Radio detection of UHE cosmic neutrinos

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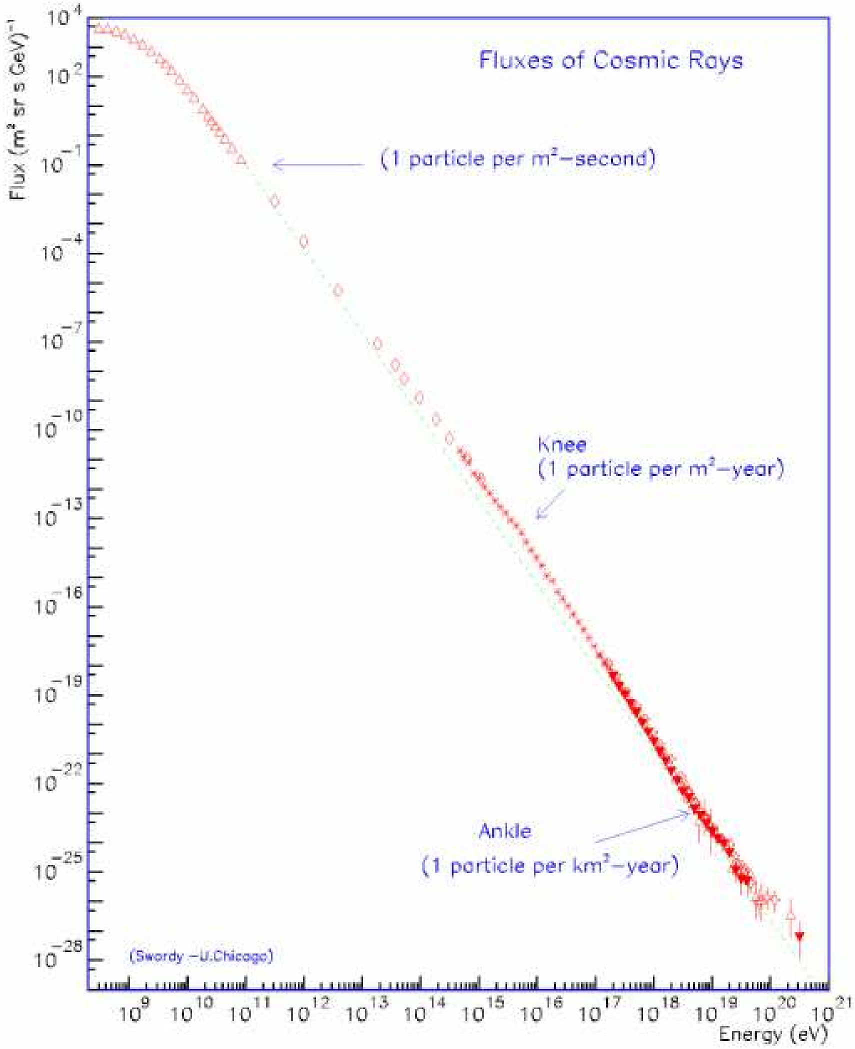
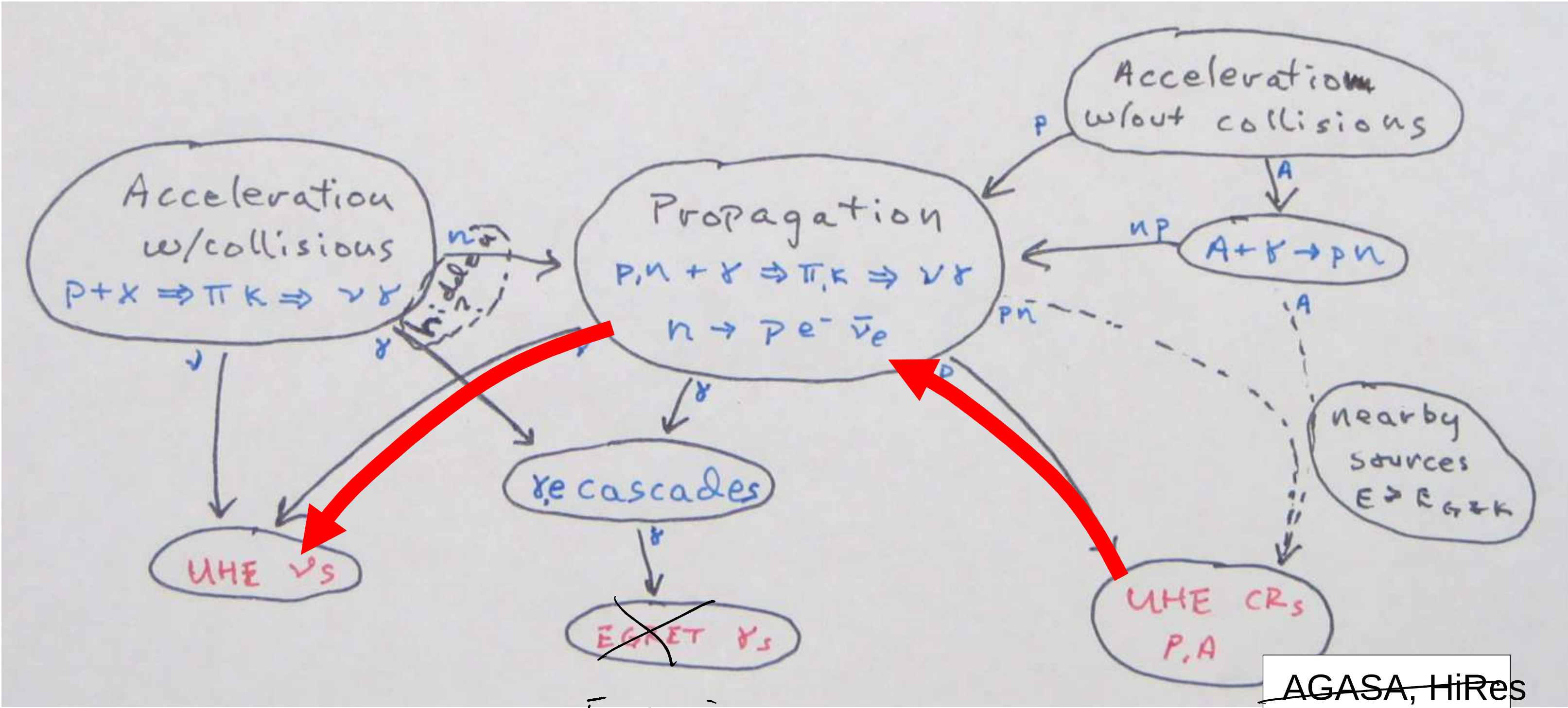
Topics

- Background
  - UHE cosmic particles & large detectors
  - Radio emission from showers
- ANITA
- ARA & ARIANNA
- Lunar observations
- Related topics (not discussed)
  - Auger, Acoustic, UHE cosmic rays

Cosmic Rays


Fluxes of Cosmic Rays
(1 particle per m²–second)
Knee
(1 particle per m²–year)
Ankle
(1 particle per km²–year)
(Swordy – U.Chicago)
Flux (m² sr s GeV)⁻¹
Energy (eV)

UHE Production: Acceleration



~~AGASA, HiRes~~

Fermi

Auger

almost

1. Acceleration predictions depend on scenario – could be "no ν's".
2. "GZK" neutrinos are almost guaranteed – a guide for experiment design.
3. Still some model dependence.
4. Constraints from ~~EGRET~~ Fermi & UHECR
5. $E_\nu \sim .05\ E_p$

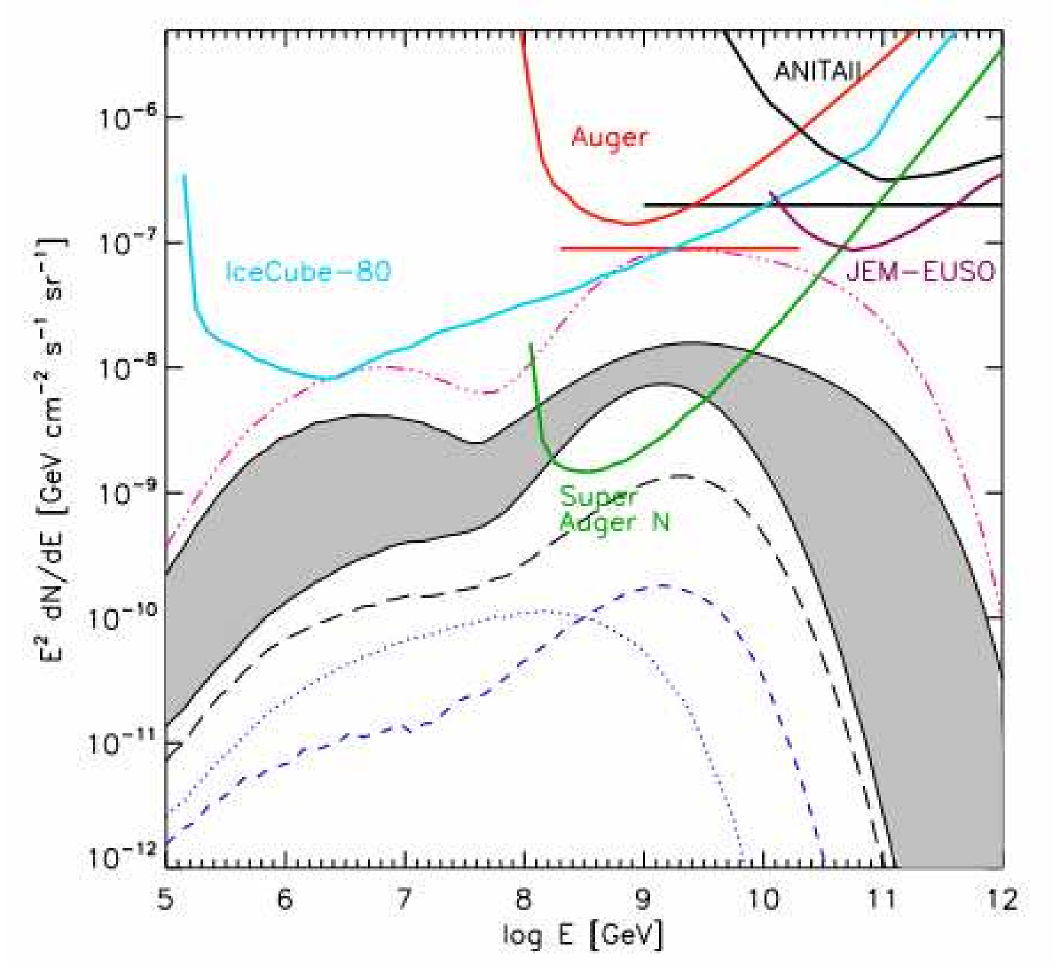
Fixed

Cosmogenic (GZK) neutrinos

(Kotera, Allard, Olinto)

Note.

- Must also fit UHECR



Detection

Large Area   E ↑   A ↑

$A = N A_1$

\$ Better Technique

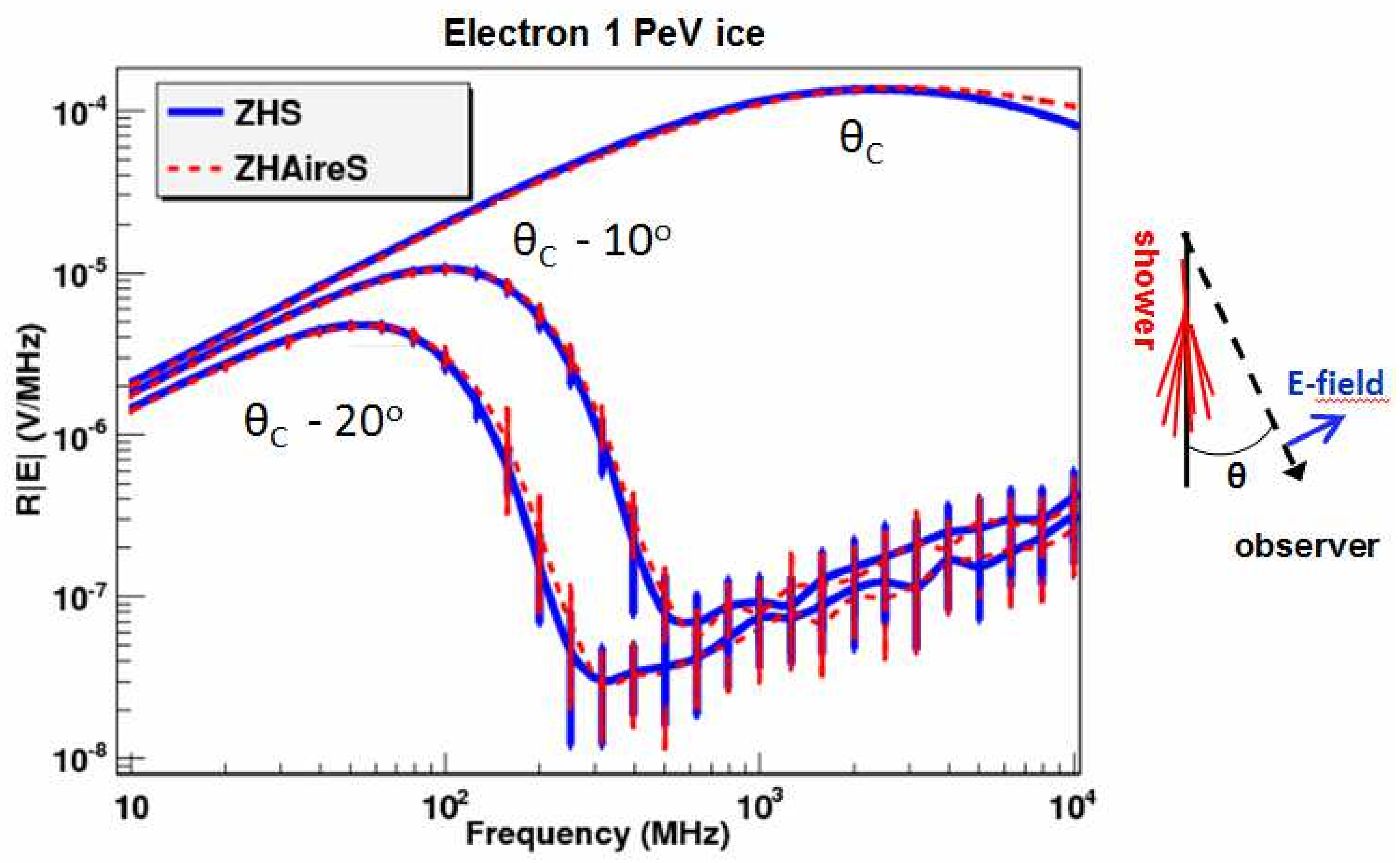
Detect showers

particles   near field   small

radiation   optical / Radio * / Acoustic   depends on attenuation

Radio emission from showers

From Jamie Alvarez-Muniz @ OSU workshop (2/12)
Also see Tim Huege for status of geo-magnetic

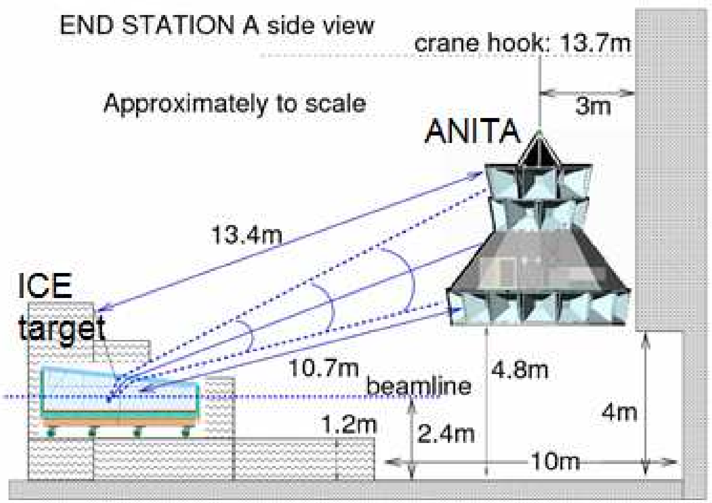


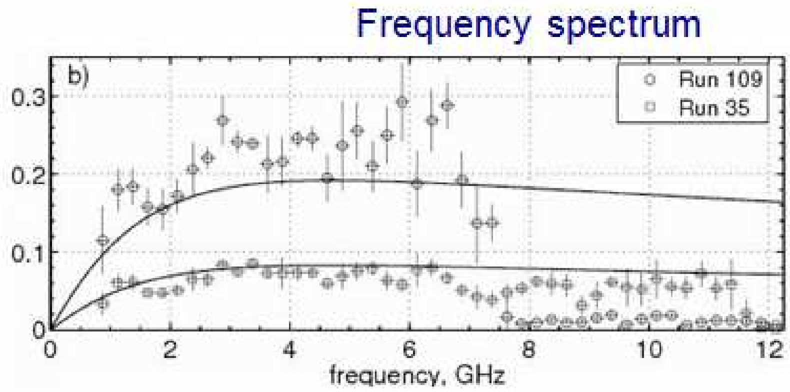
Experiment confirms theory (Jamie Alvarez-Muniz)

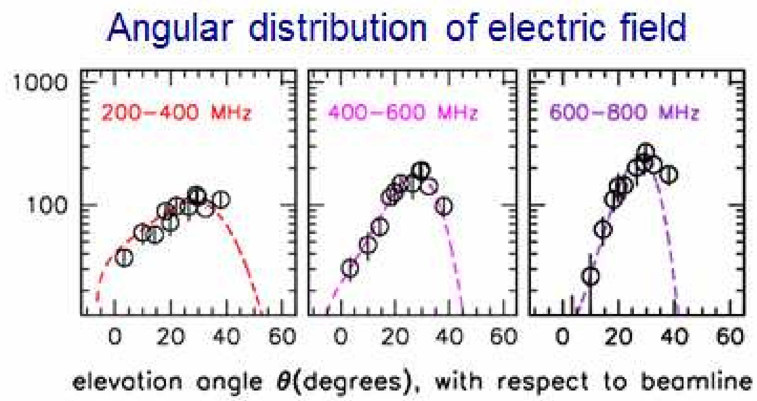
Experiments at SLAC: sand, salt & ice

Bunches of ~ GeV bremss. photons dumped in sand & salt & ice: E_0 ~ 6 x $10^{17} - 10^{19}$ eV .

- Askaryan effect seen !!!
- Linearly polarized signal
- Power in radio waves goes as E_0^2
- Bipolar pulses in time-domain
- Agreement with theoretical expectations







D. Saltzberg et al. PRL **86** (2001);
P.Miocinovic et al. PRD **74** (2006),
P. Gorham et al. PRL **99** (2007)

More attempts: K. Belov, A. Romero-Wolf @ this meeting

ANITA

- ANITA Overview
- Neutrino detection
  - event generation
  - event simulation
  - ANITA detector
  - analysis
  - results
- Cos-Ray detection
- Other
- ANITA 3, EVA

ANITA Collaboration

Pubs + Details in theses
Hoover, Romero, Goodhue,
Mottram, Javaid

University of California, Irvine

Ohio State University

University of Kansas

Washington University in St. Louis

University of Delaware

University of Minnesota

University of California, Los Angeles

University of Hawaii at Manoa

National Taiwan University

University College London

Jet Propulsion Laboratory

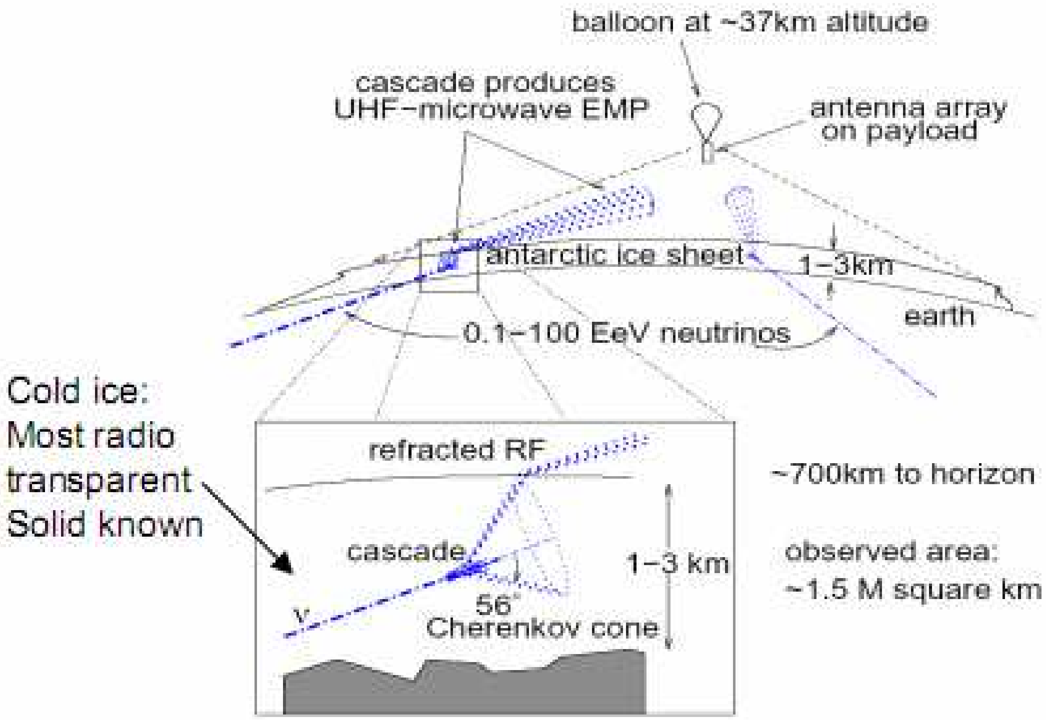
Stanford Linear Accelerator Center

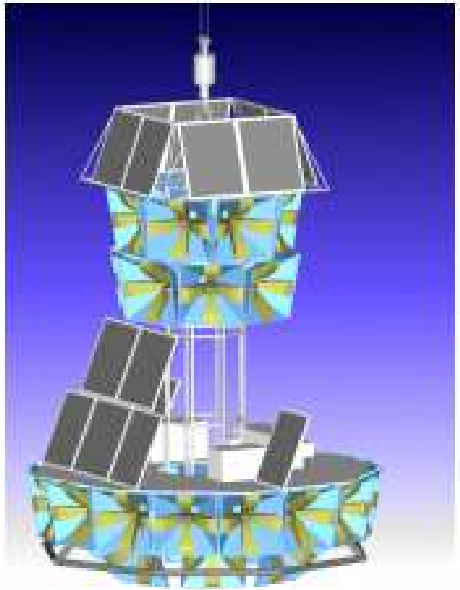
Overview

shamelessly borrowed from P. Gorham

ANITA will seek the origin of the *highest energy particles in the universe*, by turning the continent of Antarctica into an enormous

Neutrino Telescope

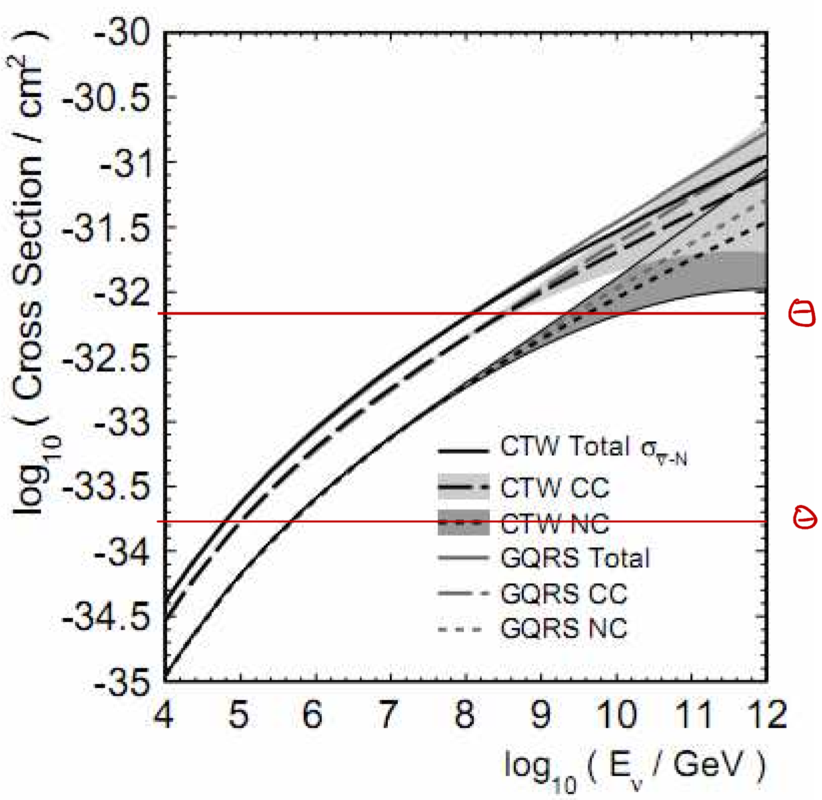




Neutrino interactions

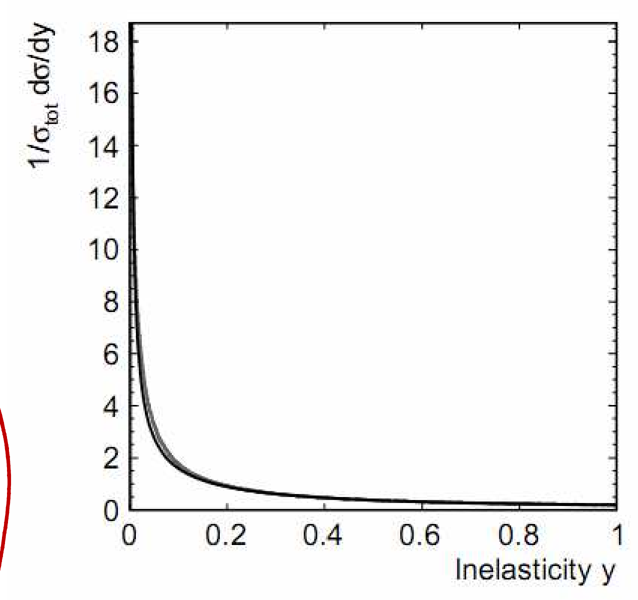
σ

dσ/dy

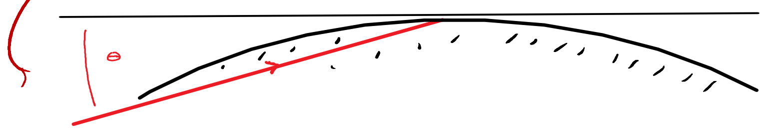


θ=5

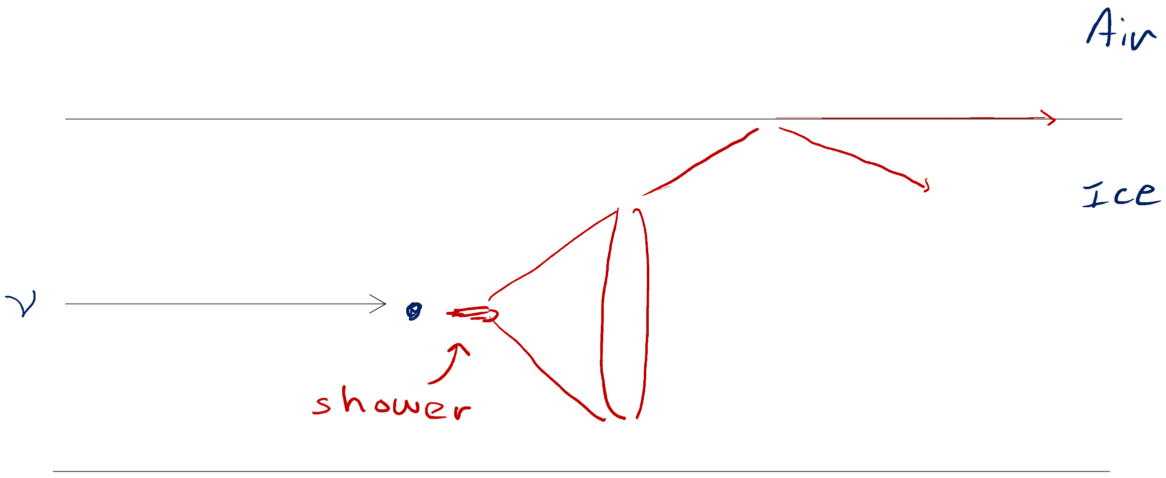
θ=90



CTW: Connolly, Thorne, Waters



Cherenkov and Total Internal Reflection



$$\Theta_c = \Theta_{TIR}$$

Aperture

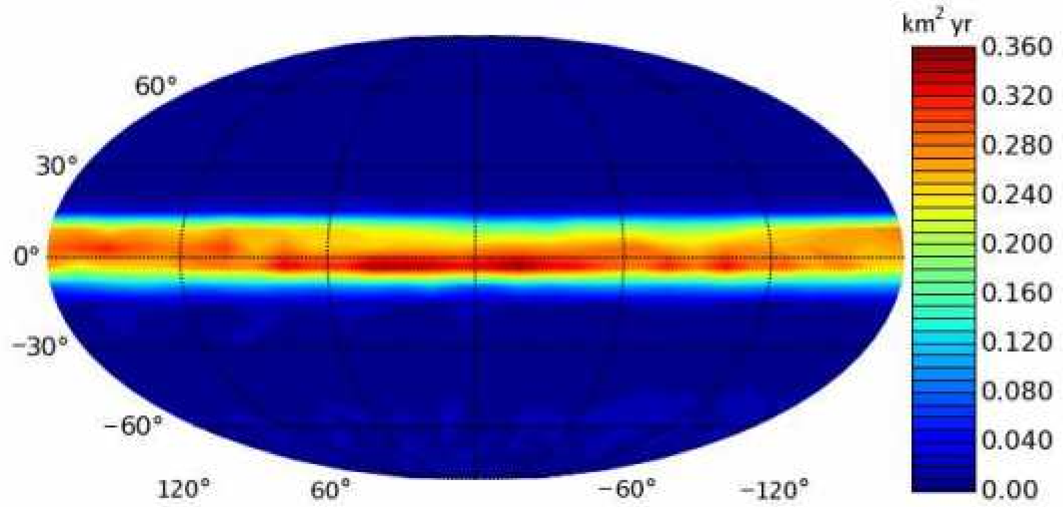
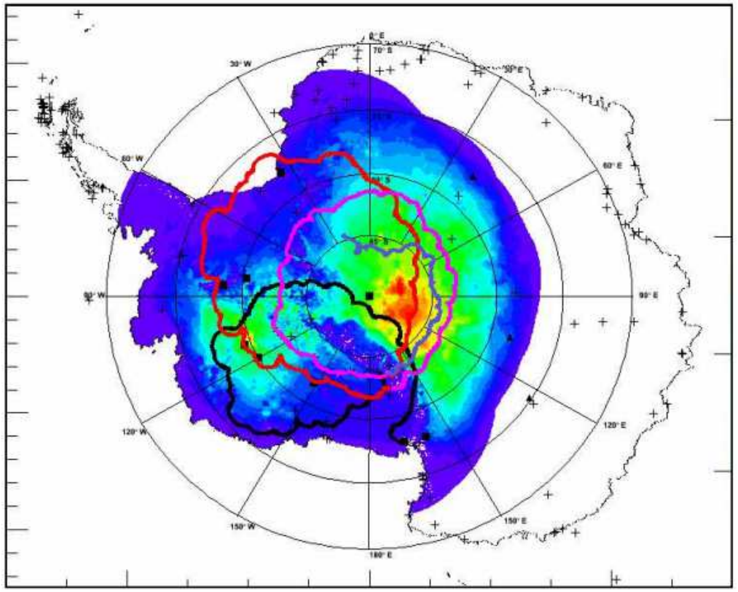


FIG. 19: A false-color map of sky exposure quantified by total neutrino aperture (here given for $E_\nu = 10^{20}$ eV) as a function of right-ascension and declination for the ANITA-1 flight.

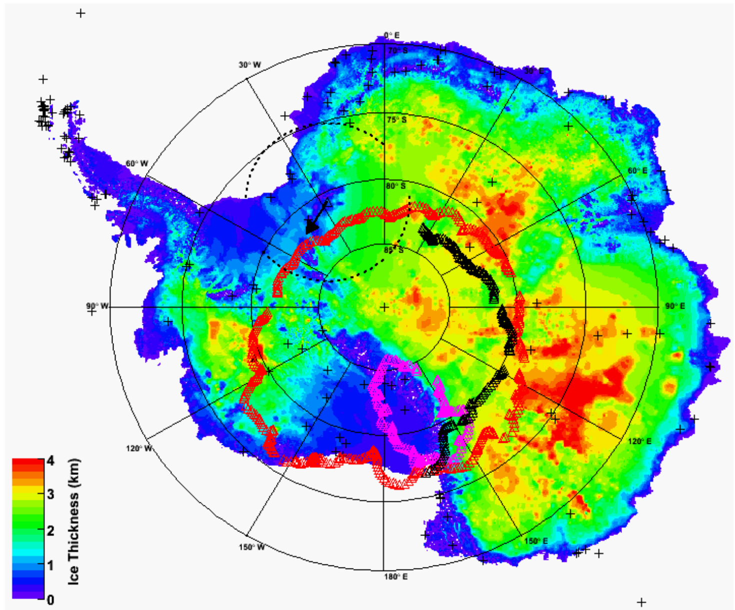
ANITA flight(s)

ANITA - I



- 3 orbits (6 weeks)
- ice depth 0-4 km
- bases

ANITA - II (1 week before end)



Also: ANITA-LITE

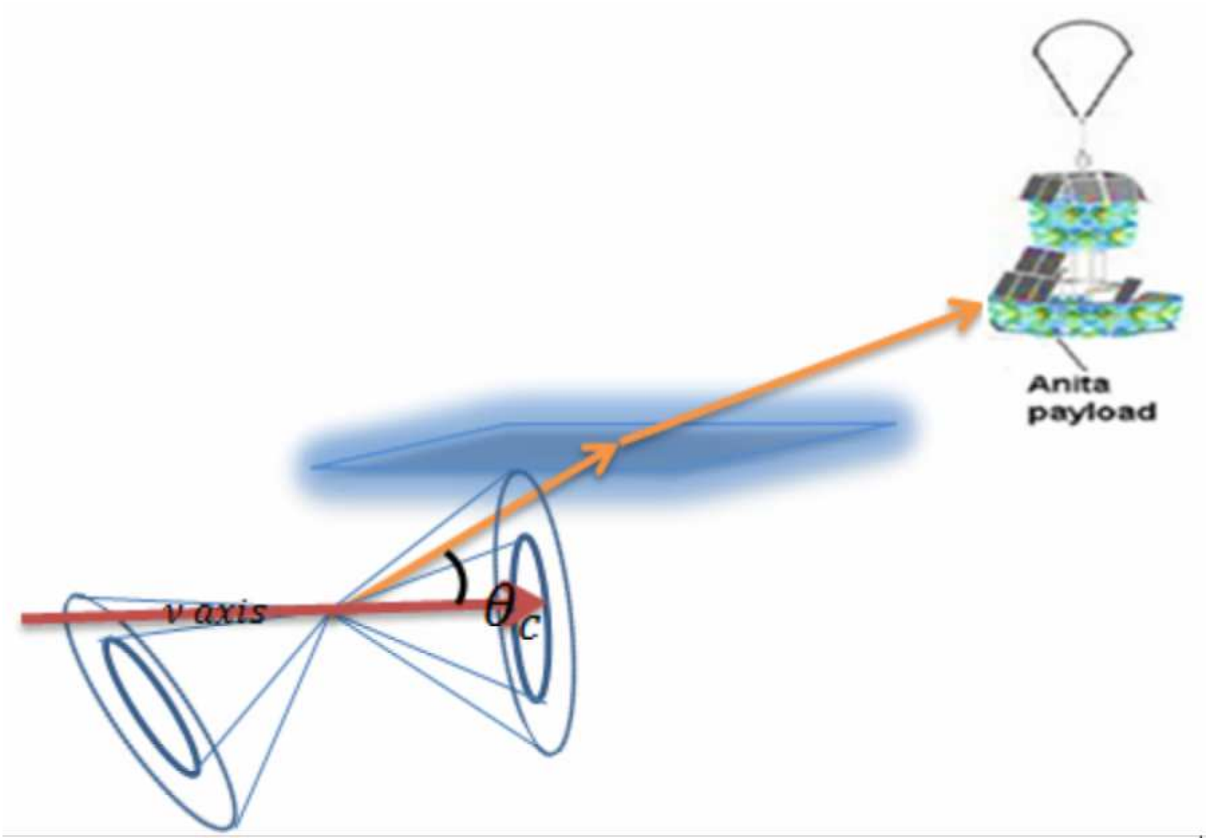
Event Simulation

- Askaryan mechanism
  - Signal Characteristics
- Determine list of sources
- For each source
  - Determine launch angle via ray tracing
  - Propagation effects
  - Emission spectrum
  - Spectrum at detector
- Sum spectra from sources

Event $\rightarrow$ source list

- NC events
  - Hadronic shower + possible 2nd interaction
- CC events
  - ν_e em + hadronic shower
  - ν_τ, ν_μ hadronic shower + brem/photonuclear $\rightarrow$ secondary showers
  - ν_τ decay
- Model fluctuations
  - multiple sub-showers
- Multiple paths
  - reflection from bottom
- Exotica
  - Monopoles: quasi-continuous photonuclear

Event Geometry



(Javaid)

Radio emission

- Frequency domain – linear response
  - ice attenuation
  - velocity of propagation
  - antenna, amps, filters (time domain for discriminators)

- Spectrum from Alvarez-Muniz, Zas, & Friends

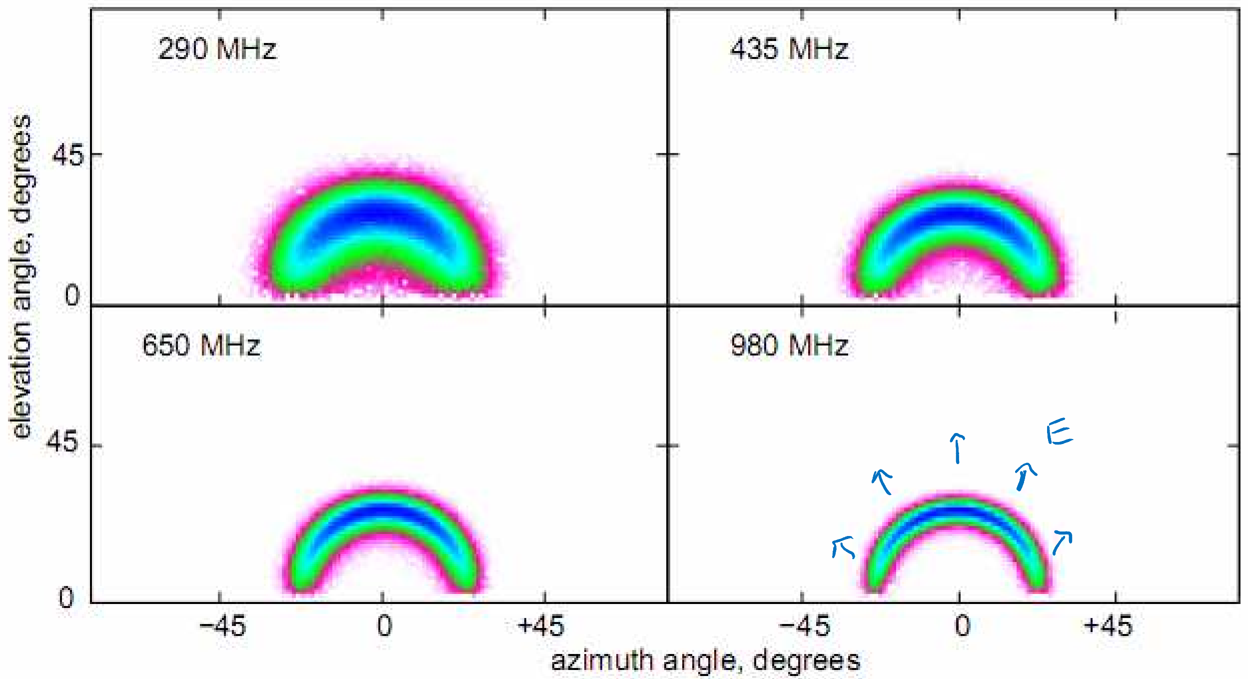
98–00

- Could be improved.

Propagation (See discussion of ice properties)

- Ray tracing (part of geometry)
- Attenuation
  - 3-zone model, with temperature/depth vertical profiles
- Refraction (de-focusing)
- Scattering: reflection/transmission
- Birefringence (not included)
- Dispersion (not included)

Cerenkov Beam



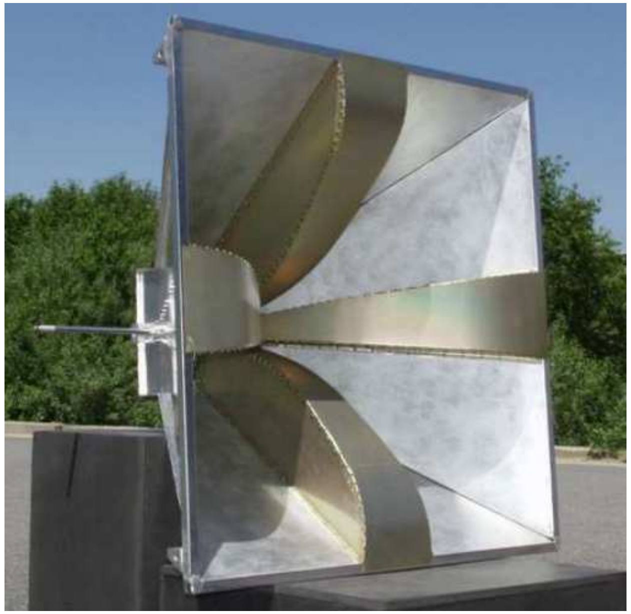
ANITA detector

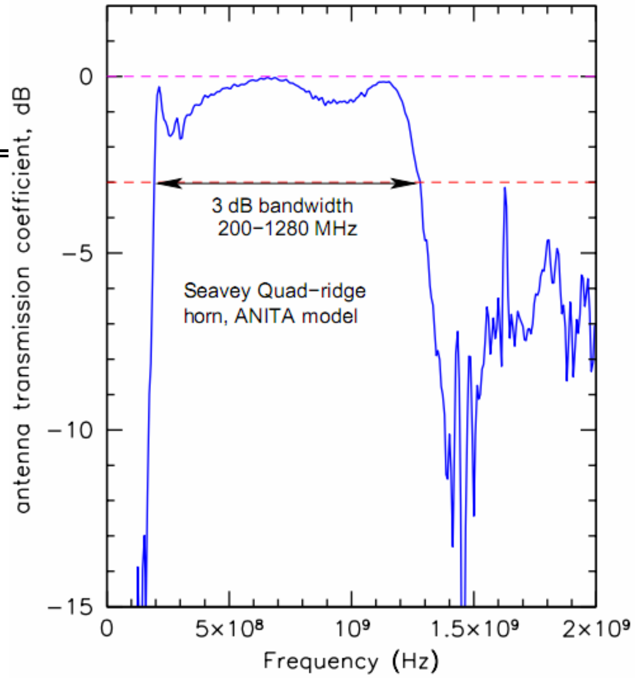
- Airframe and payload infrastructure
- Analog front end
  - Antennas
  - Low Noise Amps, filter, splitter
  - Cables/connectors/boxes
- Trigger
  - multistage, narrow dt: reduce accidentals
- Digitizer
  - Low power switched capacitor array
- Efficient data handling

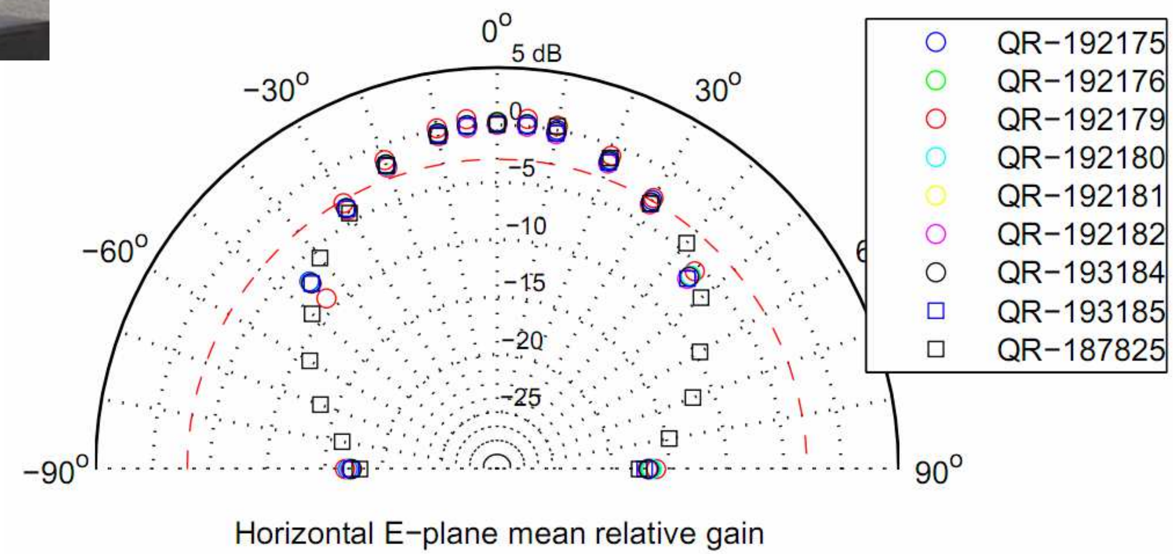
ANITA Payload

- Weight
- Rigidity
- Form-factor
- Power
- Thermal
- Remote

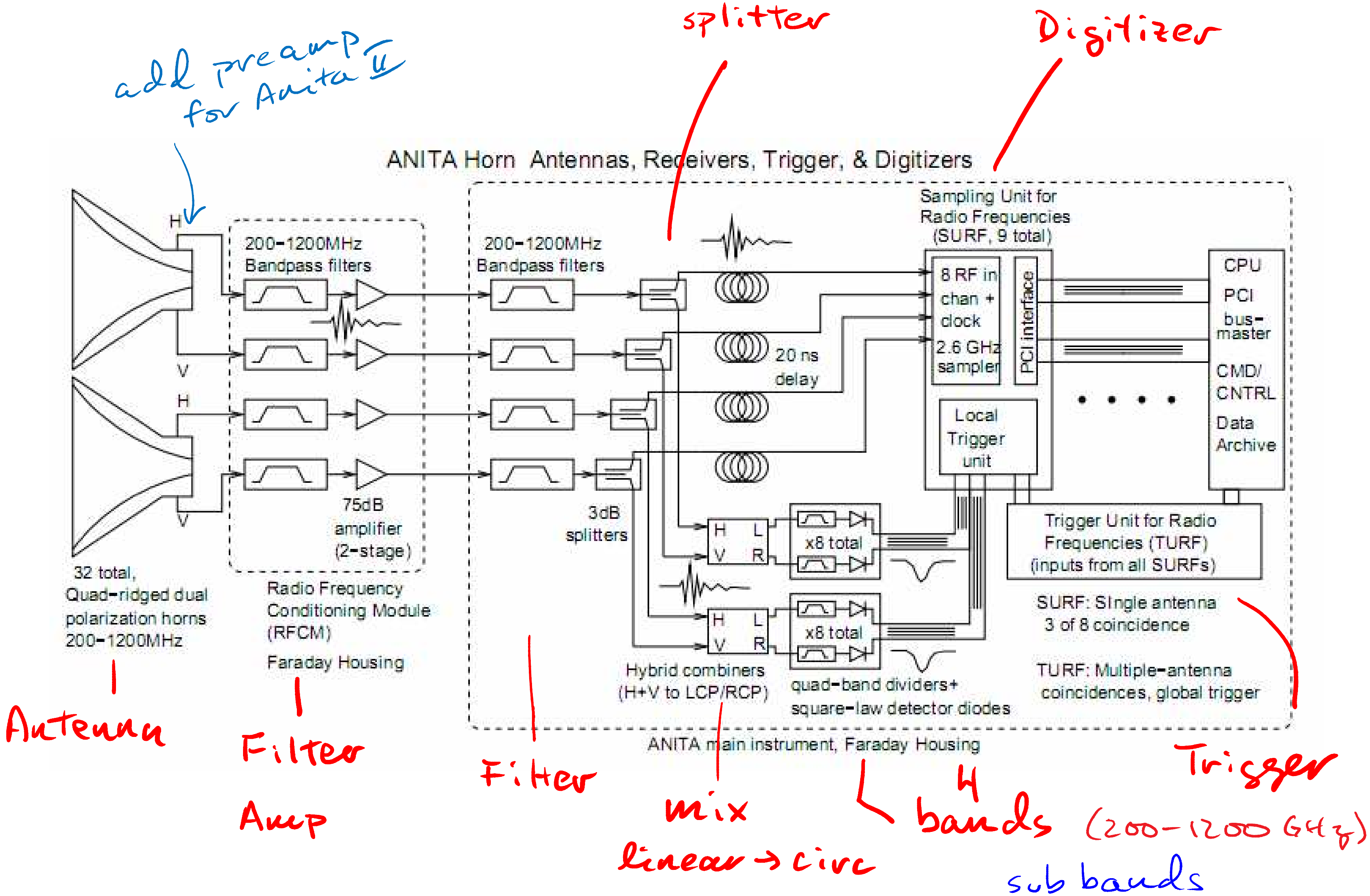
Front end: antennas



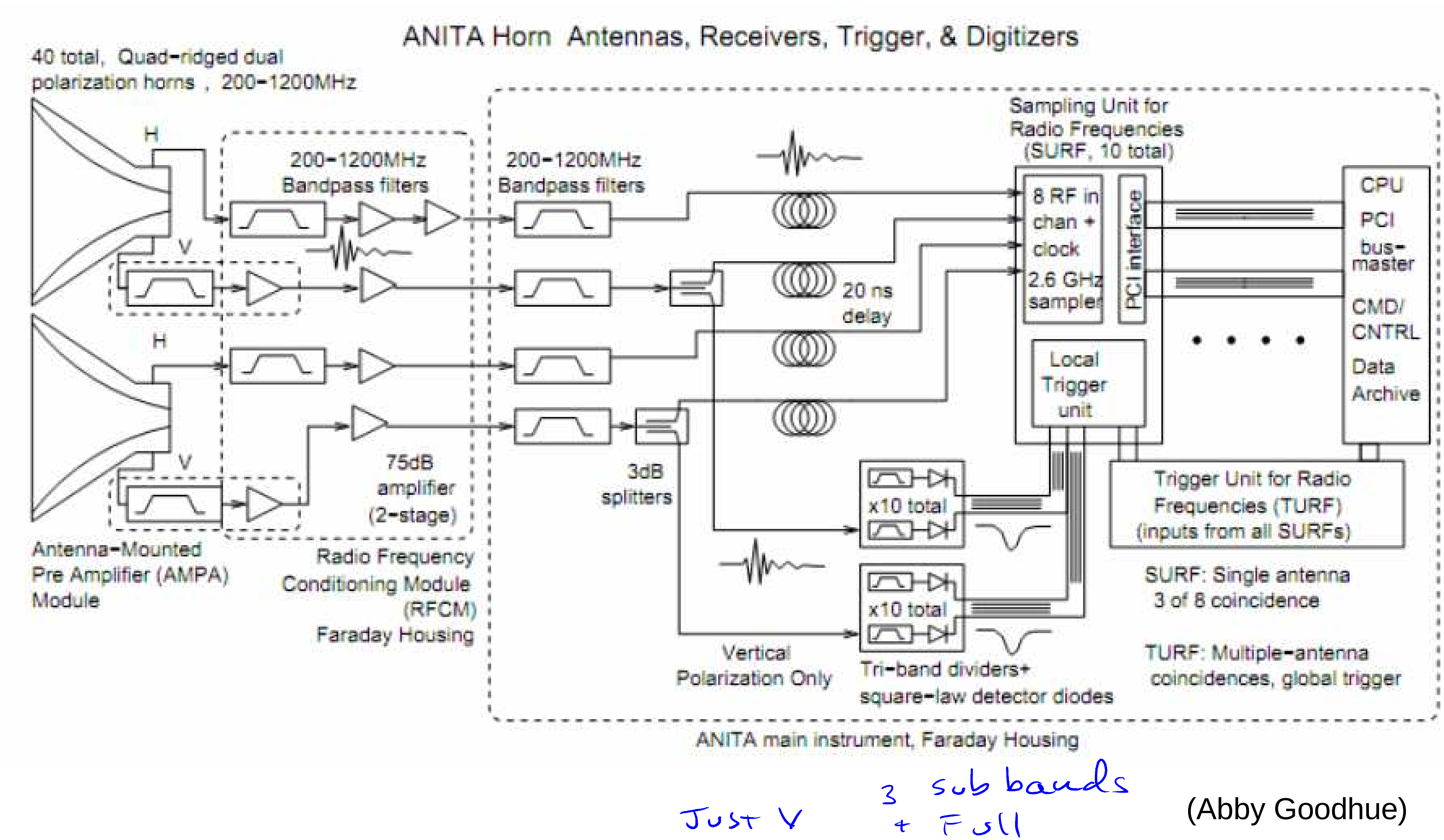




RF subsystems (ANITA-I)



ANITA-II RF system



(Abby Goodhue)

Triggers

	$L\phi$		L1	L2	L3	
	Pol	Bands	n/m	in Ring Antenna's	Top/Bottom ϕ-sectors	Focus
I	LR	4	3/8	A—A—A—A	ϕ ϕ ϕ	Č is linear
II	V	3 + full	2/3 + full	A—A—A	ϕ ϕ	ν-Geometry prefers V-pol

But bad for cos-ray

Digitizing electronics (Anita-I)

TABLE I: ANITA Electronics Specifications.

Design Parameter	As-built Value & Comments
# of RF channels	80 = 32 top, 32 bottom, 8 monitor
Sampling rate	2.6 GSa/s, greater than Nyquist
Sample resolution	$\geq$ 9 bits = 3 bits noise + dynamic range
Samples in window	260 for a 100 ns window
Buffer depth	4 to allow rapid re-trigger
Power/channel	$<$ 10W including LNA & triggering
# of Trigger bands	4, with roughly equal power per band
# of Trigger channels	8 per antenna (4 bands x 2 pols.)
Trigger threshold	$\leq 2.3\sigma$ above Gaussian thermal noise
Accidental trigger rate	$\leq$ 5 Hz, gives 'heartbeat' rate
Raw event size	$\sim$ 35 kB, uncompressed waveform samples

- Key component: Switched Capacitor Array (SCA) by G. Varner.

Operations

- Campaign operations
  - NH preparations
  - McMurdo
  - Flight
  - Recovery
  - Taylor Dome

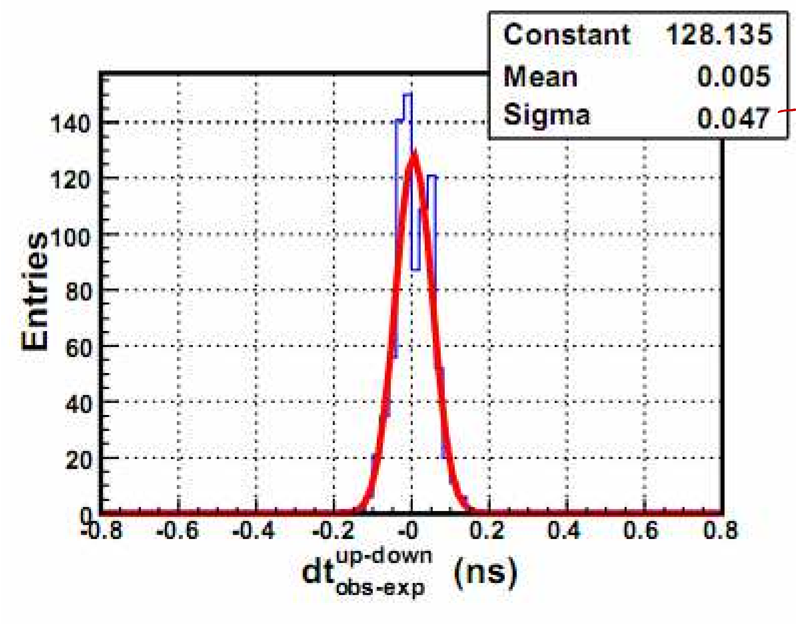
- C^3

Analysis

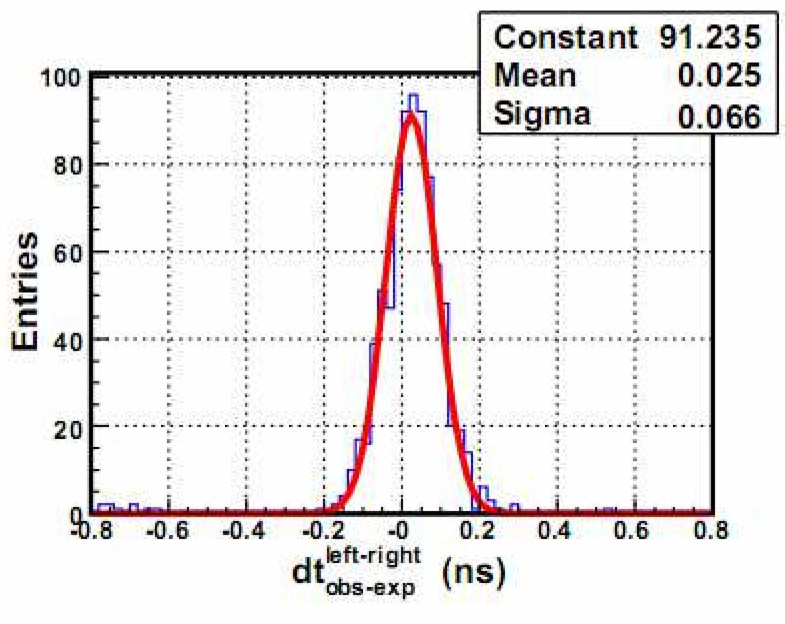
- Timing Calibration
- Interferometry
- Backgrounds
  - Thermal (reconstruction amplitude)
  - Anthropogenic (clustering)
- I: 0 neutrino candidates
- II: 1 neutrino candidate
- Limits

Calibration (ground pulses from McMurdo, Taylor Dome)

47 ps

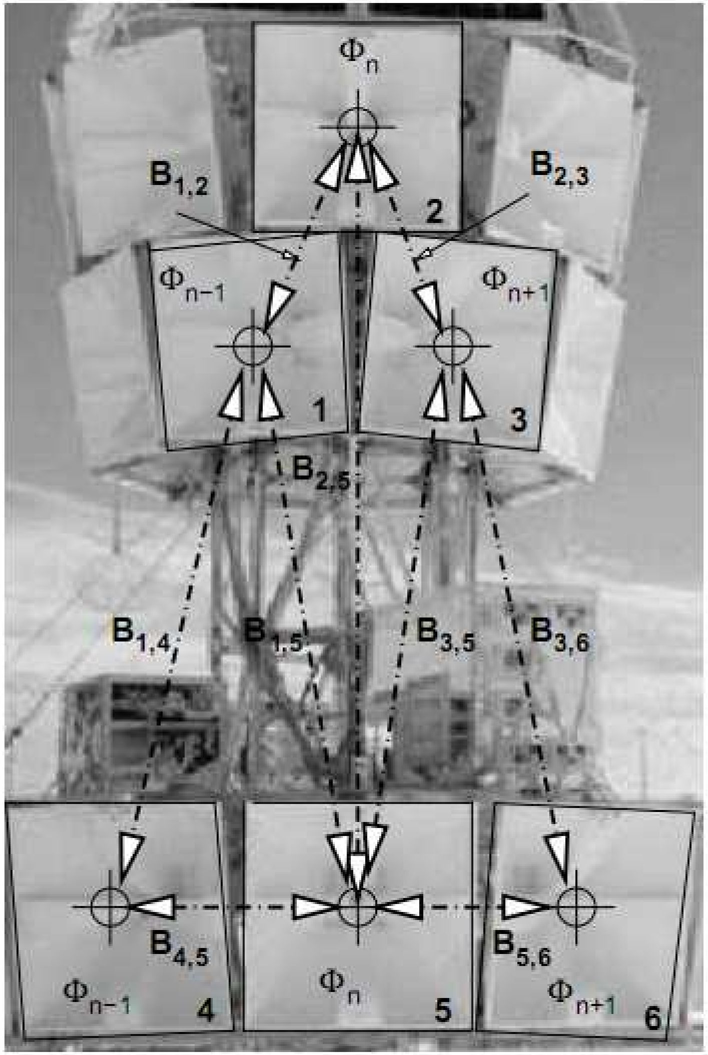


same ϕ sector

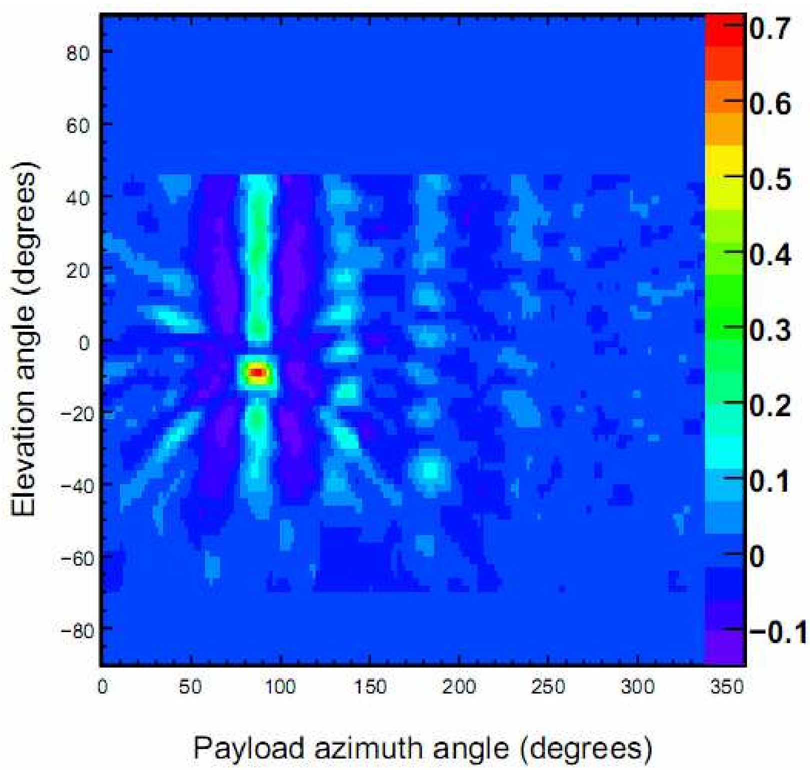


Different ϕ

Interferometry (correlations not feature extraction)



Ground pulser

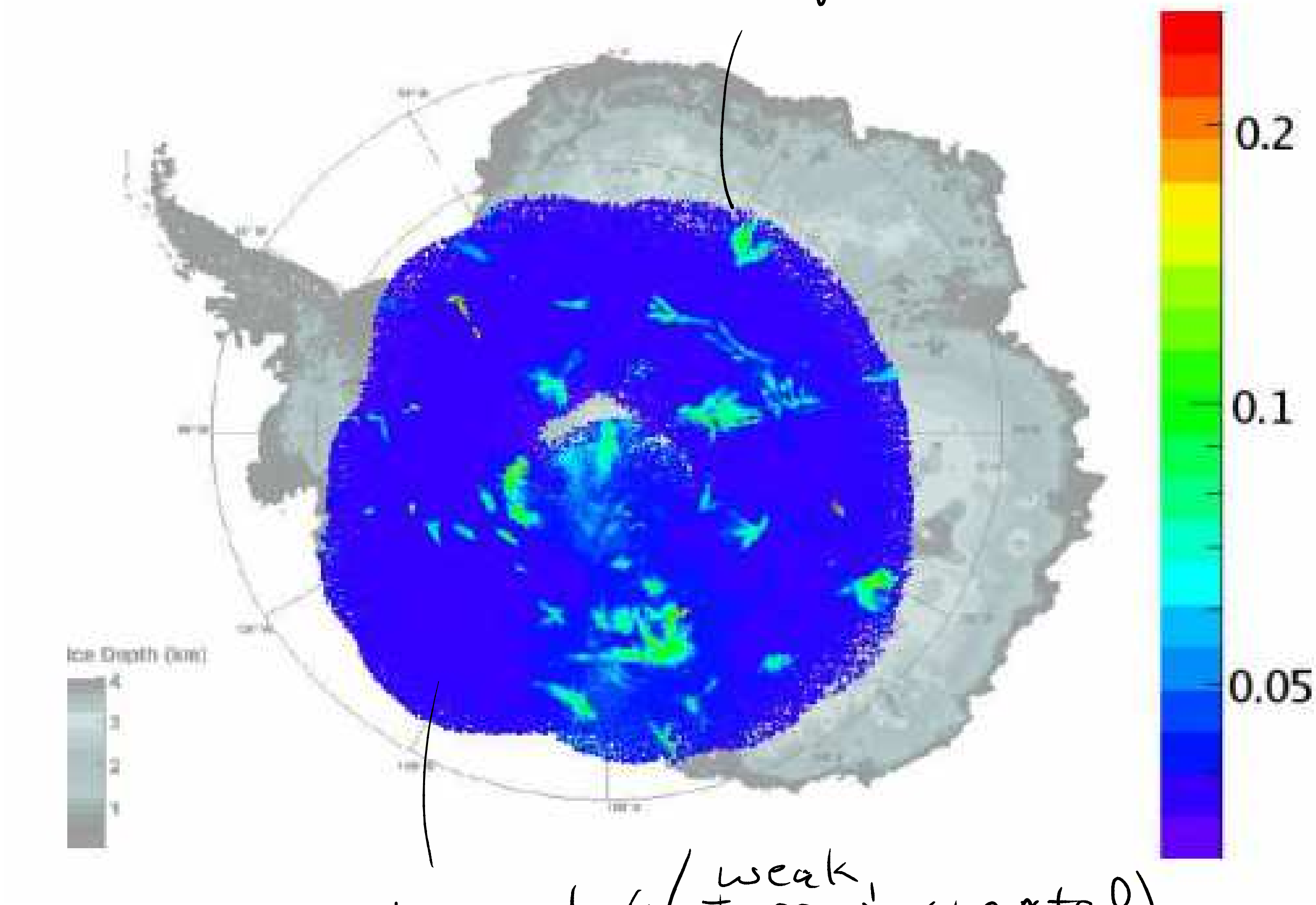


$\Delta\theta$ 0.2 – 0.4 deg

$\Delta\phi$ 0.5 – 1.1 deg

Backgrounds

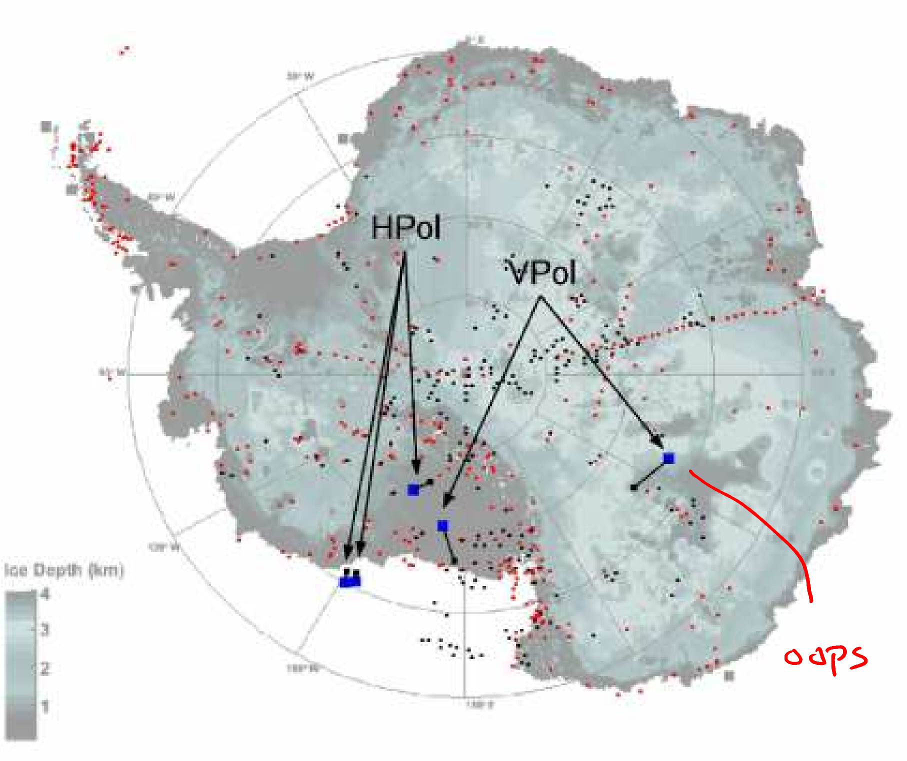
Anthropogenic (clustered)



$\langle S_I \rangle$

weak,
Thermal (not reconstructed)
not oriented

Clustering



oops

TABLE I: Event totals vs. analysis cuts and estimated signal efficiencies for ESS spectral shape [10].

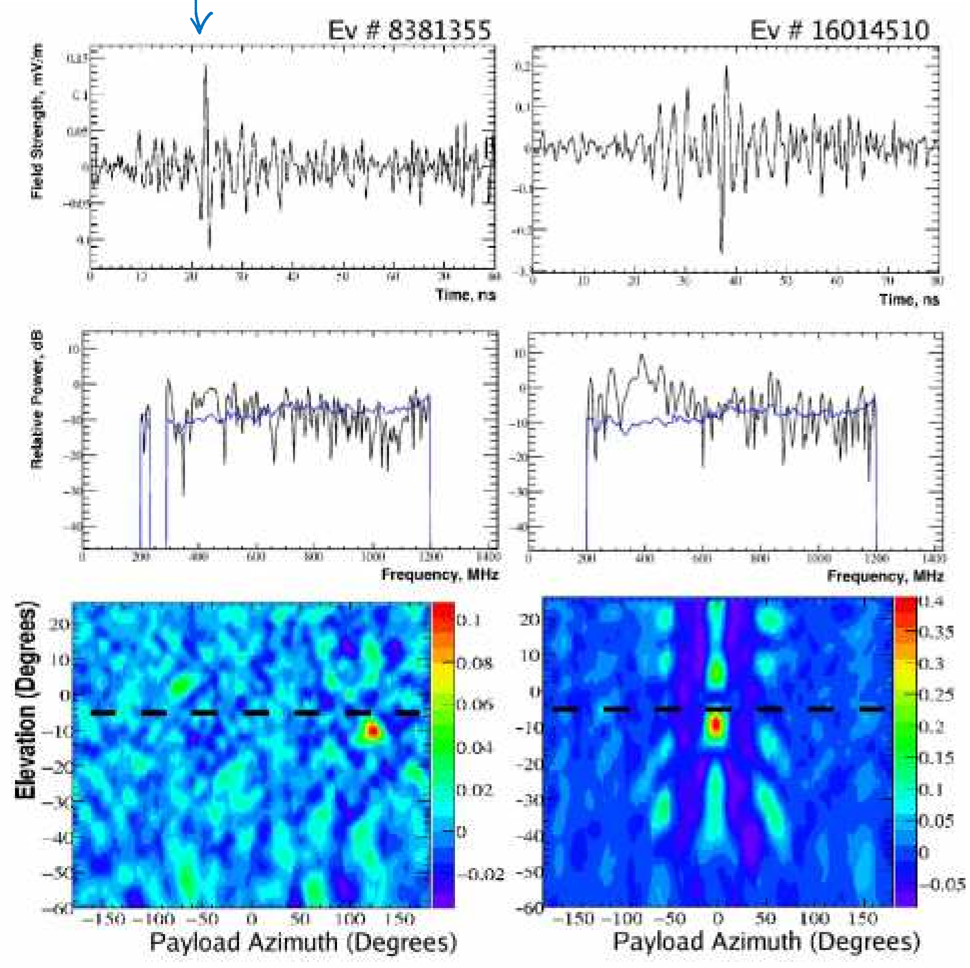
Cut requirement	Passed		Efficiency
	Vpol	Hpol	
Hardware-Triggered Events	~ 26.7M		-
(1) Quality Events	~ 21.2M		1.00
(2) Reconstructed Events	320,722		0.96
(3) Not Traverses and Aircraft	314,358		1.00
(4) In Clusters <100 Events	444		-
(5) Isolated Singles	7	4	0.64
(6) Not Misreconstructions	5	3	1.00
(7) Not of Payload Origin	~~2~~ 1	3	1.00
Total Efficiency			0.61

cut on S_I

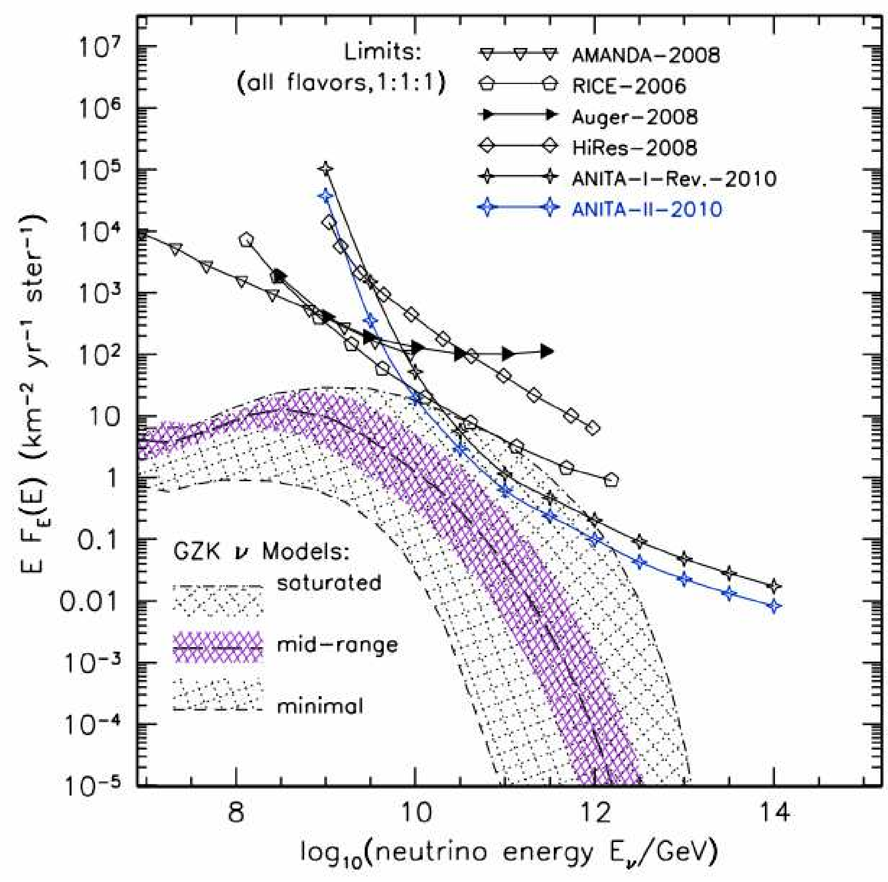
Cluster Multiplicity	Number of Clusters	
	Camp	Not Camp
10-100	8	1
5-9	7	1
4	1	0
3	0	0
2	1	1
1	7	5 (Signal Region)

Candidate even~~s~~t

inserted ground polser event



ANITA GZK flux limit



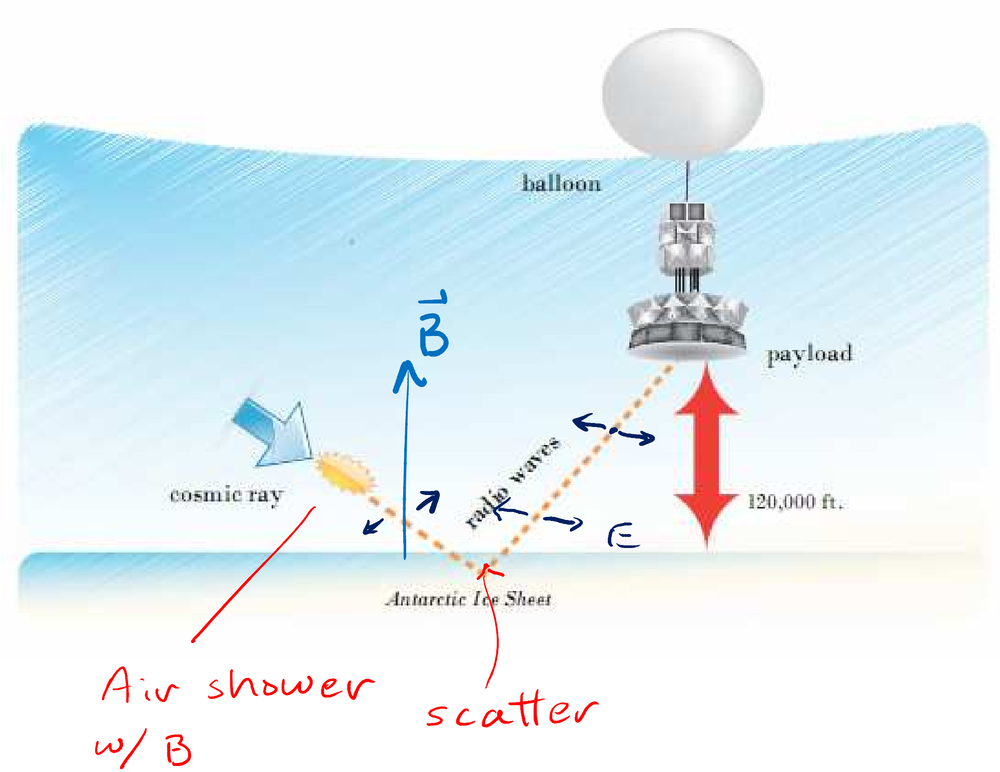
Model & references	predicted N_ν	CL,%
Baseline models:		
Various	0.3-1.0	...
Strong source evolution models:		
Aramo *et al.* 2005	2.4	85
Berezinsky 2005	5.1	98
Kalashev *et al.* 2002	5.6	99
Barger, Huber, & Marfatia 2006	3.5	93
Yuksel & Kistler 2007	1.7	74
Models that saturate all bounds:		
Yoshida *et al.* 1997	30	> 99.999
Kalashev *et al.* 2002	19	> 99.999
Aramo *et al.* 2005	16	99.999
Waxman-Bahcall fluxes:		
Waxman, Bahcall 1999, evolved sources	1.4	...
Waxman, Bahcall 1999, standard	0.5	...

Also – no news from GRBs

TABLE 1
LIST OF THE 12 GRBS INCLUDED IN THE BLIND ANALYSIS

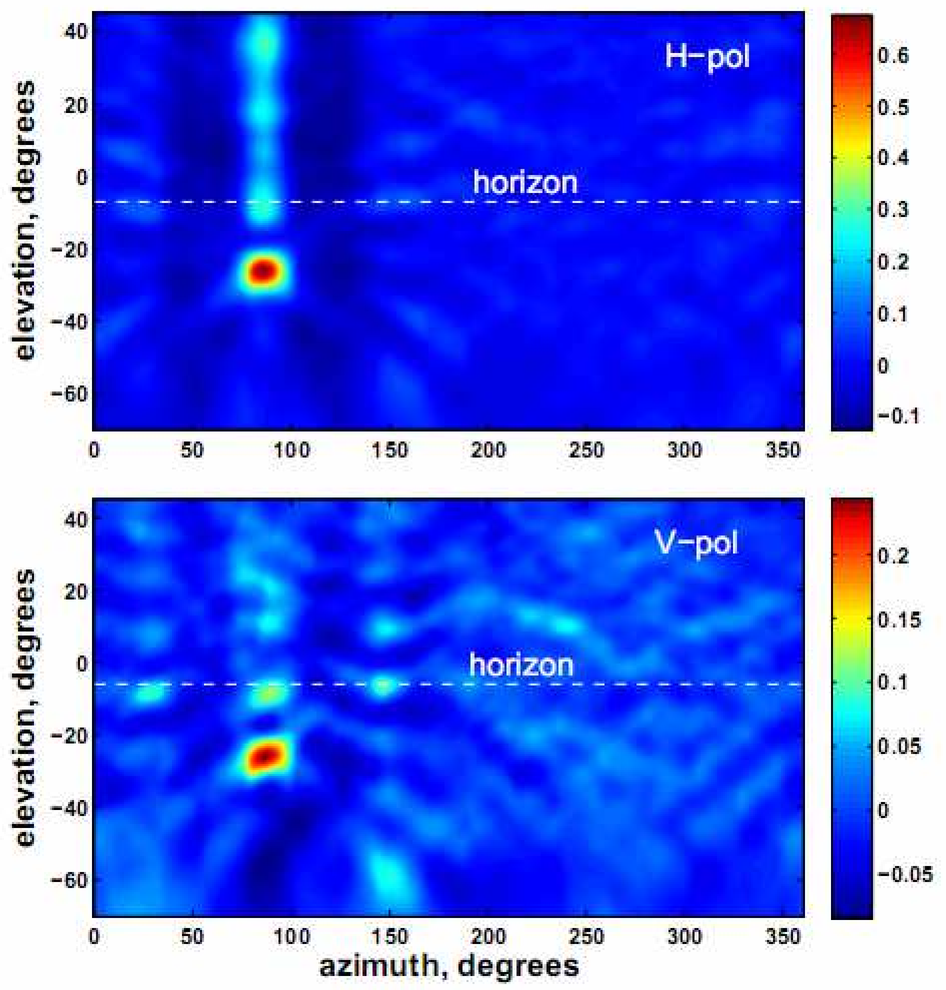
GRB	Date & Time (UTC)	Right Ascension	Declination	Payload Elevation Angle (degrees)
081228	2008 Dec 28 01:17:40	$2^h37^m50^s.94$	$30°51'10\ 50''$	-41.1
081229	2008 Dec 29 04:29:01.88	$11^h22^m0^s$	$55°6'0''$	-55.9
081230	2008 Dec 30 20:36:12	$2^h29^m19^s.51$	$-25°8'49\ 95''$	28.8
081231	2008 Dec 31 03:21:01.93	$14^h35^m0^s$	$-38°43'0''$	47.0
090102	2009 Jan 2 02:55:36	$8^h32^m58^s.54$	$33°6'51\ 10''$	-26.3
090108B	2009 Jan 8 07:43:23.36	$0^h15^m0^s$	$-32°12'0''$	42.9
090109	2009 Jan 9 07:58:29.49	$8^h11^m0^s$	$54°48'0''$	-59.2
090111	2009 Jan 11 23:58:21	$16^h46^m42^s.14$	$0°4'38\ 21''$	1.7
090112A	2009 Jan 12 07:57:23.11	$7^h27^m0^s$	$-30°17'0''$	23.5
090112B	2009 Jan 12 17:30:15.45	$12^h51^m0^s$	$22°12'0''$	-26.8
090113	2009 Jan 13 18:40:39	$2^h8^m13^s.63$	$33°25'42\ 85''$	-25.7
090117B	2009 Jan 17 08:02:02.23	$15^h32^m0^s$	$27°36'0''$	-28.1

Cosmic Ray Detection



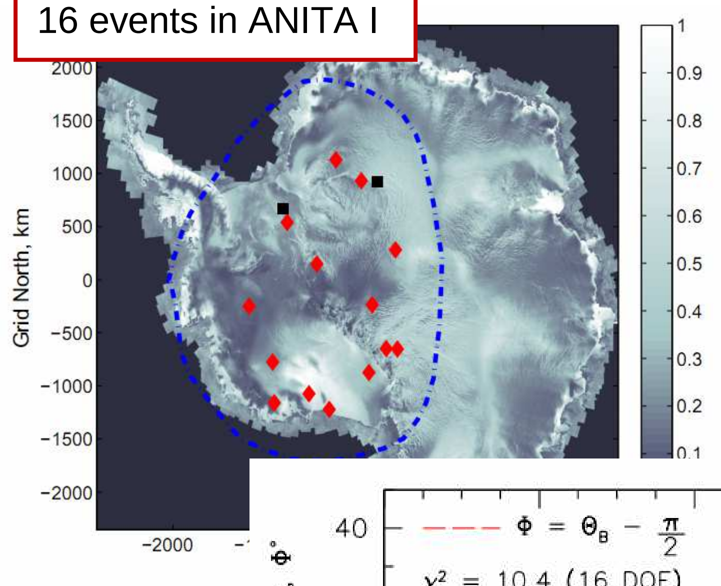
ANITA-I analysis

- Event selection
- Strong interference amplitude
- 16 events
  - 14 below horizon
  - 2 above
- Consistent waveforms w/reflection
- Correlated with B

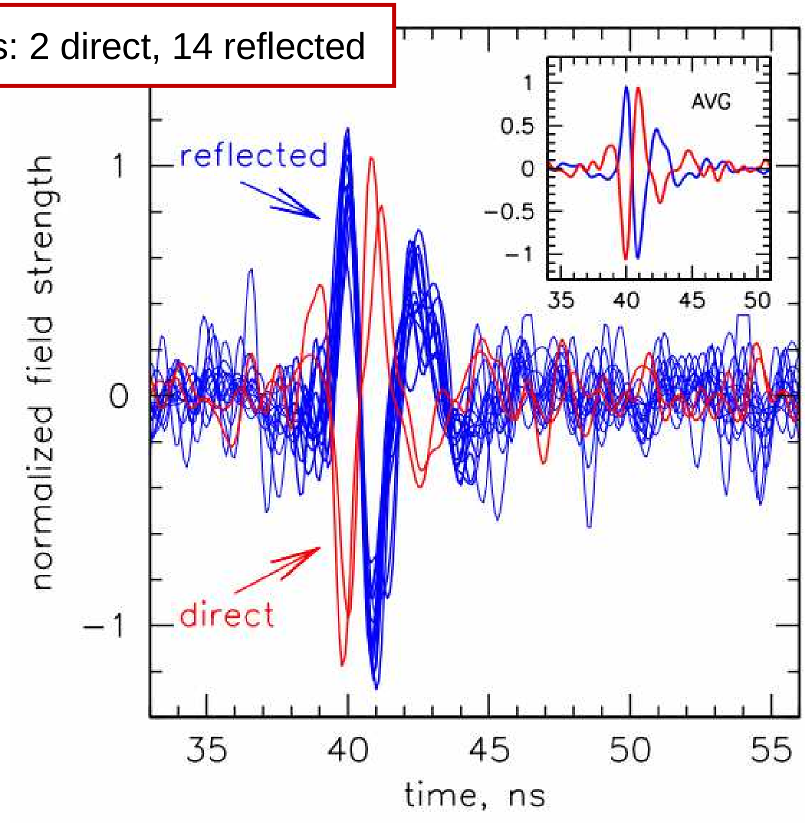


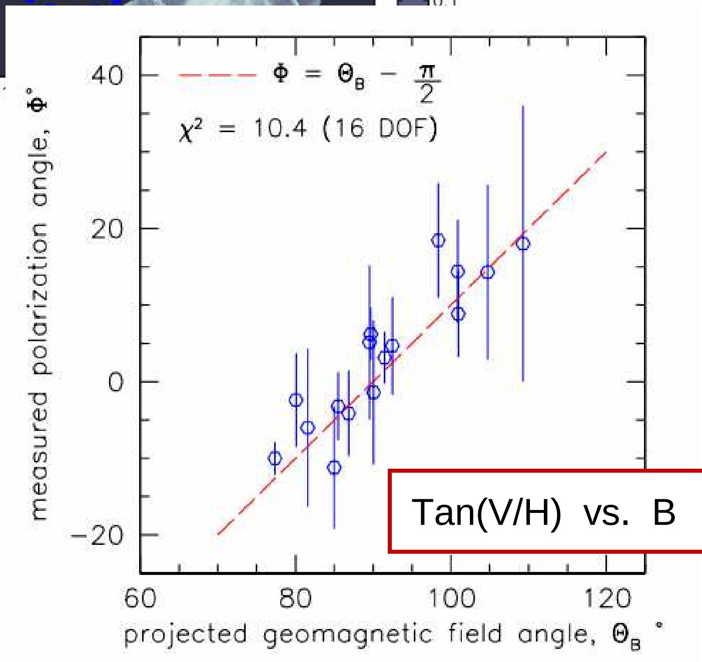
Air shower highlites

16 events in ANITA I



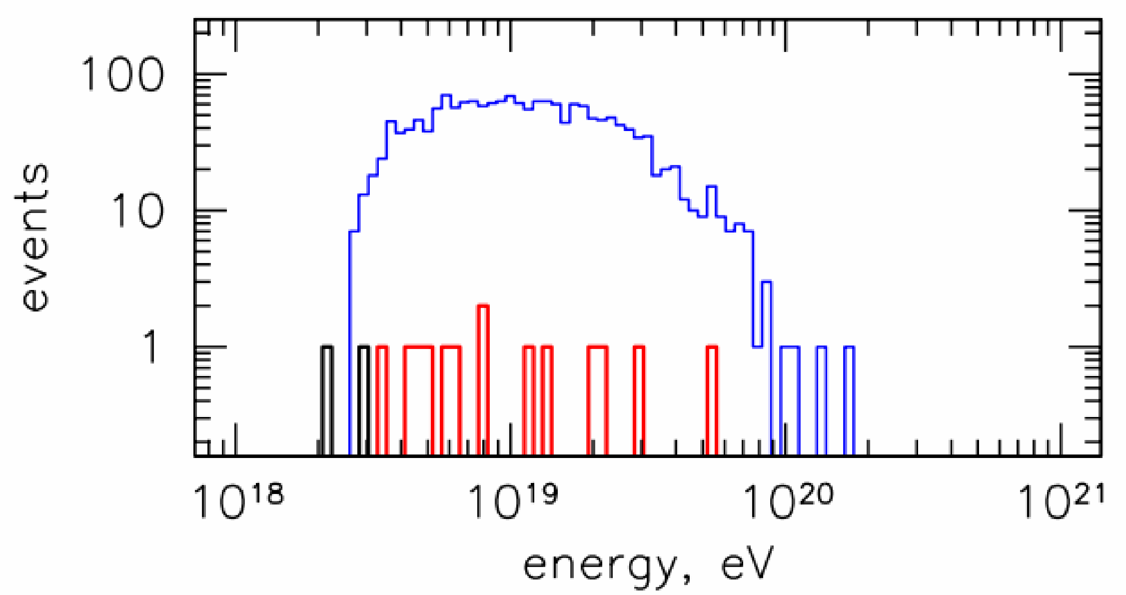
WaveForms: 2 direct, 14 reflected





Tan(V/H) vs. B

MC and Energy Scale



- exposure
- reflection w/roughness
- freq-spectrum
- E-spectrum
- angular offset

- $N \propto \Omega \int_{E_T} \phi(E)\, dE = \Theta^2 / E_T^2$ for E^{-3}

  $\Rightarrow$ if $\Theta \downarrow$ then $E \downarrow$

- $E(\gamma, \Theta)$ reasonable but extrapolated

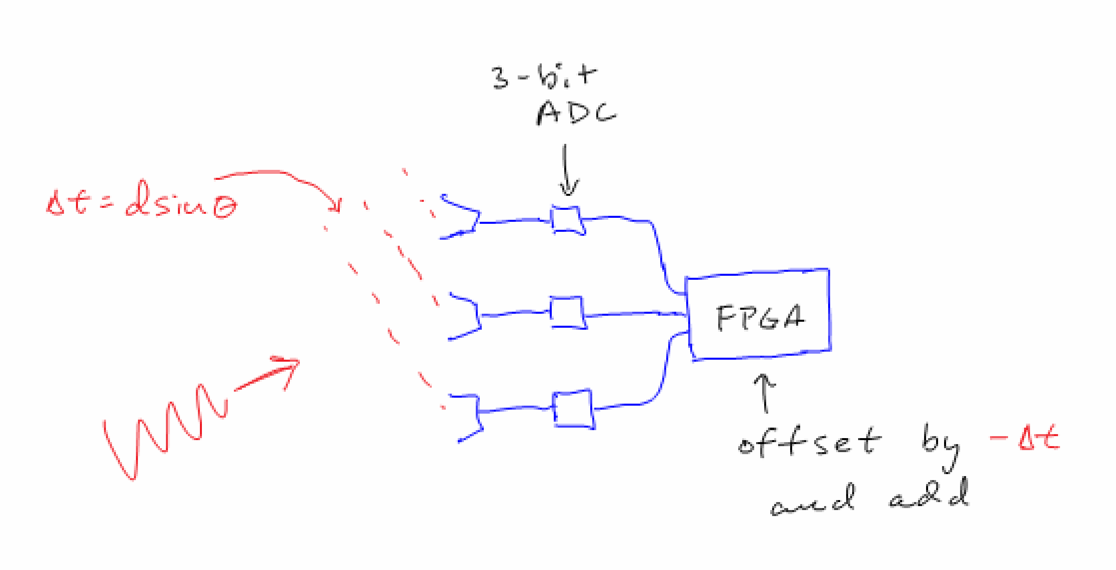
- Issues w/ REAS 2

Other – check the archives

- Magnetic Monopoles
  - Worlds best limits on relativistic “light” monopoles
- Neutrino cross-section
  - Constraint is actually on $\Phi * \sigma$
  - If flux is known – constraint on cross-section
- Lorentz invariance violation
  - Perhaps no neutrinos due to LIV ?
- Anti-nuclear nuggets
  - Non-thermal emission from bow shock in air

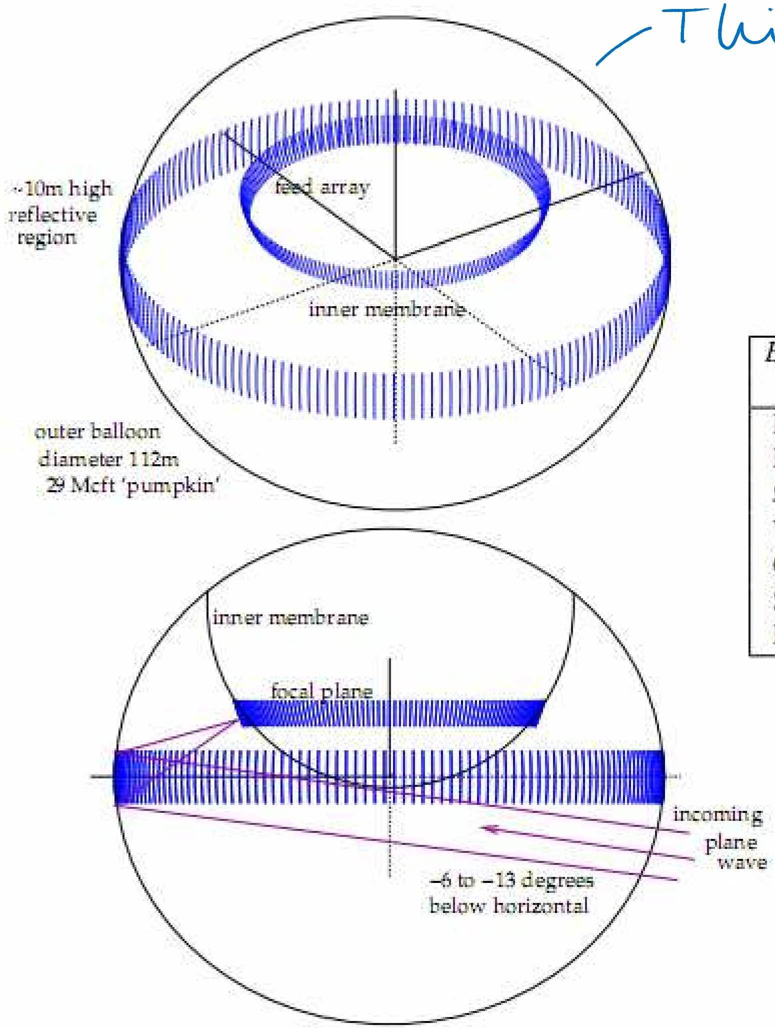
ANITA-III

- ANITA-III
  - Fly 2013/14
  - Low resolution phased trigger (improve S/N)
  - Dual triggers UHECR/UHEN
  - More antennas



ExaVolt Antenna (Gorham, etal - 1102.3883v2)

This is the balloon.



BZ neutrino models	*Events, ANITA-II,28d*	*Events, EVA,50d*	*ratio, EVA/ANITA*
Mixed UHECR composition [30]	0.05	5.0	100
Minimal, no evolution [3, 32, 33]	0.3-0.9	9.2-38	~ 40
$\Omega_m = 0.3, \Omega_\Lambda = 0.7$, Standard model [3]	0.7	29	41
Waxman-Bahcall E^{-2} flux (minimal) [34]	0.49	6.5	13
GRB UHECR-sources [46]	1.44	66	46
Strong source z-evolution [3, 31, 33]	2.2-5.3	40-60	11-18
Maximal, saturate all bounds [31, 33]	16-25	180-220	~ 10

Ice Properties

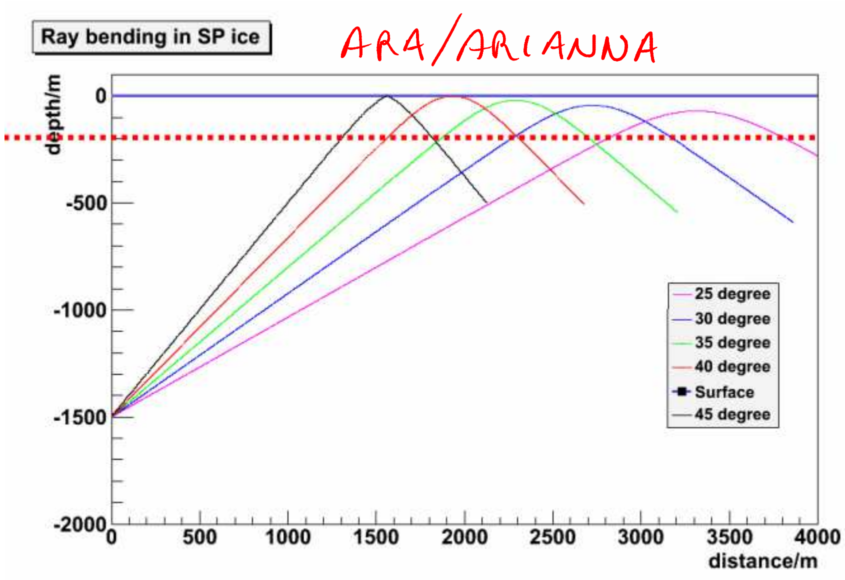
- Index of refraction
  - polarization tensor
  - real
  - imaginary
  - two states: birefringence
  - dispersion

Ray tracing

We don't trace. Just

set $\sin\theta_s = \frac{n}{n_s} \sin\theta$

and use θ_s for Fresnel



NB: two solutions

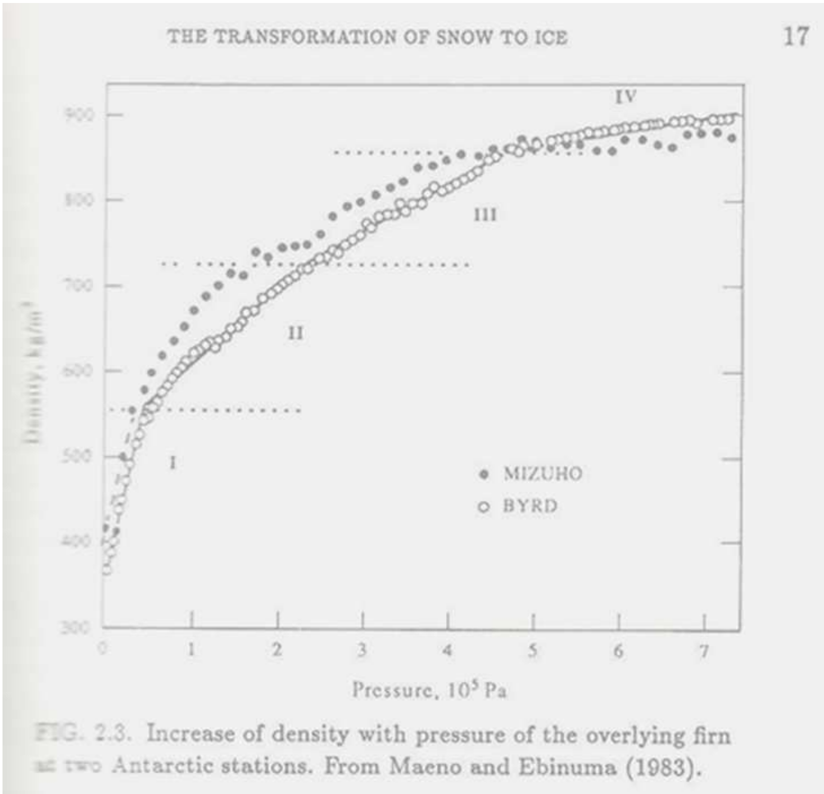
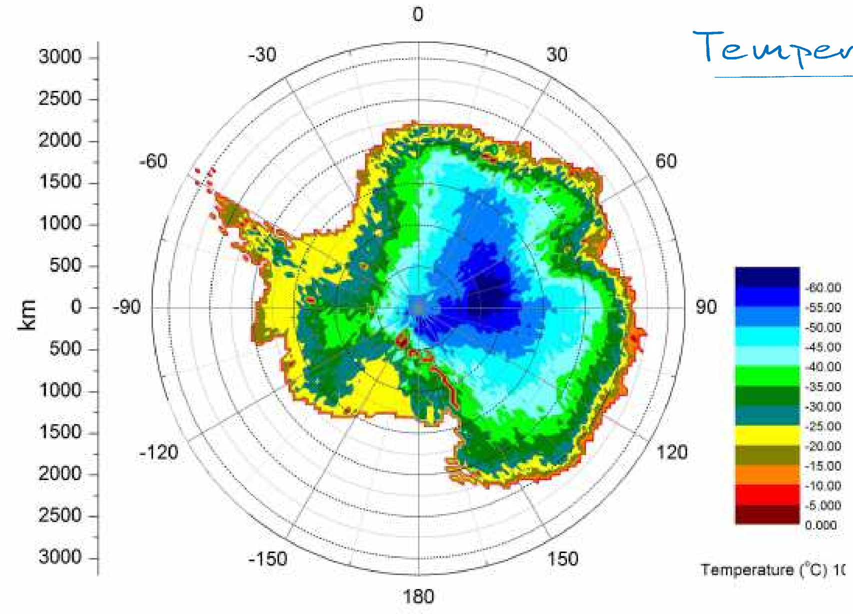

THE TRANSFORMATION OF SNOW TO ICE 17

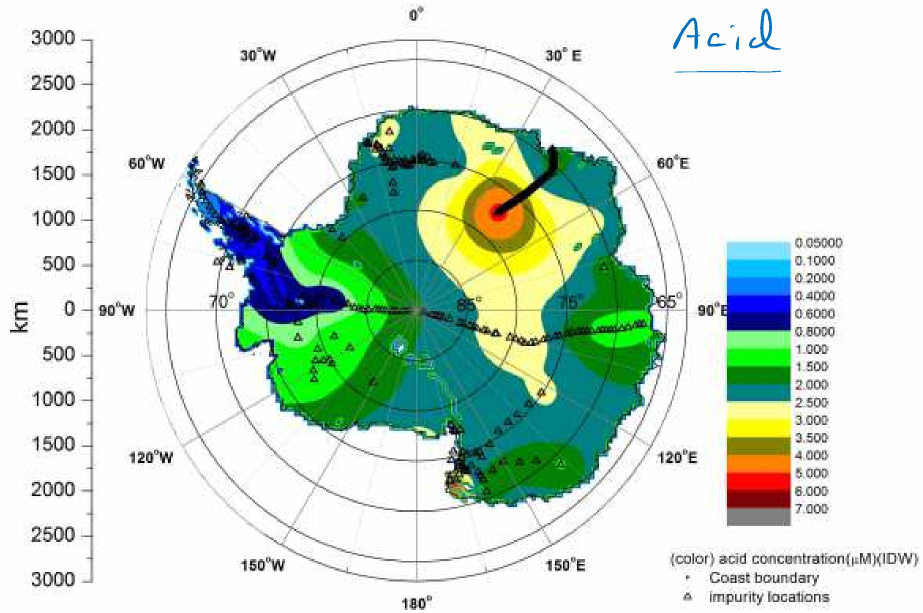
FIG. 2.3. Increase of density with pressure of the overlying firn at two Antarctic stations. From Maeno and Ebinuma (1983).

Propagation: Attenuation (Amir Javaid)

Temperature



Acid



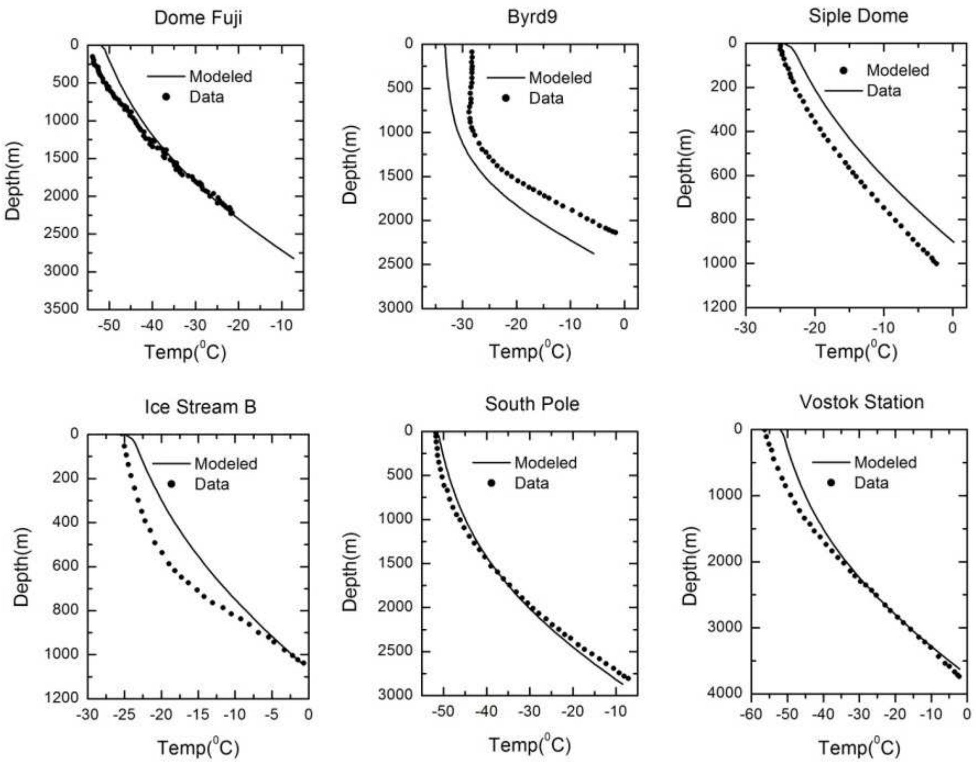
3D Temperature Model

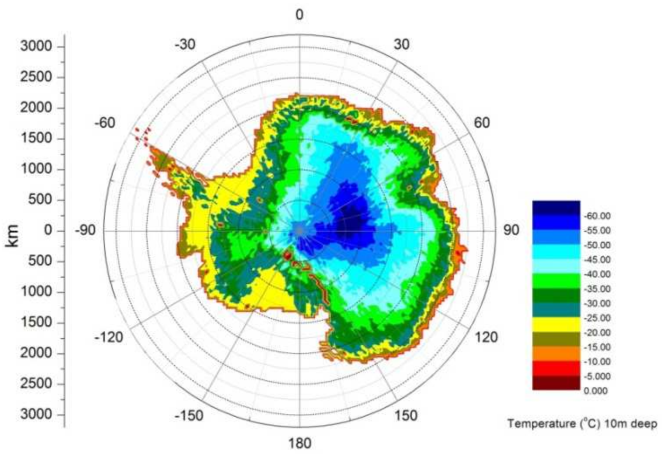
Data for this model is provided by Dr. James Fastook, University of Maine, extracted from UMISM, the University of Maine Ice Sheet Model

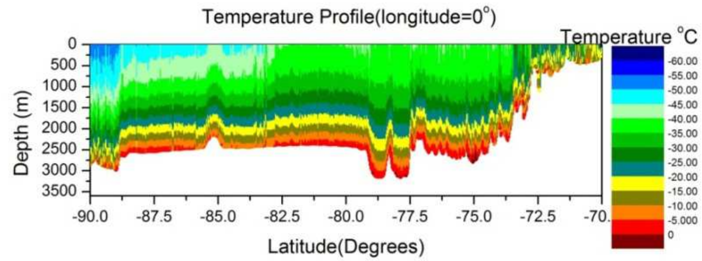
Weighted Interpolation:

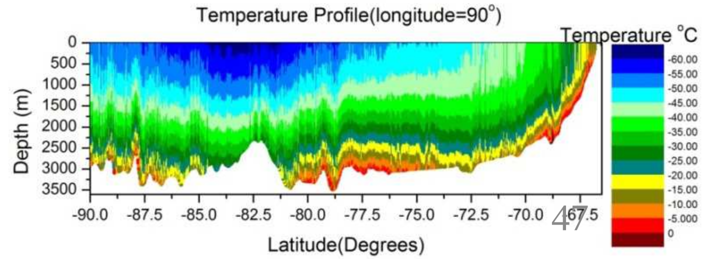
- Inverse square radial distance weights (200 km max)

- Inverse square ice thickness (200 m max diff)





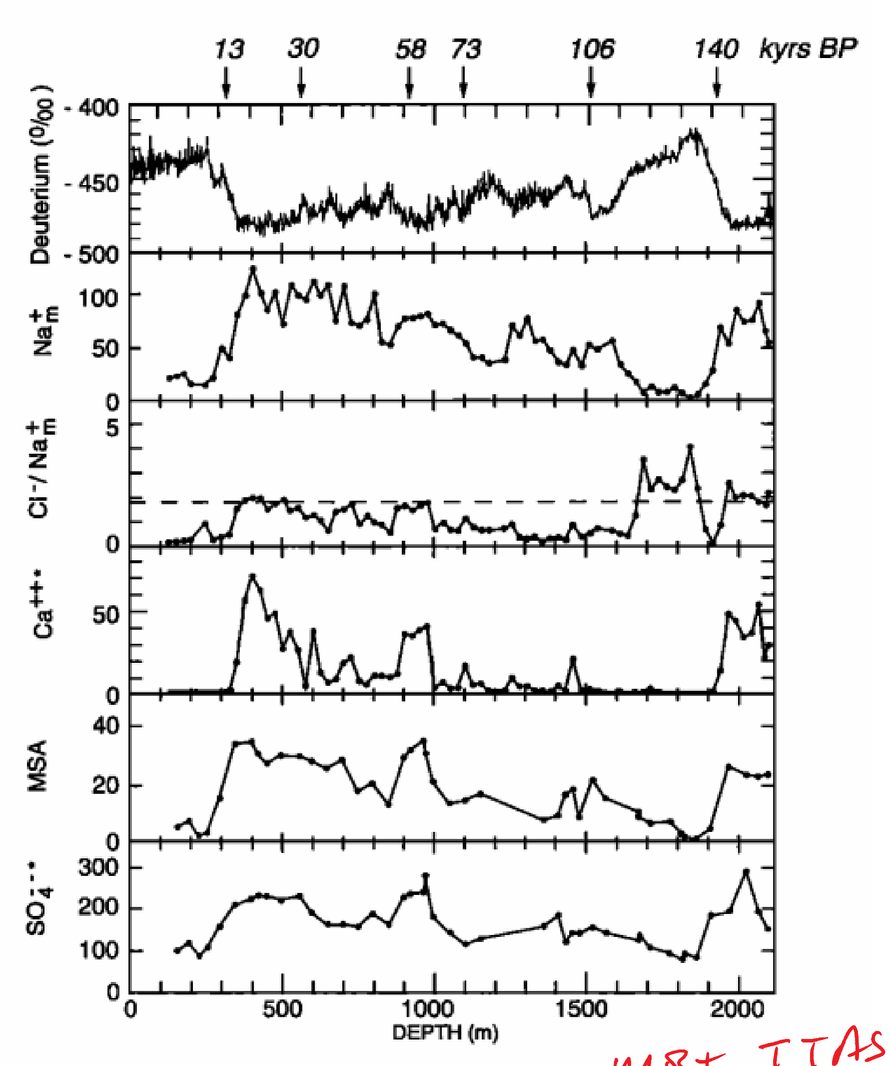




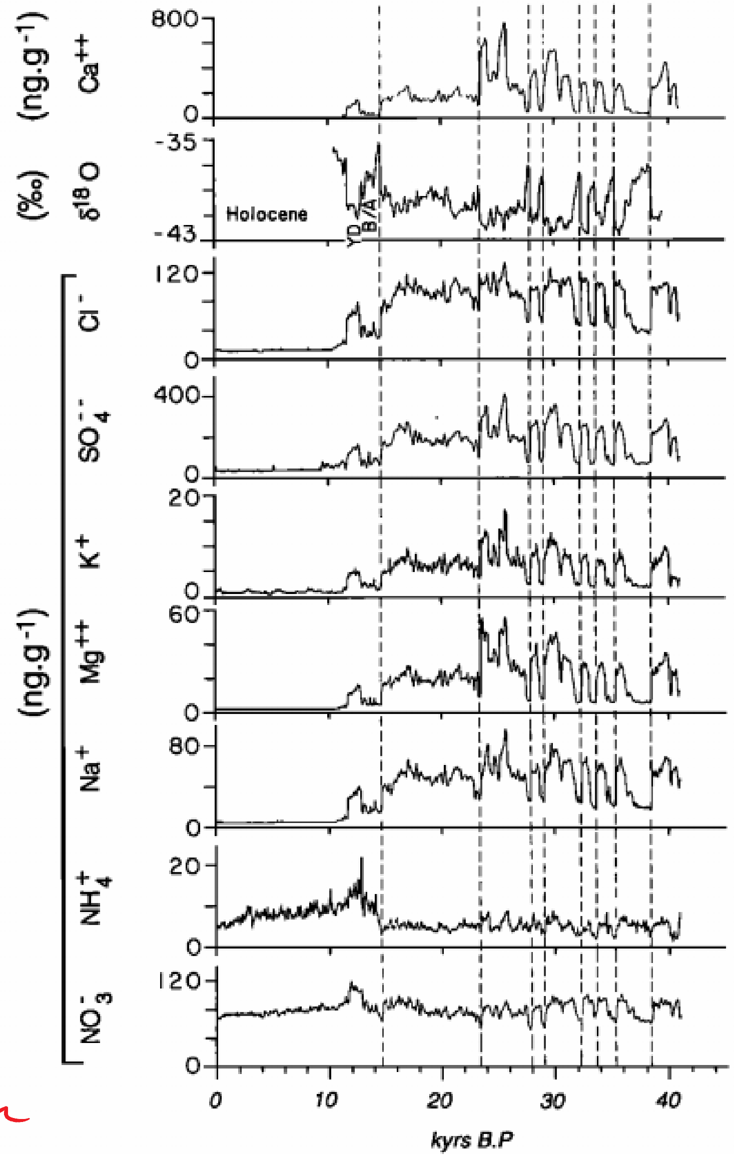
Legrand Mayewski '97

Impurity vs depth (climate considerations)

Vostok



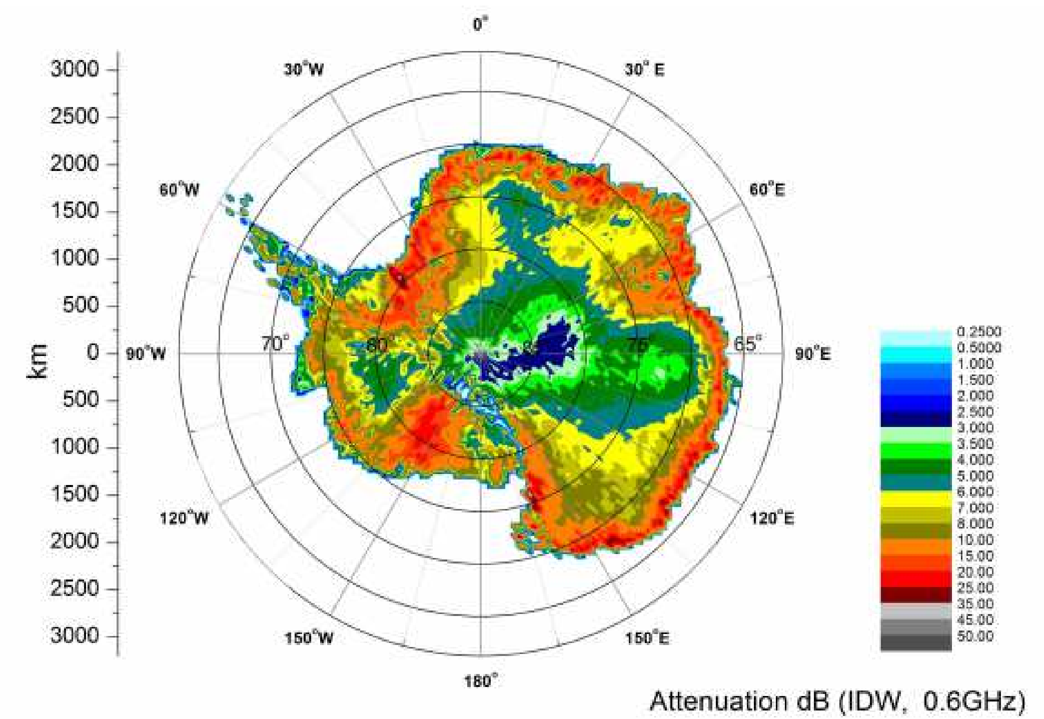
GISP

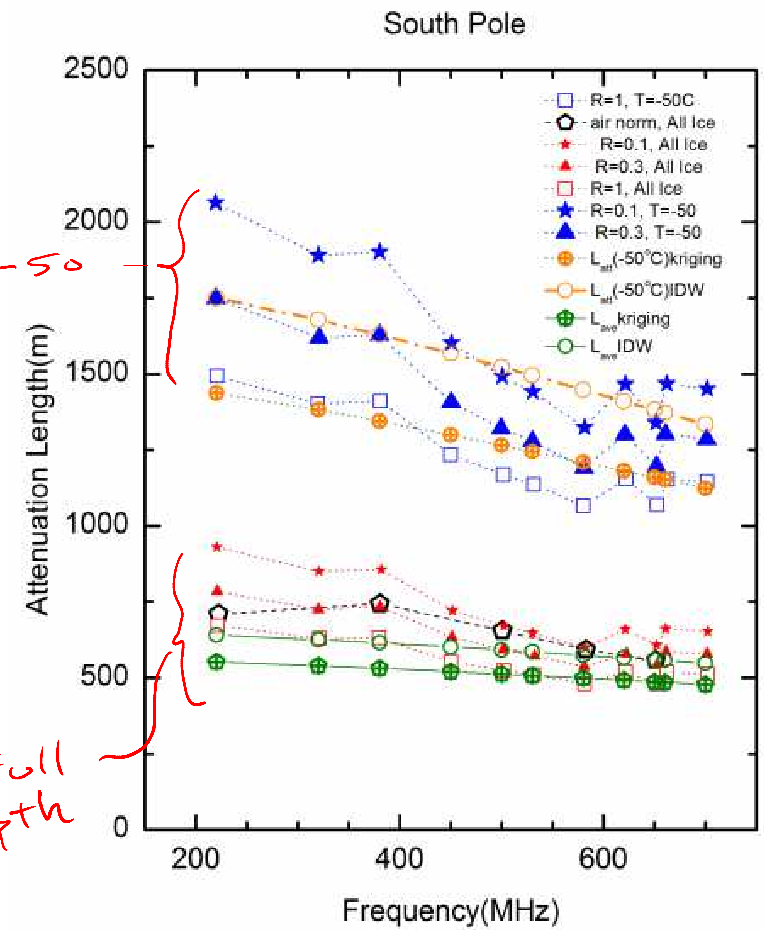


MBT ITASE < 150m

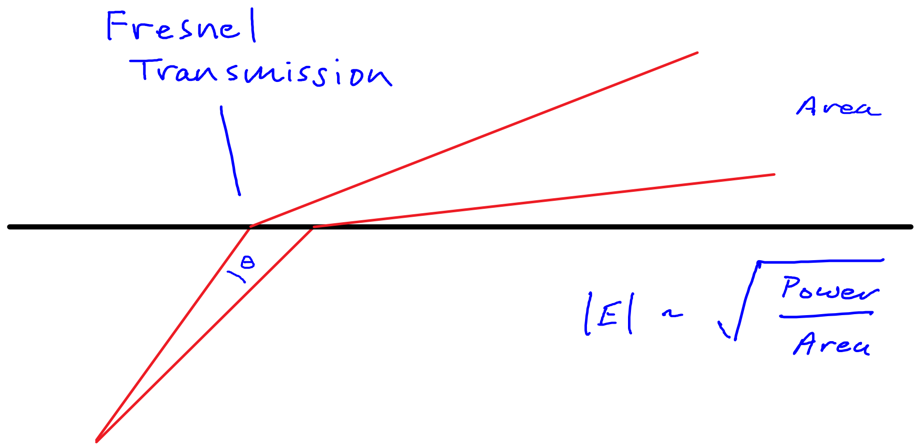
Propagation: Attenuation

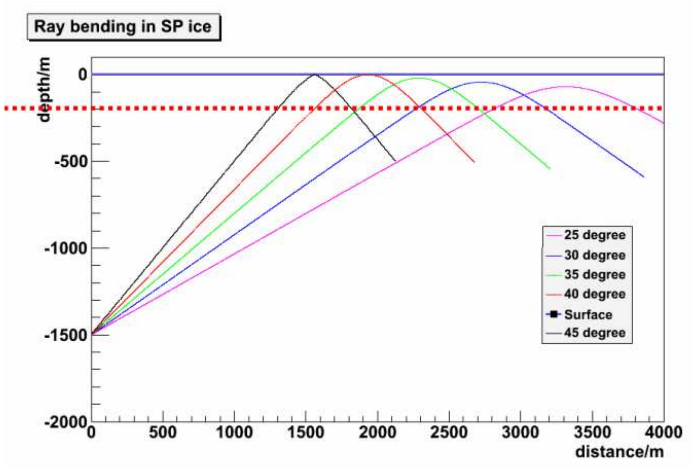
Top 1 km





Propagation: focusing



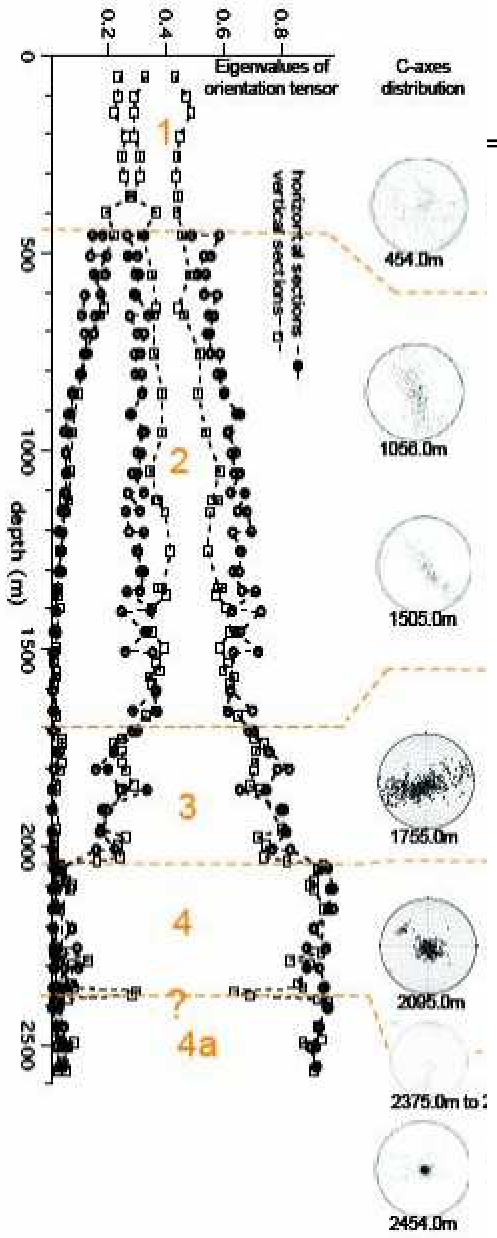


Ice acts like lens.
Can focus and increase E-field.
Caustic at “shadow point”
– point of stationary phase.

Propagation: birefringence

- We don’t simulate this, but …
- dn/n ~ 10^{-3} is possible
- dt = 5 ns per km.
- Predict Hpol arrives first

c-axis at vostok

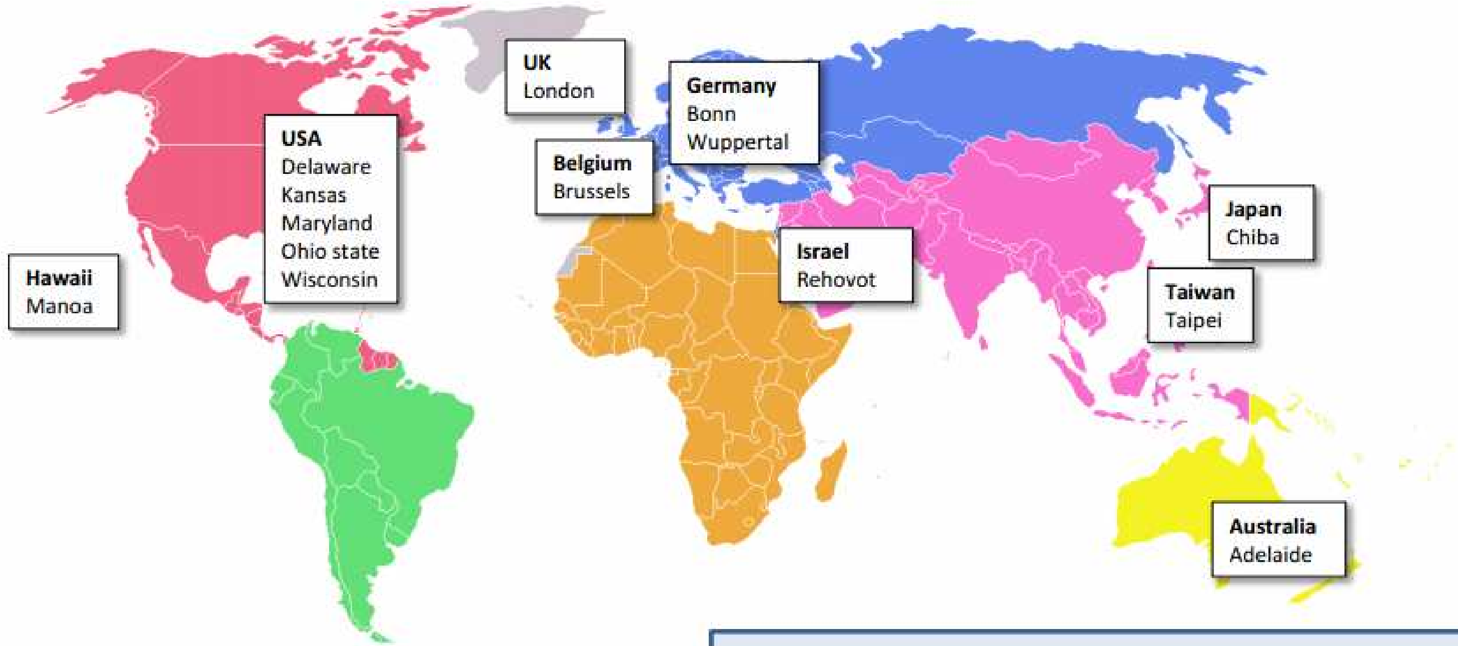


Summary

- Attenuation
  - Temp & impurity model including in-grain and grain boundary
  - Temp and impurity model for Antarctic ice
  - Continent wide attenuation model (SP/Ross comparisons)
  - Most impurity data is “recent” – biased?
  - Could alter vertical profile. - would improve upper region.

- Birefringence
  - Crystal fabric likely anisotropic from 500-2000 m?
  - delta-n ~ few 10^-3
  - ~5 ns per km
  - observed ~50 ns over 6 km ?
  - for ARA possible that two polarizations displaced by ~10 ns.

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~~ 3 ← program review
2013/2014:	station 5 - 13
2014/2015:	station 14 - 25
2015/2016:	station 26 – 37, detector finished

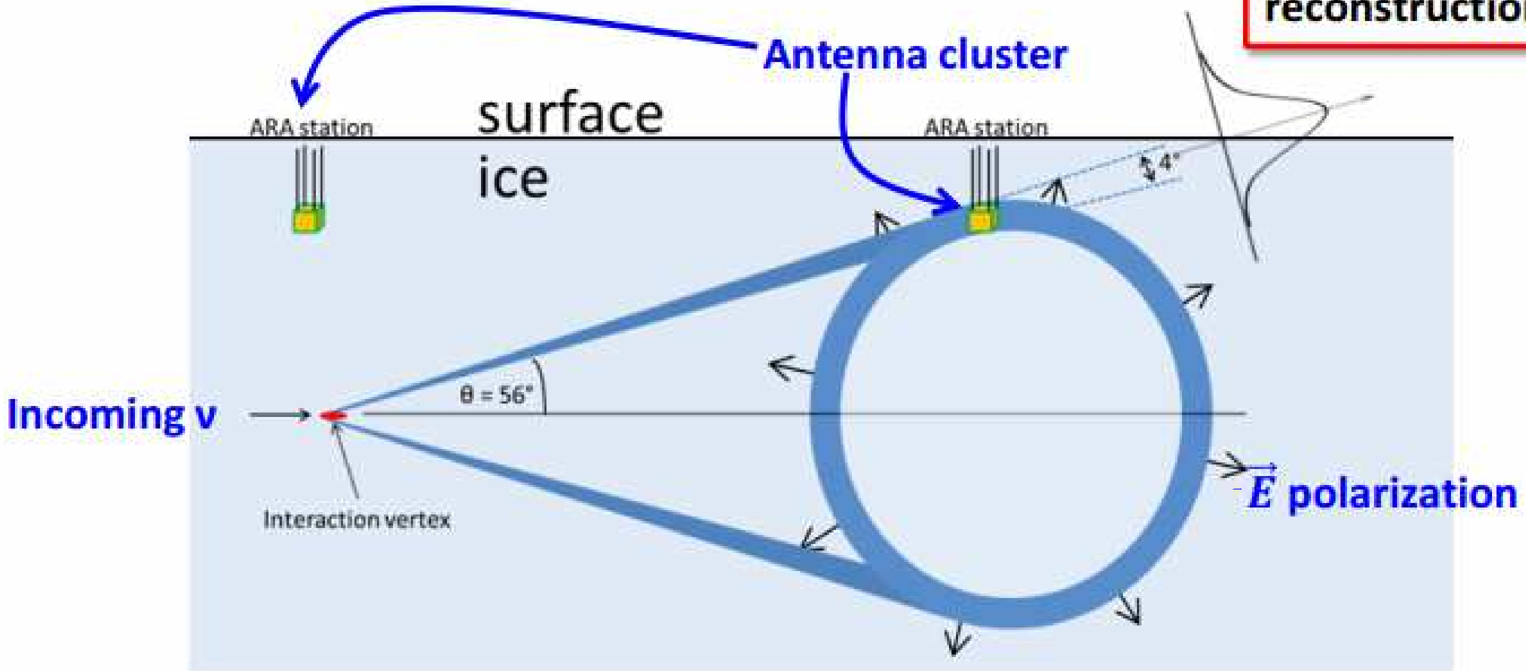
The principal idea of ARA

(Thomas Meures)

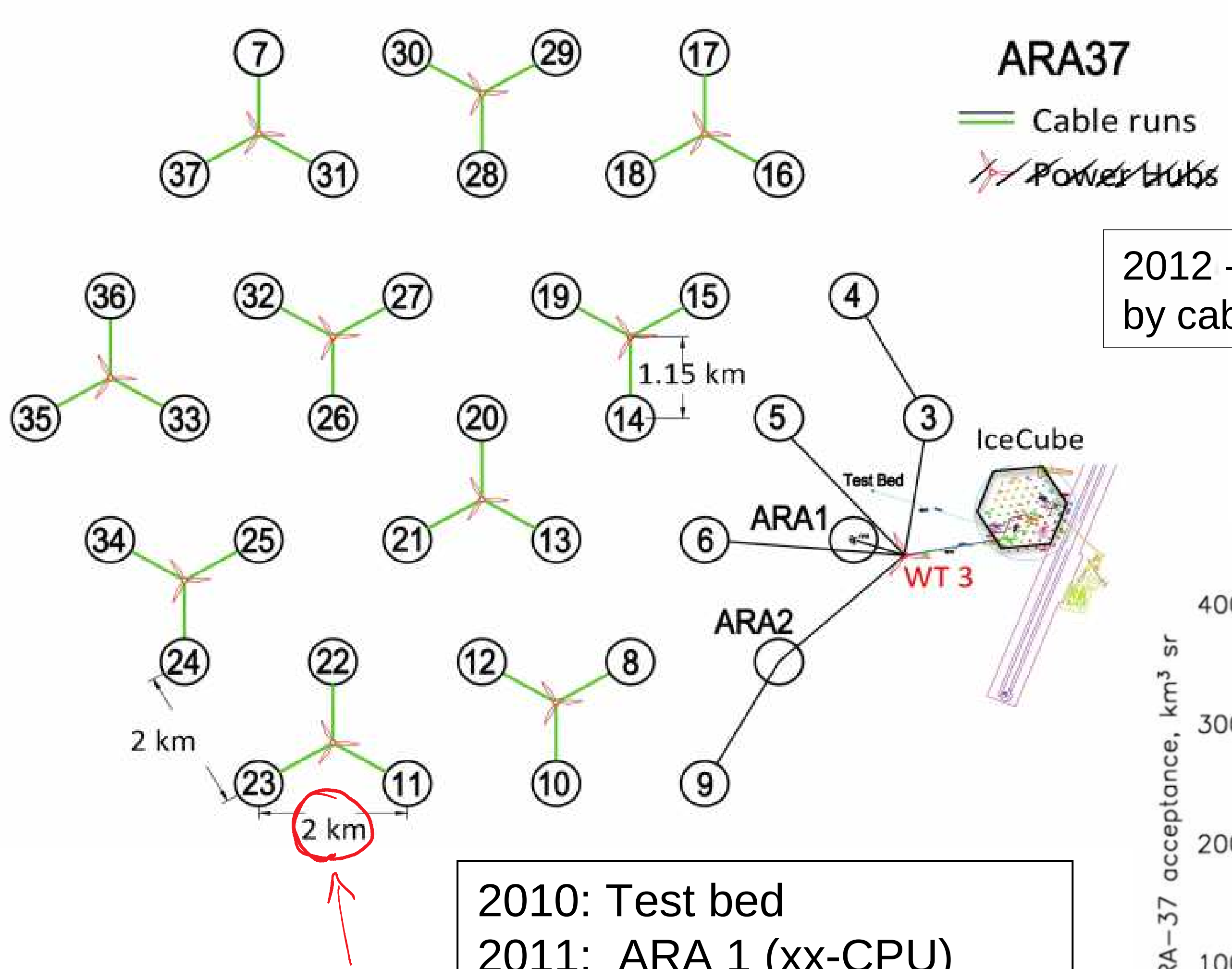
1) Detection of Radio waves, emitted by neutrino induced cascades in ice

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

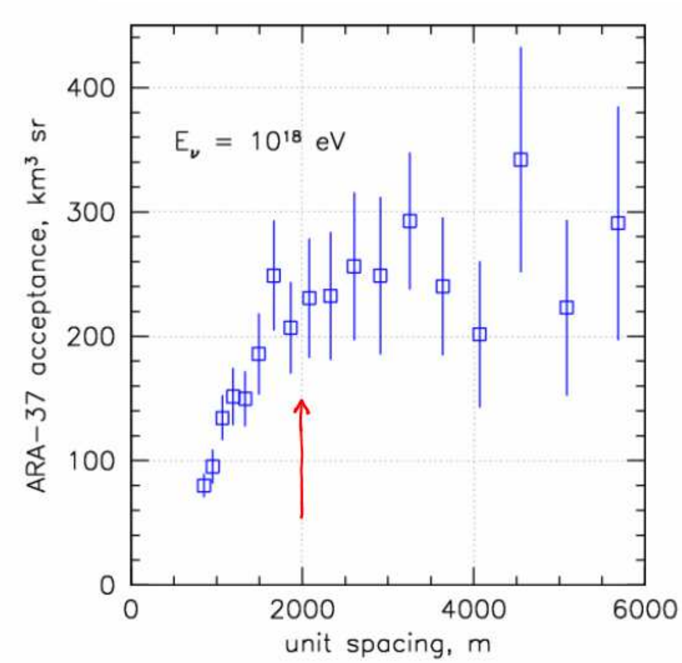


Array Layout



2012 - All power and data by cable/fiber to SP station.

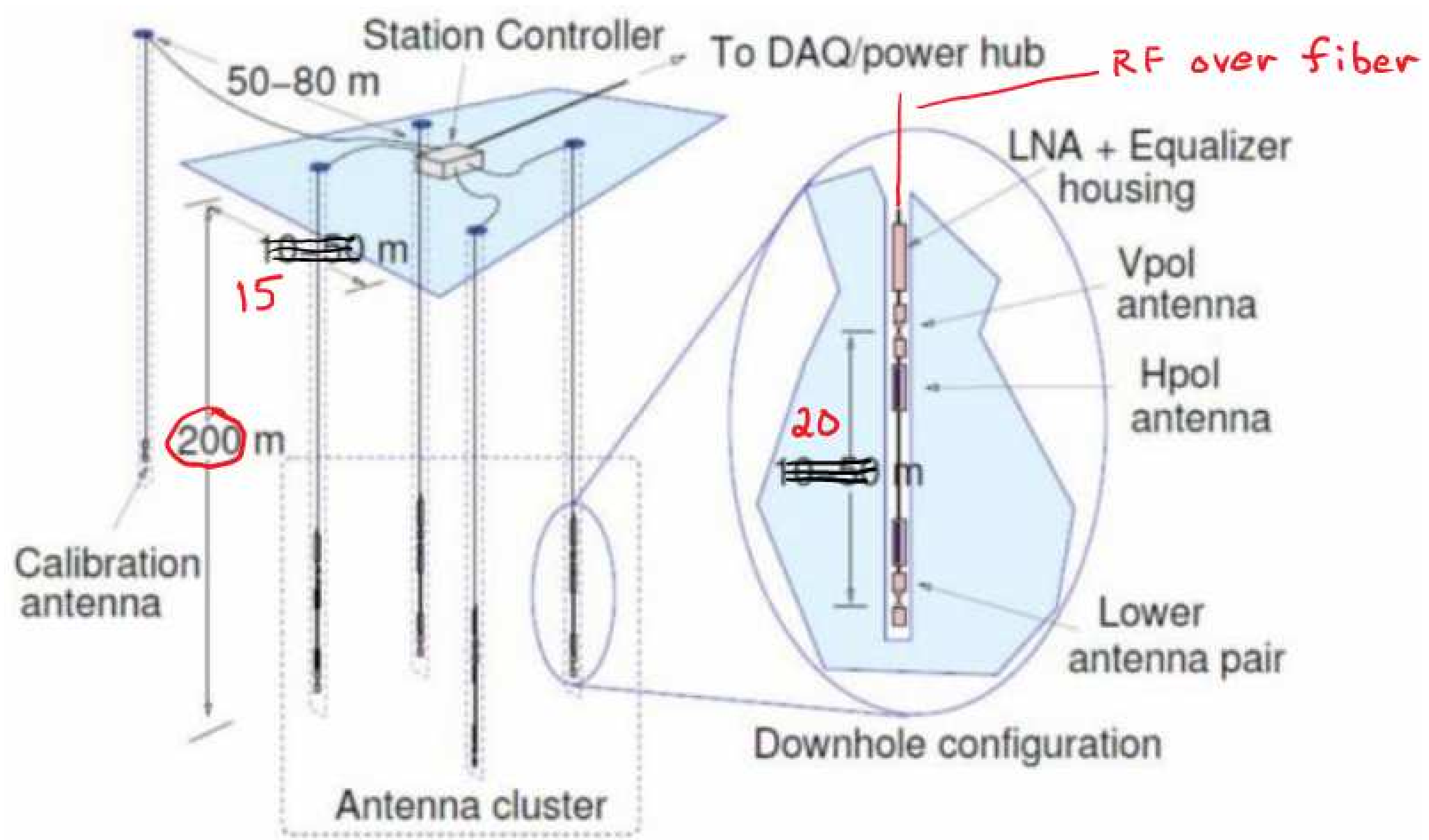
2010: Test bed
2011: ARA 1 (xx-CPU)
2012: ARA 2,3



Station Layout

Spacing reduced to improve trigger.

$$R_{k:N} = \sum_{k}^{N} \binom{N}{k} R_{single}^{k}\, \tau^{k-1}$$

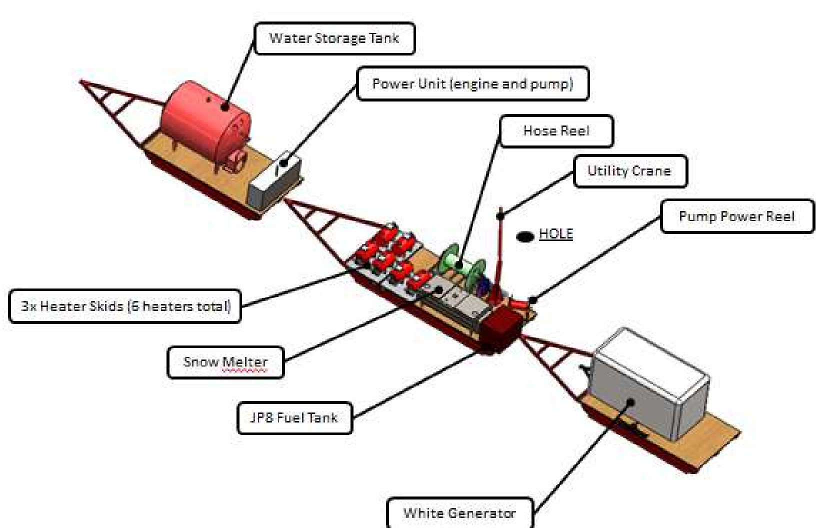


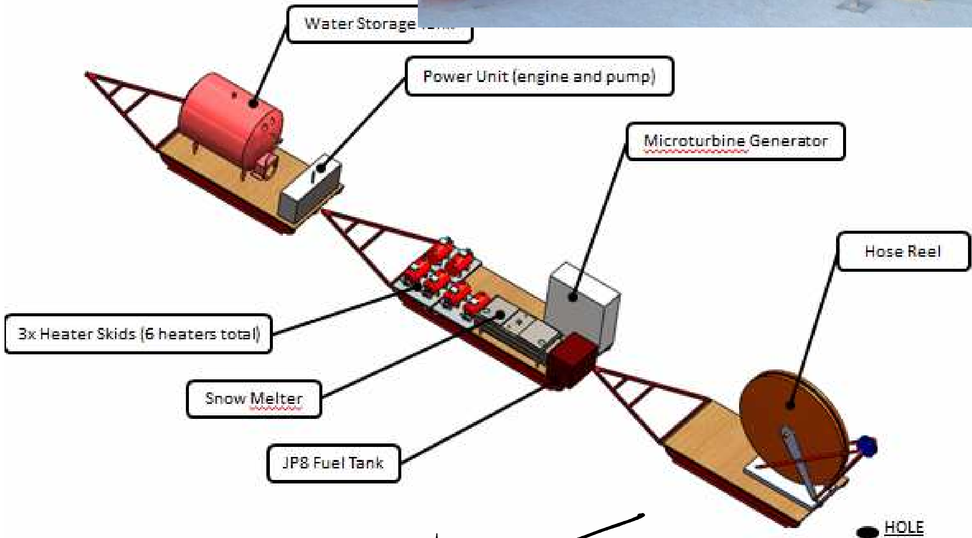
Drill system

- Dry hole
- Φ6”, minimum
- 200m usable depth
- 2 holes/day (achievable with 2 shifts/day)

2011-12

2012-13





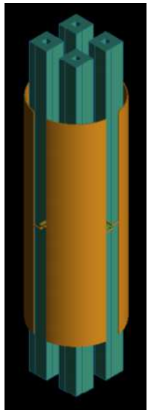
supply and return

Antennas

Low freq: (>25 MHz)
surface antennas

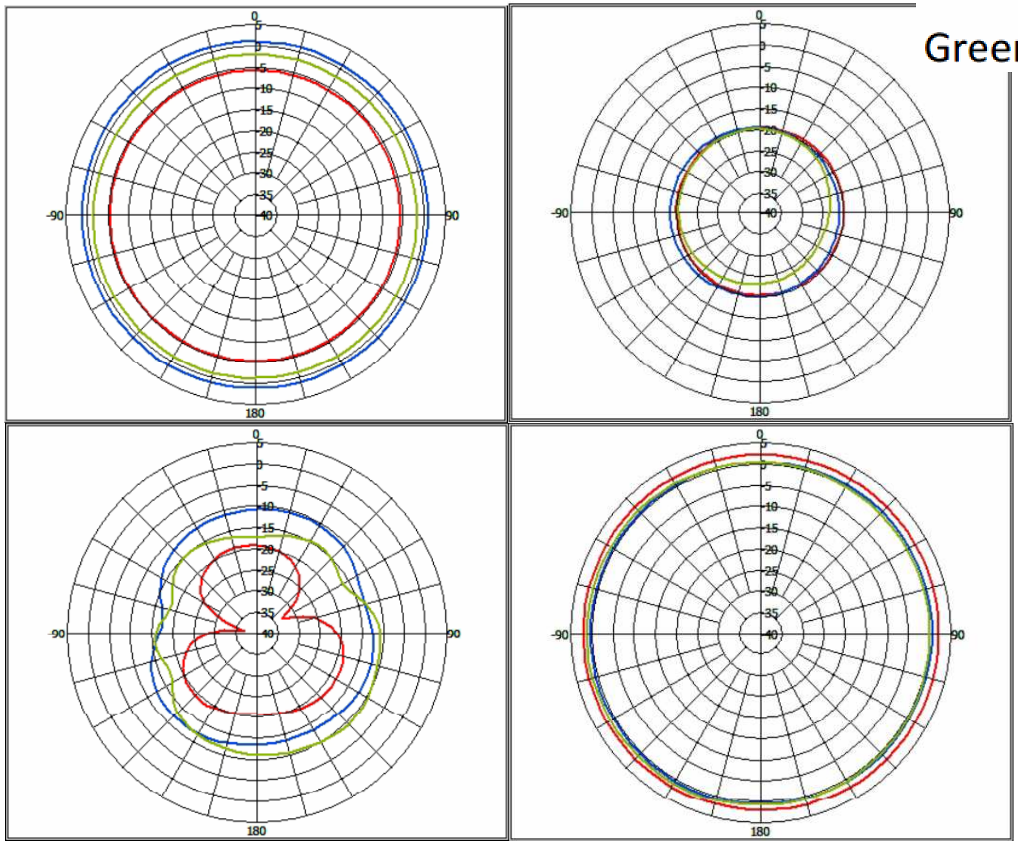
H_{pol}: Quad slot w/ferrite core

V_{pol}: Bird cage



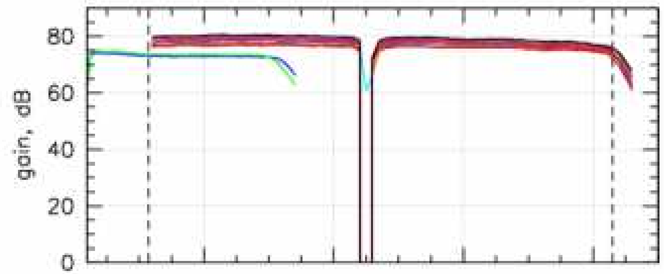
H-pol V-pol

Red 200 MHz
Blue 300
Green 500

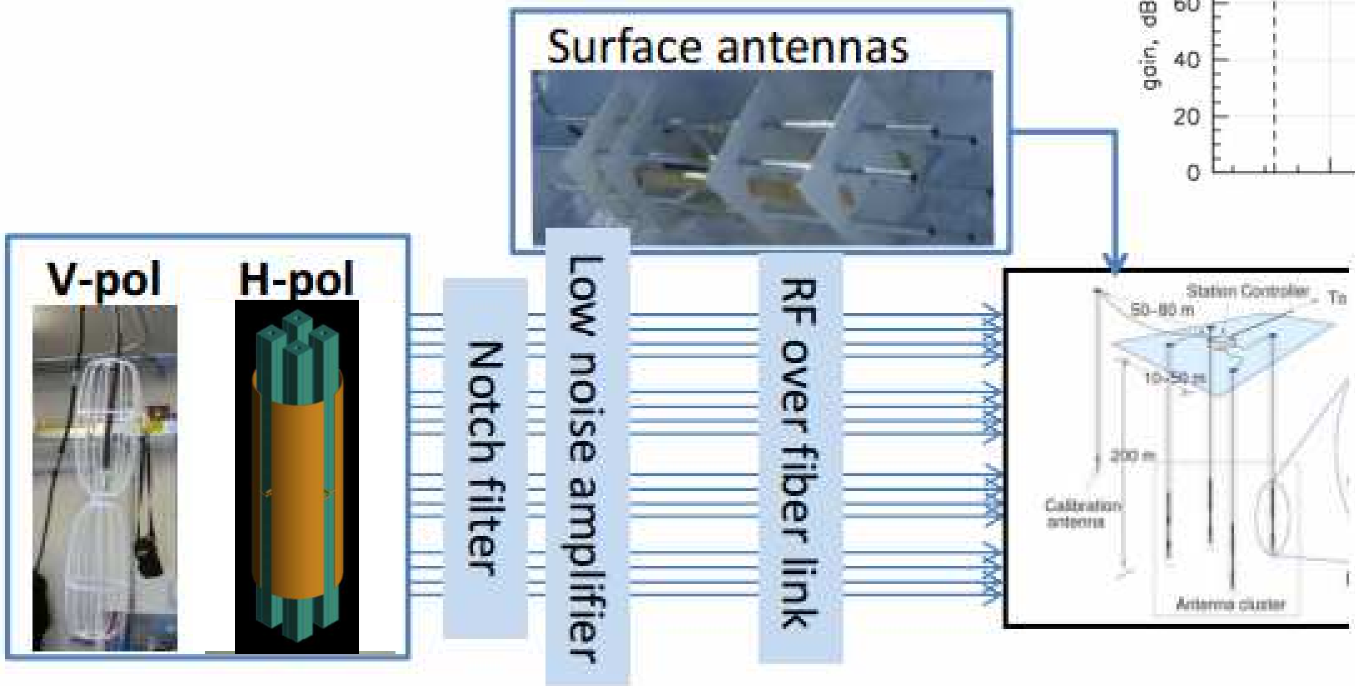


Antenna to central DAQ

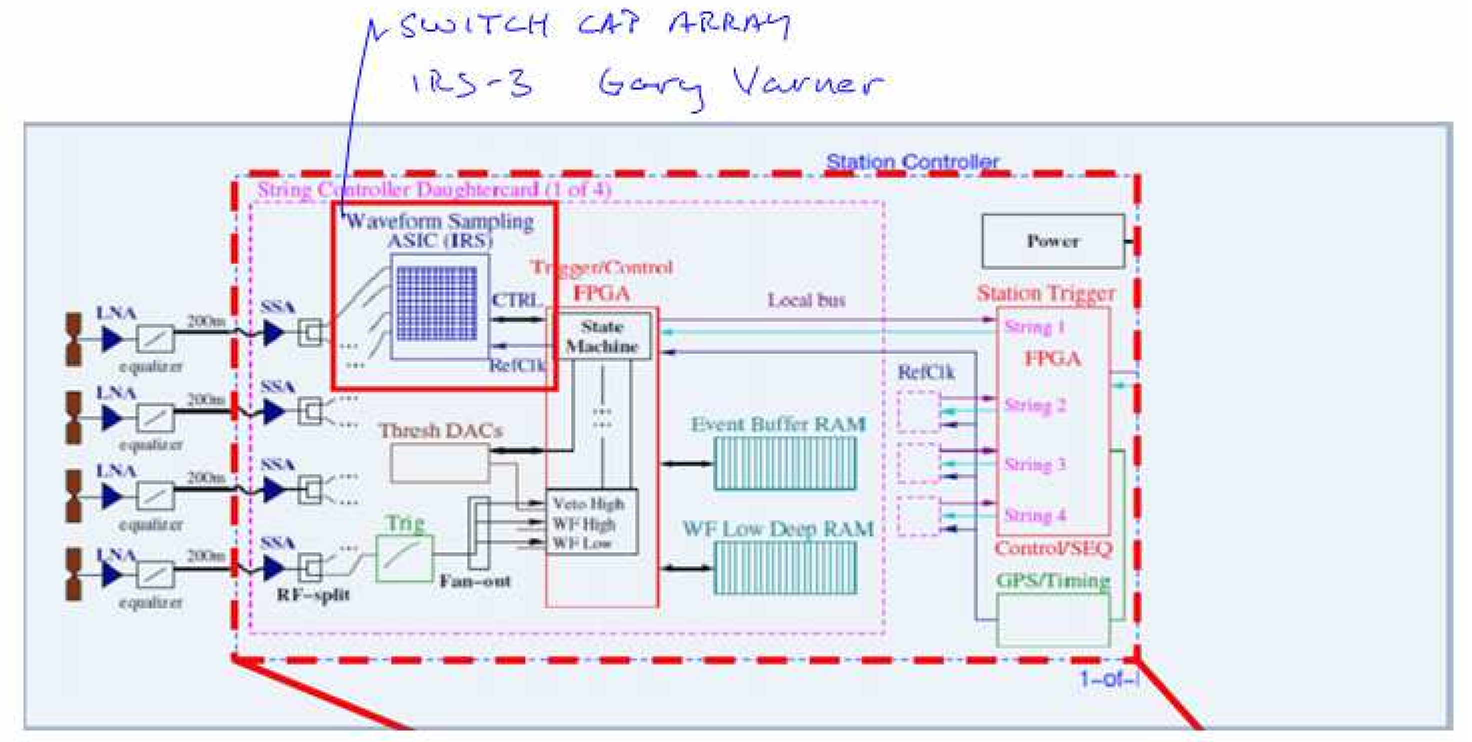
- Band + notch filter, to limit the LNA input to **“our”** signal
- **L**ow **N**oise **A**mplifier to enhance the signal for the data acquisition system



450
SP Sta
comm's

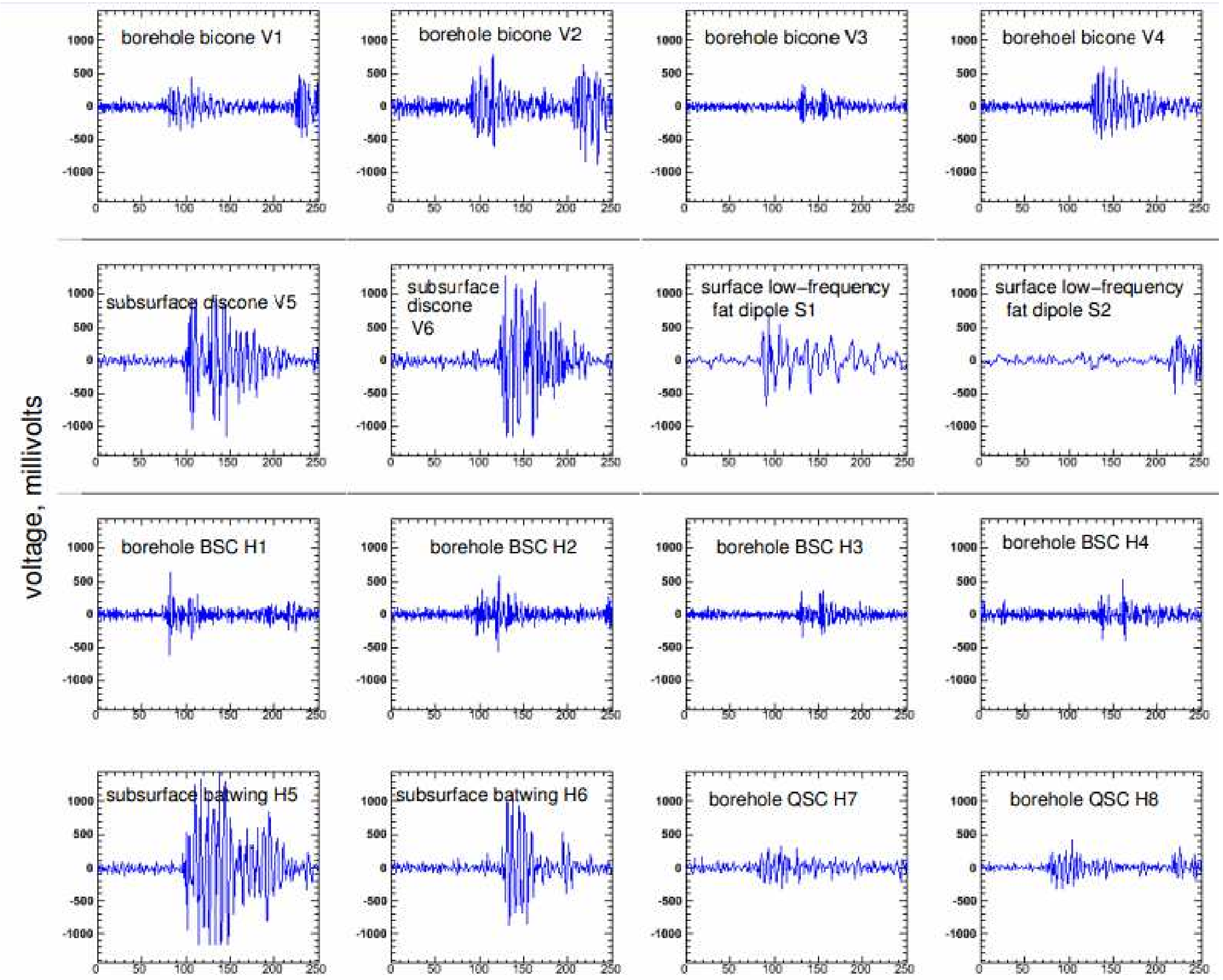


Central DAQ



SWITCH CAP ARRAY
IRS-3 Gary Varner
Station Controller
String Controller Daughtercard (1 of 4)
Waveform Sampling ASIC (IRS)
Trigger/Control FPGA
CTRL
RefClk
State Machine
Local bus
Station Trigger
String 1
FPGA
String 2
String 3
String 4
Control/SEQ
GPS/Timing
Power
LNA
200m
equalizer
SSA
Thresh DACs
Event Buffer RAM
WF Low Deep RAM
Veto High
WF High
WF Low
Trig
Fan-out
RF-split
1-of-N

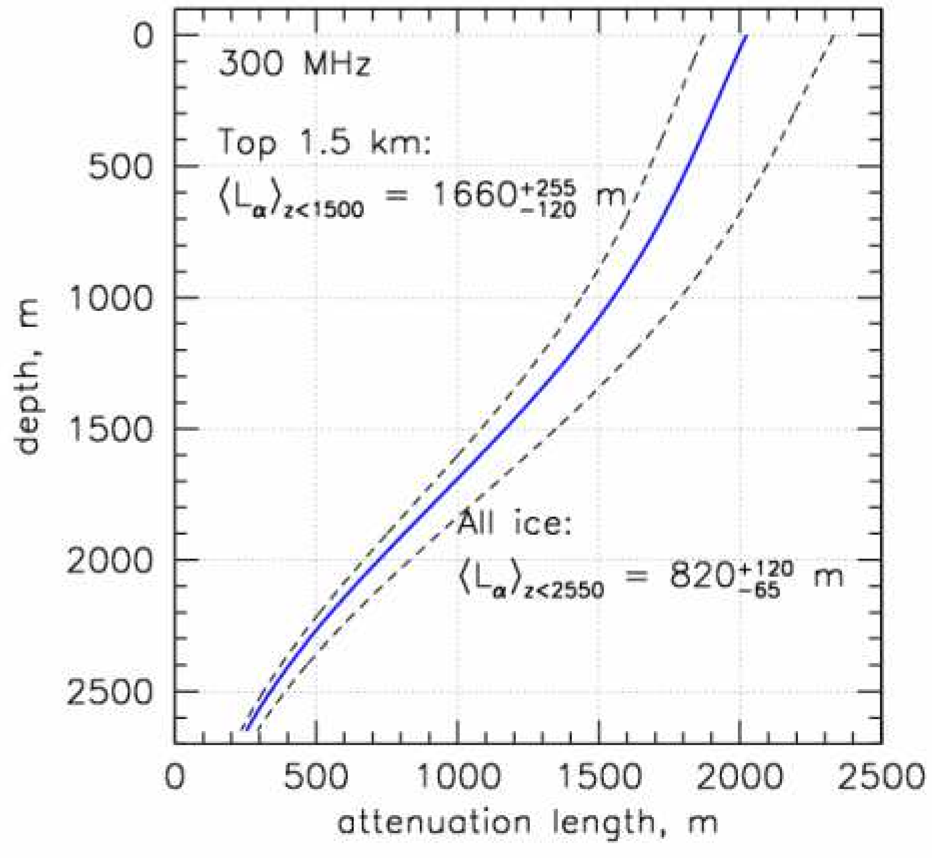
Calibration pulser event from testbed

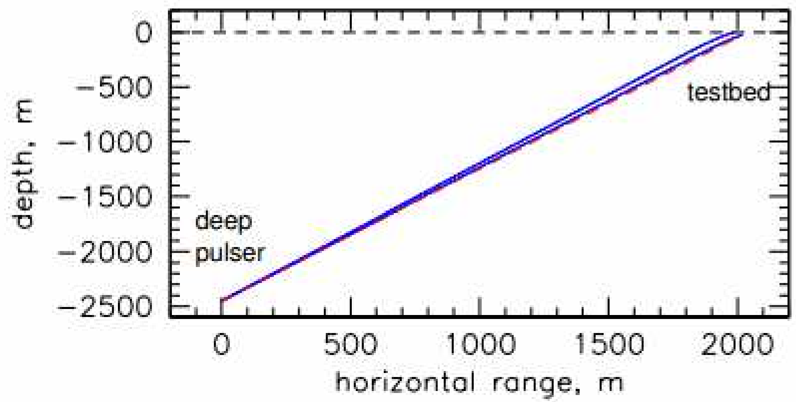


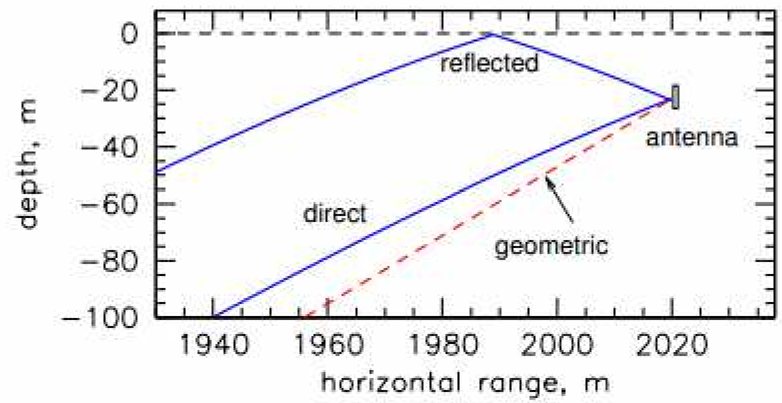
Interpretation

amplitude analysis
⇒ attenuation

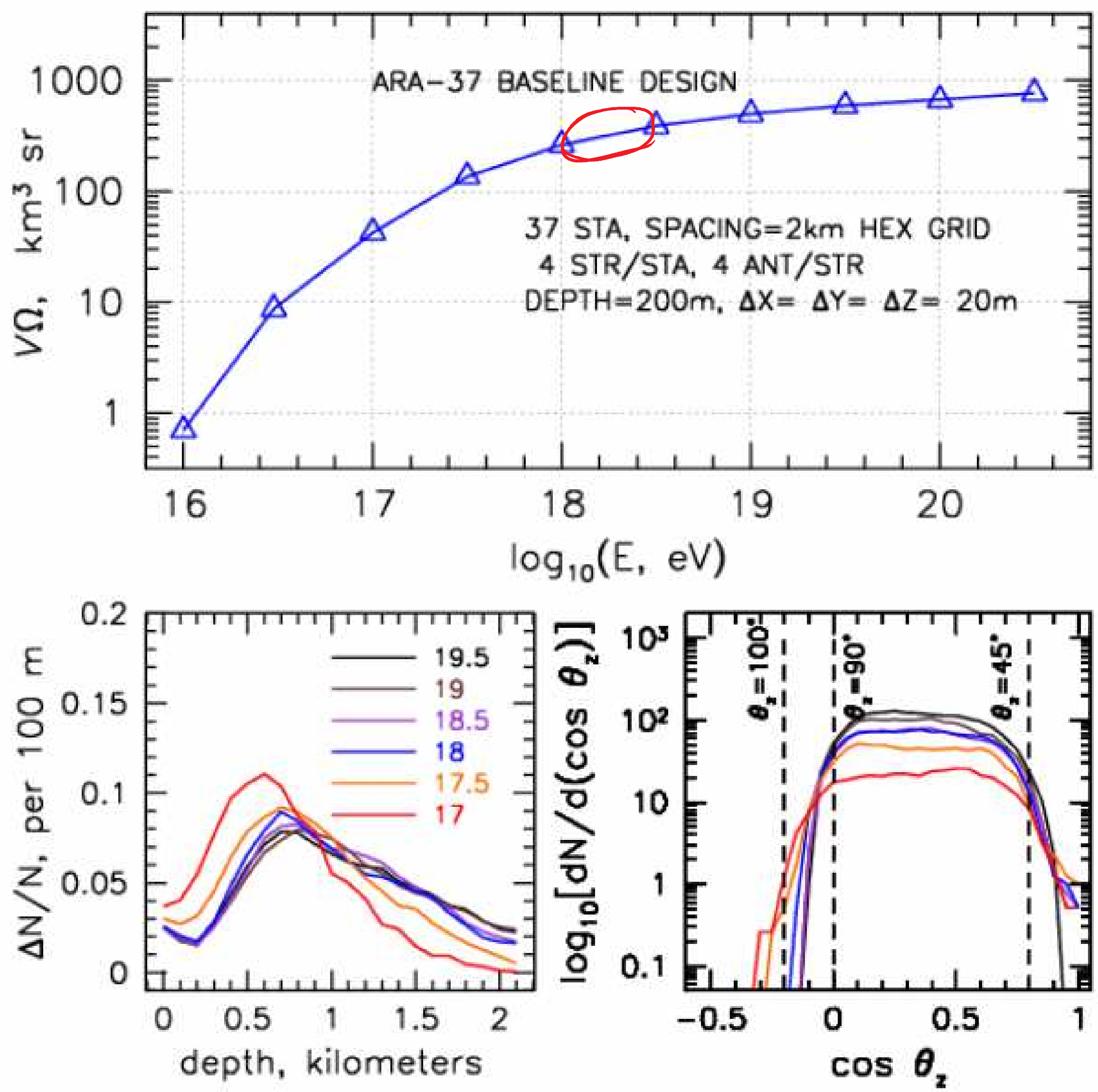
timing of Two pulses







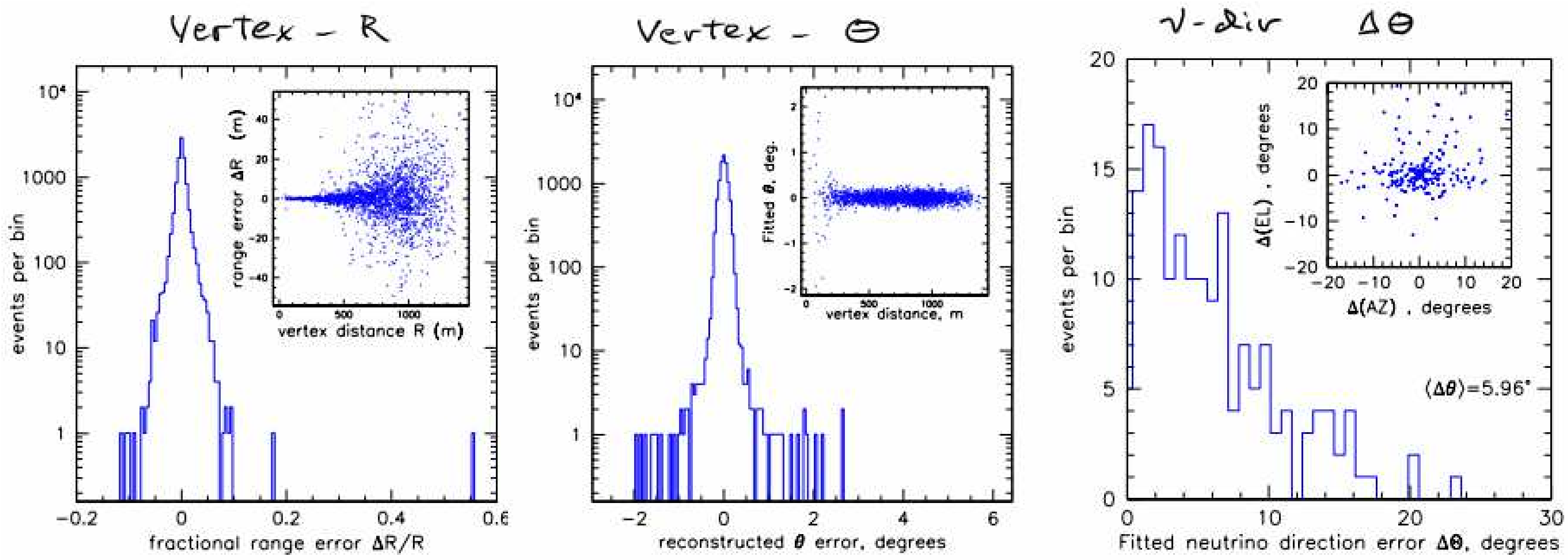
ARA-37 sensitivity

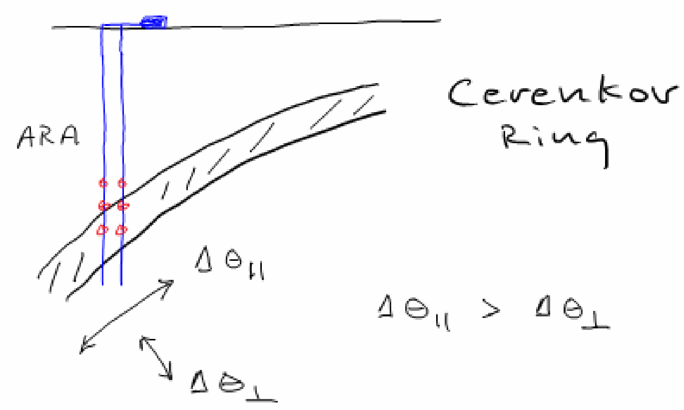


300 km^2 sr
@ $10^{18} - 10^{18.5}$

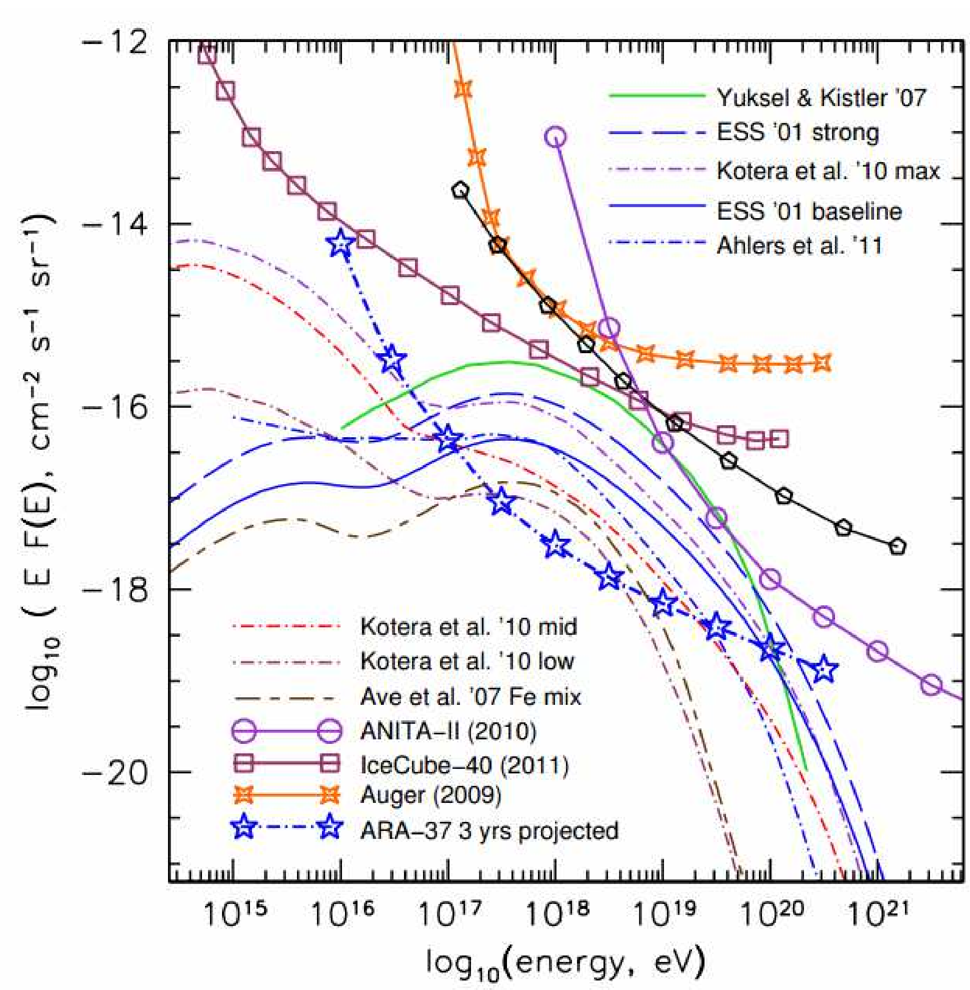
Area 120 km^2
Depth 2

Reconstruction





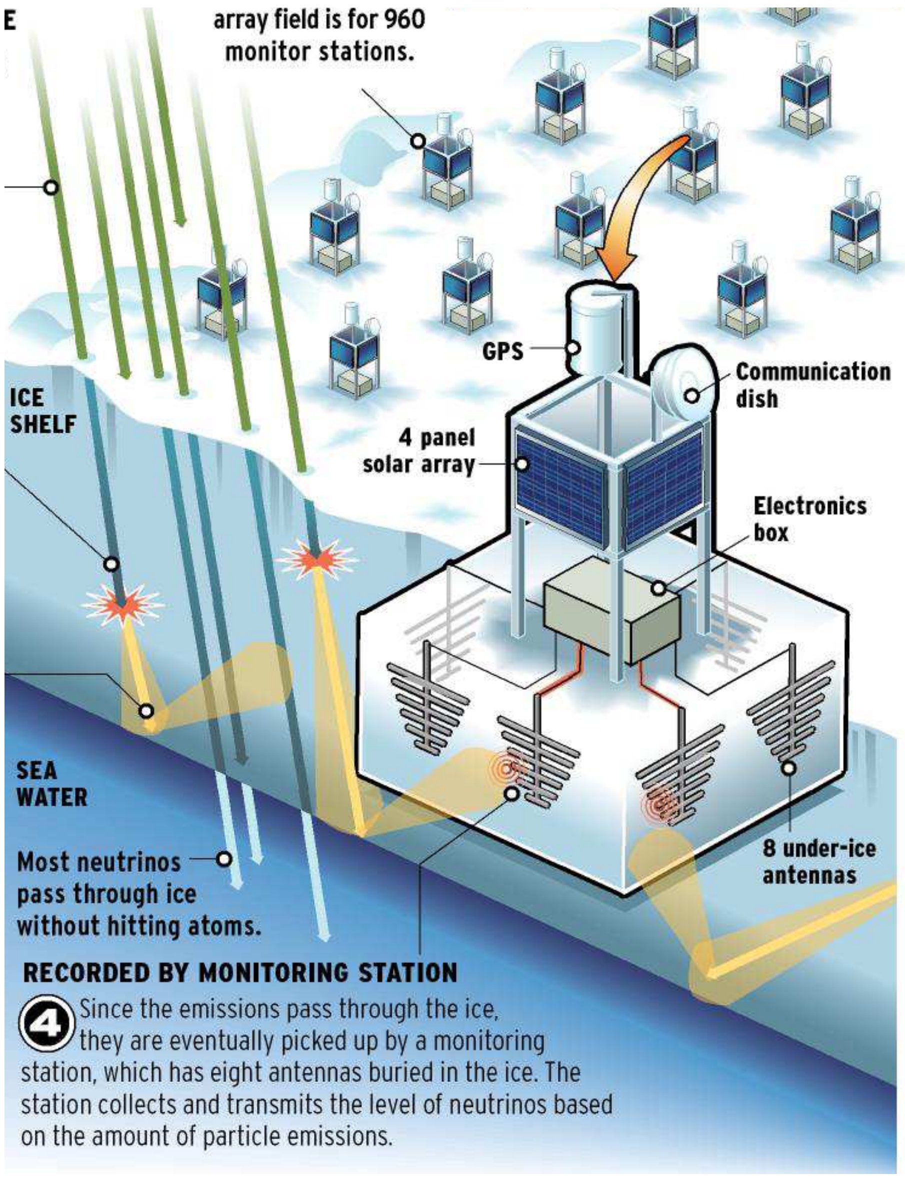
Science expectations



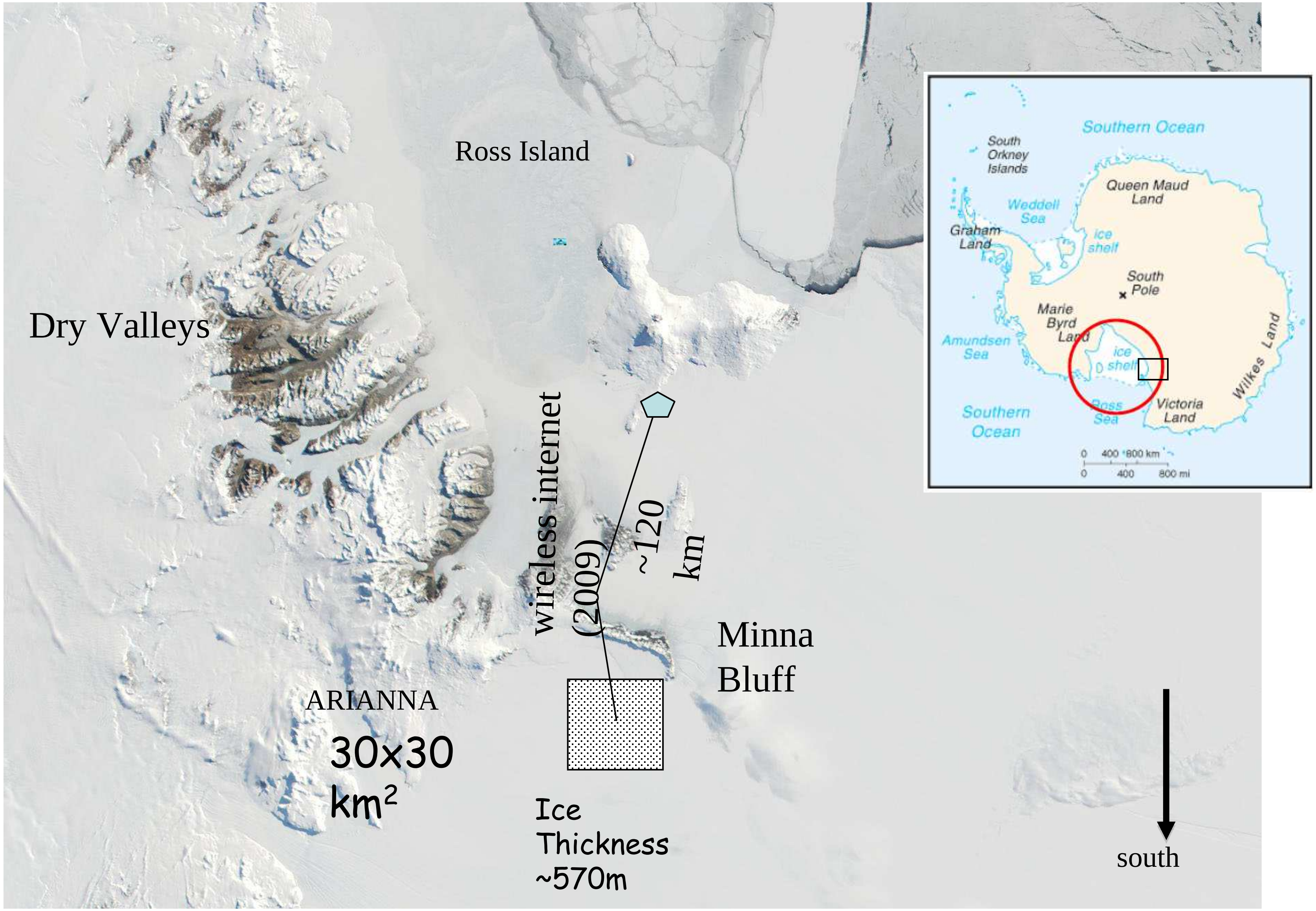
Model & references N_ν:	ANITA-II, (2008 flight)	ARA, 3 years
Baseline cosmogenic models:		
Protheroe & Johnson 1996 [27]	0.6	59
Engel, Seckel, Stanev 2001 [28]	0.33	47
Kotera,Allard, & Olinto 2010 [29]	0.5	59
Strong source evolution models:		
Engel, Seckel, Stanev 2001 [28]	1.0	148
Kalashev *et al.* 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

ARIANNA

- Source: S. Barwick, (IAU 2012)
- K. Dookayka, PhD Thesis, 2011
- http://arianna.ps.uci.edu
- US, Sweden, New Zealand

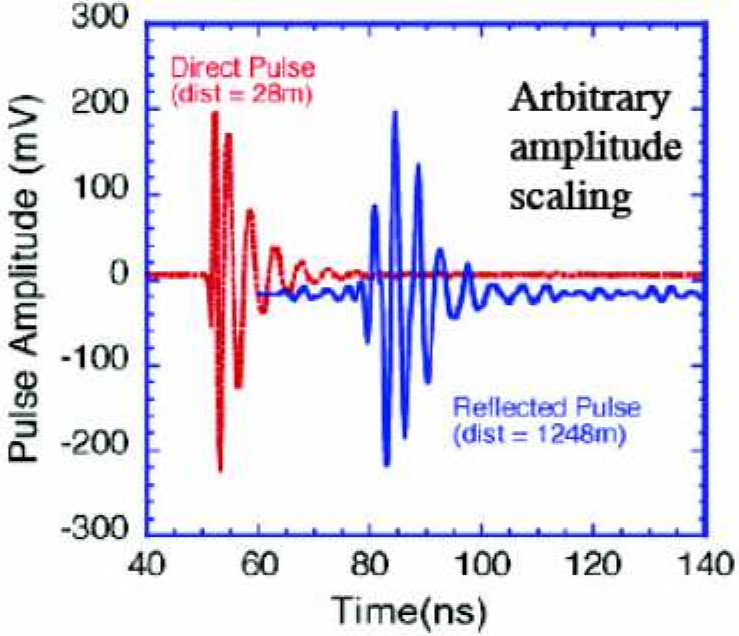


Arianna site

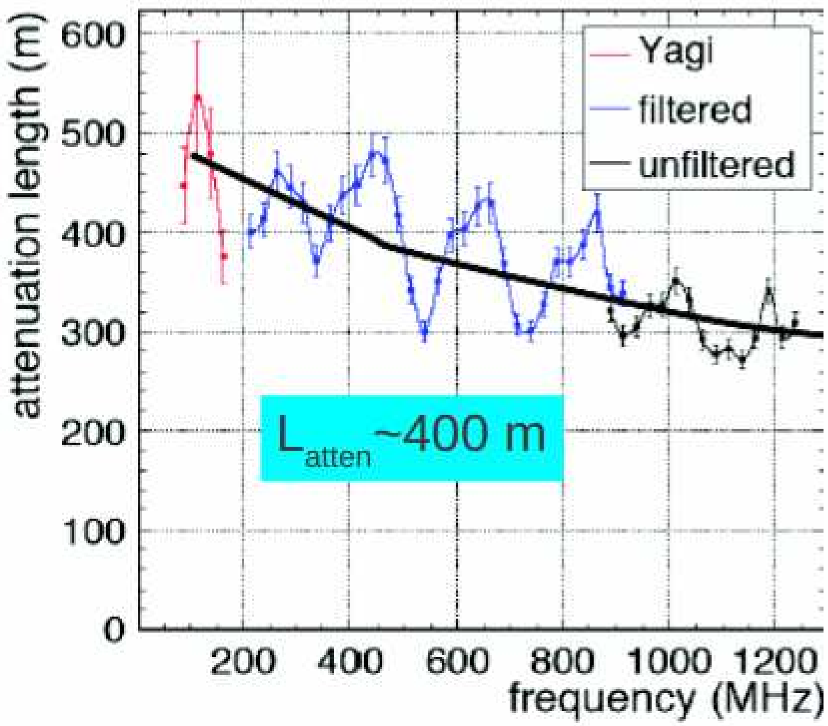


Ice properties

T. Barrella, et al., J. Glaciology, 2010



Amazing fidelity of reflected pulse from sea-water bottom -behaves as nearly flawless mirror

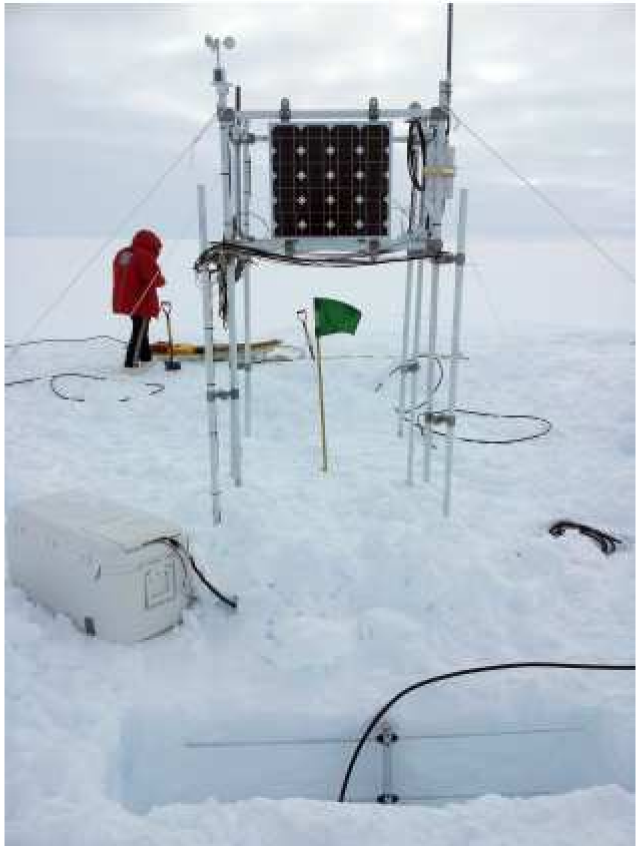


1-way attenuation length, averaged over depth and temperature

Station design

ATWD based DAQ

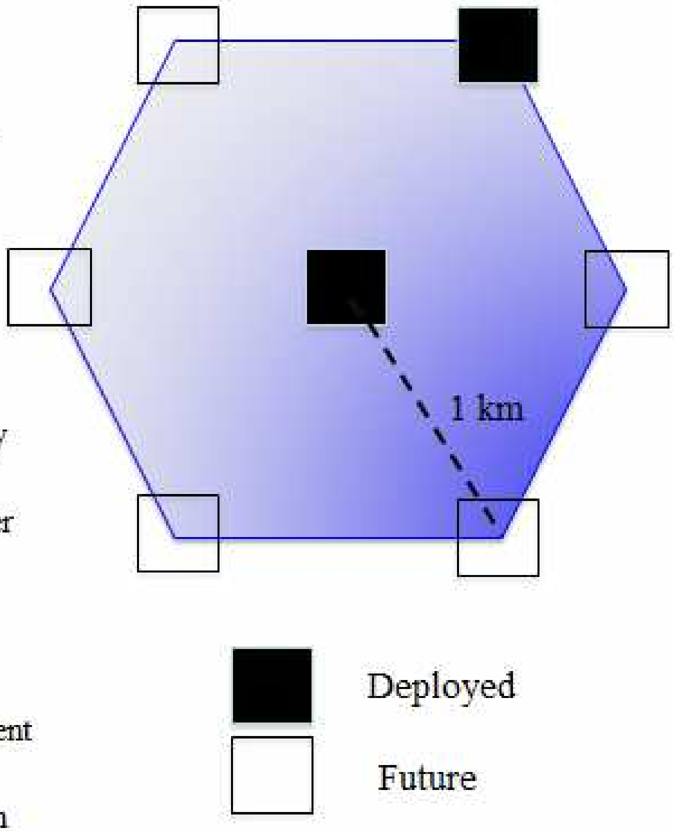
Solar + wind



8 LPDA antennas

Hexagonal array

- Nov 2011:
  - Deploy 1 protostation w/new DAQ technologies
  - Establish wireless communication
- Nov 2012:
  - Deploy 3 stations for operation during sunlit months
  - Reduce power consumption to 10W
  - Deploy Wind/Solar system with $LiFePO_4$ battery technology
  - Establish communication/control with low power microcomputer
- Nov 2013
  - Deploy 4 stations to complete hex array
  - Focus on cost reduction and simplified deployment and commissioning
  - Investigate technologies for overwinter operation

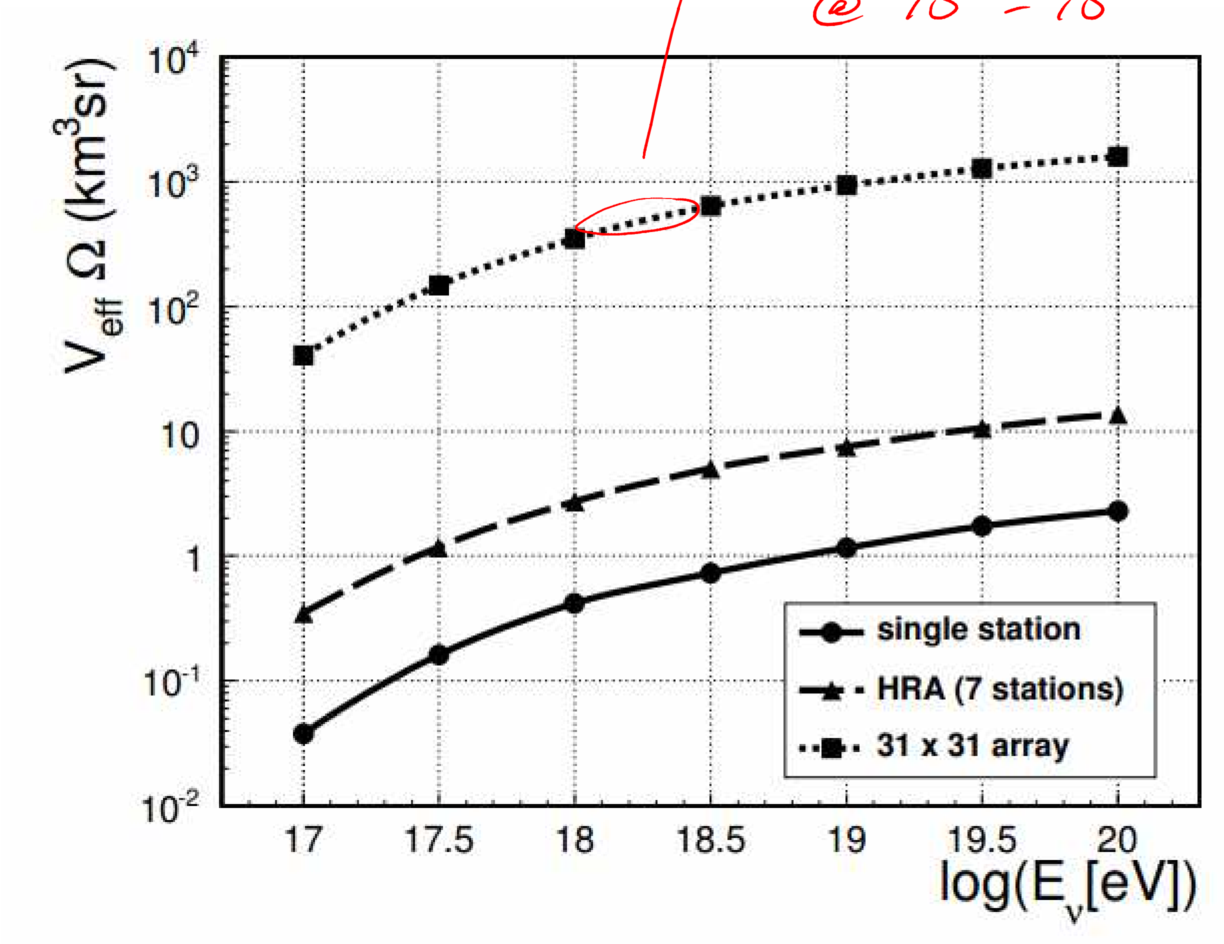


Technical Goals for 1000 km^2

- Station costs: ~$10k US per station
- Fully "green" power system
  - Solar and wind only; no fossil fuels
  - Scalable to vary large areas
- Deployment at rate of 1 station/person/day
- 3 year construction for 960 stations

Sensitivity expectations

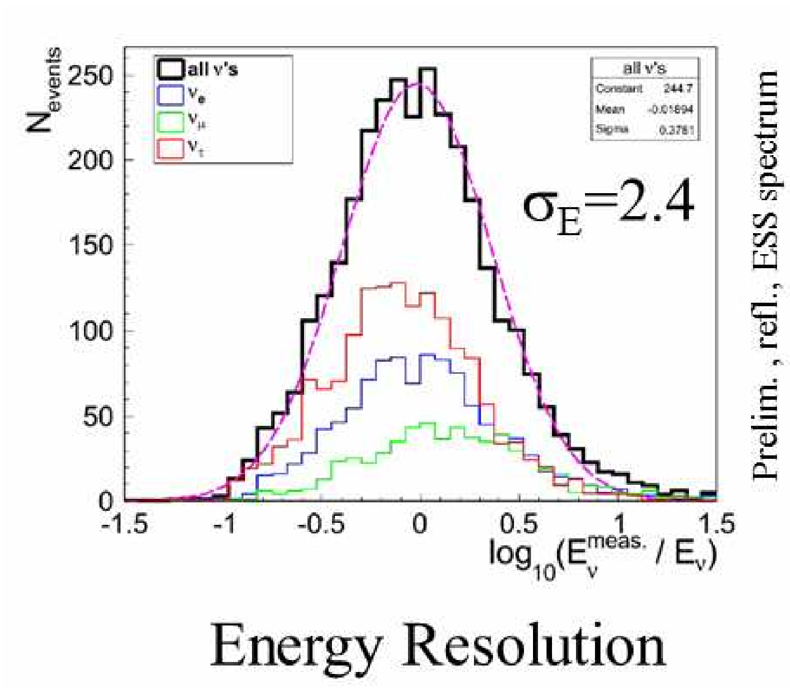
400 km^2 sr
@ $10^{18} - 10^{18.5}$

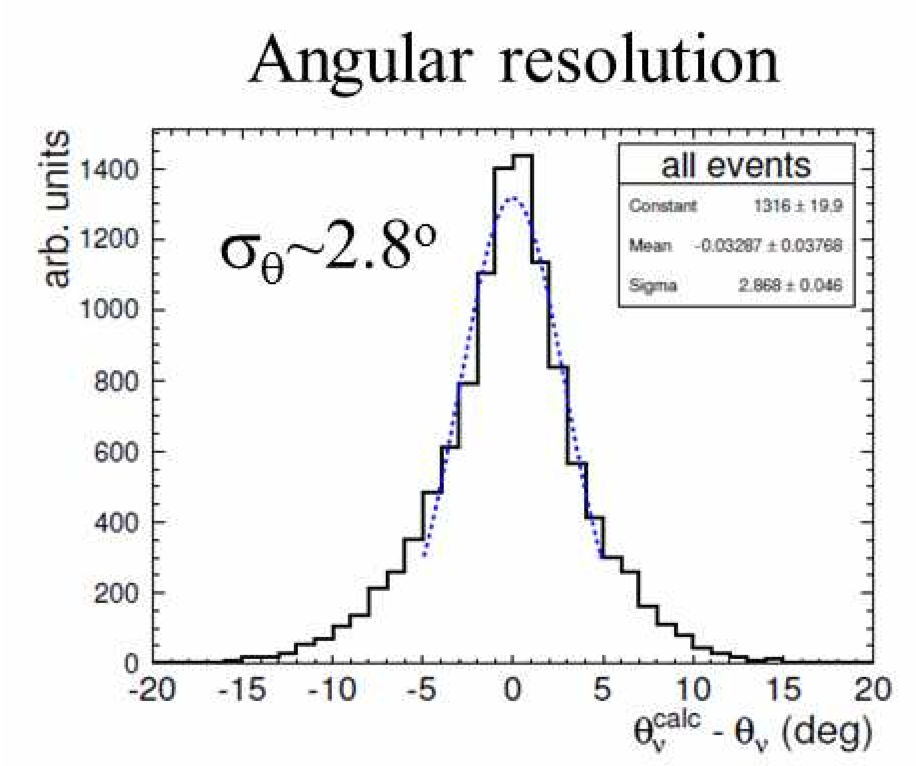


Physical Area
~ 1000 km^2

Depth
~ 0.6 km

Reconstruction



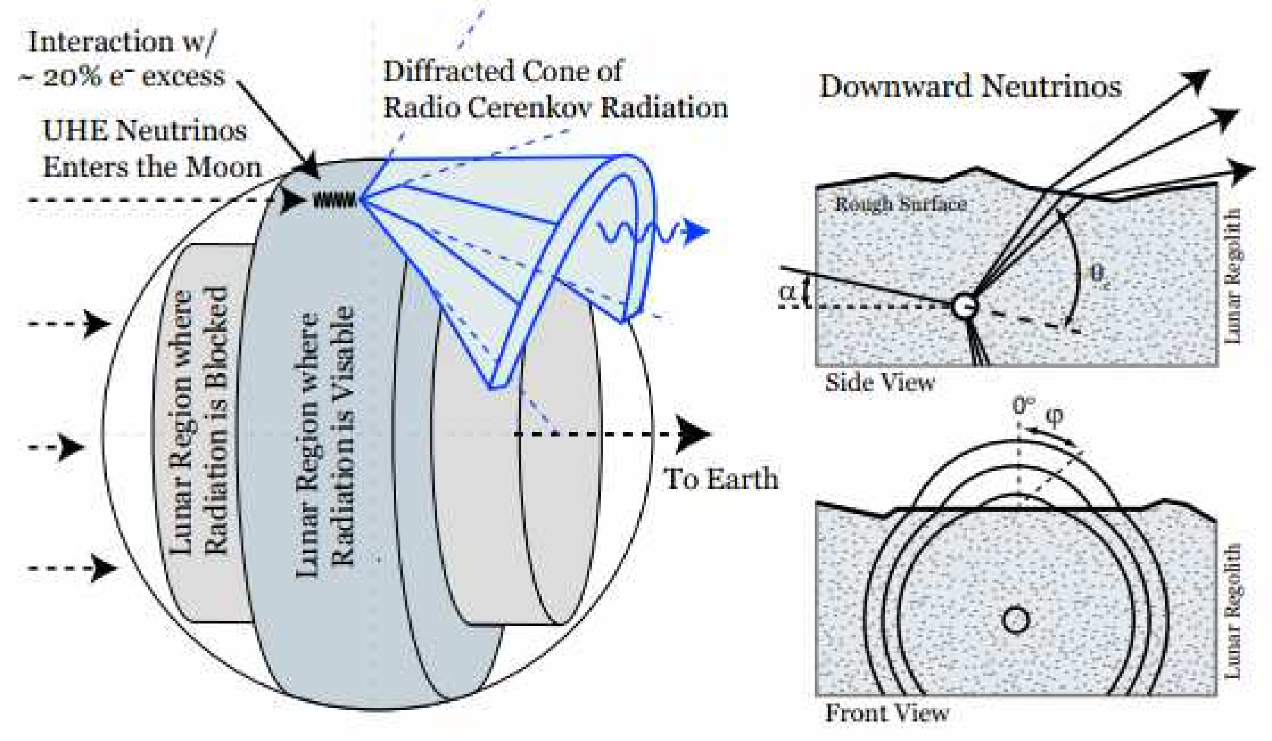


Radio telescope observations of moon

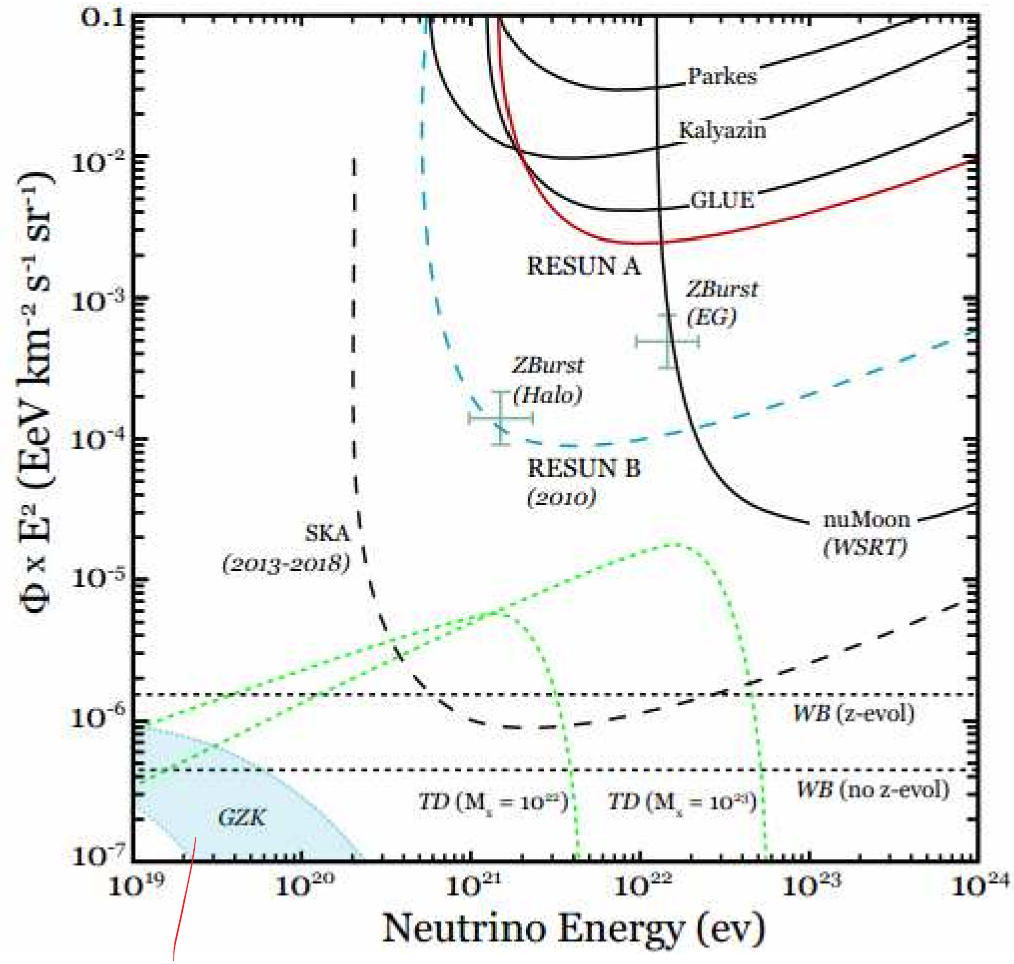
- Parkes
- GLUE (Goldstone)
- Kalyazin
- LUNASKA (Parkes/ACTA)
- nuMoon (WSRT)
- RESUN (EVLA)
- LOFAR
- SKA

(Ron Ekers)

Lunar concept (Jeager, Mutel, Gayley)



Overview of lunar cherenkov (JMG)



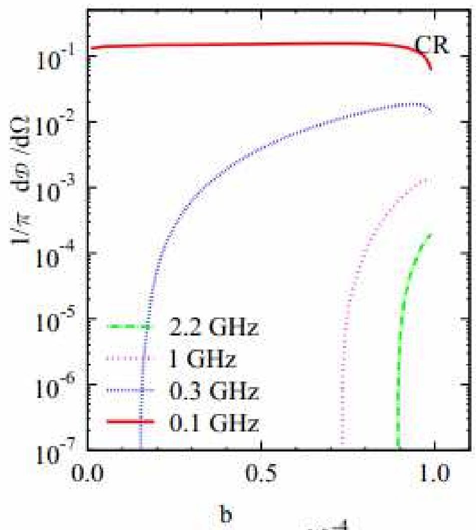
> 1 GHz

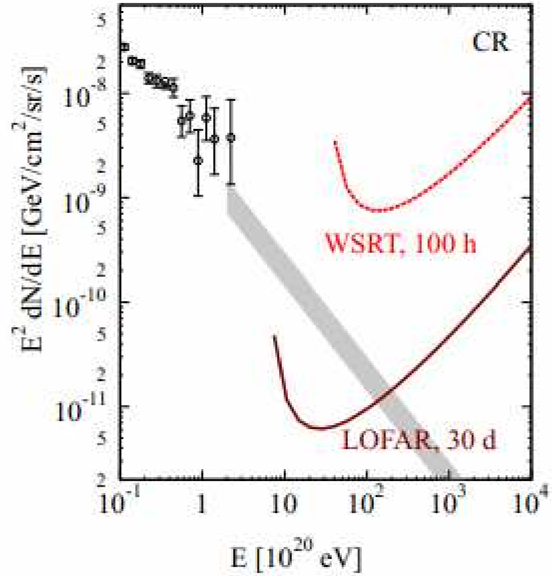
~ 150 MHz

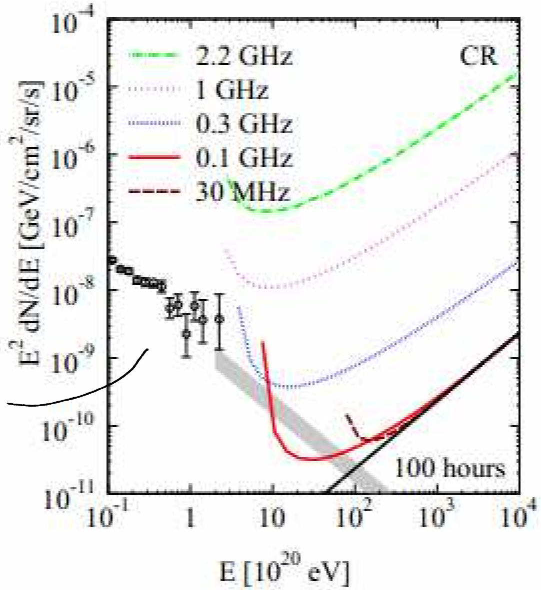
sigh

Frequency, TIR, and $\Delta\theta$

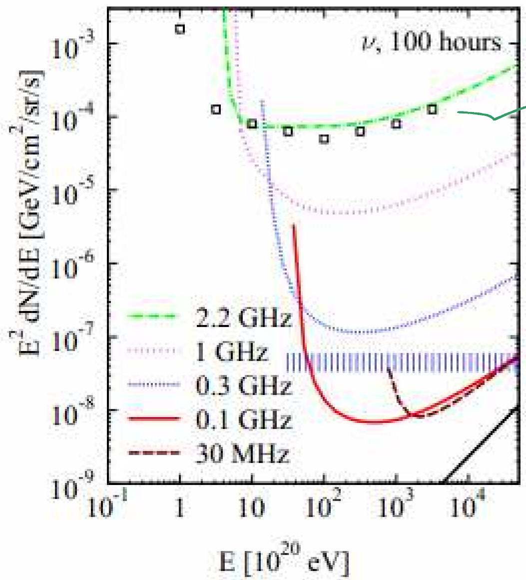
Scholten, etal (2006)







AGASA

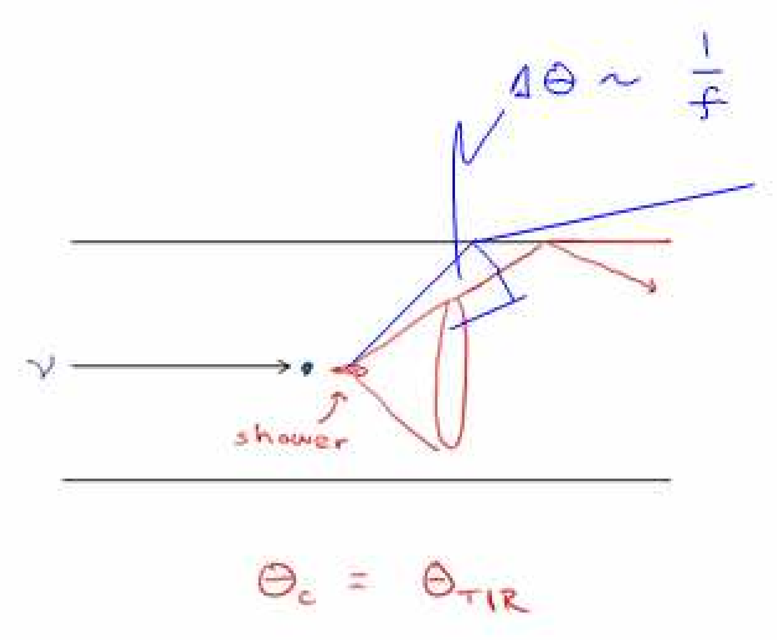


GLUE

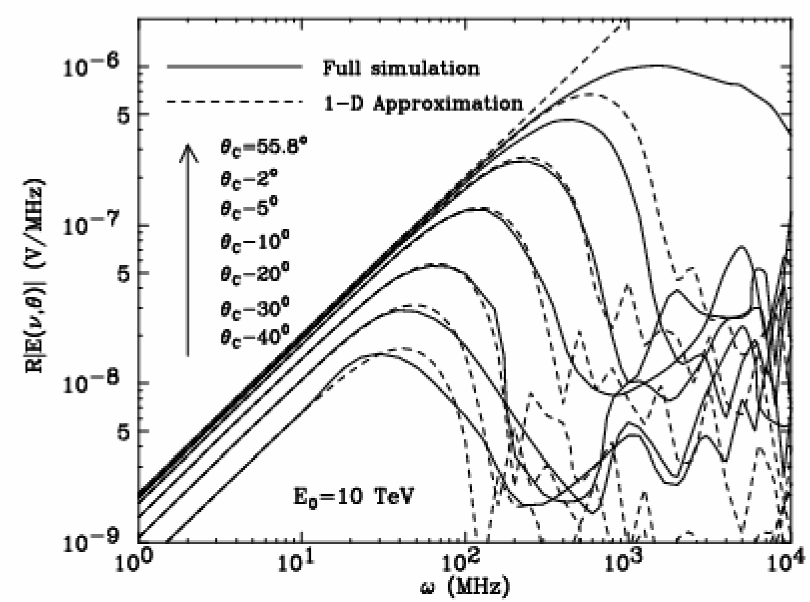
WB

frequency: aperture v threshold

Escape

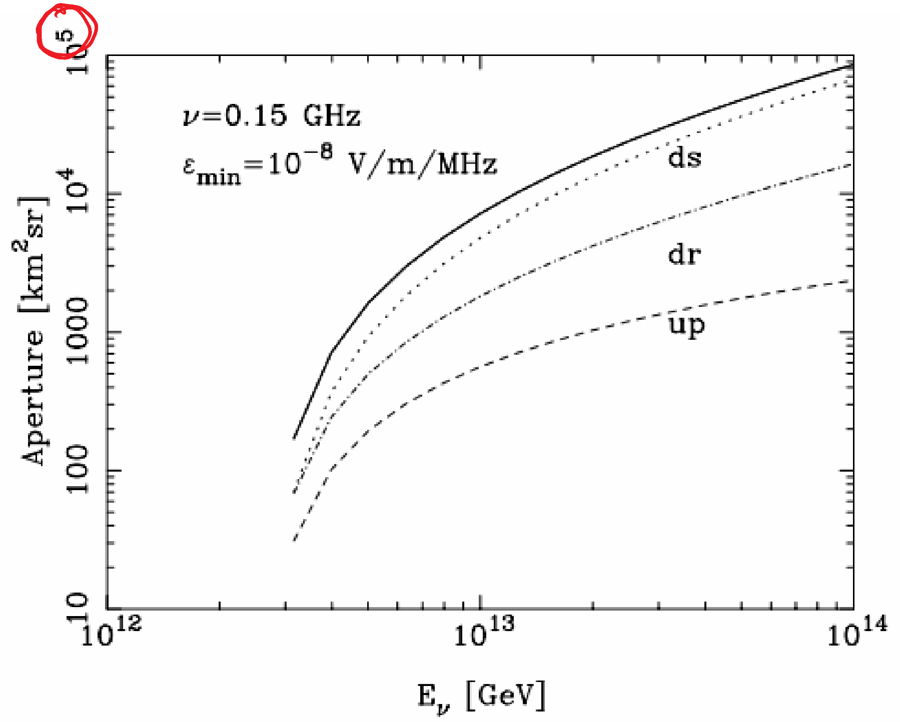


Signal

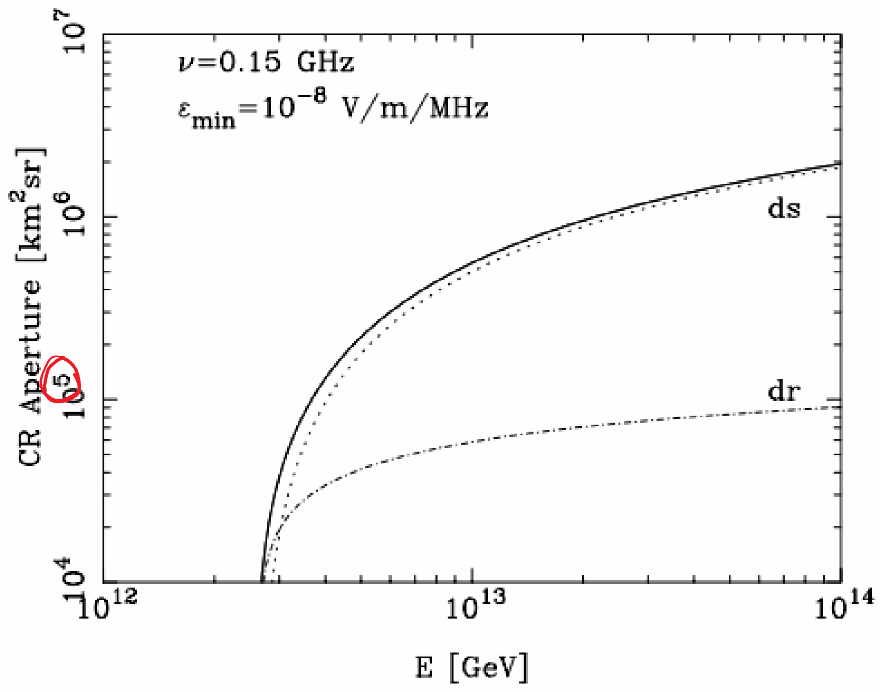


Fine … until compare to CR events: Jeong, Reno, Sarkevic

ν

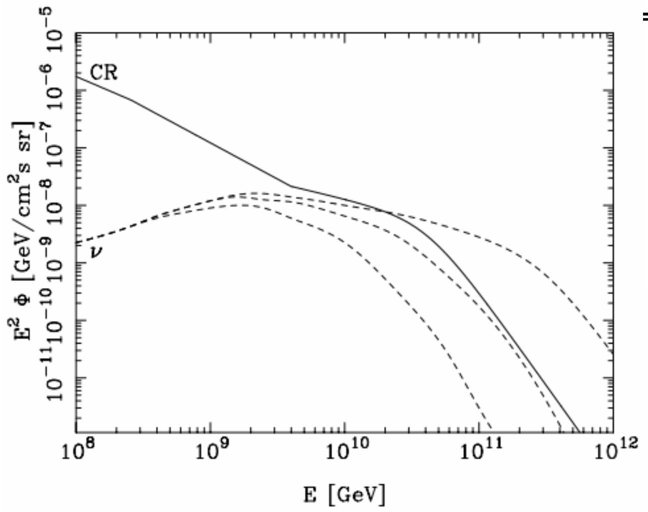


CR

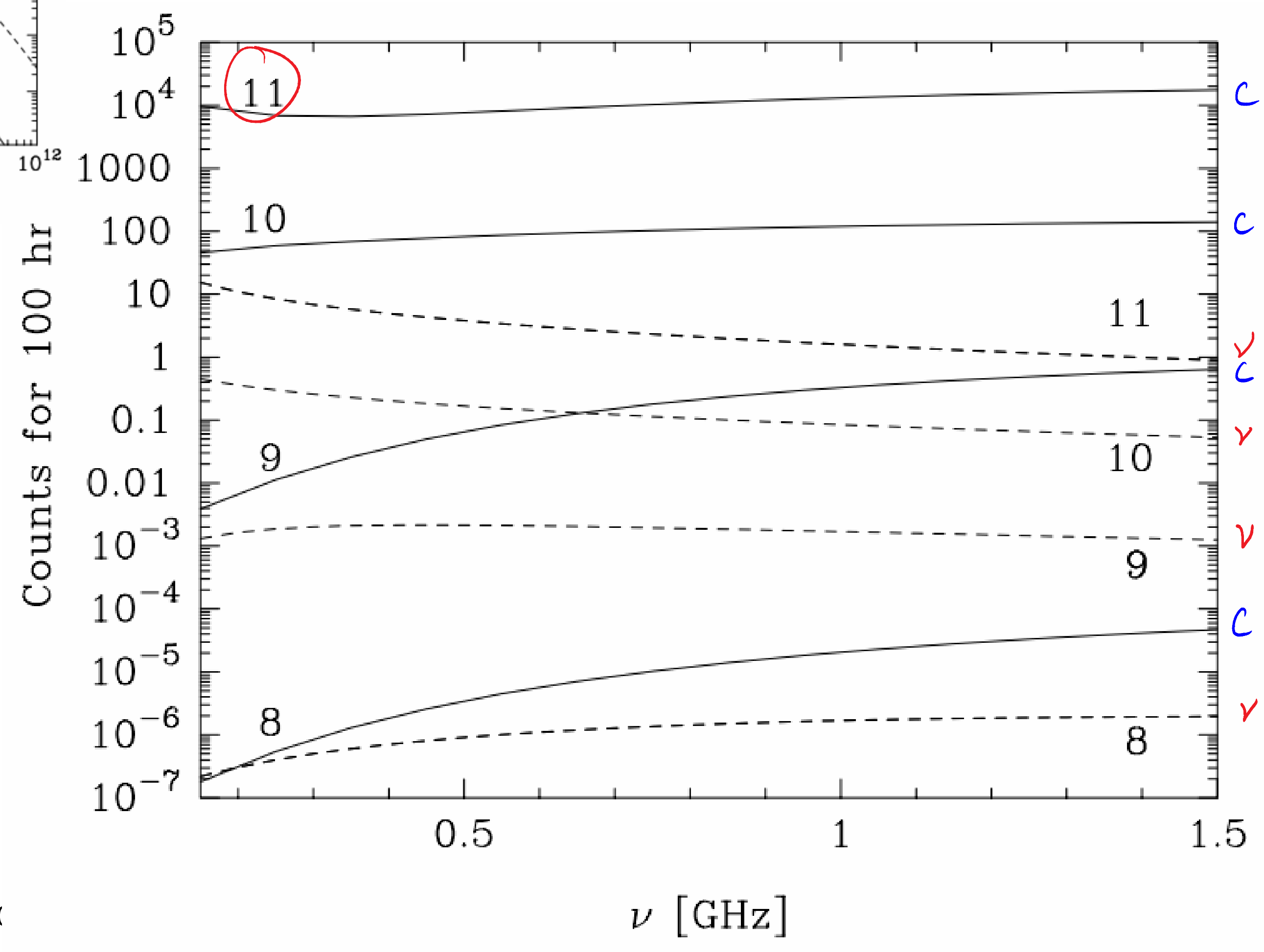


Also in Scholten et al

Events



10⁻¹¹ V/m/MHz theshold



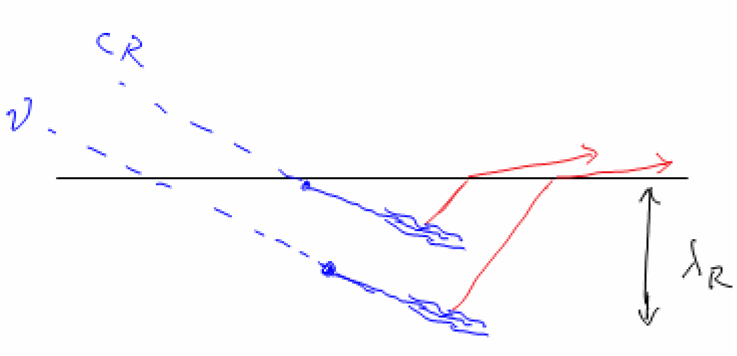
Radio detection of cosmic neutrinos, N(

CR 100x ν – what to do

- separate ν from CR? (spatially, by features (e.g. γ-ray astronomy))

- proximity of surface suppresses CR signal
- up rate dominates?
- return to high-f?

- true for orbiter, too. (LORD)



- (JRS) fluxes already nu-optimistic

- some science still OK?
  - point sources
  - cross-sections

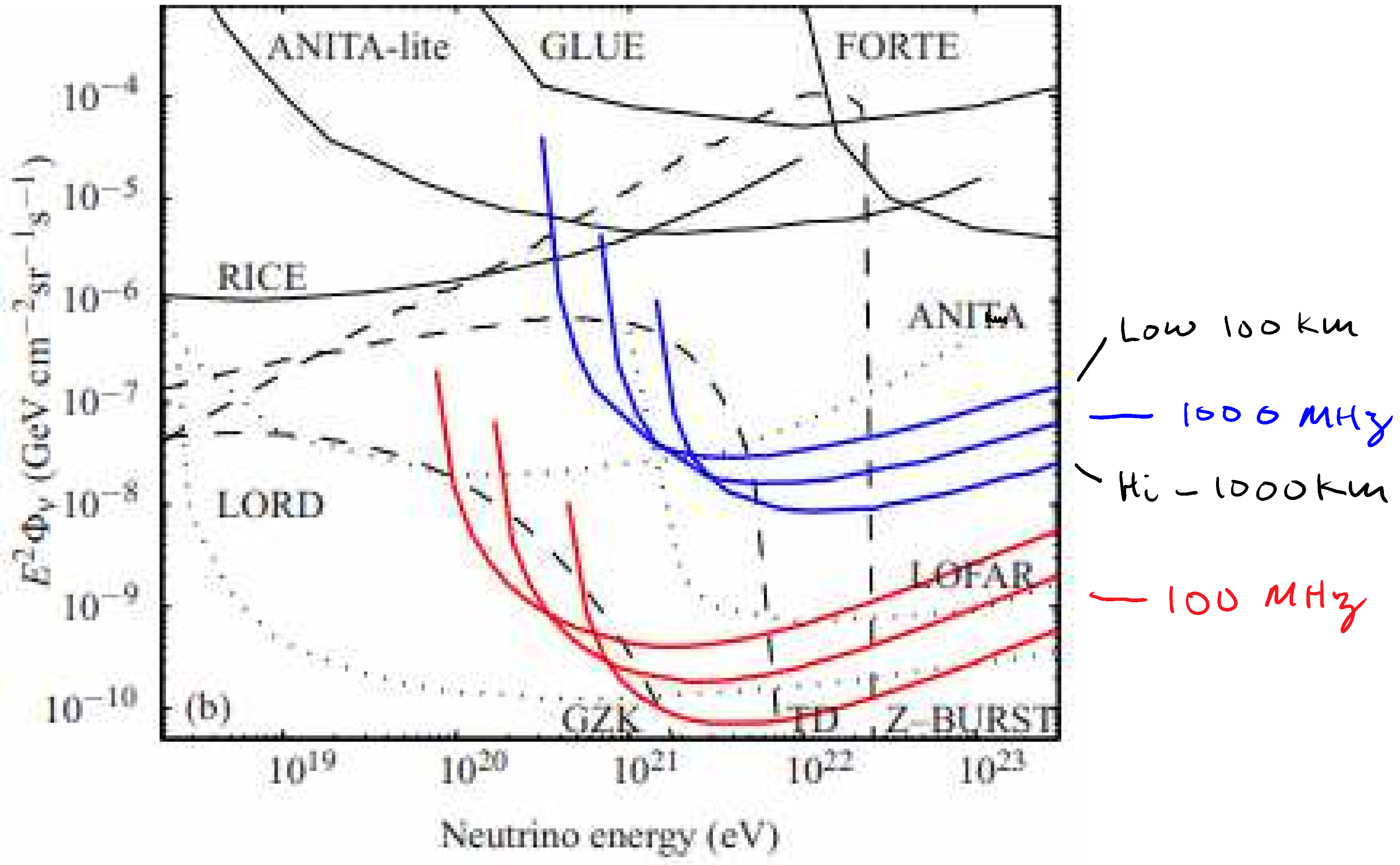
$$P_\nu = \frac{\lambda_R}{L_\nu} = n\sigma\lambda_R$$

Lunar technique

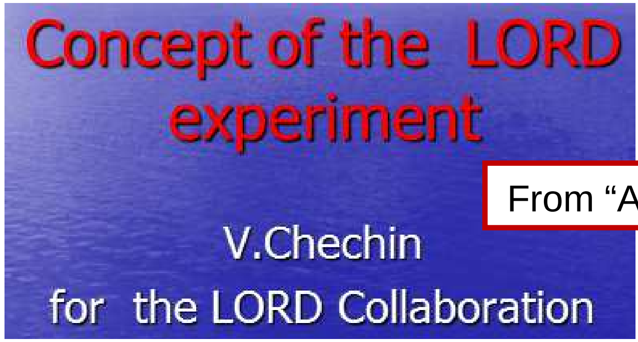
- promising for CR
- techniques going forward – see other talks
  - ATCA: coherent addition of signals from several ants
  - LOFAR: triggering(?)
- difficult for nu's
- a lot of detail still to be done
  - see ANITA list of details

Satellites: Lunar satellites

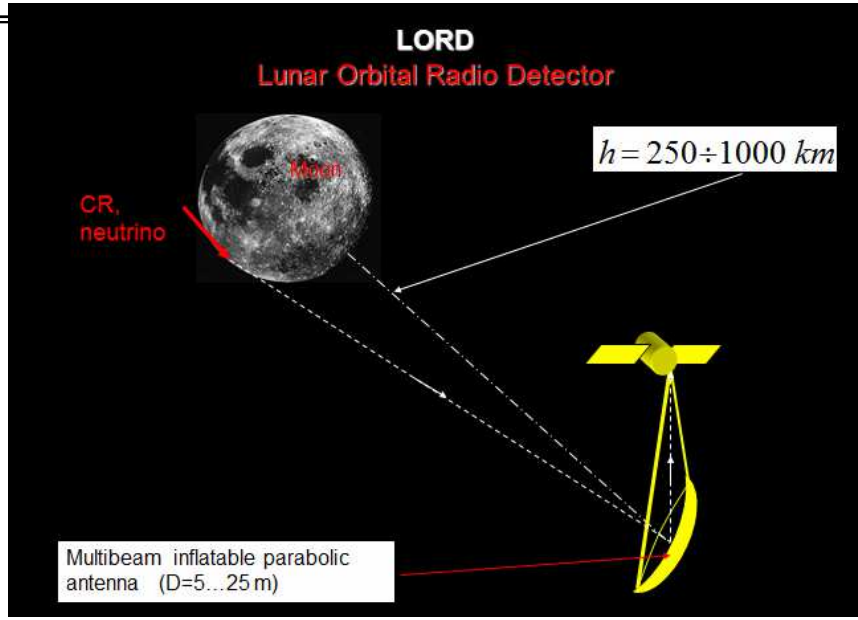
Stal, etal

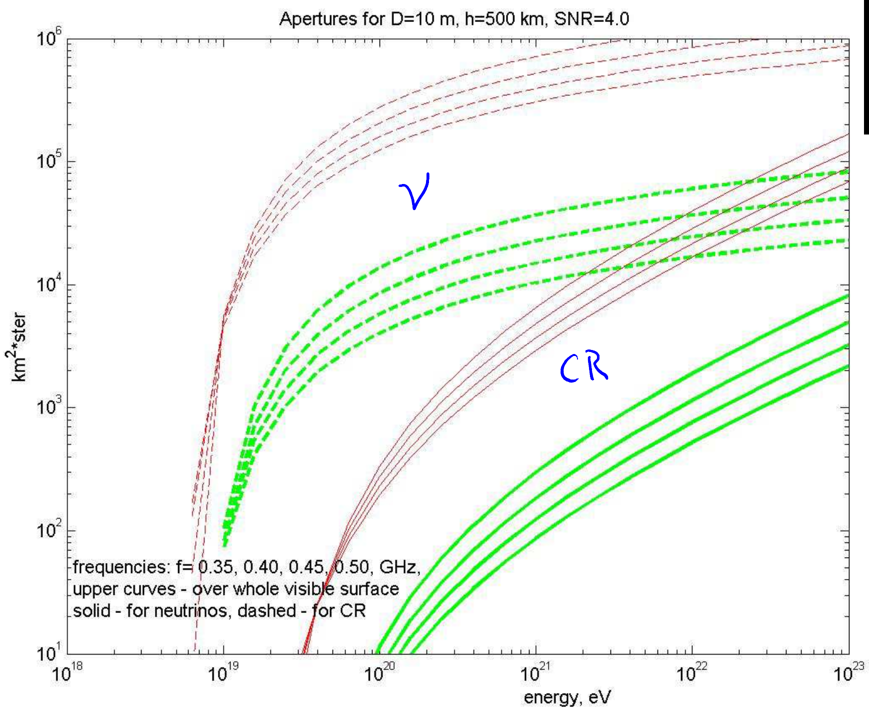


LORD

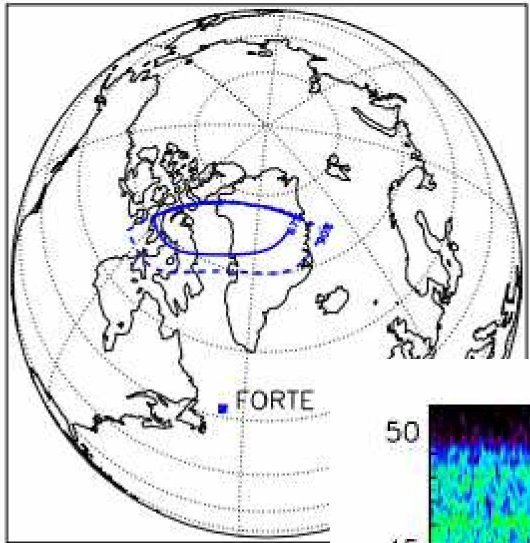


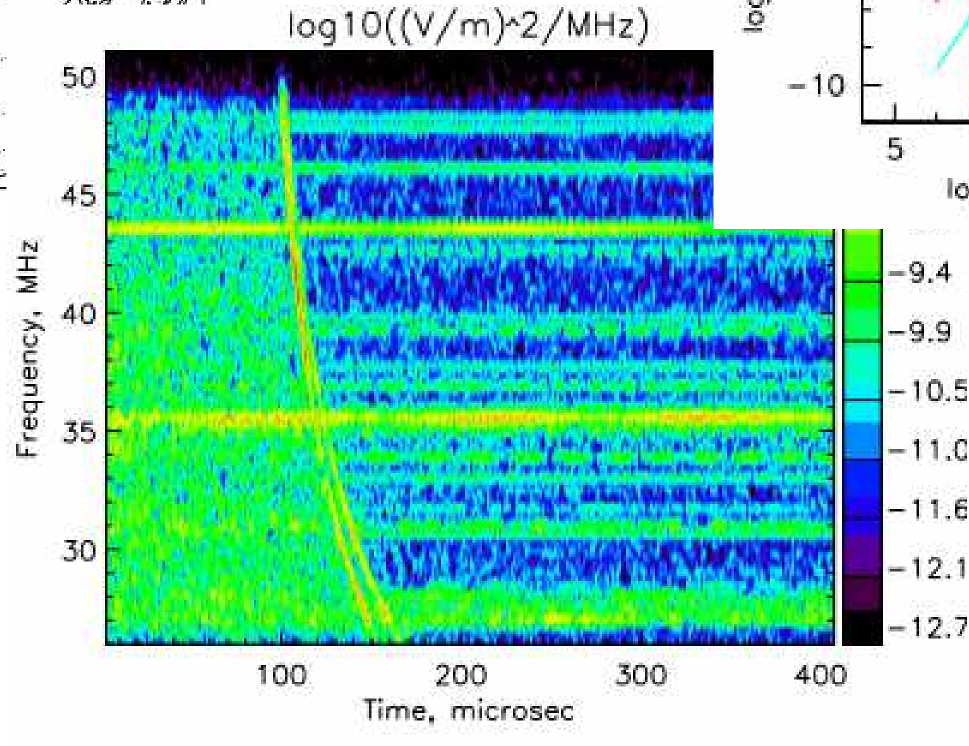
From “ARENA”

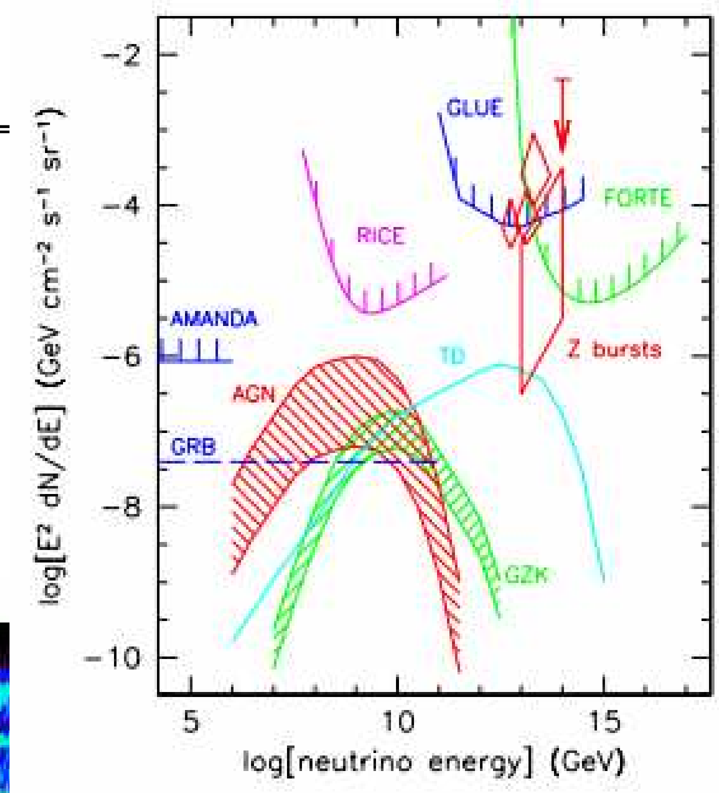




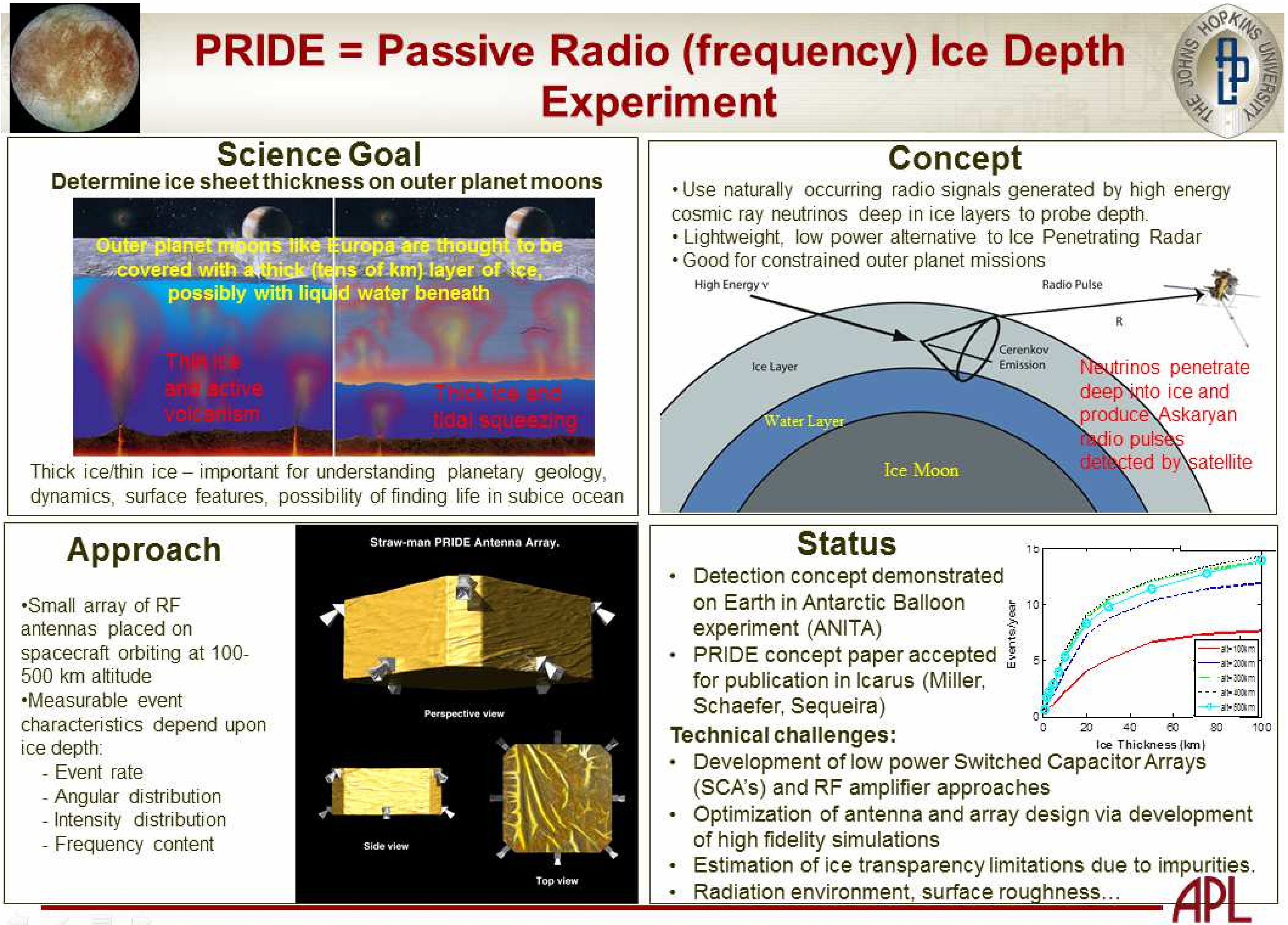
FORTE (Lehtinen, etal.)







PRIDE (Miller, etal.: Europa)



Summary

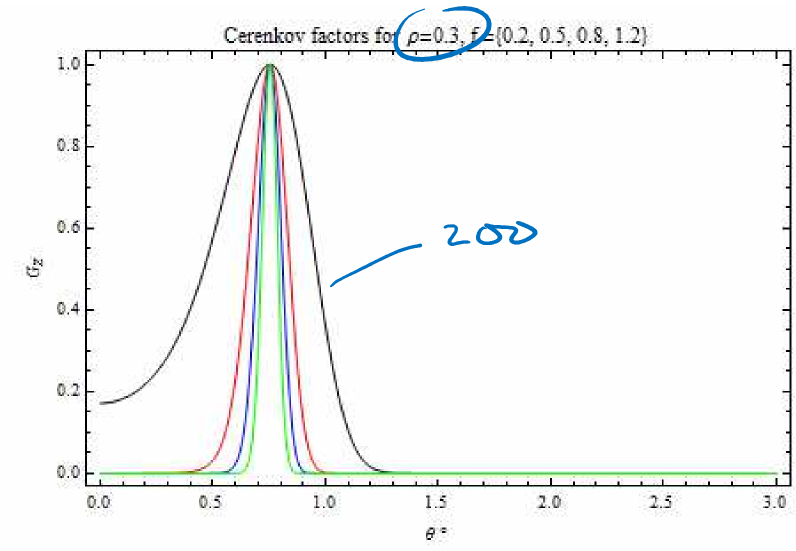
- Cosmogenic neutrinos have something to say about UHECR origins
- Askaryan effect verified. Common understanding of Askaryan and geomagnetic
- ANITA: self triggered detection of cosmic particles? Maybe too small.
- Next generation of in-situ arrays ARA/ARIANNA 10's of events/yr
- Lunar observations difficult for UHE neutrinos due to UHECR background

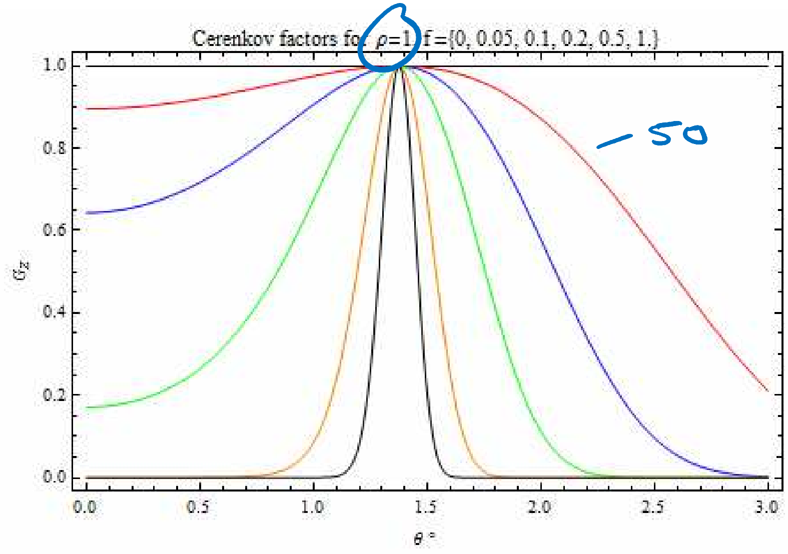
extra slides

Constant index of refraction

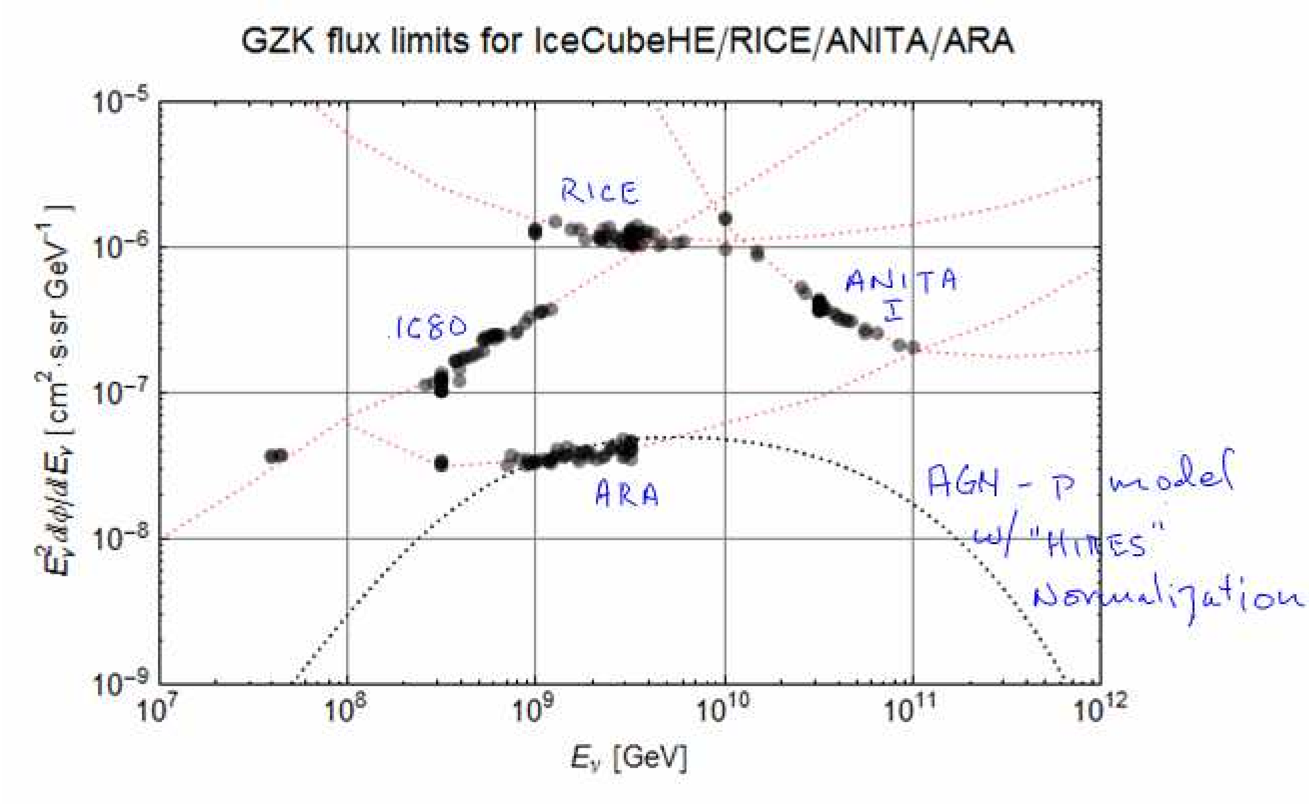
8000 m

ground





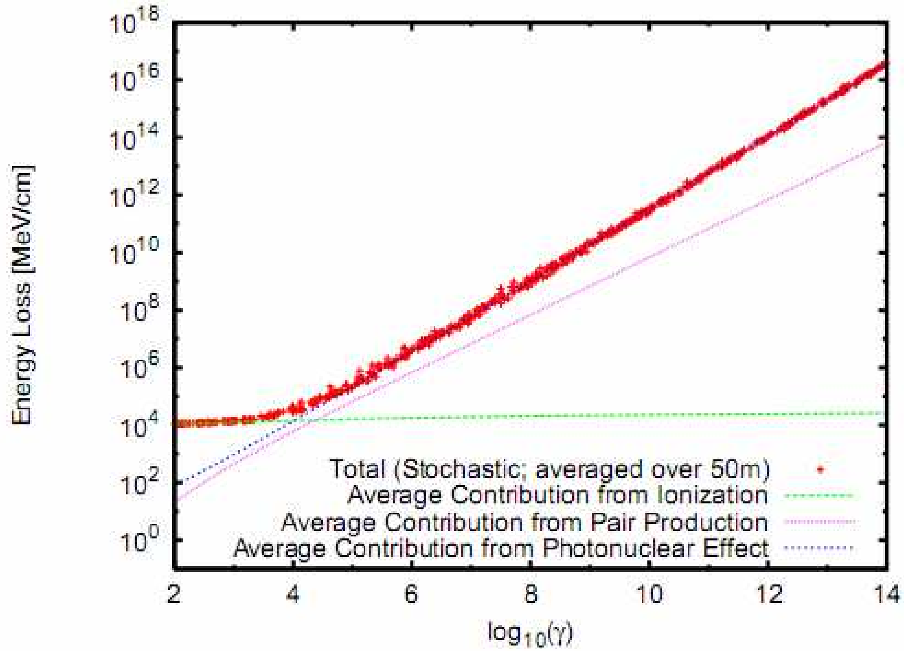
Comparison – for discussion only (Dec 2009)



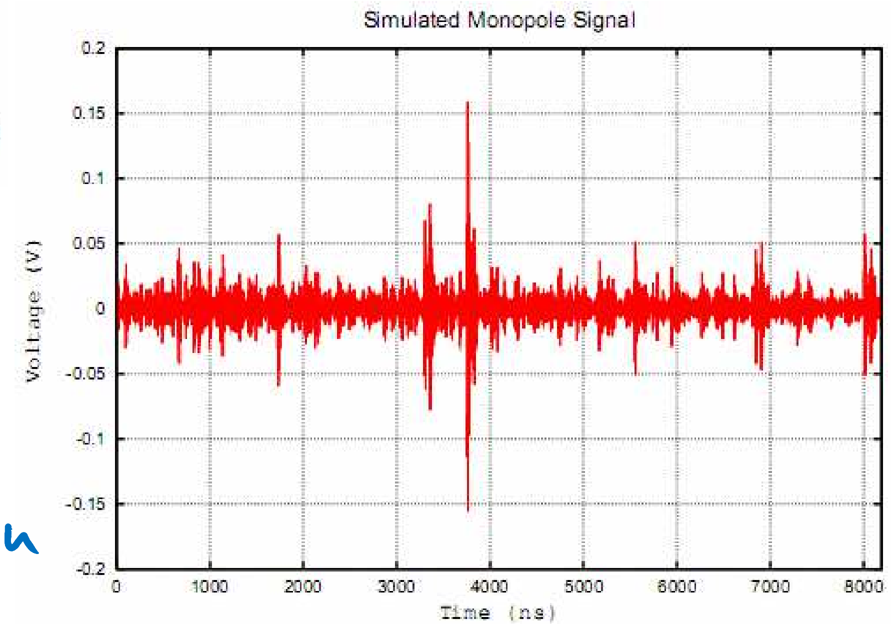
Neutrino detection

- Simulation
  - event generator
  - event simulation
- Detector
- Operations
- Analysis
  - calibration
  - backgrounds
  - reconstruction

Magnetic Monopoles



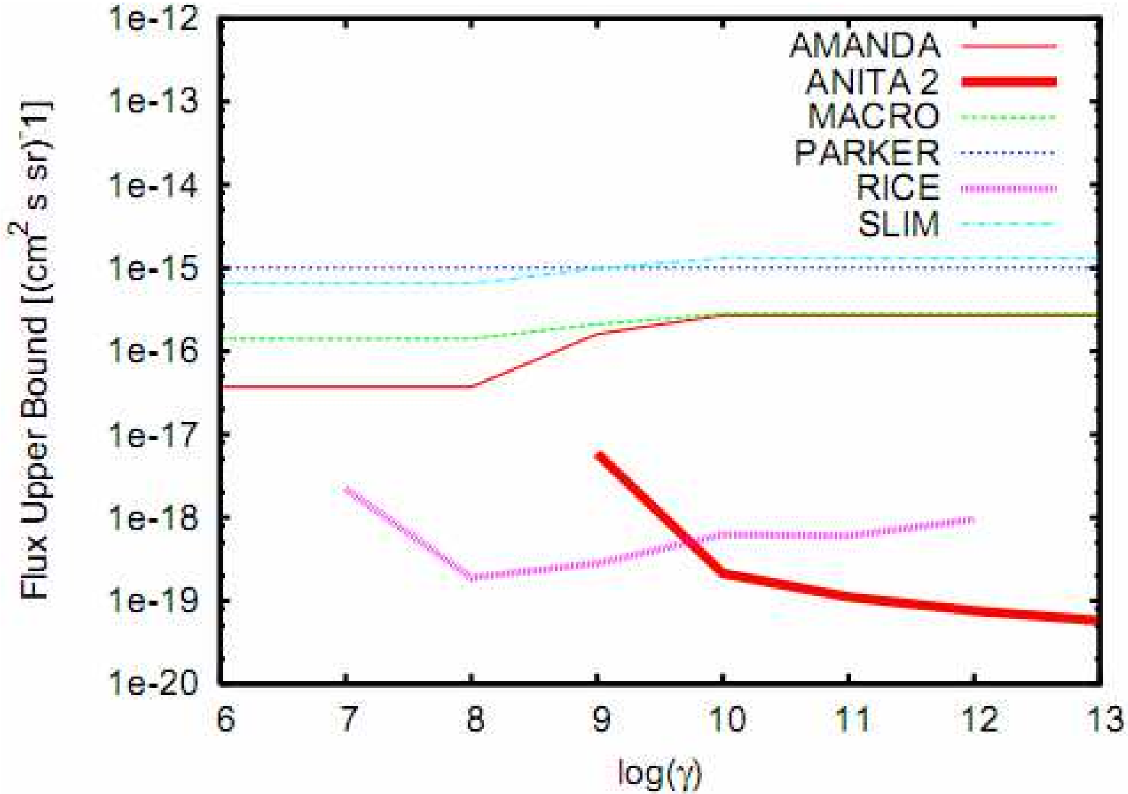
dE/dx



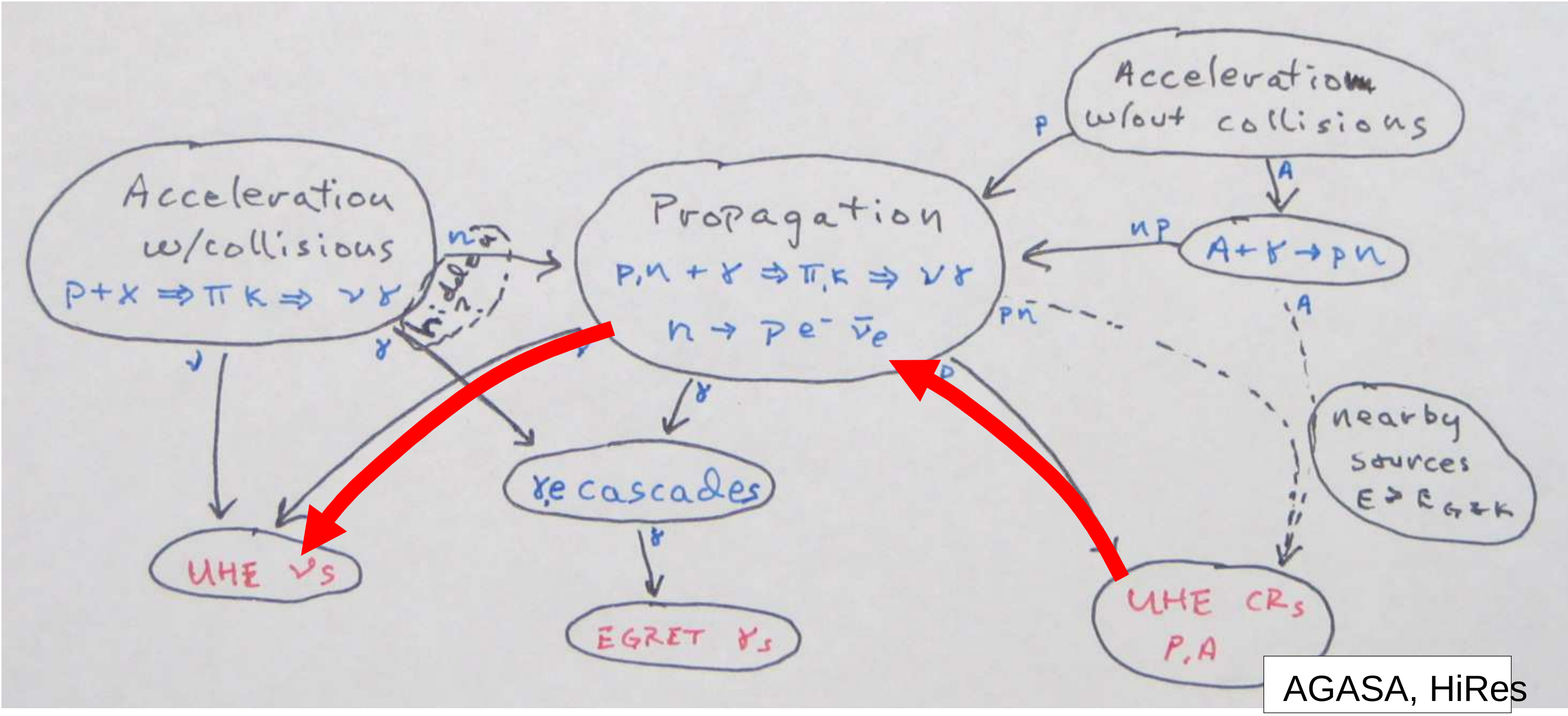
RF
pulse train

Radio detection of cosmic neutrinos, NOW-12 (Seckel)

Worlds best limit for (relativistic) monopoles

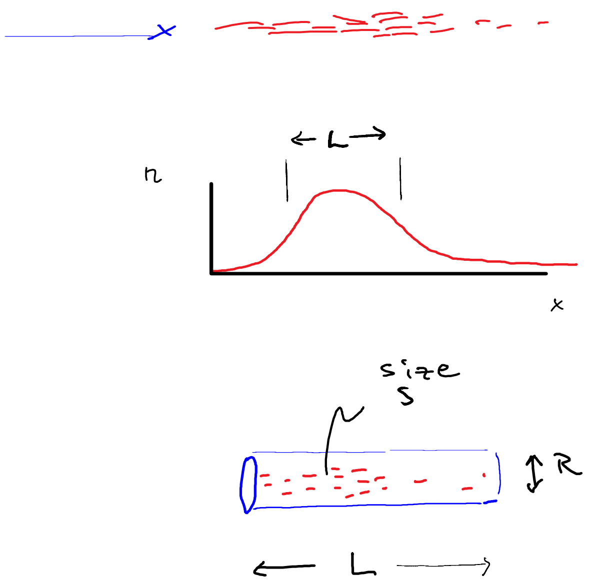


UHE Production: Acceleration



1. Acceleration predictions depend on scenario – could be “no ν’s”.
2. “GZK” neutrinos are guaranteed – a guide for experiment design.
3. Still some model dependence.
4. Constraints from EGRET & UHECR
5. $E_\nu \sim .05\ E_p$

Scaling of Askaryan signals

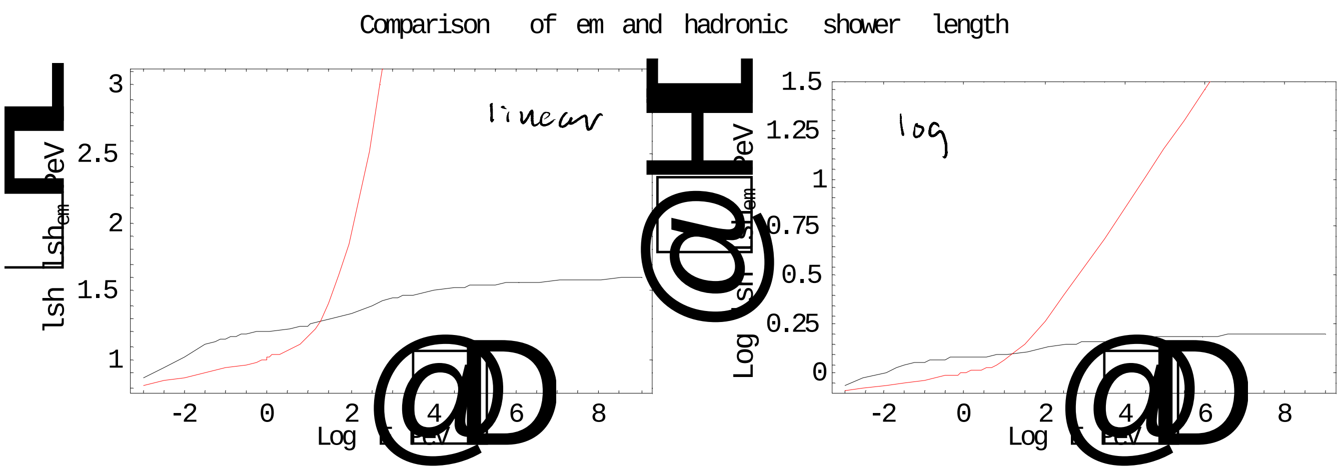


- R: Moliere radius   changes slowly

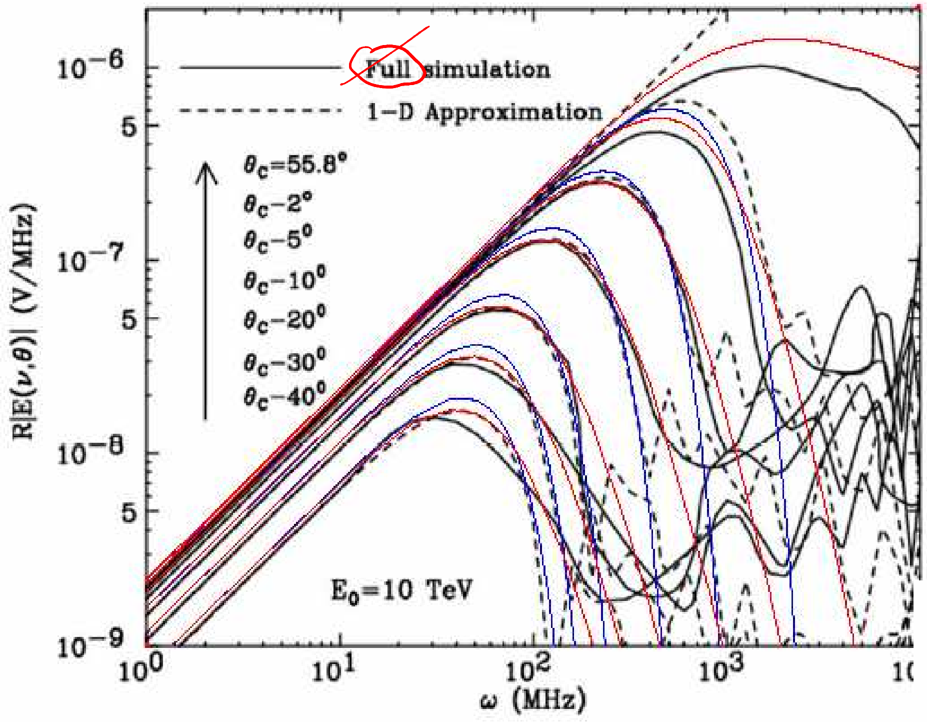
- $\text{total track length} = \frac{E}{dE/dx} = S * L$

- L: Width of shower max
  - Hadronic
  - EM: LPM effect

should be updated



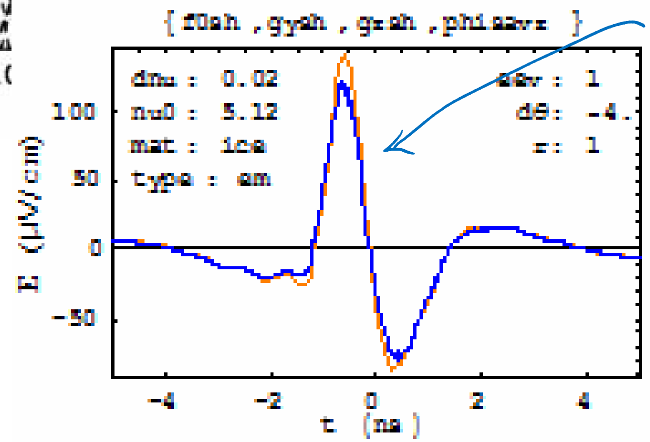
Askaryan



Blue – what we use. with Gaussian profile

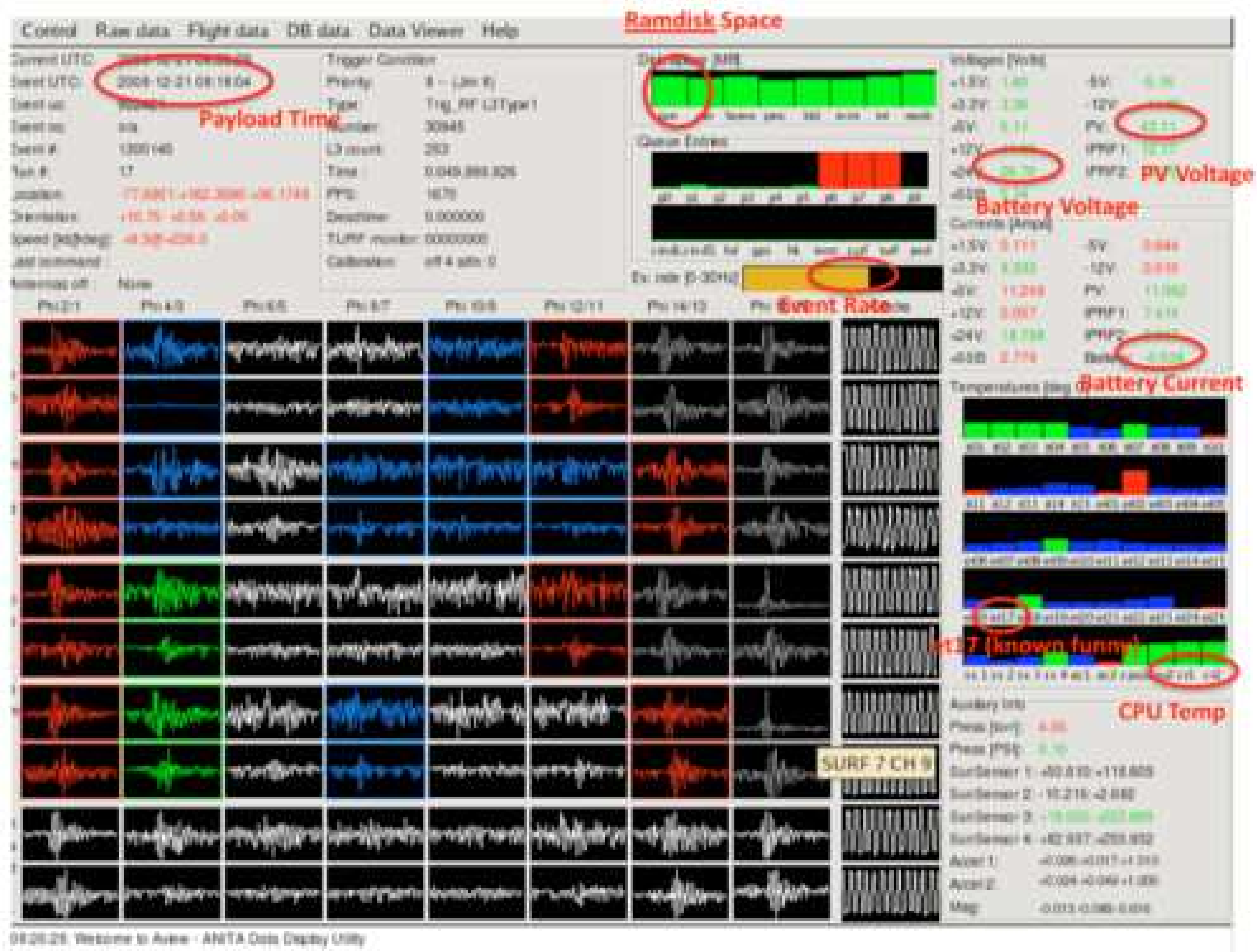
Red – Griesen profile

(gives asymmetric pulse

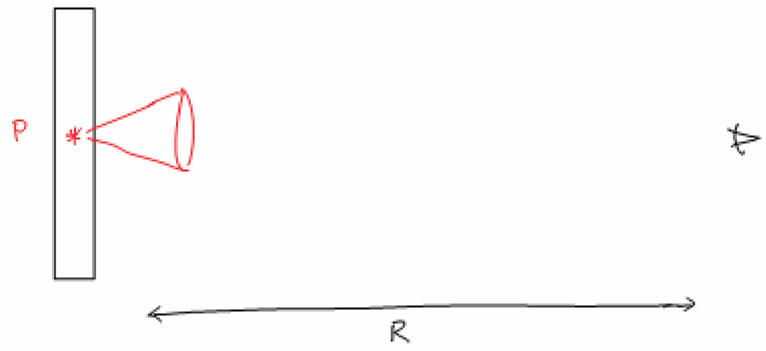


polarity

ANITA-View display



Go Remote: aperture v threshold



$$\Gamma \sim \int_{E_{thr}} E^{-\alpha} R^2 \, dE = E_{thr}^{1-\alpha} R^2$$

$$\Gamma \sim R^{3-\alpha} \qquad \left.\begin{array}{ll} E^{-3} & \text{ok} \\ E^{-2} & \text{wins} \end{array}\right\} \text{ Go Remote!}$$