Status of the Radio Ice Cherenkov Experiment (RICE)

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Outline

- Primarily discuss new RICE limit on highly relativistic magnetic monopoles
- Brief mention of future plans

Magnetic Monopole Overview

- Dirac, 1931

$$g = \frac{e}{2\alpha} \approx 68.5e$$

- GUT Scale Monopoles ~ 10^{17} GeV
  - Diluted by inflation

- “Intermediate Mass Monopoles” (IMM’s)
  - 10^{8} GeV?
  - 10^{5} GeV?

Relativistic Magnetic Monopoles?

- Wick et al. (’03):
  - Mass<10^{14} GeV $\rightarrow$ relativistic
  - Energy ~ 10^{16} GeV

- Relativistic monopoles cause particle showers in ice.

  $\rightarrow$ Showers give off Cherenkov radiation.

  $\rightarrow$ Detection mechanism!

Radio Ice Cherenkov Experiment

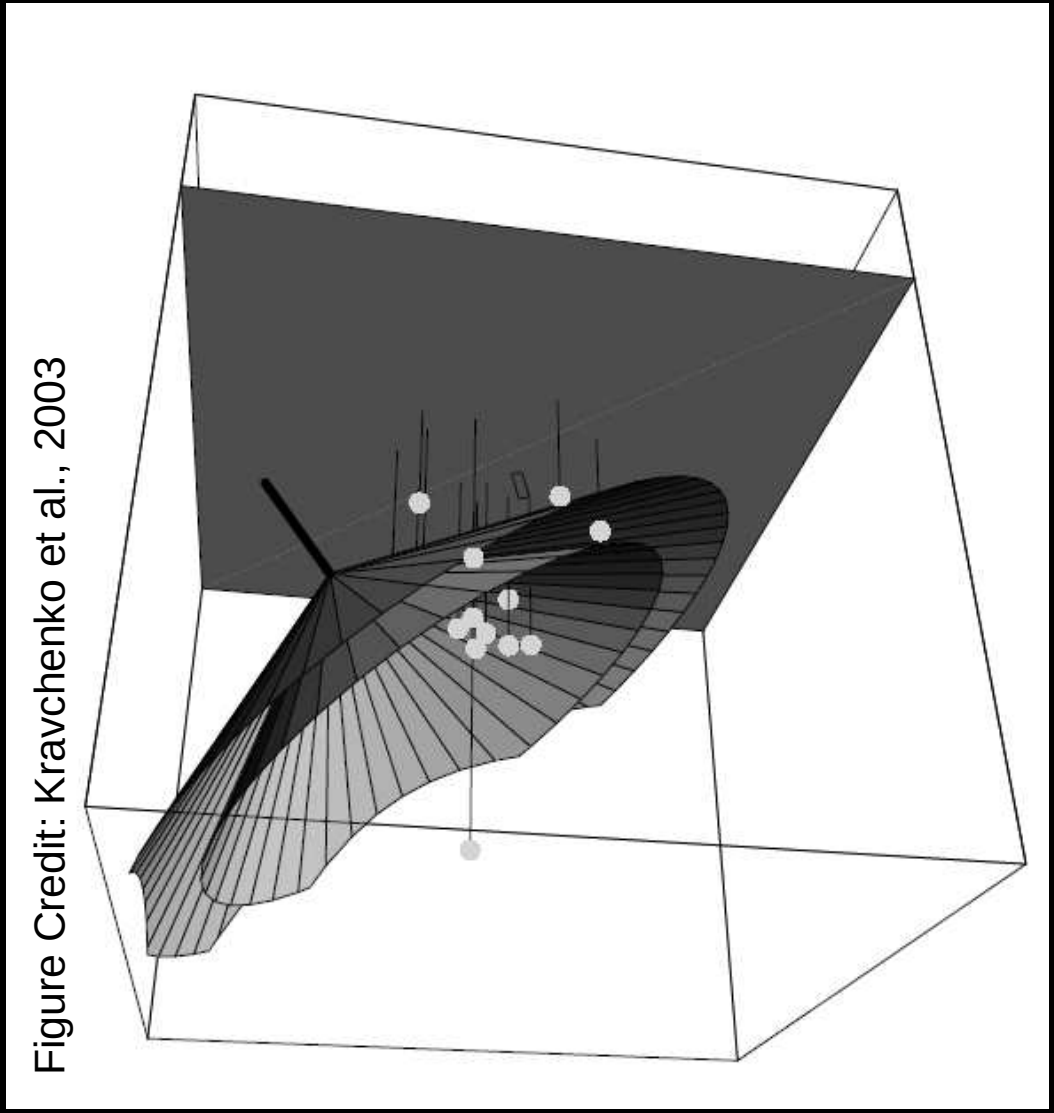


Figure Credit: Kravchenko et al., 2003

- Martin A. Pomerantz Observatory

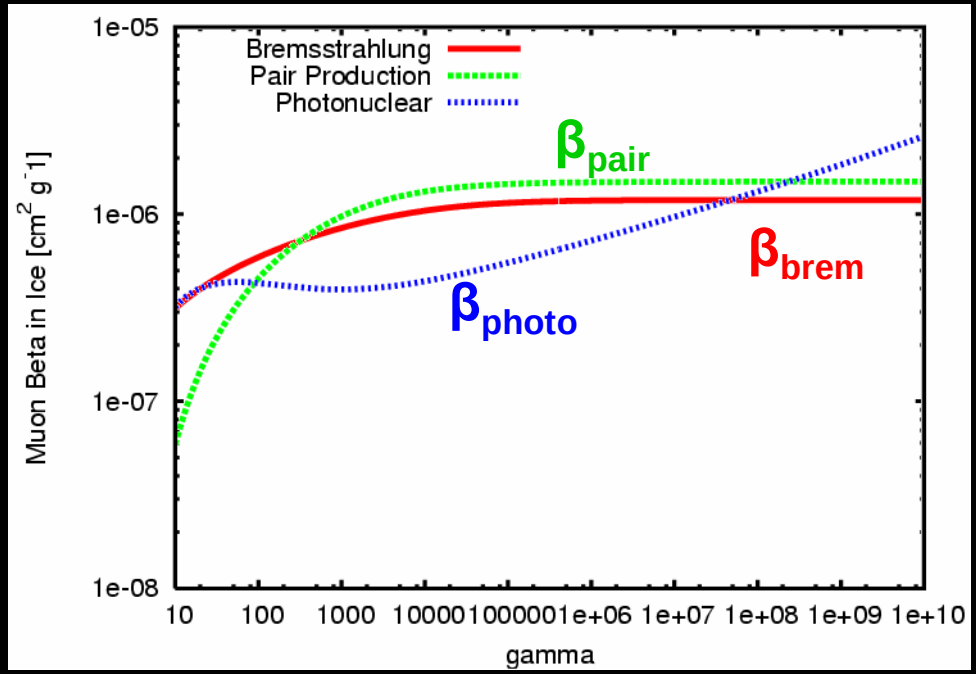
  (1km from S. Pole)
- 16 buried radio receivers in 200m by 200m by 200m area
- Detects Cherenkov radiation in 0.2GHz to 1GHz frequency range
- 2001-2005: No high-energy neutrino detected in 58.3 Msec of livetime.

Kravchenko et al., 2006

A Muon Energy Loss Model

Dutta, Reno, Sarcevic, & Seckel; hep-ph/0012350

$$-\frac{dE}{dx} = \alpha + \beta E$$



α = Ionization Energy Loss

$\beta = \beta_{brem} + \beta_{pair} + \beta_{photo}$

β_{brem} = Fractional energy loss from bremsstrahlung
β_{pair} = Fractional energy loss from pair production
β_{photo} = Fractional energy loss from photonuclear effect

From Muon to Monopole

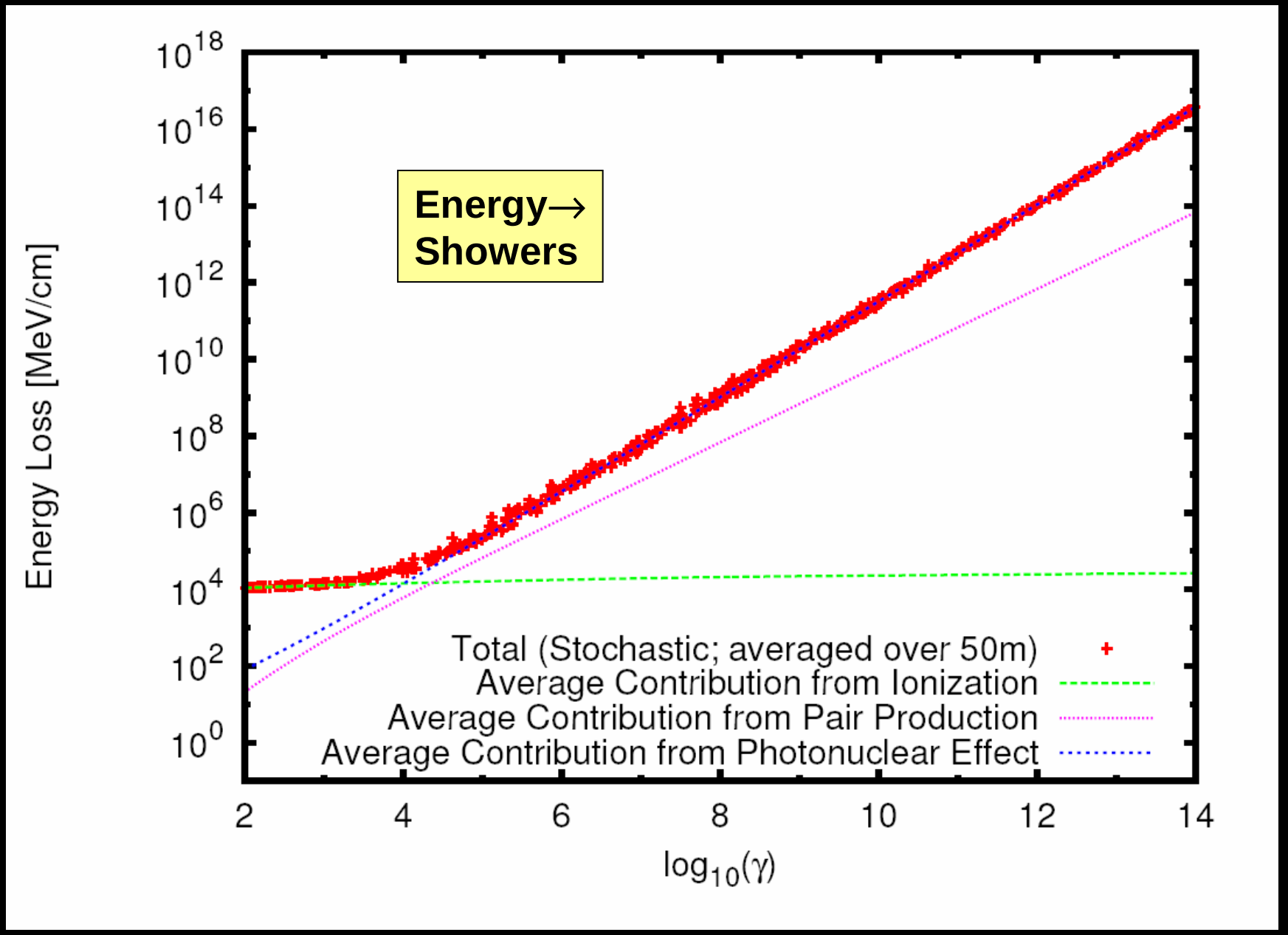
Changes:

- Muon mass → Monopole mass
- Neglect Bremsstrahlung ($dE/dx \propto 1/M$)
- Multiply dE/dx by $z^2 = (68.5)^2$

$$g = \frac{e}{2\alpha} \approx 68.5e$$

- Model-dependent hadronic interactions ignored

Energy Loss by 10^{16} GeV Monopoles



Monte Carlo 1: Random Trajectory

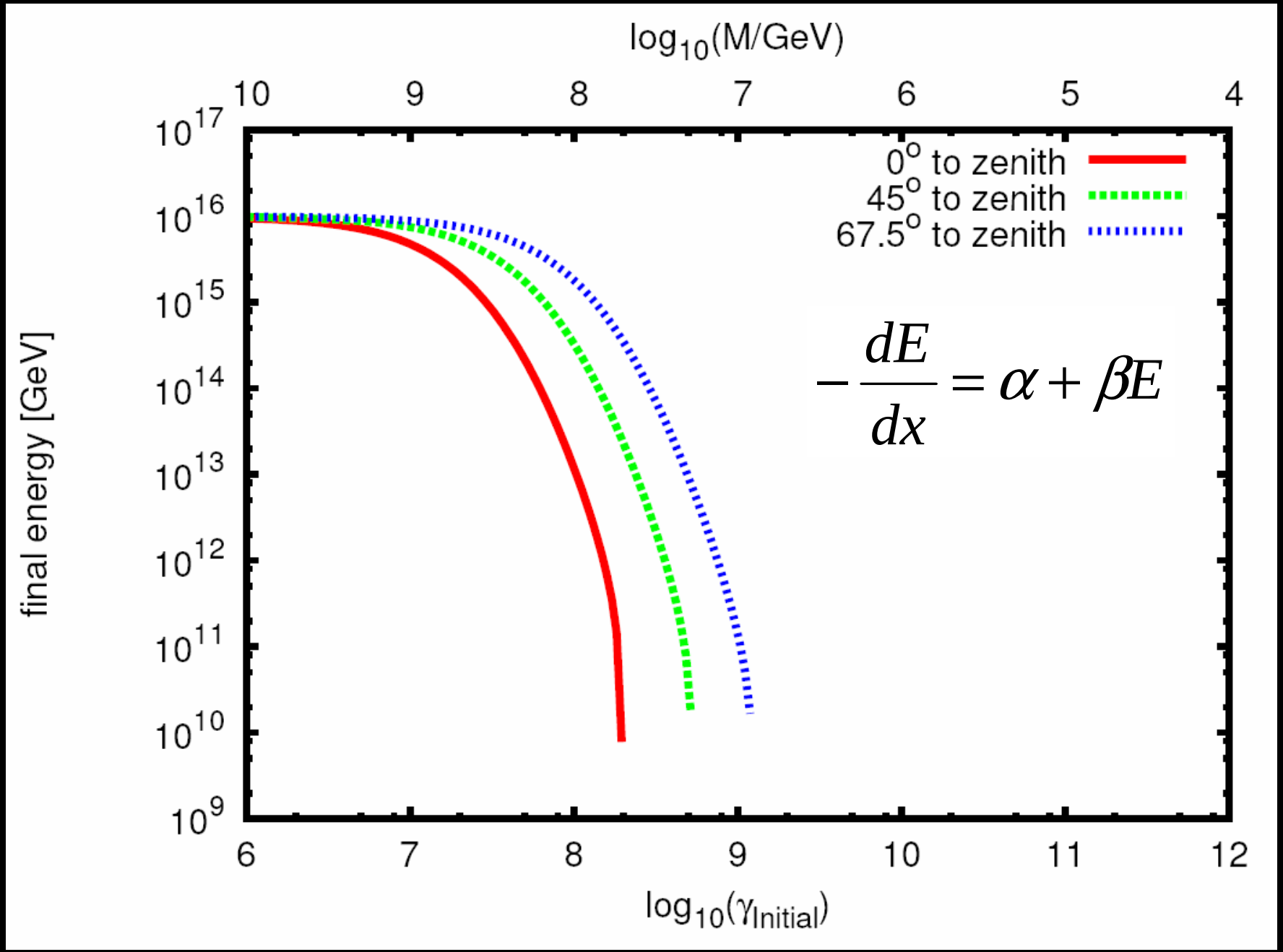
Generate random trajectory within 20km of RICE.

Upgoing:

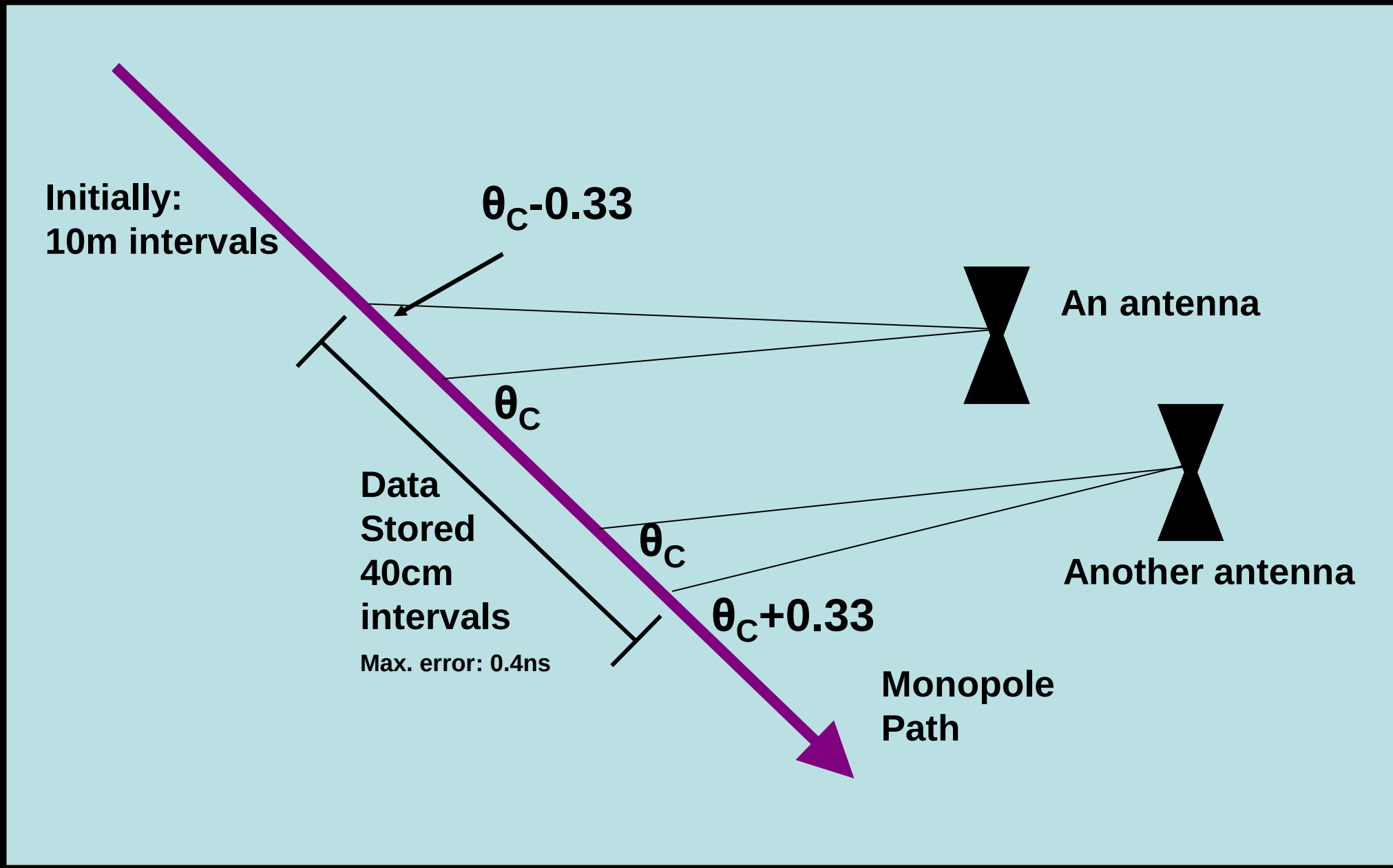
- Propagate monopole through:
  - Distance: column thickness in g/cm^2 from PREM
  - Medium: “standard rock”

Dziewonski & Anderson, 1981

Energy after Crossing Earth



Monte Carlo 2: Passage through Ice



More on Alignment

- 0.33rad = 2σ in Cherenkov angular distribution.

Half width is:

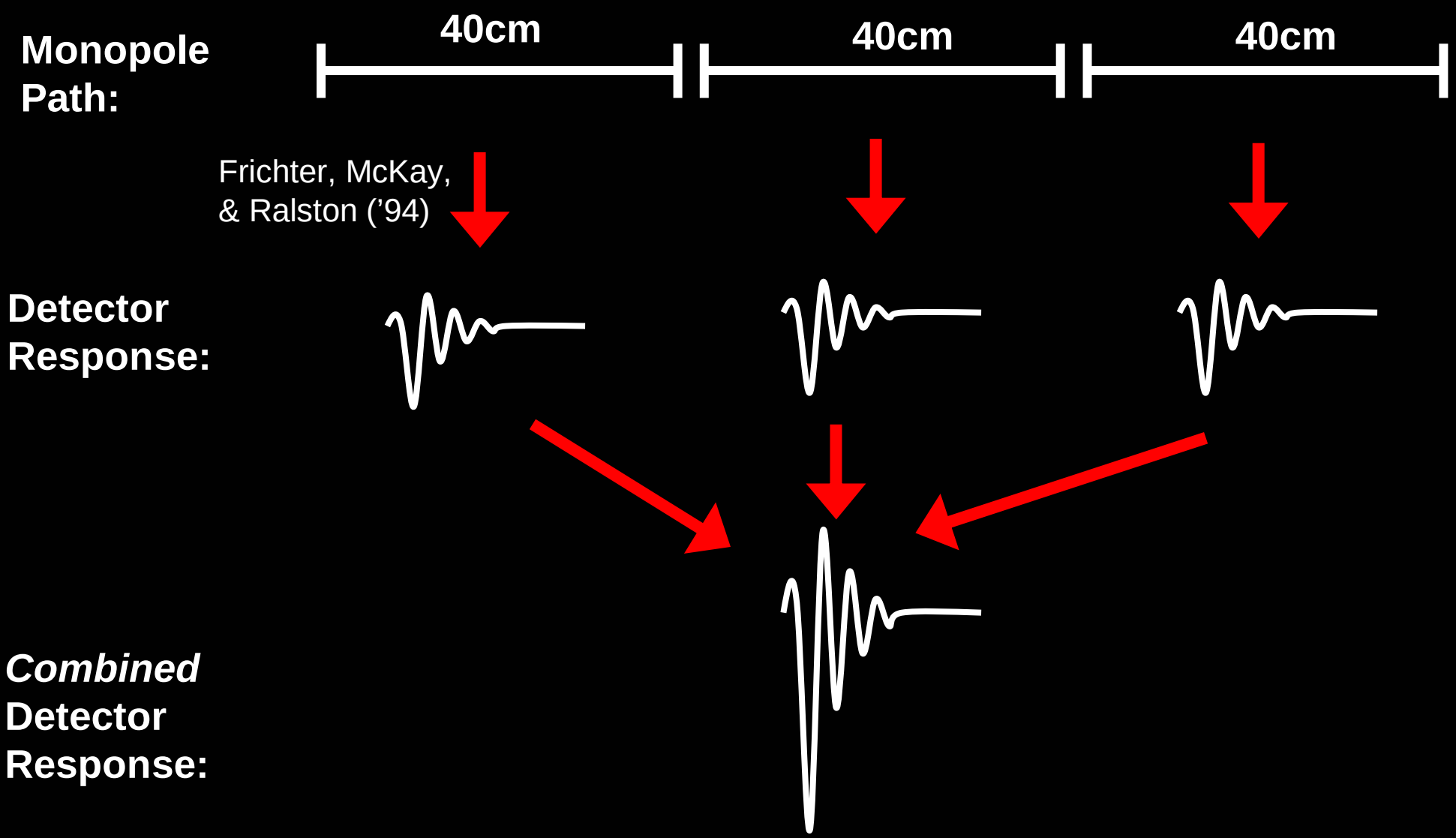
$$\sigma_\theta = 2.2^\circ \left[\frac{1 \ \text{GHz}}{\nu} \right].$$

Alvaraz-Muñiz, Vázquez, and Zas, 2000

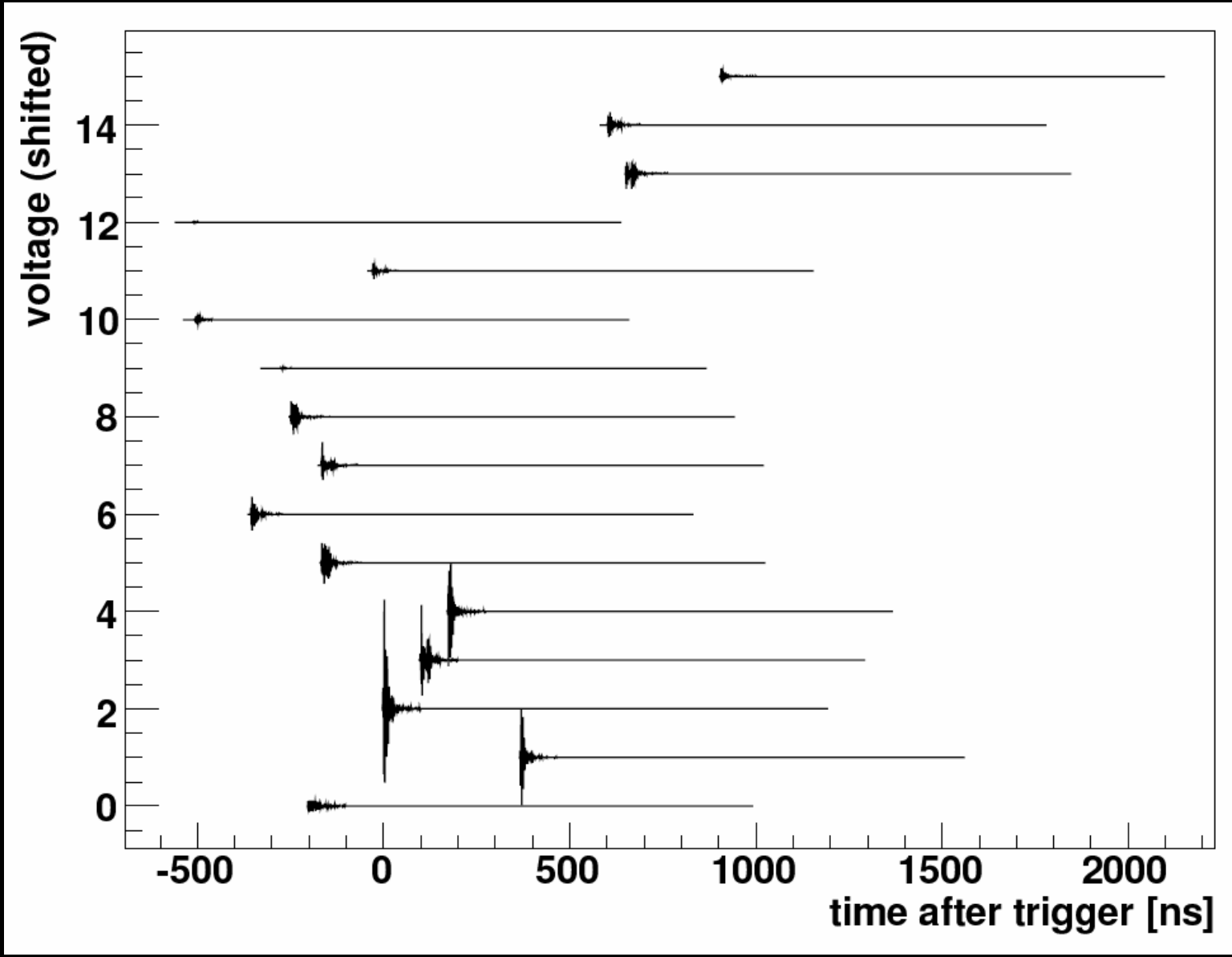
- Start data recording 550m before entering alignment and end 350m after leaving it.
  - Why? To always include first 1.2μs of signal at antennas

Monte Carlo 3: Detector Response

Treat each interval's energy loss as separate shower.



A Typical Voltage Profile



Monte Carlo 4: Analysis Cuts

- Send triggering monopoles through same reconstruction as RICE data.
- Greatest obstacle: Time over threshold cut
- 5% to 50% of events pass

Monte Carlo Corrections (1)

RadioMC

↓ **Remove ray tracing.**

“FriedRice”

Corrections:

- Ignore showers beyond visibility “horizon.”
  - Horizon is function of antenna depth & source depth.
- Shift waveforms in time.
  - Based on parameterization of index of refraction in upper 175m of ice

Monte Carlo Corrections (2)

- 20km maximum impact parameter unnecessary.
- Run code once to estimate actual distance distribution of triggering monopoles, then run it again with gamma-dependent maximum impact parameter.

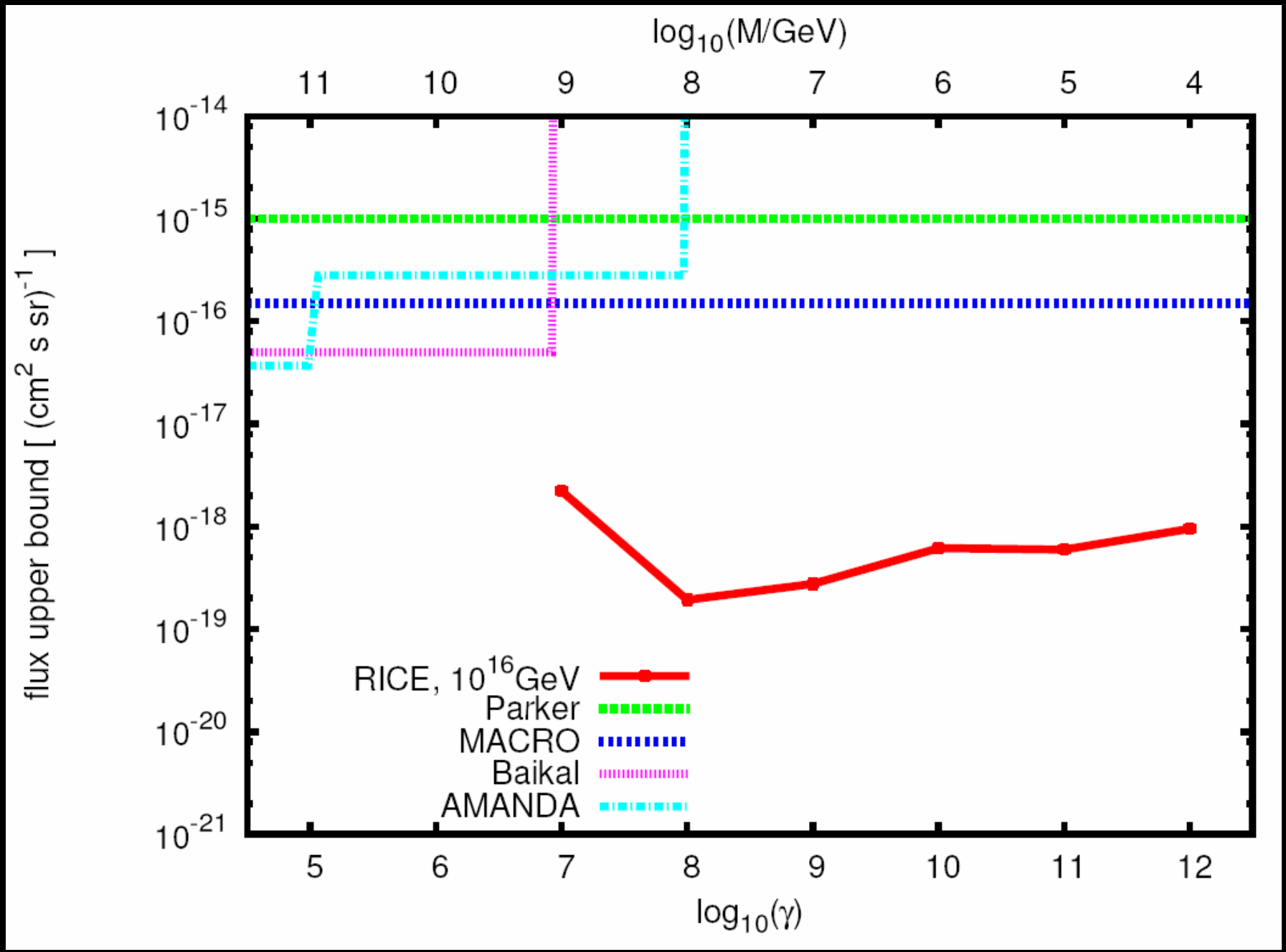
Calculation of Flux

$$\sigma_{eff} = \pi r^2 \cdot \left(\frac{\#\,\text{Monopoles Detected}}{\#\,\text{Monopoles Simulated}} \right)$$

$$F_b = \frac{n}{L \Omega \varepsilon \sigma_{eff}}$$

- σ_{eff} = cross-section
- r = maximum impact parameter
- F_b = upper bound on flux
- n=2.996 (gives 95% chance of event)
- L = livetime = 58.3×10^6 s
- Ω = 4π
- ε = birefringence factor = .84

Flux Upper Bounds



Error Analysis

- Re-ran simulation at intermediate gamma value ($\gamma=10^{10}$) under following conditions:
  - Reduce voltage amplification by factor of 2
  - Reduce attenuation length by factor of 2
  - Add viewing-angle-based phase shifts
  - Increase energy loss by factor 10
- Changes not statistically significant

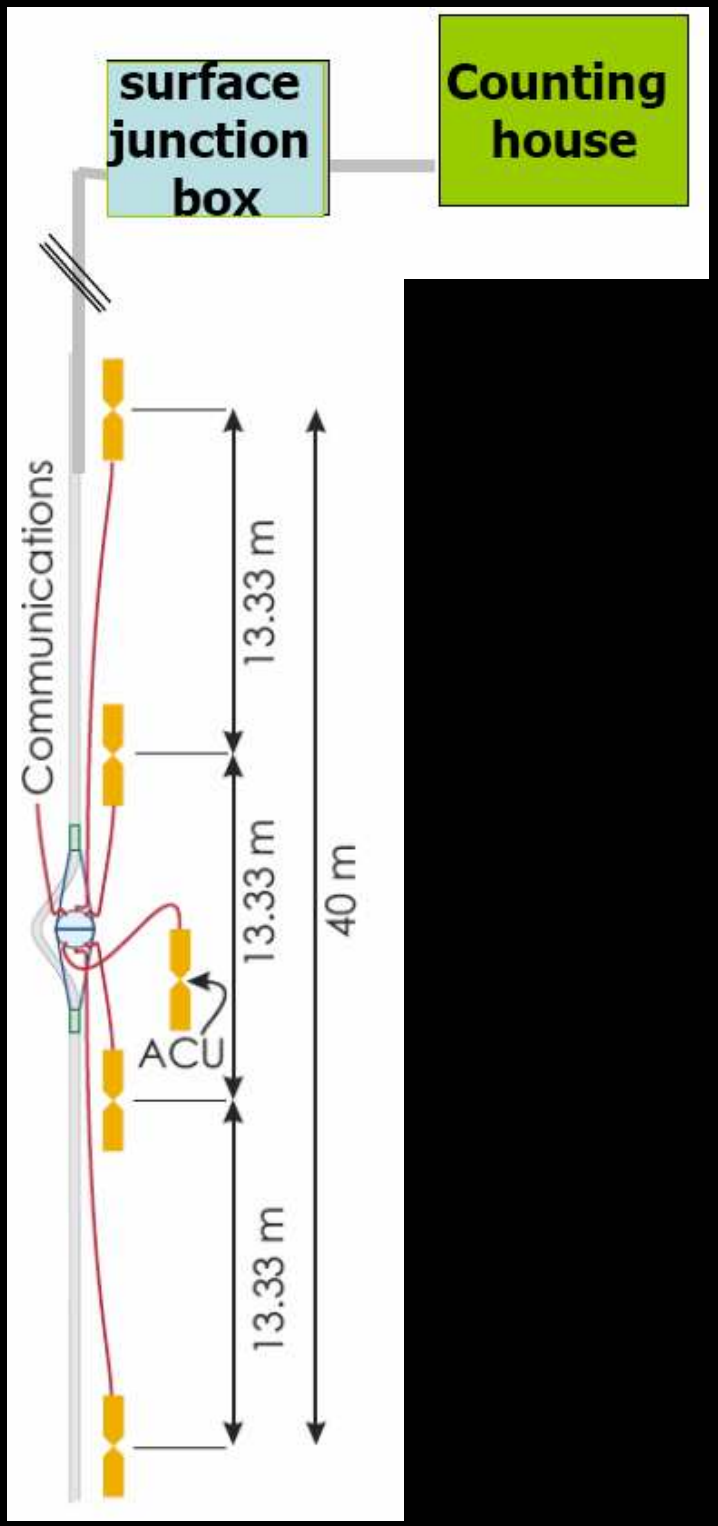
simulation	#detec.	$\frac{\sigma}{10^9 \mathrm{cm}^2}$
Original	24	6.6
Voltage Amplification Reduction	21	5.7
Attenuation Length Reduction	26	7.3
Signal Phase Shifting	21	5.7
Energy Loss Increase	19	5.0

The Next Step…

- AURA = Askaryan Under-ice Radio Array
- Goal: Take advantage of IceCube construction to implement next-generation radio neutrino telescope.

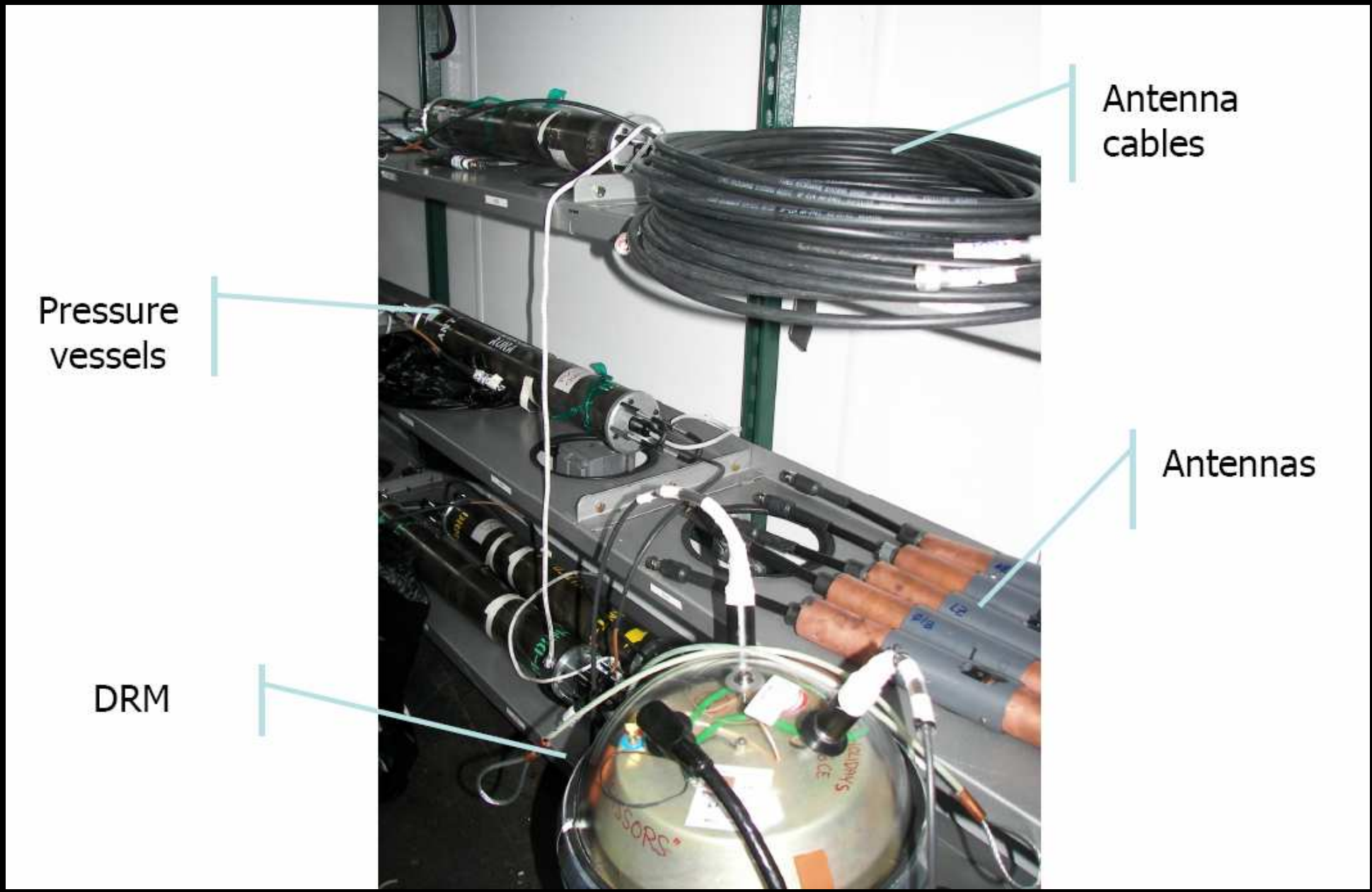
AURA Radio Clusters

- Make use of existing technology: deep holes, IceCube communications and power
  - Digital Radio Module (DRM) – Electronics
  - 4 Antennas
  - 1 Antenna Calibration Unit (ACU)
- Signal conditioning and amplification happen at the front end; signal is digitized and triggers formed in DRM.
- A cluster uses standard IceCube sphere, DOM main board, and surface cable lines.



Slide Credit: Hagar Landsman

Waiting to be Deployed



Slide Credit: Hagar Landsman

Deployment 2006-2007

Hole 78 :"rock"
1st deployment,
Deep
4 Receivers, 1Transmitters

Hole 57: "scissors"
2nd deployment,
Shallow
4 Receivers, 1 Transm

Hole 47: "paper"
3rd Deployment,
Deep
1 Transmitter

Slide Credit: Hagar Landsman

Calibration / Characterization

- 2 full clusters (+3rd transmitter) in ice now.
- 3 more being lab-tested at U. Wisconsin & U. Kansas, to be deployed this (Antarctic) summer.

Summary

- Intermediate mass monopoles become relativistic.
- Monte Carlo shows RICE can detect these.
- Flux upper bounds < 10^{-18} $(cm^2\ s\ sr)^{-1}$
- AURA -- greater sensitivity; incorporated into IceCube

See it now…

arXiv:0806.2129