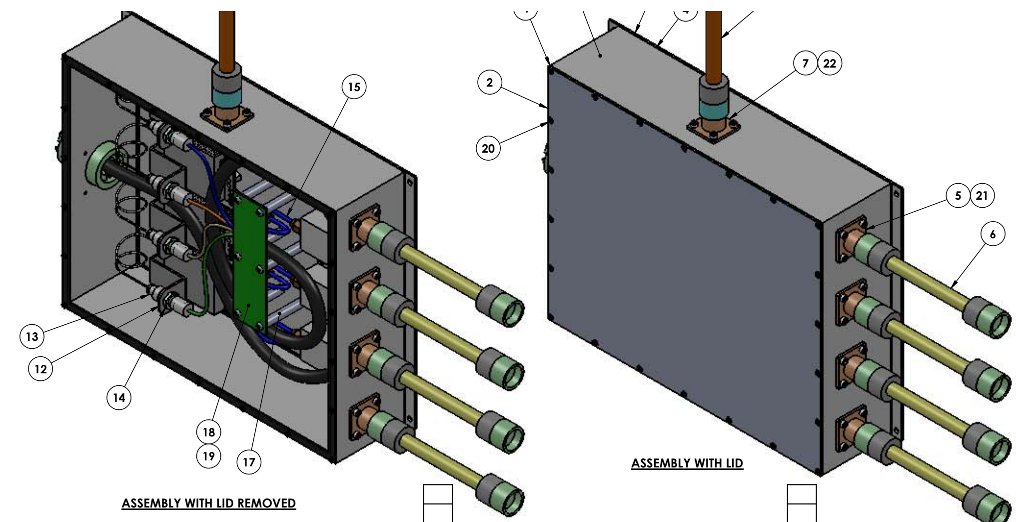


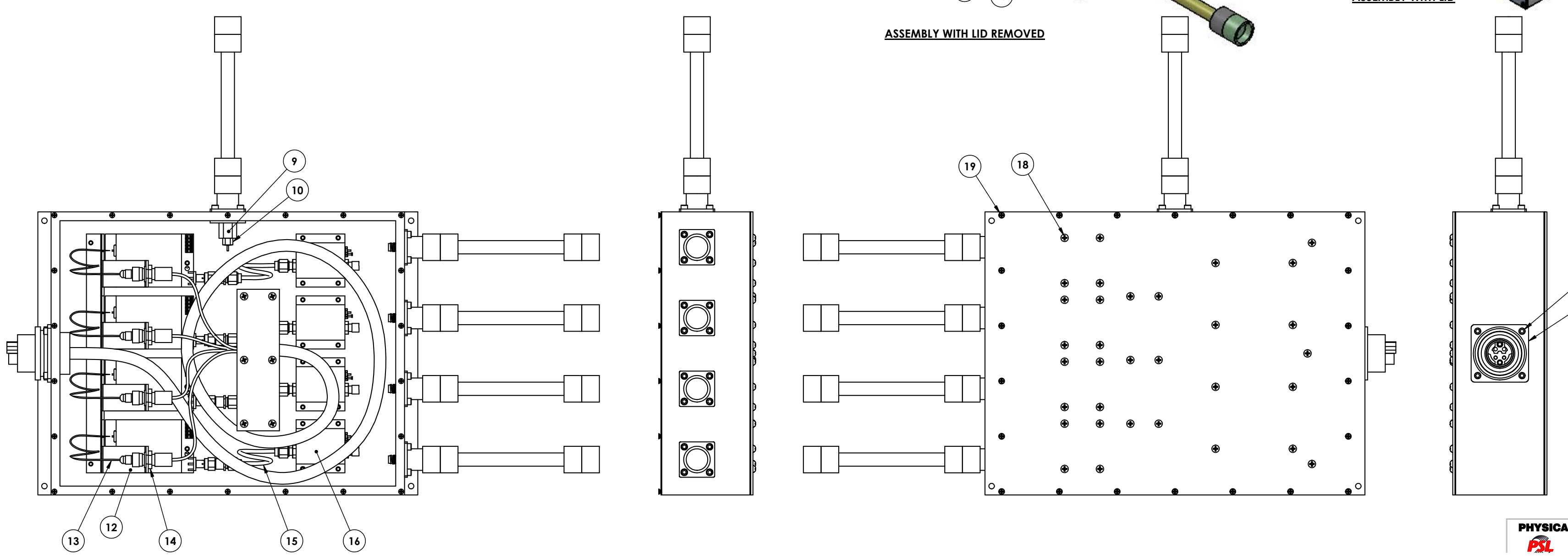
Receiver boxes

6	4	XXXXC20106M	ANDREW	-	COAX LINK 6	20200
7	1	26FC4PN	COMPAERO	-	POWER BULKHEAD CONNECTOR	20110
8	1	XXXXB20106M	-	-	OF POWER CABLE	20300
9	1	-	-		FILTER PIN BOX	201XX
10	1	100-100X	COMPAC-RF	-	FILTER PIN	20108
11	1	CPA110211CPAS-2	CABLES PLUS	-	FO BULKHEAD PLUG	20106
12	1	XXXXC20105M	-	6061-T6 ALUMINUM	FIBER STRAIN PLATE	
13	4	OZ450-LNA	OPTICAL ZONU	-	RF-over-fiber-RECEIVER	20116
14	4	-	-	-	FIBER BULKHEAD	201XX
15	4	-	UH CUSTOM	-	INTERNAL RF CABLE	20109
16	4	ZKL-1R5	MINI-CIRCUITS	-	2nd STAGE AMPLIFIER	20101
17	6	-	-	18-8 STAINLESS STEEL	POWER DISTRIBUTION BOARD STANDOFF	
18	1	-	UH CUSTOM	-	POWER DISTRIBUTION BOARD	
19	39	-	-	18-8 STAINLESS STEEL	#4-40 x 1/4 LG FILLISTER HEAD	
20	44	-	-	18-8 STAINLESS STEEL	#2-56 X 1/8 LG FLATHEAD	
21	20	-	-	18-8 STAINLESS STEEL	#4-40 x .250 LG SHCAP	
22	4	-	-	18-8 STAINLESS STEEL	#4-40 x .375 LG SHCAP	



DETAIL ITEM 17

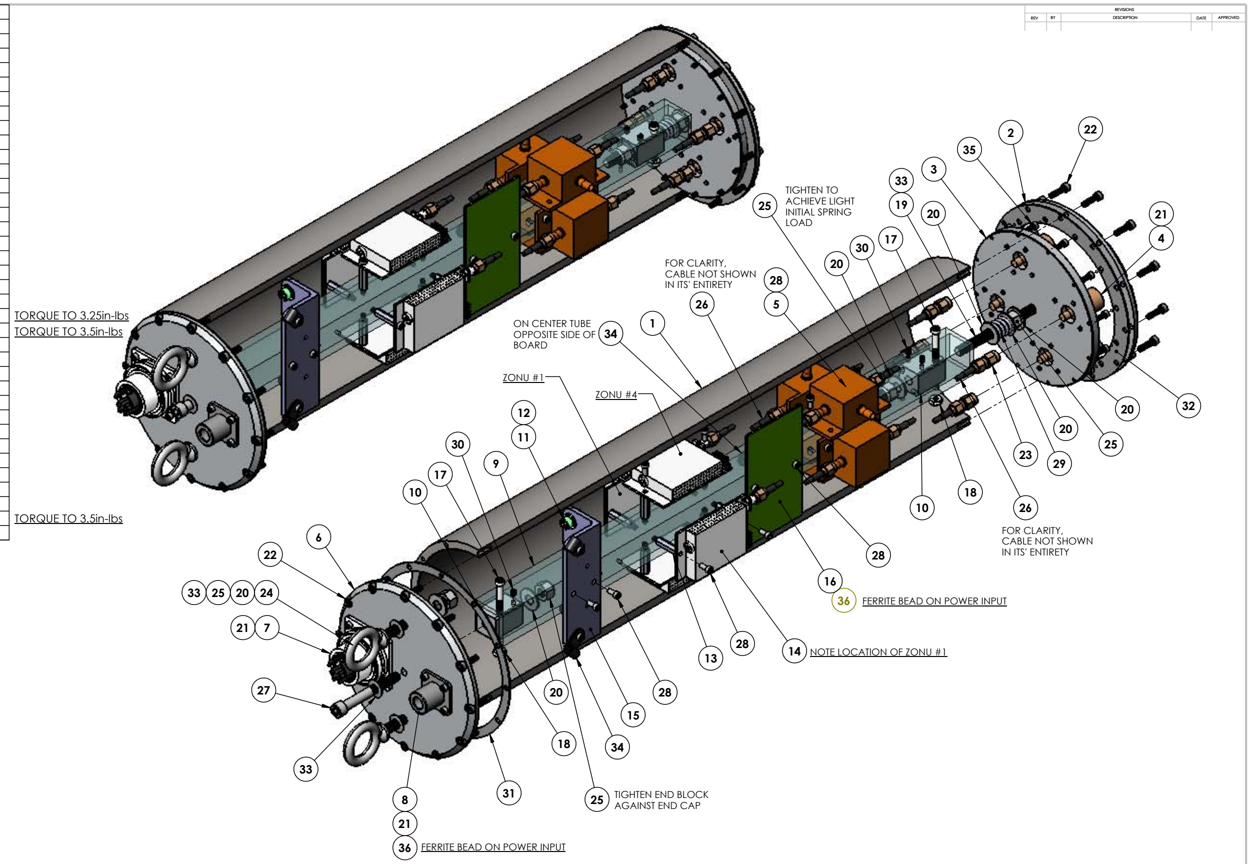


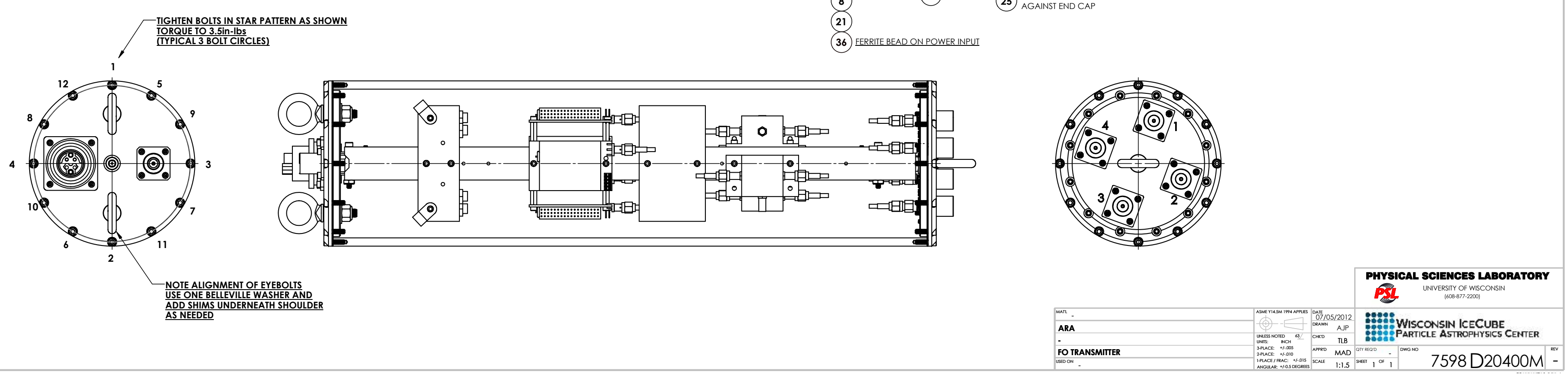


PHYSICAL SCIENCES LABORATORY
UNIVERSITY OF WISCONSIN

RFoF Transmitter

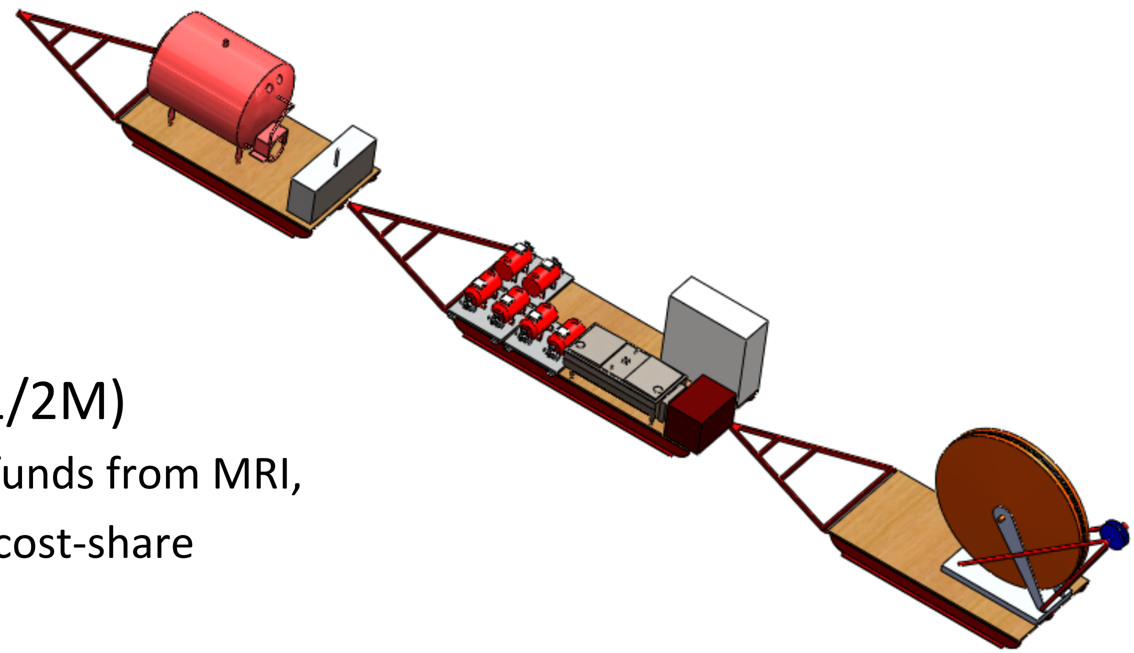
KEY	QTY	PART NO	VENDOR	MATERIAL	DESCRIPTION	
1	1	7598C20401M	-	6061-T6 ALUMINUM	HOUSING	
2	1	7598B20402M	-	6061-T6 ALUMINUM	RETAINING RING	
3	1	7598B20403M	-	6061-T6 ALUMINUM	END CAP-NSma	
4	4	SM4228	FAIRVIEW MICROWAVE	-	BULKHEAD RF ADAPTER	
5	4	ZFBT-282-1.5A+	MINI-CIRCUITS	-	BIAS-TEE	
6	1	7598B20404M	-	6061-T6 ALUMINUM	END CAP FIBER	
7	1	COTS83526	-	-	CONNECTOR	
8	1	SC9239	-	-	-	
9	1	7598B20405M	-	6061-T6 ALUMINUM	CENTER TUBE	
10	2	7598A20406M	-	6061-T6 ALUMINUM	END BLOCK	
11	4	-	-	-	FIBER BARREL	
12	4	-	-	-	FIBER BARREL NUT	
13	8	#91075A105	McMASTER-CARR	18-8 STAINLESS STEEL	MALE-FEMALE #4-40 THD STANDOFF	
14	4	-	-	-	FO TRANSMITTER	
15	1	7598A20407M	-	6061-T6 ALUMINUM	FO ADAPTER BRACKET	
16	1	-	-	-	PCB POWER BOARD	
17	2	#92196A155	McMASTER-CARR	18-8 STAINLESS STEEL	#6-32 x 1.25 LG SHCAP	
18	2	#90101A007	McMASTER-CARR	18-8 STAINLESS STEEL	#6-32 NYLON INSERT LOCKNUT	
19	1	#8891T550	McMASTER-CARR	316 STAINLESS STEEL	EYE BOLT - 1/4-20 x 3" LG	
20	7	#90107A029	McMASTER-CARR	316 STAINLESS STEEL	1/4 FLATWASHER	
21	24	#92196A108	McMASTER-CARR	18-8 STAINLESS STEEL	#4-40 x 3/8 LG SHCAP	TORQUE TO 3.25in-lbs
22	24	#92196A148	McMASTER-CARR	18-8 STAINLESS STEEL	#6-32 x .50 LG SHCAP	TORQUE TO 3.5in-lbs
23	4	-	-	-	SMA-SMA CONNECTOR	
24	2	#8891T72	McMASTER-CARR	316 STAINLESS STEEL	EYEBOLT - 1/4-20 x 1" LG	
25	5	#90715A125	McMASTER-CARR	316 STAINLESS STEEL	1/4-20 NYLON INSERT LOCKNUT	
26	16	-	-	-	CABLE	
27	1	#92200A550	McMASTER-CARR	316 STAINLESS STEEL	1/4-20 x 2" LG SHCAP	
28	22	-	-	18-8 STAINLESS STEEL	#4-40 x .250 LG SHCAP	
29	1	LC 062GG 03S	LEE SPRING	-	COMPRESSION SPRING	
30	4	#90251A110	McMASTER-CARR	18-8 STAINLESS STEEL	#4-40 x 3/16 LG SHSS	
31	1	7598A20408M	-	-	RF GASKET (END CAP FIBER)	
32	1	7598A20409M	-	-	RF GASKET (END CAP NSma)	
33	4	#9713K610	McMASTER-CARR	302 STAINLESS STEEL	BELLEVILLE DISC SPRING	
34	3	-	-	PLASTIC	WIRE CLIP	
35	12	#92196A110	McMASTER-CARR	18-8 STAINLESS STEEL	#4-40 x .50 LG SHCAP	TORQUE TO 3.5in-lbs
36	2	-	-	-	FERRITE BEAD	



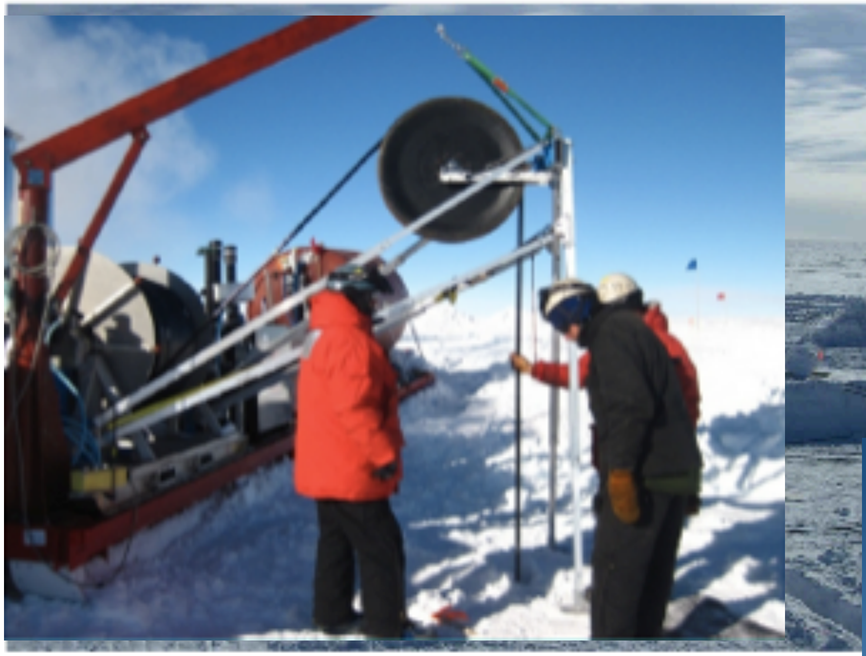


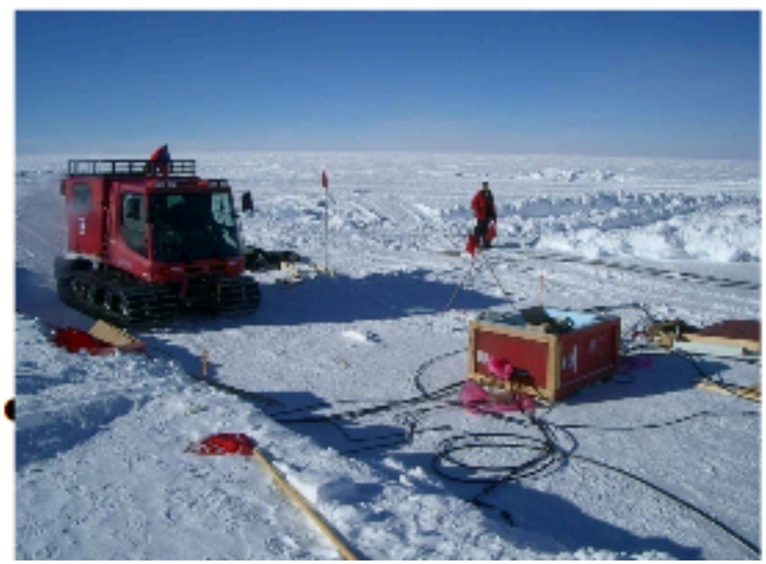
Drilling: Upgrades 2012

- Substantial upgrades were originally planned for 2013, but 2011/12 experience showed the upgrade was needed to be able to drill to 200m
- Switch to a full recirculation system with water recovery.
- Replaced lost equipment
  - Drill Head
  - Pump
  - Hose
  - Cable
  - Hose reel damaged
- Substantial effort (>$1/2M)
  - Used redirected some funds from MRI, and located additional cost-share



ARA field activities on the ice





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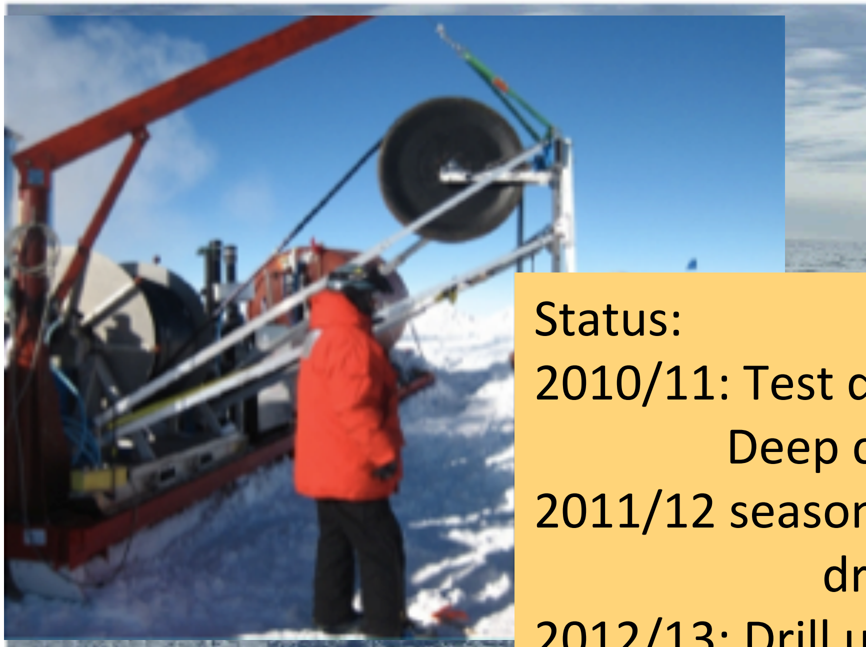
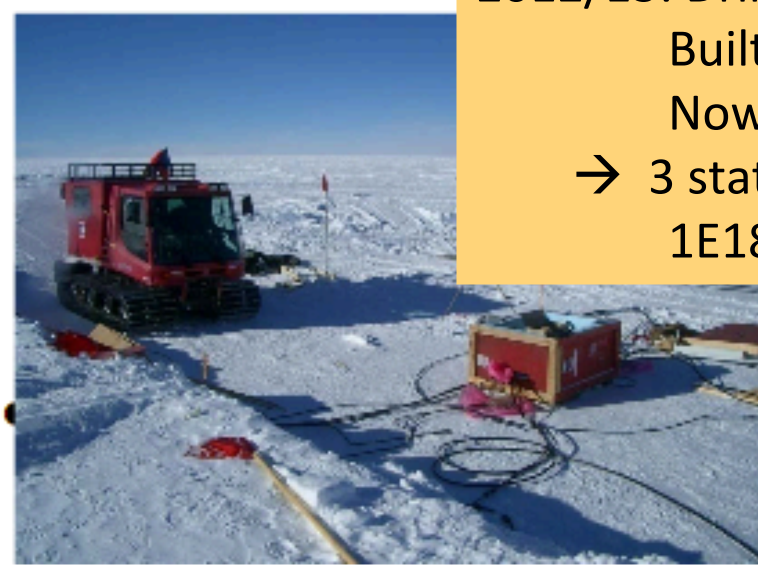
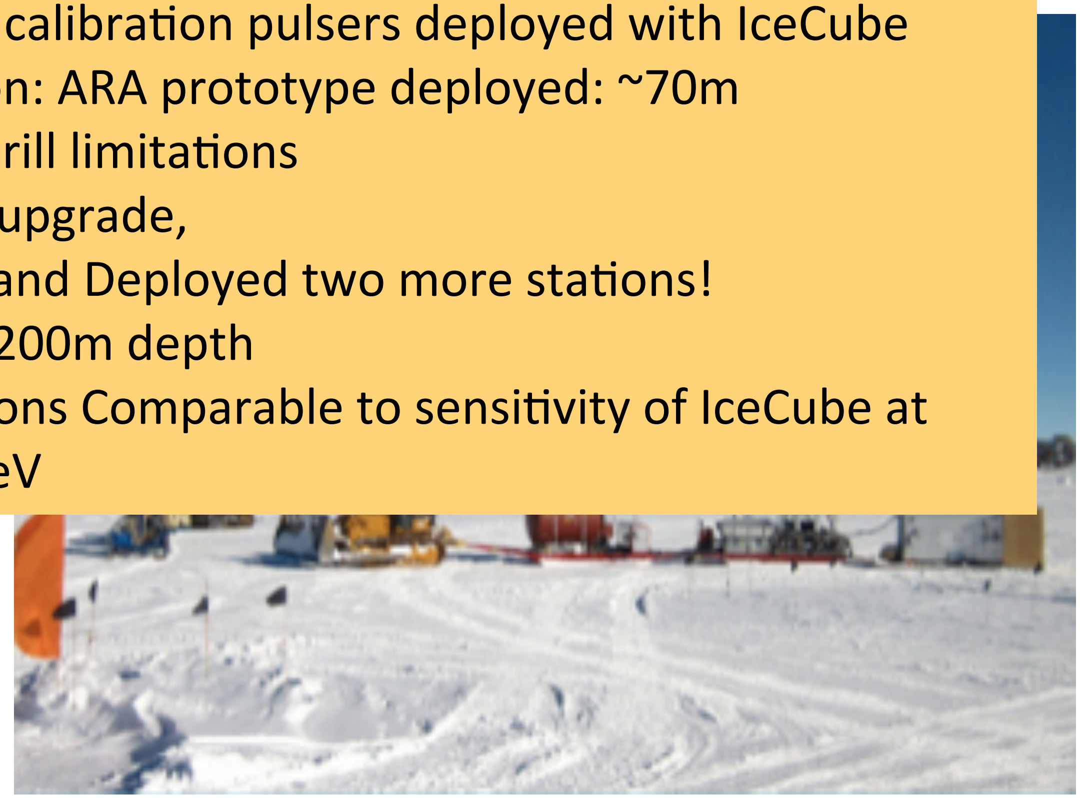






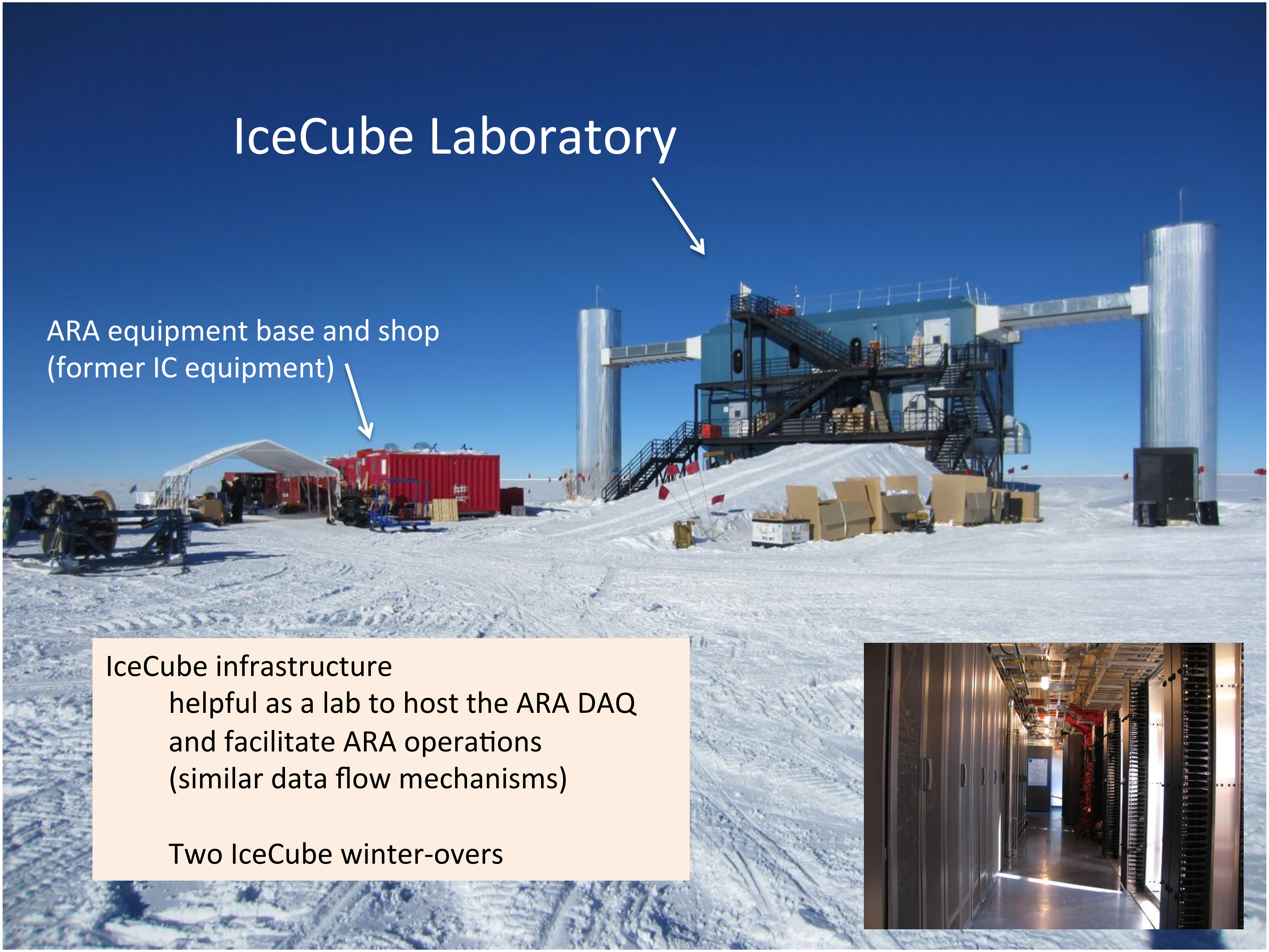
Status:

2010/11: Test detector (Test bed, shallow) deployed
Deep calibration pulsers deployed with IceCube

2011/12 season: ARA prototype deployed: ~70m
drill limitations

2012/13: Drill upgrade,
Built and Deployed two more stations!
Now 200m depth

→ 3 stations Comparable to sensitivity of IceCube at 1E18eV


IceCube Laboratory
ARA equipment base and shop
(former IC equipment)
IceCube infrastructure
helpful as a lab to host the ARA DAQ
and facilitate ARA operations
(similar data flow mechanisms)
Two IceCube winter-overs

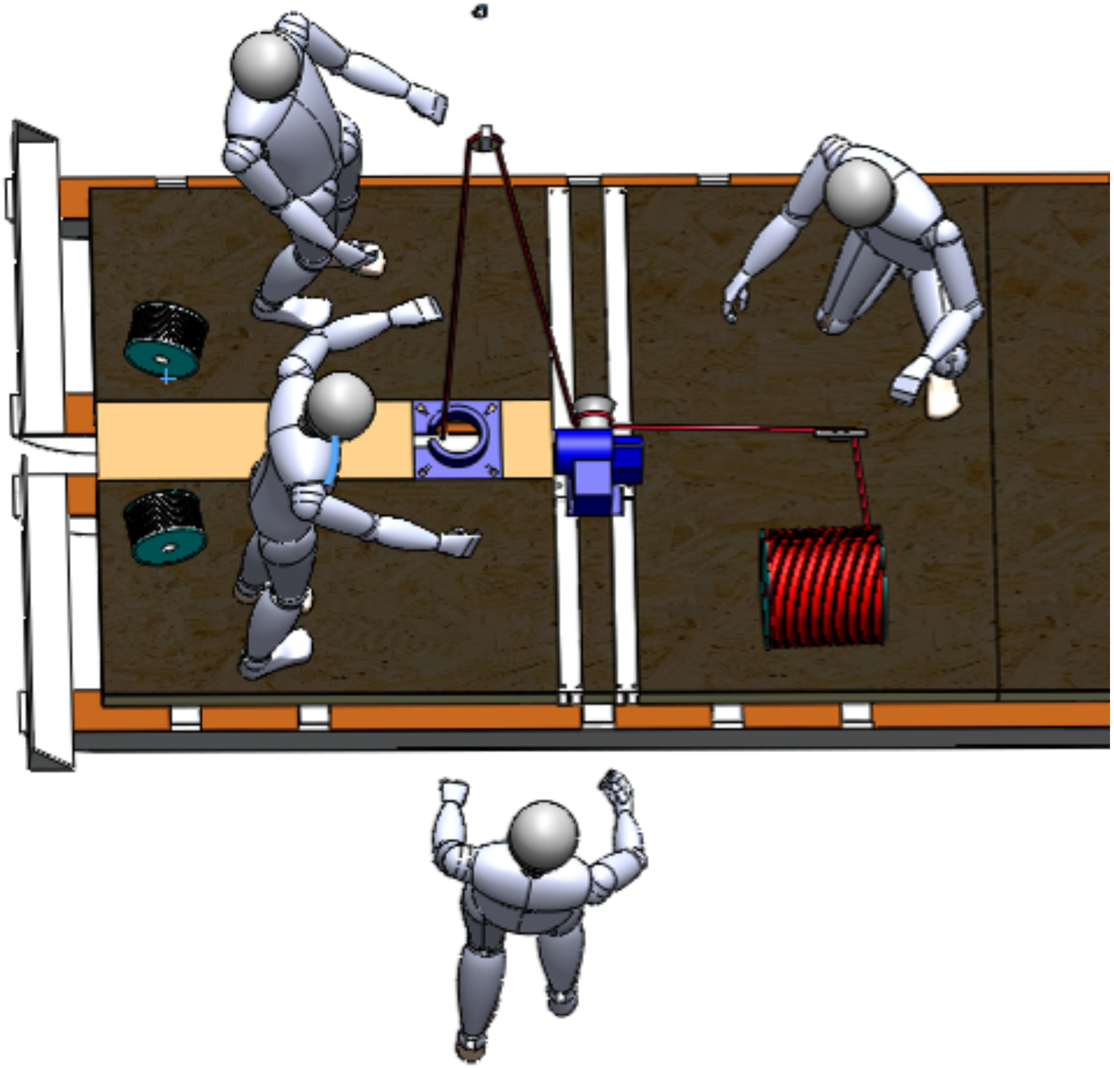
New Year Day Photo of ARA and IceCube field team members

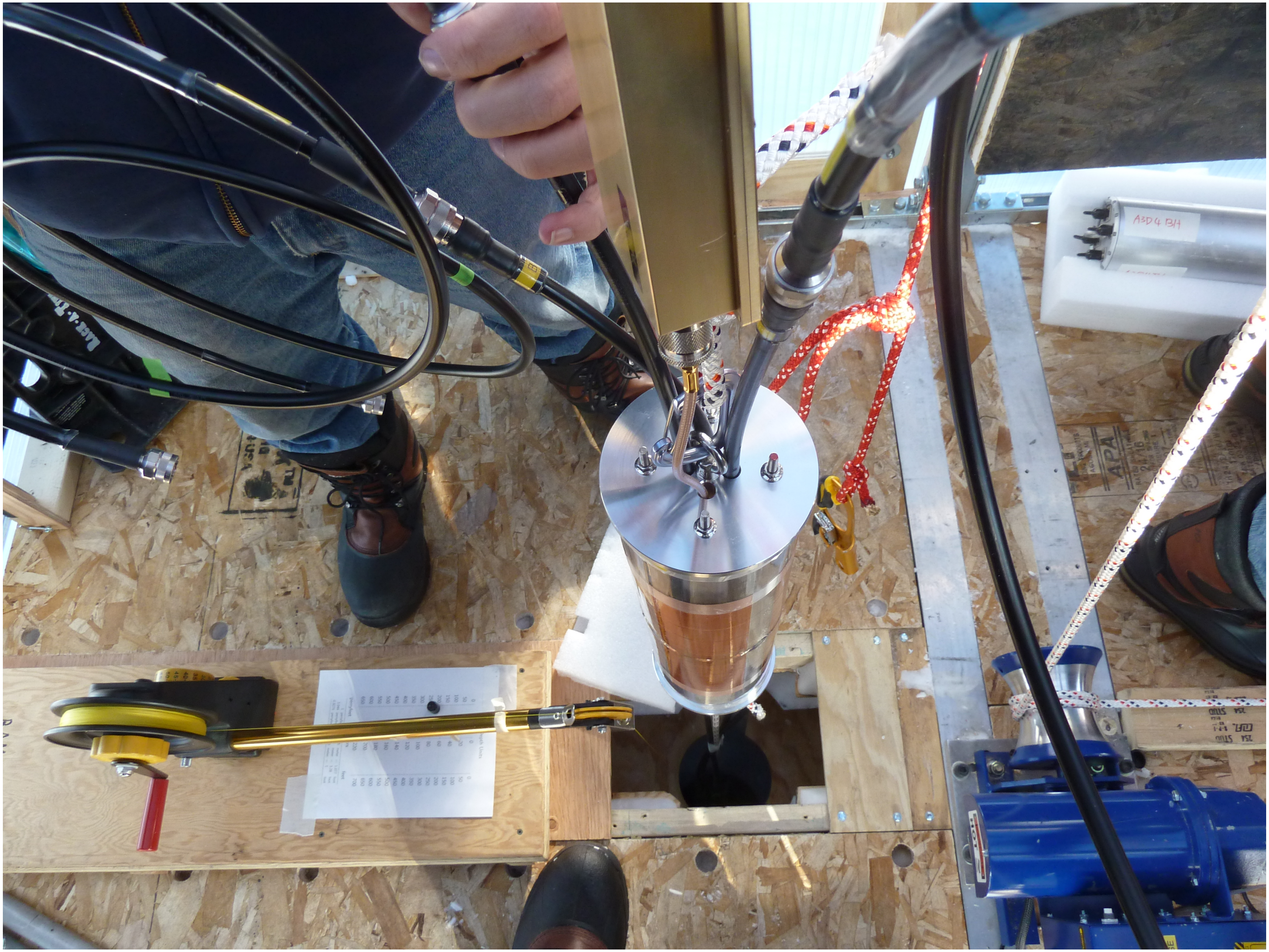
The Future…

- NSF funding uncertainty this year, probably no field season at Pole
- Looking ahead for a four year deployment push to complete the ARA-37 design
  - Electronics updates
  - Better trigger algorithms
  - Data reduction at on-line & off-line
- Farther out, even larger detector…

BACKUP SLIDES

Deployment setup



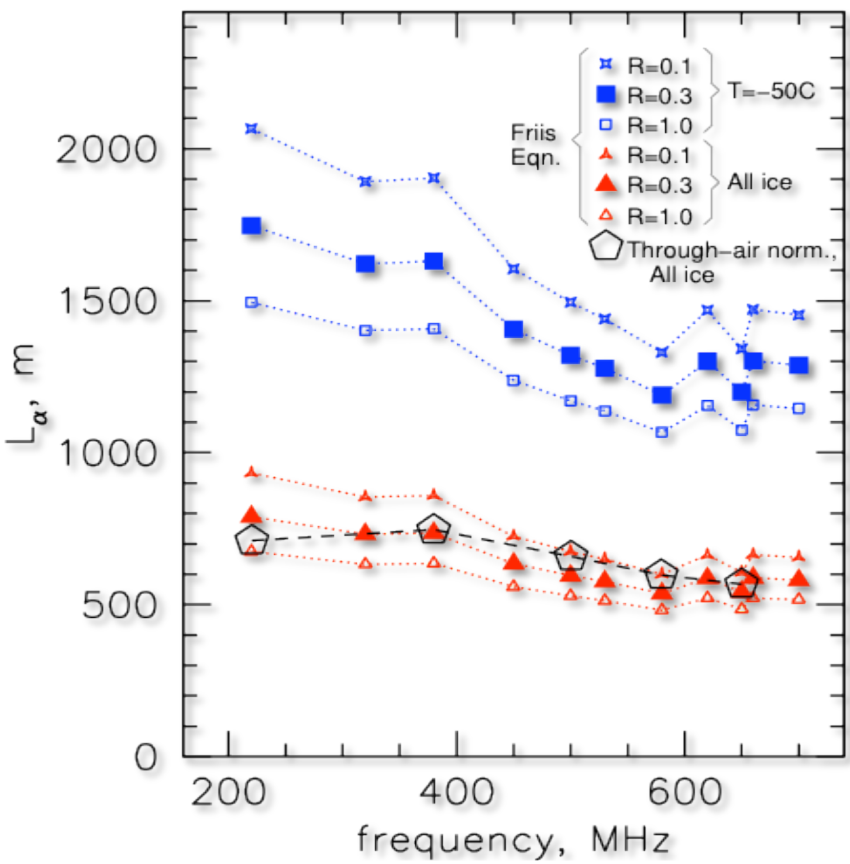

A3D4 BH

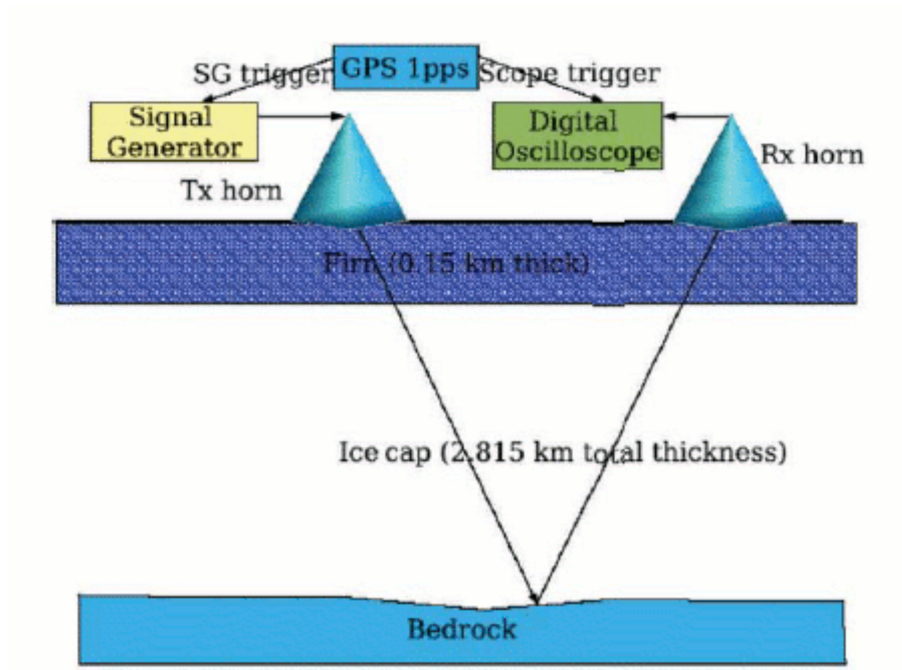
Cutting main trench

Hole qualifier

Ice Attenuation Length

- Most radio transparent material on Earth!
- Depends on ice temperature. Colder ice at the top.
- Reflection Studies (2004) (Down to bedrock, 200-700MHz): "normalize" average attenuation according to temperature profile.





Besson et al. *J.Glaciology*, 51,173,231,2005