A Higher Altitude Water Chernkov Detector for TeV gamma-rays

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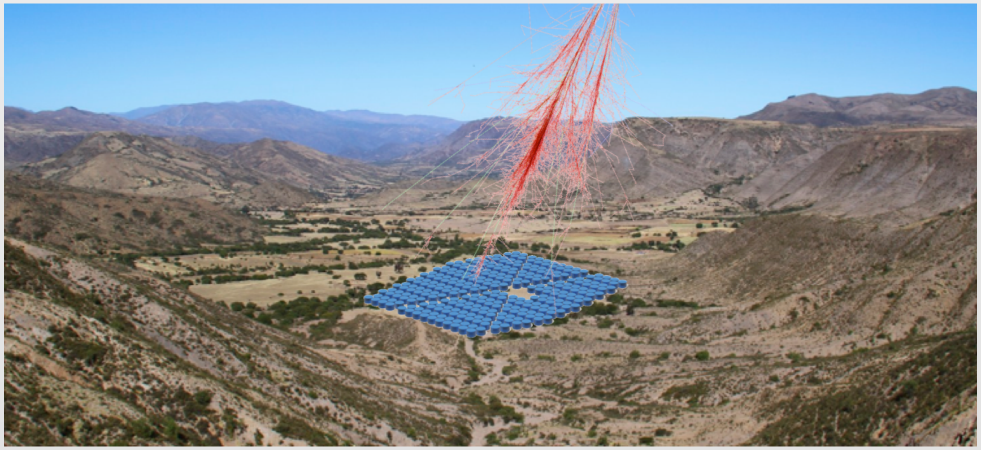
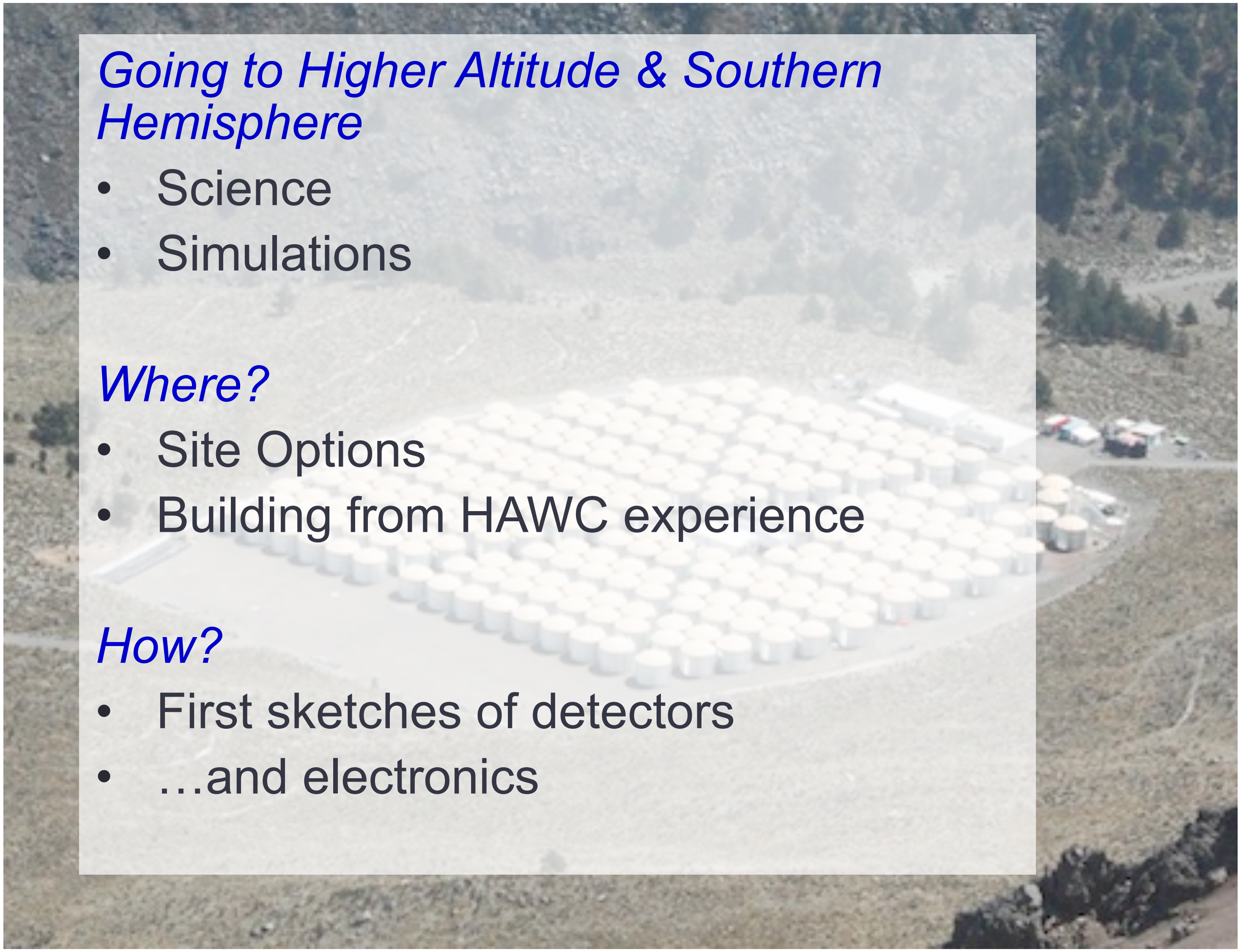


Paris Workshop
26 May 2014

Starting from the HAWC Observatory, thinking about the Southern Hemisphere

Outline



Going to Higher Altitude & Southern Hemisphere

- Science
- Simulations

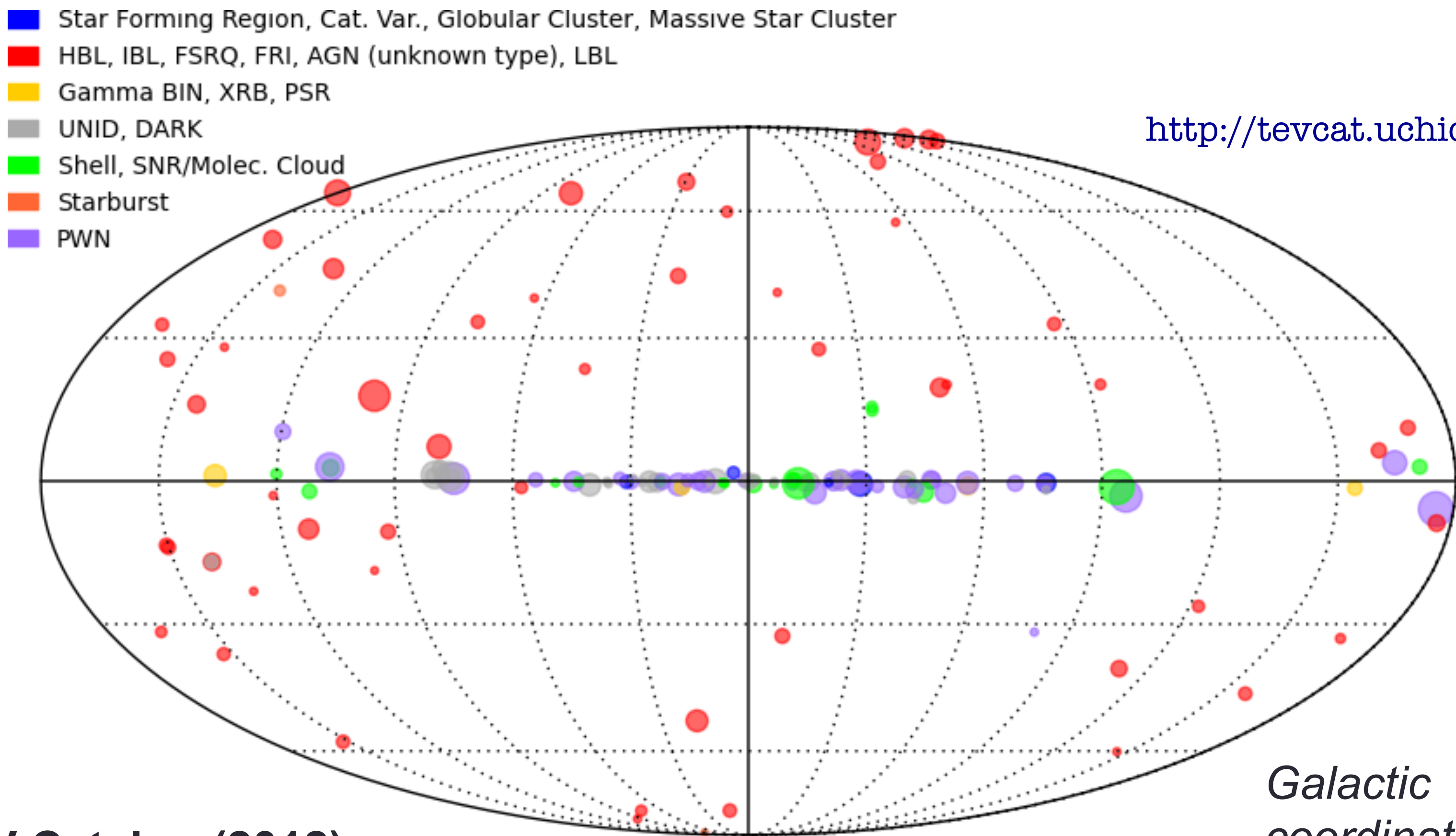
Where?

- Site Options
- Building from HAWC experience

How?

- First sketches of detectors
- …and electronics

TeV Sky



http://tevcat.uchicago.edu

Galactic coordinates

TeV Catalog (2012)

- ~140 sources (~90 Galactic).
- Not an all-sky survey - catalog is strongly *biased*.

Altitude Effects

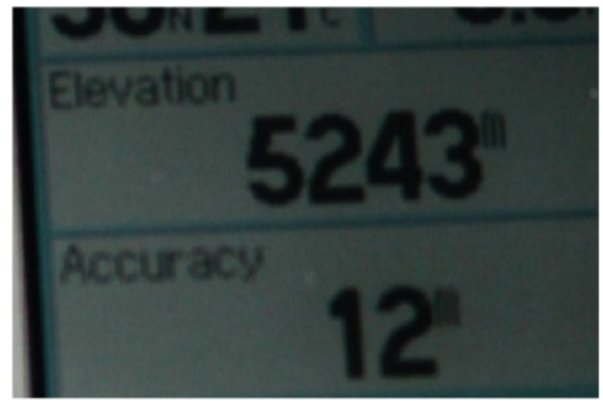
- Higher altitude leads to lower energy threshold
  - Higher in the air shower
  - Improves ability to cross-check with IACTs
  - EBL cutoff becomes negligible at lower energy
  - Better to determine spectral shape
- Higher backgrounds, still on the exponential decay of the showers
  - Need to be able to deal with rates

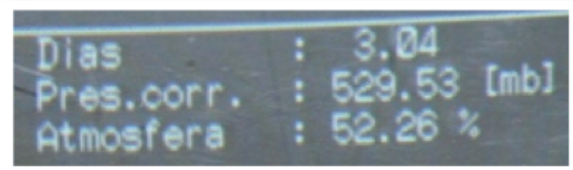
- Simulate a strawman water Cherenkov detector at differing altitudes
  - Includes work of Asif Imran & Gus Sinnis & Andy Smith (UMD)

- Show this is plausible with real sites

Implementation

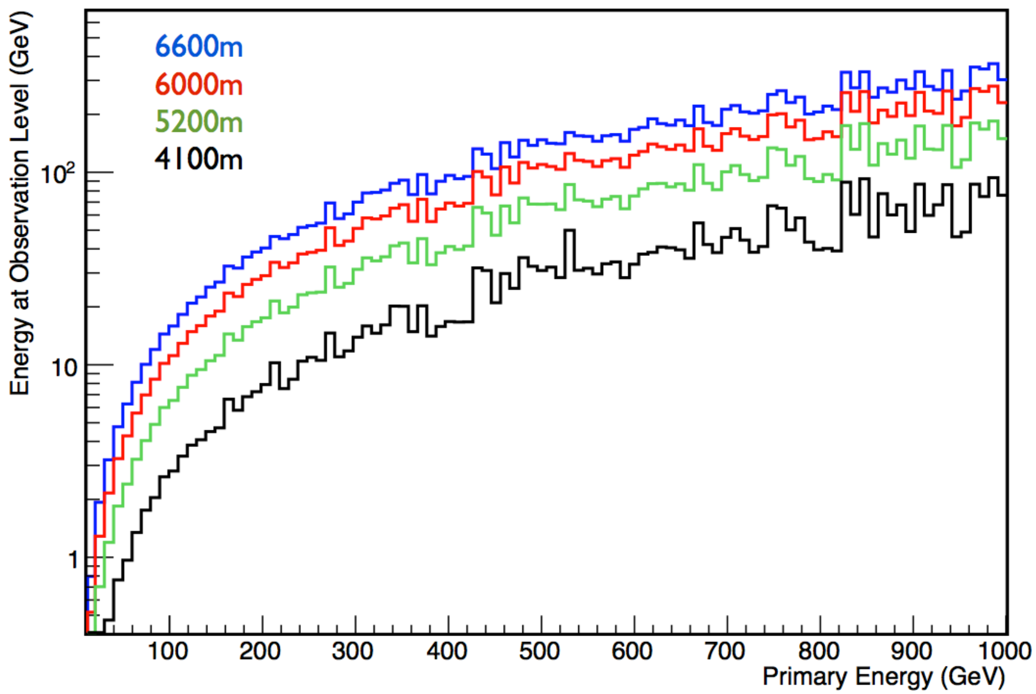
- Use CORSIKA (v6990) capability to save particle output for 10 different observation levels
  - 6600m, 6000m, 5200m, 4100m
- QGSJET for high-energy interactions
- GHEISHA for low-energy hadronic interactions
- Followed electrons to 3 MeV, muons and hadrons to 300 MeV
- CORSIKA atmospheric model (US standard):
  - 6600m = 445 g/cm^2
  - 6000m = 483 g/cm^2
  - 5200m = 538 g/cm^2
  - 4100m = 623 g/cm^2
- Gammas thrown on $E^{-2.3}$ spectrum
- Protons thrown on $E^{-2.7}$ spectrum
- Fixed zenith angle runs (0, 20, 30, 40, 45, 50)

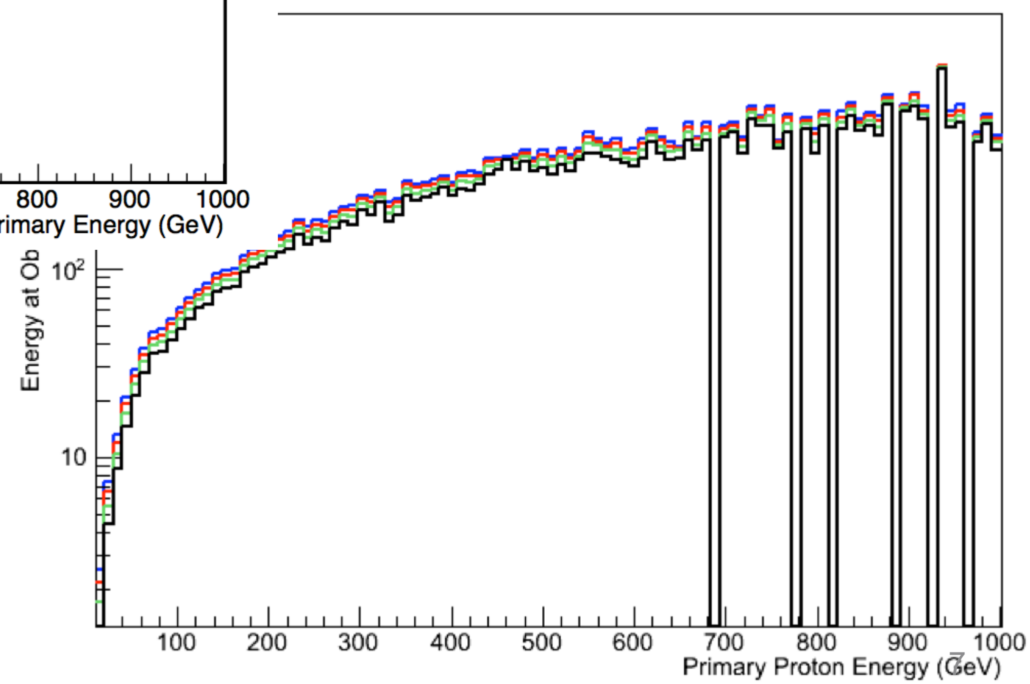




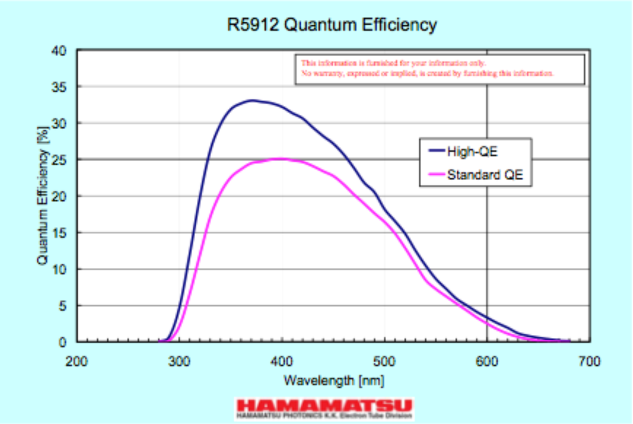
Energy at Ground (gamma & proton)

Zenith





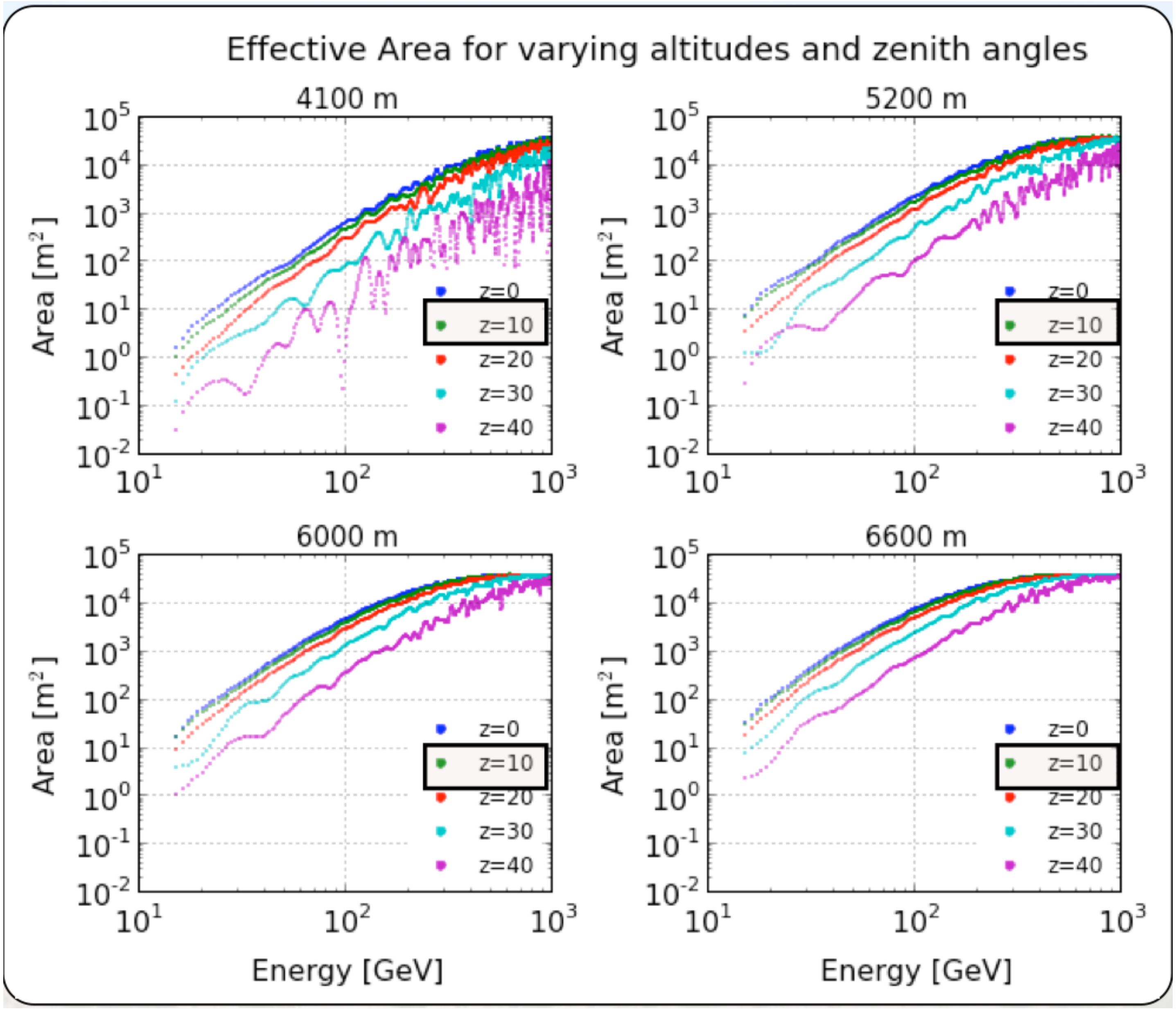
Array Simulation



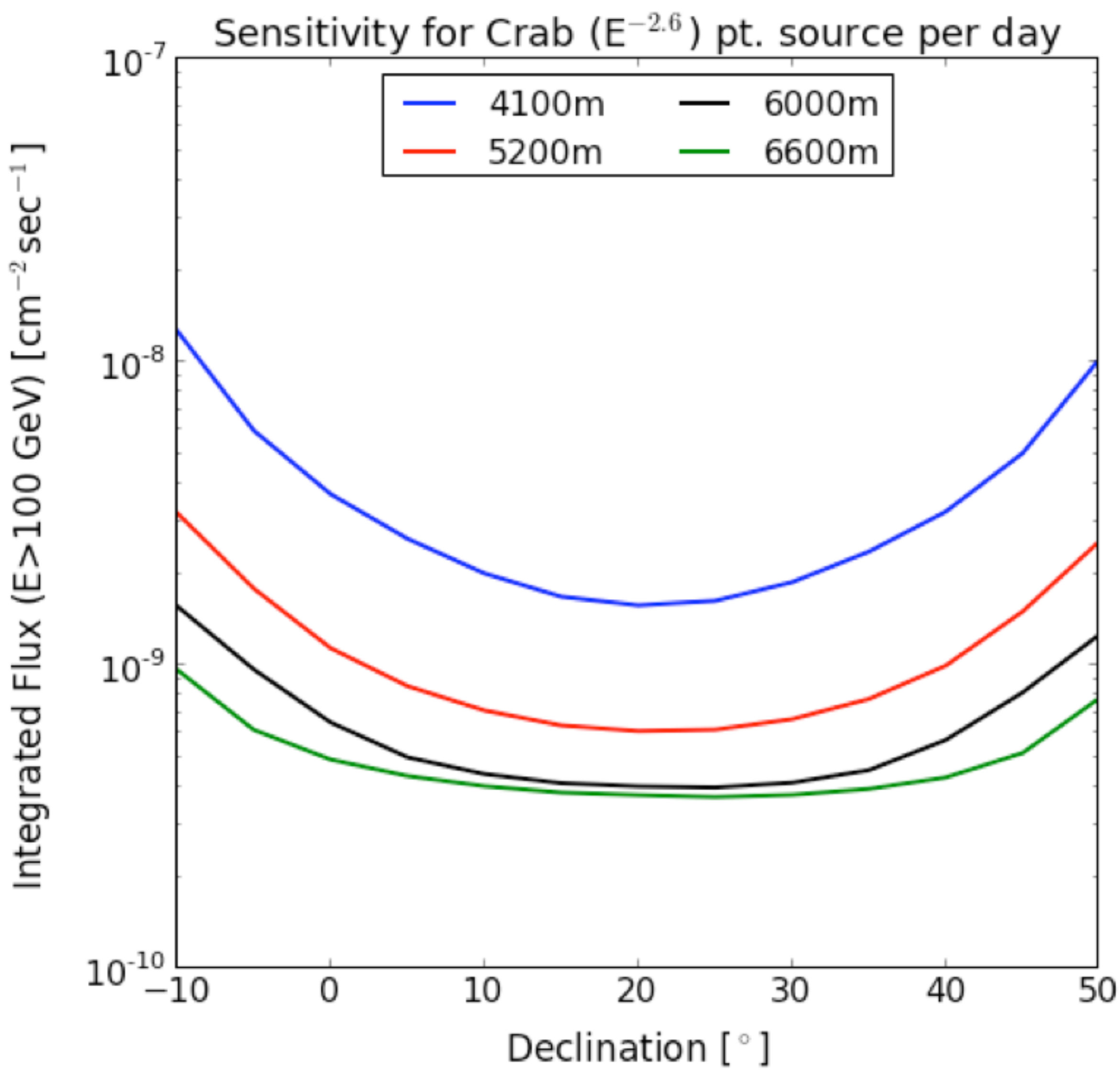
- Dense array 30x30 tanks
- Each tank 1.5m radius and 1.5m tall
- Tank separation 3m
- 1 10" High QE PMT in each tank
- Convolve PMT QE curve with Cherenkov spectrum: 35 PEs/MeV for high QE (27 PEs/MeV for R5912)
- Results in ~4 MeV/detected PE (ratio of PMT:tank area)
- Simulation:
  - Throw core over 200mx200m area (800mx800m for protons)
  - Translate each particle position by core location (and array center)
  - Loop over particles in shower at each elevation
    - Determine if particle hits a tank
    - <detected PES> = MAX(particle energy/2 MeV, 75 MeV) / 4
    - detected PES = Poisson(mu=<detected PES>)
  - Enforce trigger - 30 tanks with >=1 detected PE

20deg South

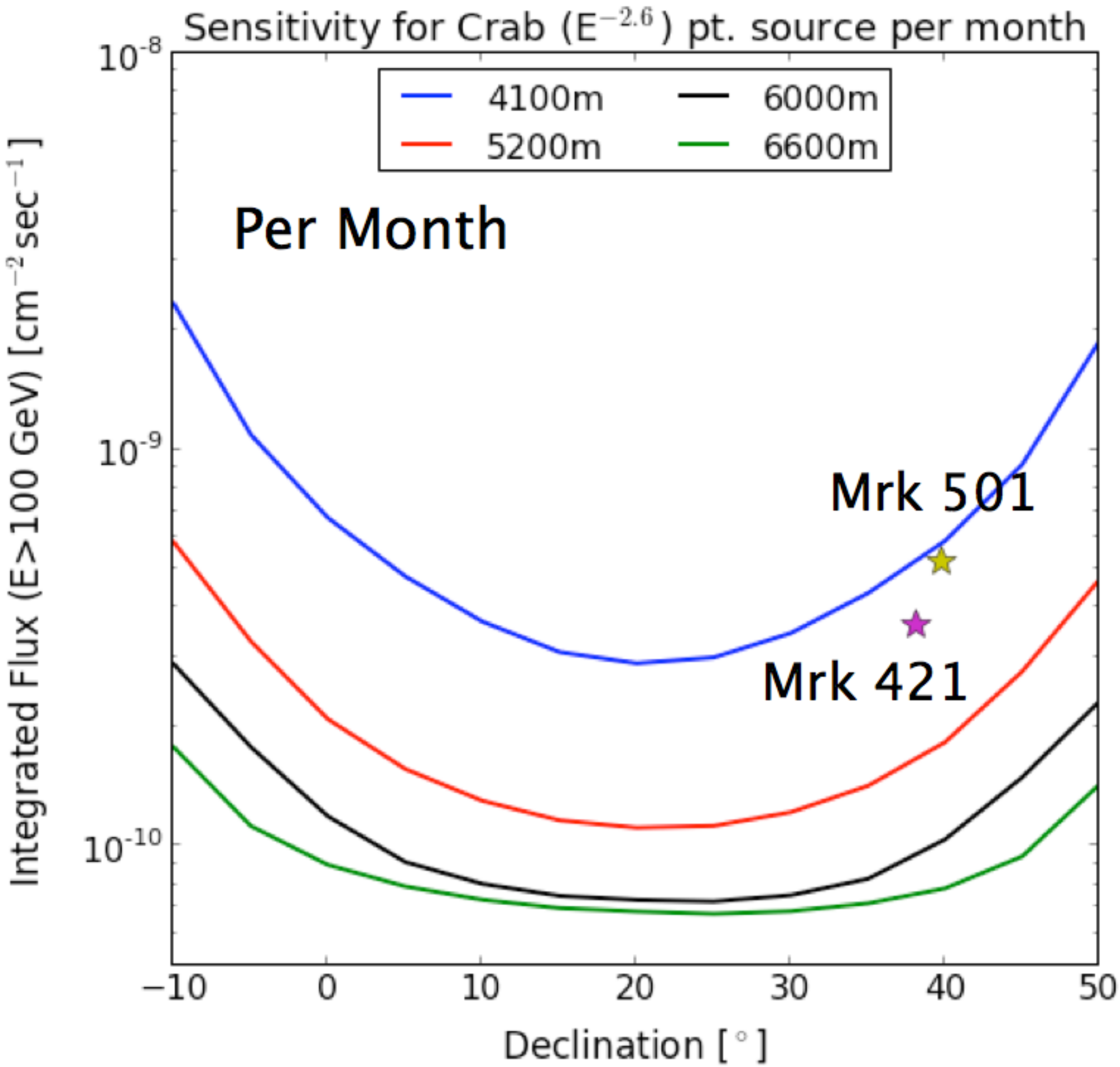
Moving detector around…



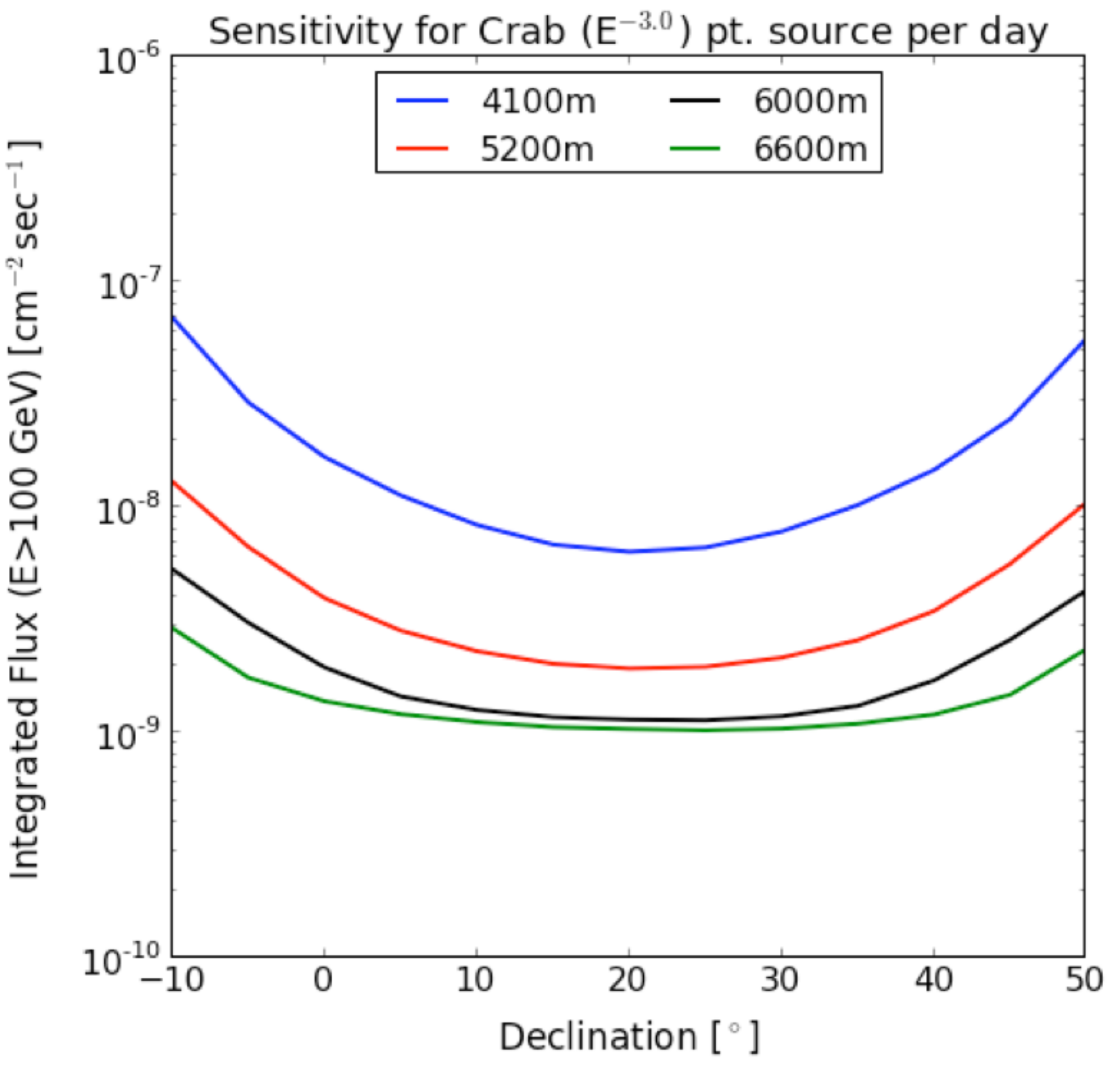
Sensitivity to a Crab-like Point Source



Adding some sources (per month)

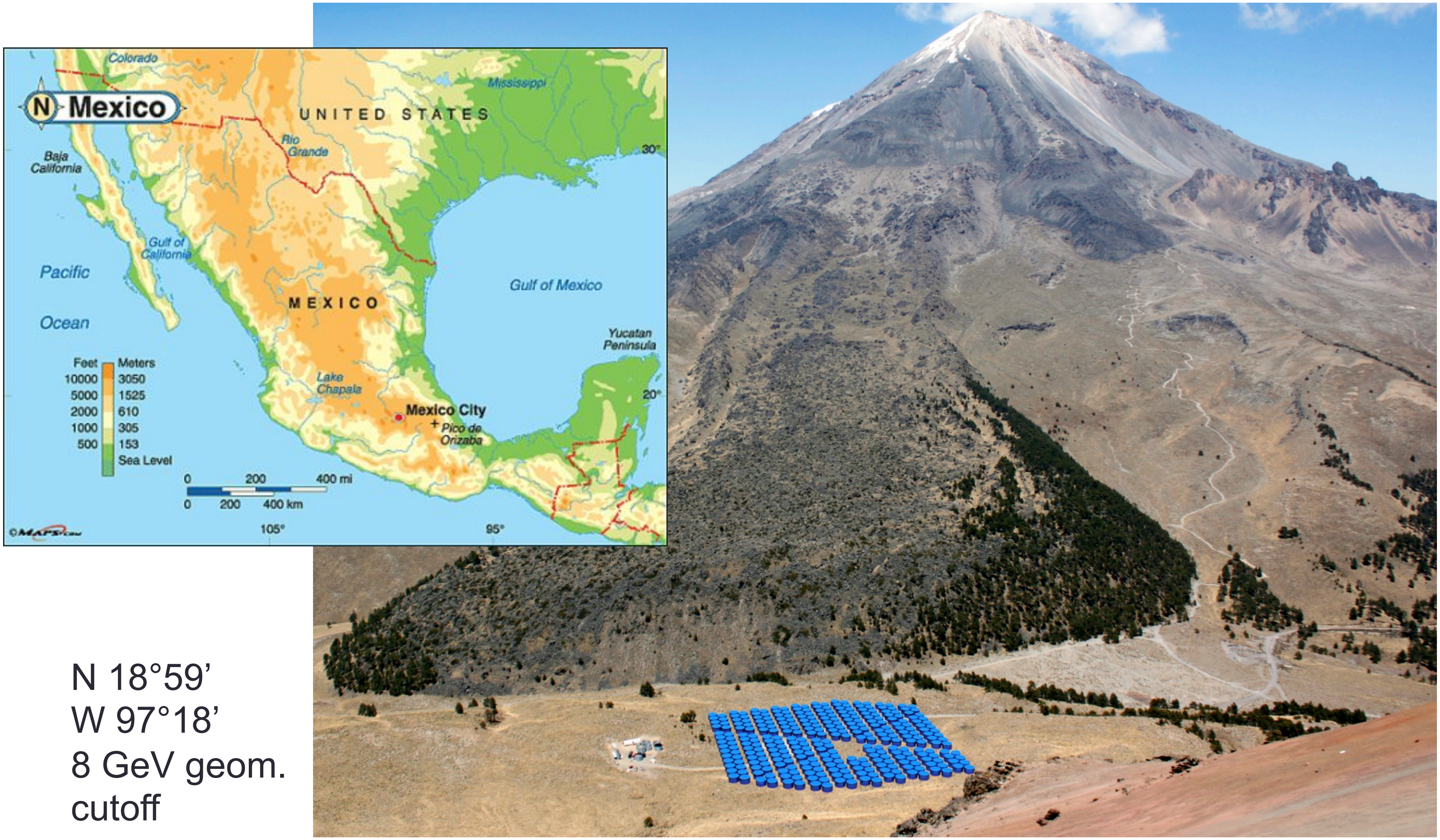


Softer spectrum (per day)



HAWC REMINDER

HAWC Site: Pico de Orizaba/Sierra Negra



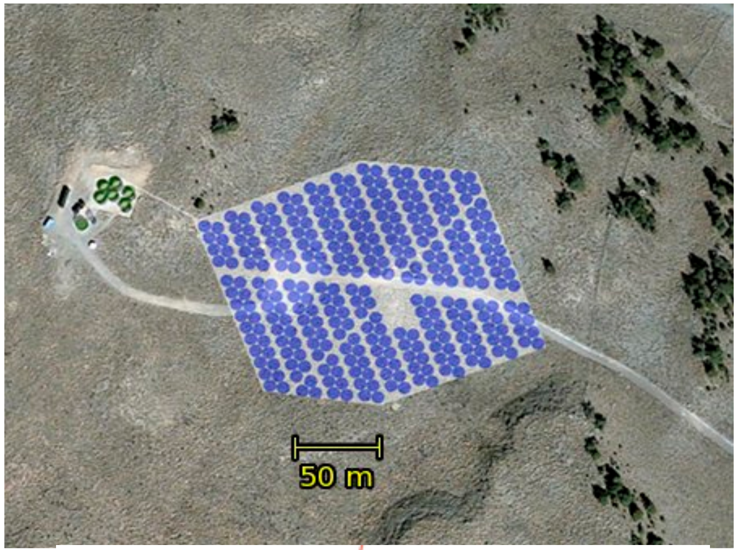
N 18°59'
W 97°18'
8 GeV geom. cutoff

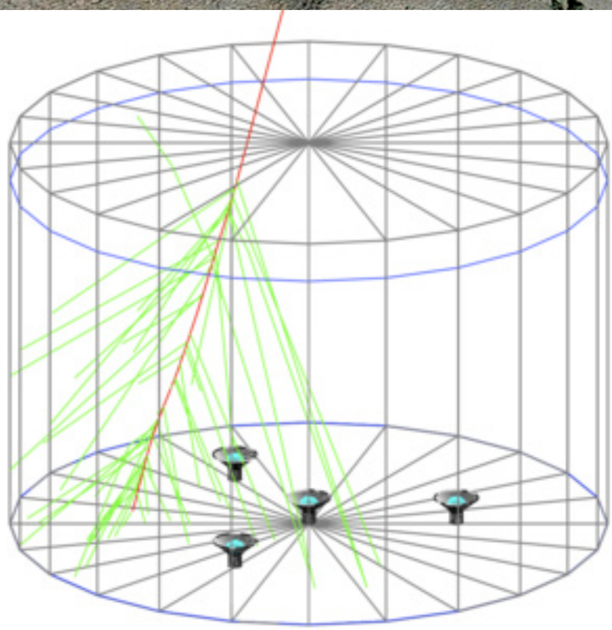
The HAWC Detector

- 4,100 altitude meter site at *Sierra Negra, Mexico* (~19º N), near the Large Millimeter Telescope.

- 22,000 m² area (57% coverage).
- 300 water tanks:
  - 7.3 m diameter × 4.5 m depth.
  - 3 upward-facing 8" PMTs and one upward-facing 10" PMT (with high quantum efficiency) on the bottom of each tank.

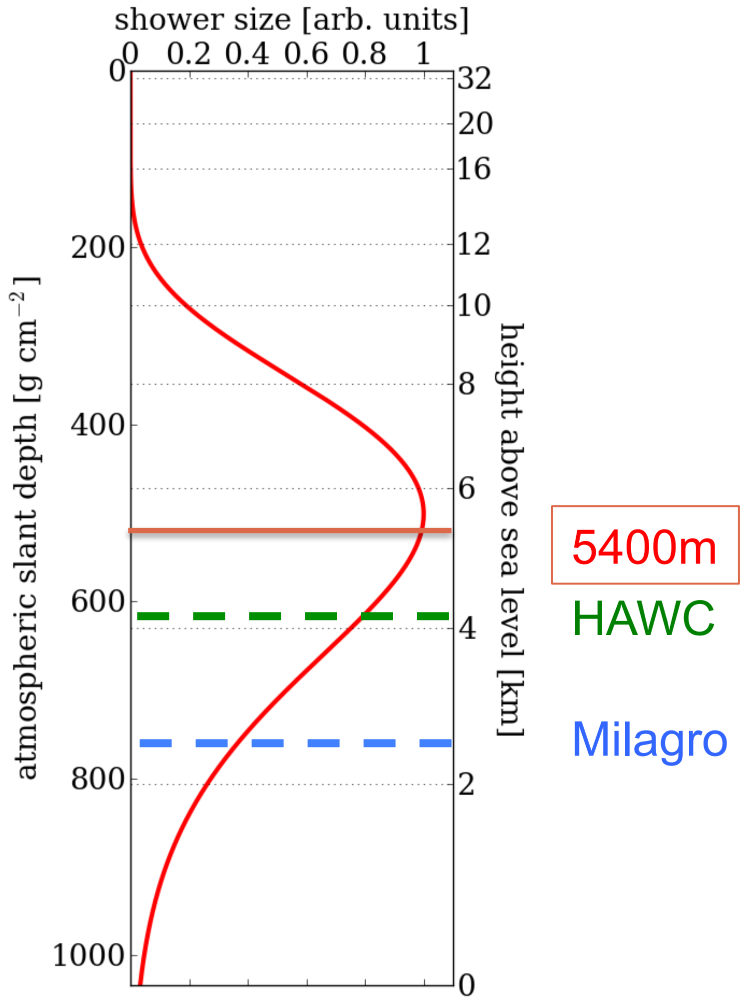
- 1 Crab (5σ) per day.

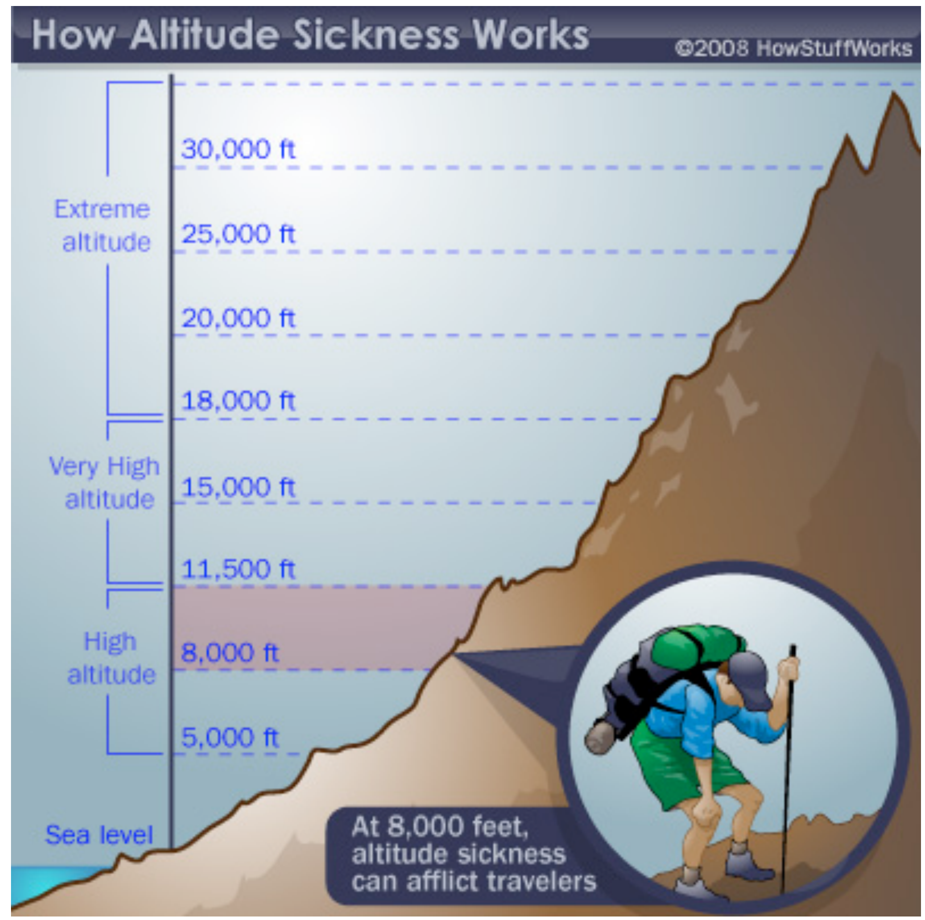




The HAWC Detector

- HAWC tank construction, bladder, and 8’’ photomultiplier.


shower size [arb. units]
0 0.2 0.4 0.6 0.8 1
0
200
400
600
800
1000
atmospheric slant depth [g cm^{-2}]
32
20
16
12
10
8
6
4
2
0
height above sea level [km]
5400m
HAWC
Milagro


How Altitude Sickness Works
©2008 HowStuffWorks
30,000 ft
25,000 ft
20,000 ft
18,000 ft
15,000 ft
11,500 ft
8,000 ft
5,000 ft
Extreme altitude
Very High altitude
High altitude
Sea level
At 8,000 feet, altitude sickness can afflict travelers

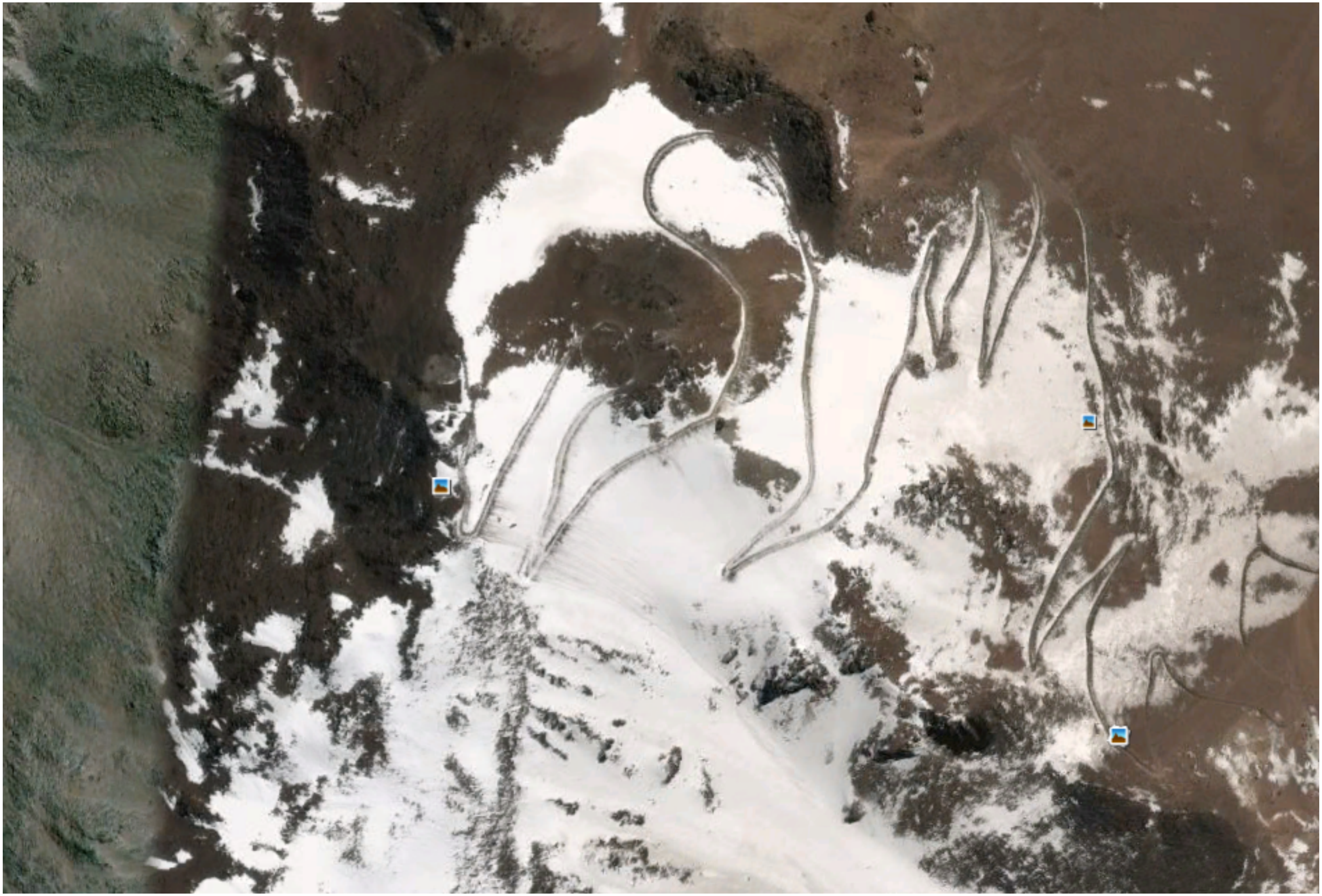
Wikipedia…

Highest permanent observatories [edit]

Permanent observatories above 3,000 m:

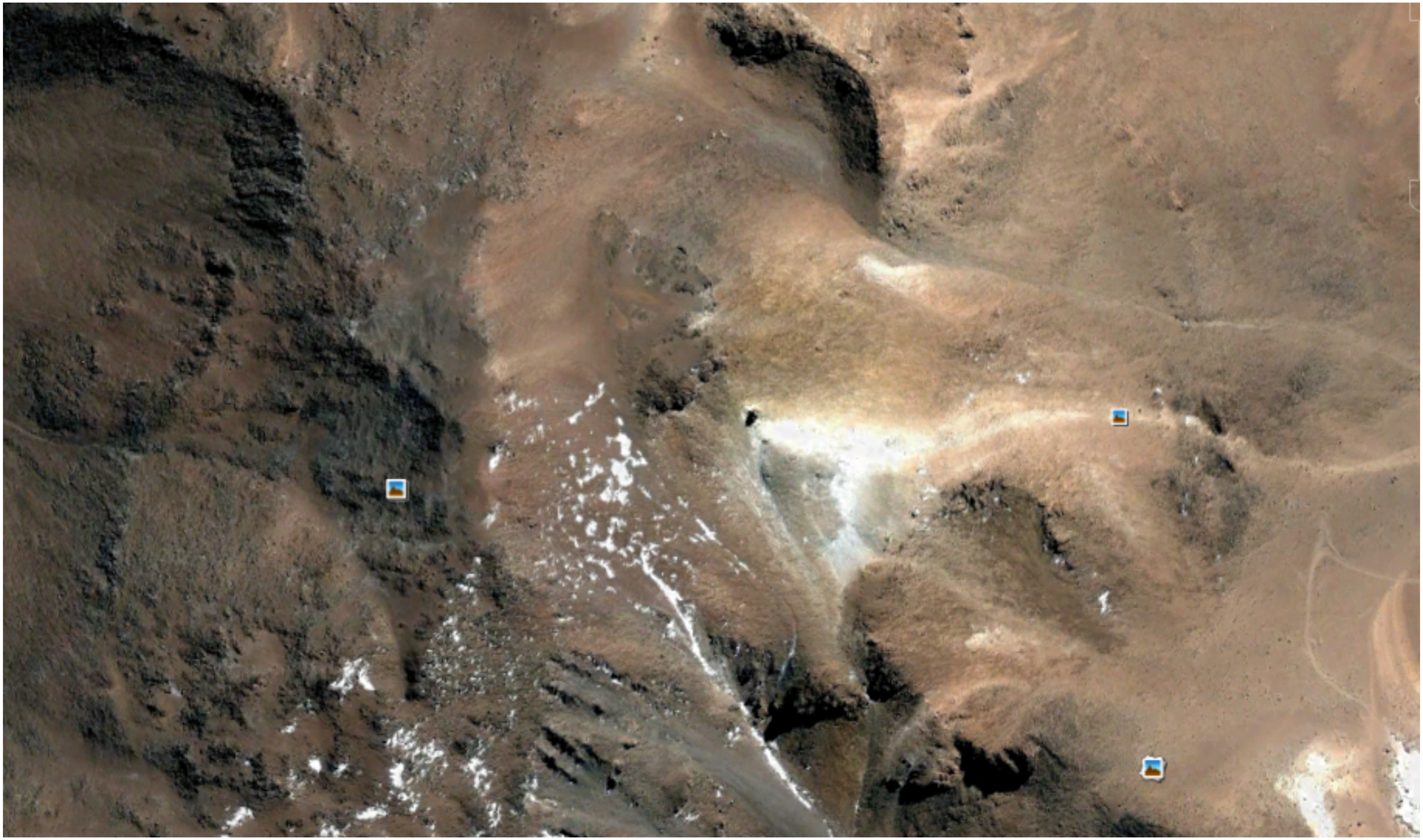
Observatory Name	Elevation	Observatory Site	Location	Coordinates	Established	Type of Observatory
University of Tokyo Atacama Observatory (TAO)	5,640 m (18,500 ft)[10]	Cerro Chajnantor	Atacama Desert, Chile	22°59′12″S 67°44′32″W	2009[10]	Optical, infrared
Chacaltaya Astrophysical Observatory	5,230 m (17,160 ft)[9]	Chacaltaya	Andes, Bolivia	16°21′12″S 68°07′53″W	1946[9]	Cosmic ray, gamma ray
James Ax Observatory	5,200 m (17,030 ft)	Cerro Toco	Atacama Desert, Chile	22°57′30″S 67°47′10″W	2011	Microwave
Atacama Cosmology Telescope	5,190 m (17,030 ft)	Cerro Toco	Atacama Desert, Chile	22°57′31″S 67°47′16″W	2007	Microwave
Llano de Chajnantor Observatory	5,104 m (16,745 ft)	Llano de Chajnantor	Atacama Desert, Chile	23°01′22″S 67°45′17″W	1999	Millimeter wave, submillimeter
Shiquanhe Observatory (NAOC Ali Observatory)[11]	5,100 m (16,700 ft)[12]	Shiquanhe, Ngari Plateau	Tibet Autonomous Region, China	32°19′N 80°01′E	2011	Optical

Road to 5600m…

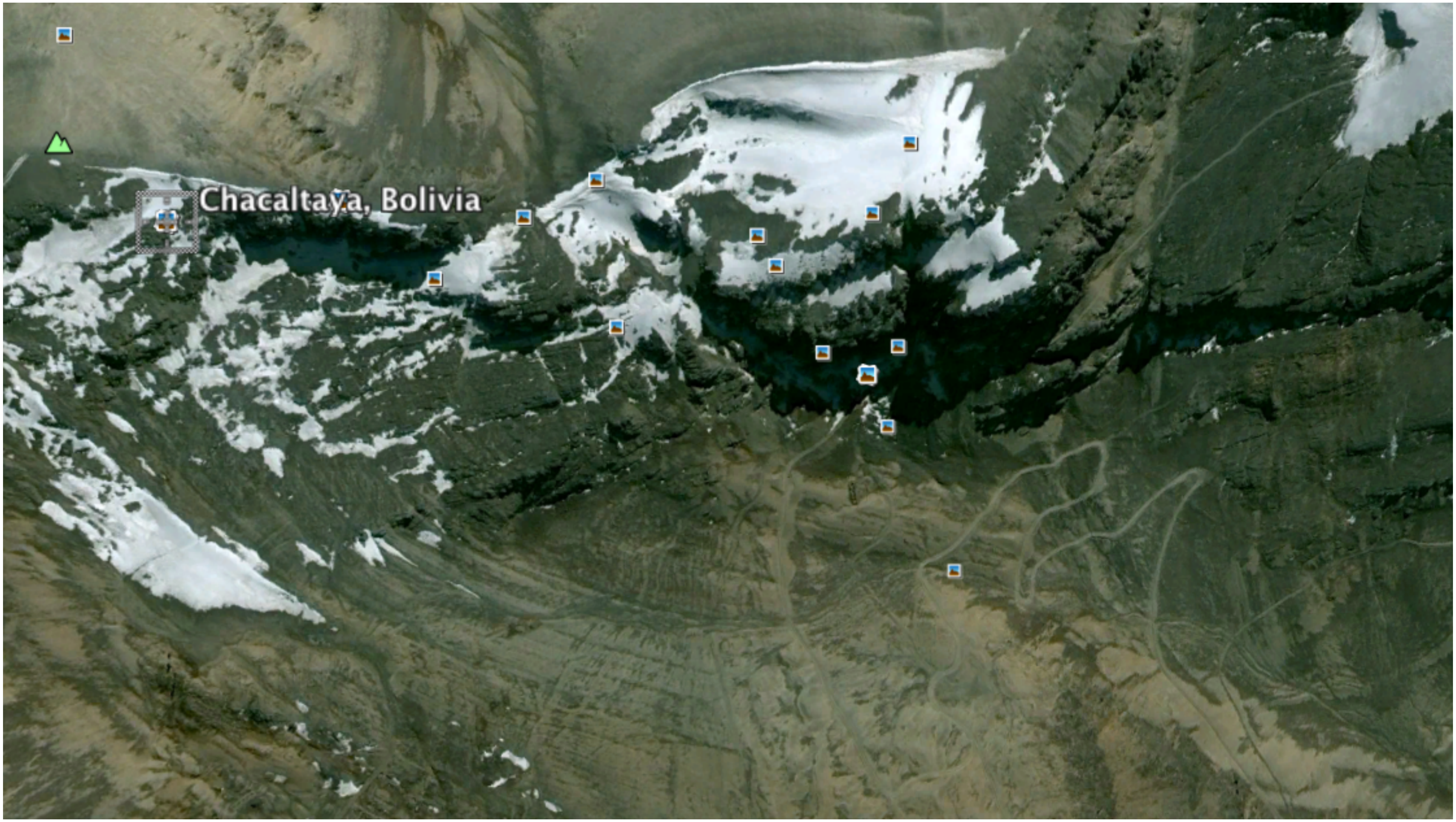



06/01/2010

Back in 2005



Chacaltaya, with long cosmic ray history



Detector ideas

Electronics synergy with Next Generation IceCube & PINGU

- New PDOM electronics are being produced
- These are fairly general purpose, digital readouts with feature extraction, good for all environments, closely coupled to a 10” PMT
- Power consumption <2W (could be <0.5W)
- Built in communications, capable of 1Mb over random wire
- FADC with >100MHz bandwidth & >14b resolution
- Timing to <5ns either cabled or via Ethernet/White Rabbit

Strawman PINGU "PDOM" Design

Keep these parts/designs:

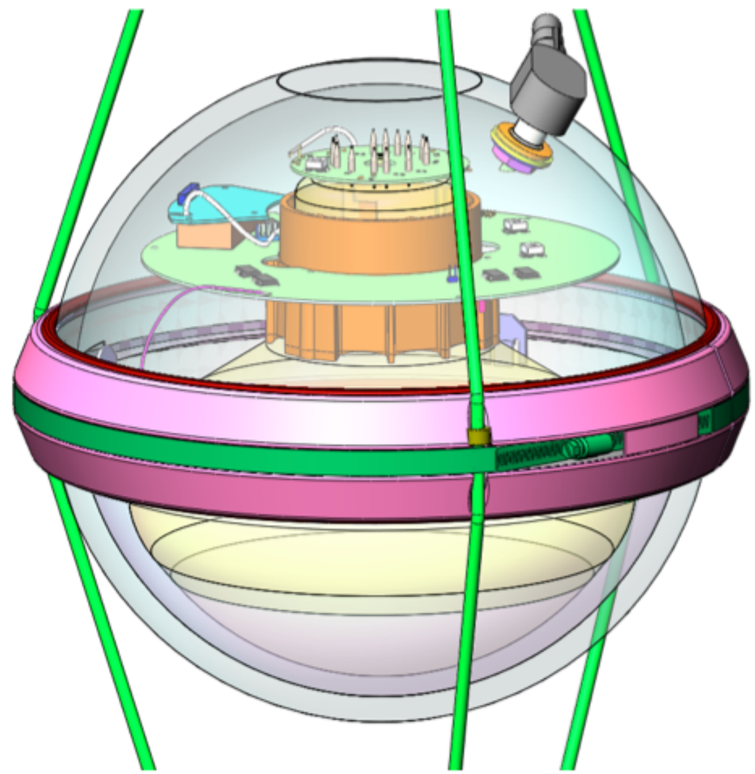
- Sphere
- Penetrator
- PMT, Collar, Gel
- Harness
- HV generator and Base
- Quad Cable technology

Develop new:

- Digitizer (ADC)
- Comms circuitry
- Flasher
- FPGA logic
- Power Supply
- PCB & packaging

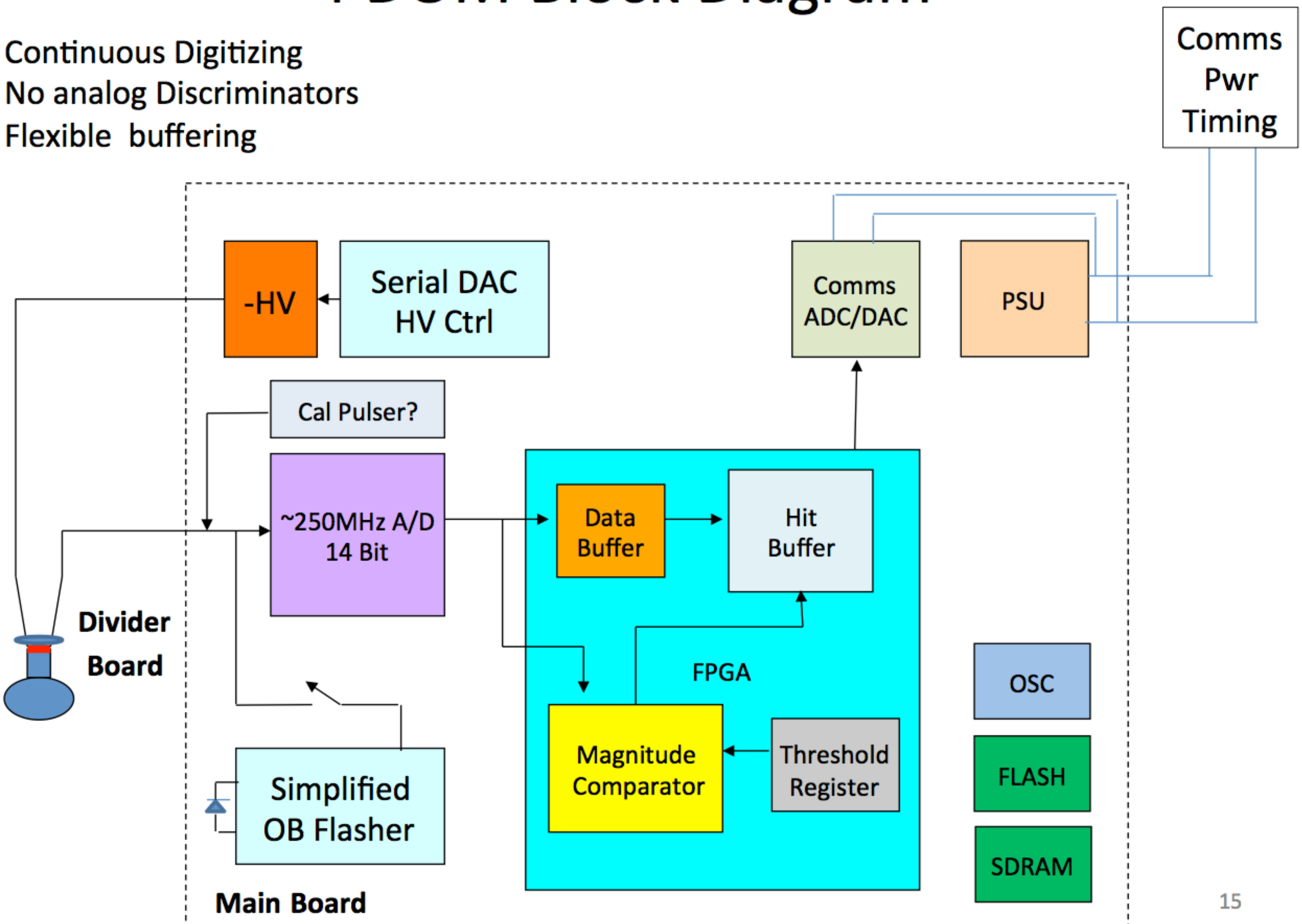
Keep/upgrade these Designs:

- DOMAPP
- CONFIGBOOT (Built into FPGA now)
- DAQ
- DOR FUNCTIONALITY



PDOM Block Diagram

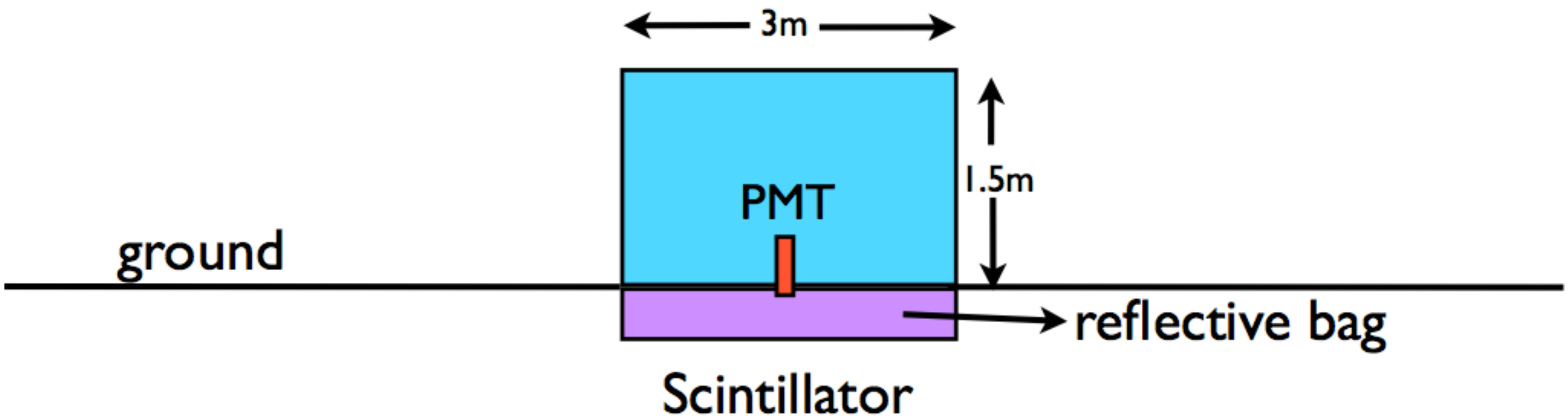
- Continuous Digitizing
- No analog Discriminators
- Flexible buffering



Rough Cost: IC DOM vs. PDOM

ITEM	High QE IC DOM	PDOM
PMT	2000	2000
PMT Base Board	130	130
~~Sphere/Harness~~	~~650~~	~~650~~
~~Penetrator~~	~~400~~	~~400~~
Main Board	1900	1000
ATWD Test /pkg	500	0
Delay Board	130	0
~~Engineering (project)~~	~~(3mo)~~	~~(36mo)~~
Flasher Board	150	0
Flasher Parts	50	50
HV Supply Board	190	0
HV Module	380	380
Mu Metal	150	150
TOTALS	**$ 6630 (+6mo)**	**$ 4760 (+36mo)**

Inexpensive and Compact muon detection



10 cm of scintillator yields 2e5 photons for a through-mu
~ 40 PE detected in a 2" PMT
0.75 m^3 of LAB scintillator
~$850/detector (~1/4 cost of plastic scintillator)
Much easier to construct and deploy

Not exactly conclusions

- Going higher is possible, quite desirable, and plausible for a Southern Hemisphere experiment using WCD
- Probably needs a different construction technique than HAWC, build lower and bring units up, tanks more like Auger perhaps
- Electronics could have significant synergies with Next Generation IceCube and other experiments

BACKUP SLIDES