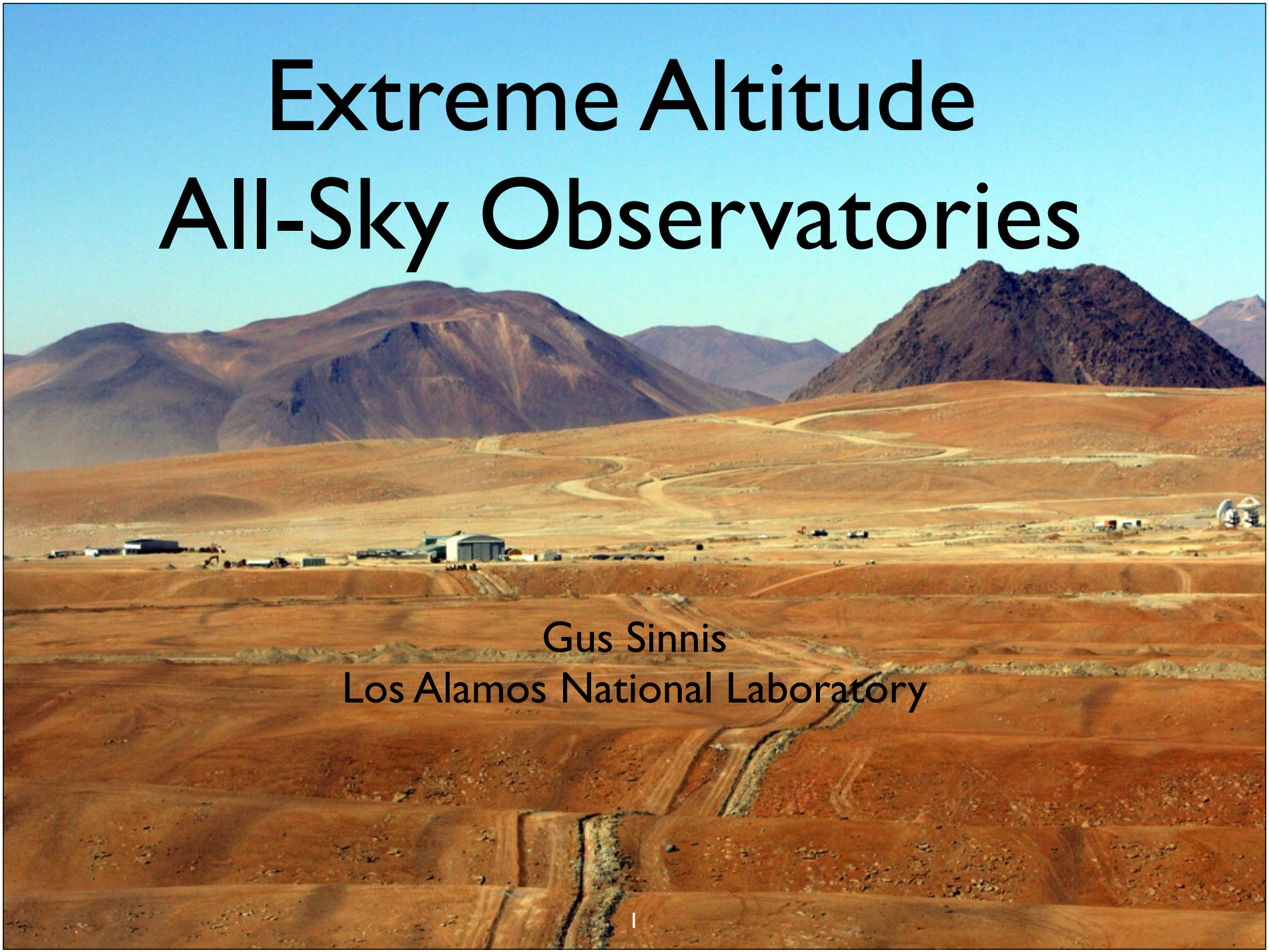
Extreme Altitude All-Sky Observatories



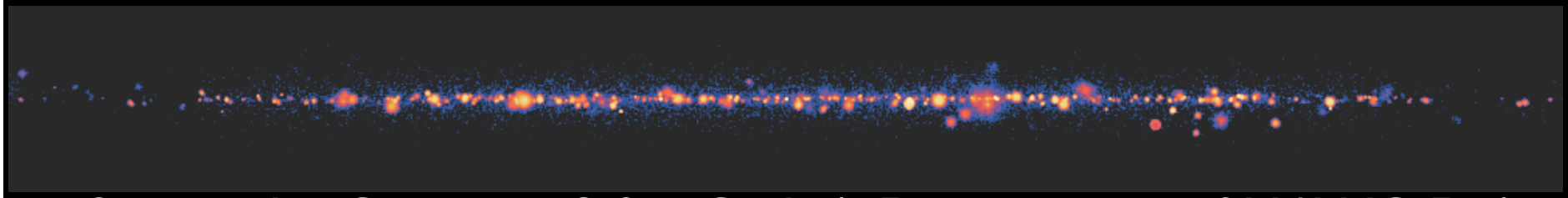
Gus Sinnis
Los Alamos National Laboratory

Friends, Collaborators, Colleagues, lend me your ears.
I come to bury Caesar, not to praise him.

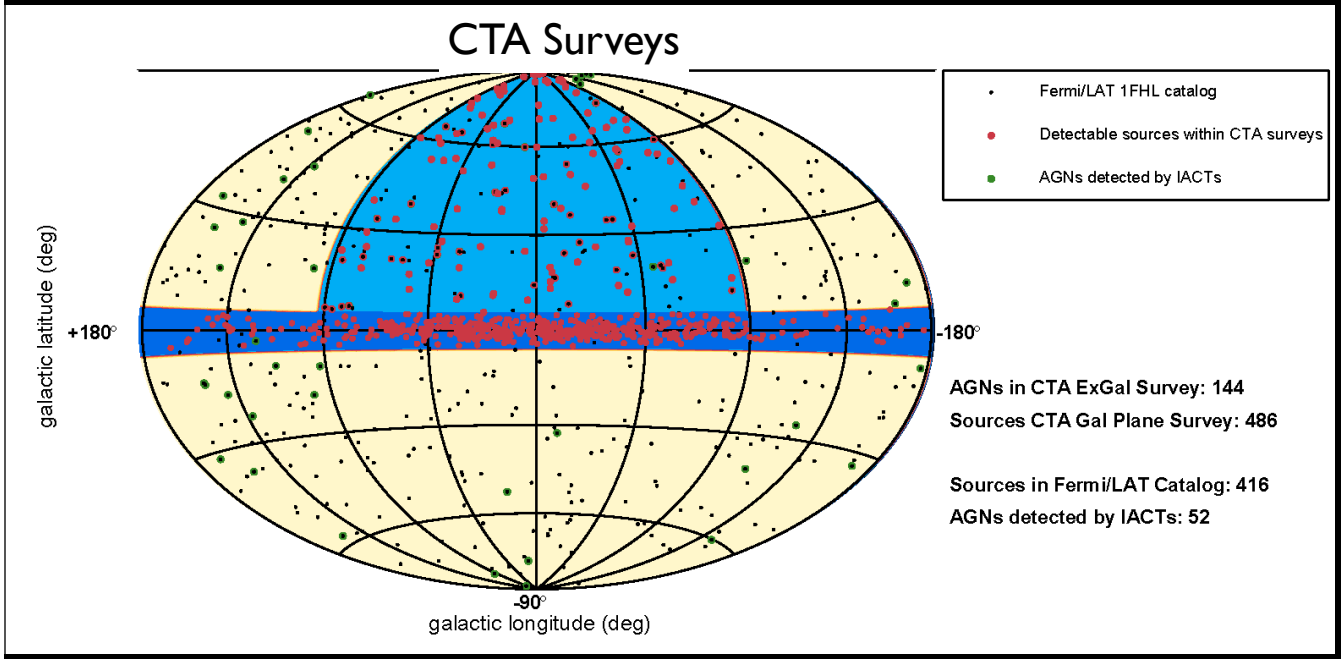
Conclusions

- The scientific justification for a future southern observatory must be made in the context of CTA
- Transient phenomena will be the rationale for an extreme altitude observatory
- Relative to HAWC we must significantly increase the redshift horizon of a future instrument
- Altitude is the only guaranteed method to do so
- Dense sampling of all particles (gammas and "electrons") is essential
- Need to establish metrics before site selection: horizon & sensitivity
- There are several sites at 5600m - is this sufficient?

CTA Survey Plans



Survey the Galaxy to 3.8 mCrab (~5x sensitivity of HAWC 5yr)



1/4 of the sky to 6.5 mCrab
~3x HAWC 5yr

BUT - at much lower energy

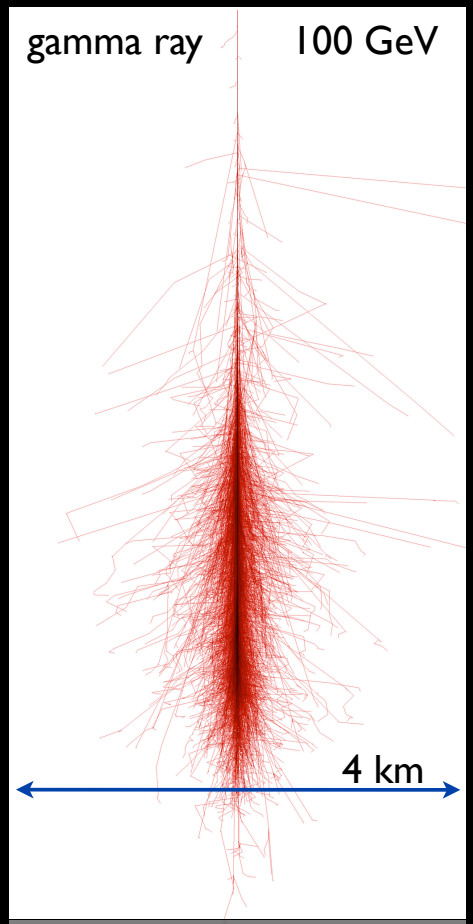
MUCH - deeper horizon

from R. Ong

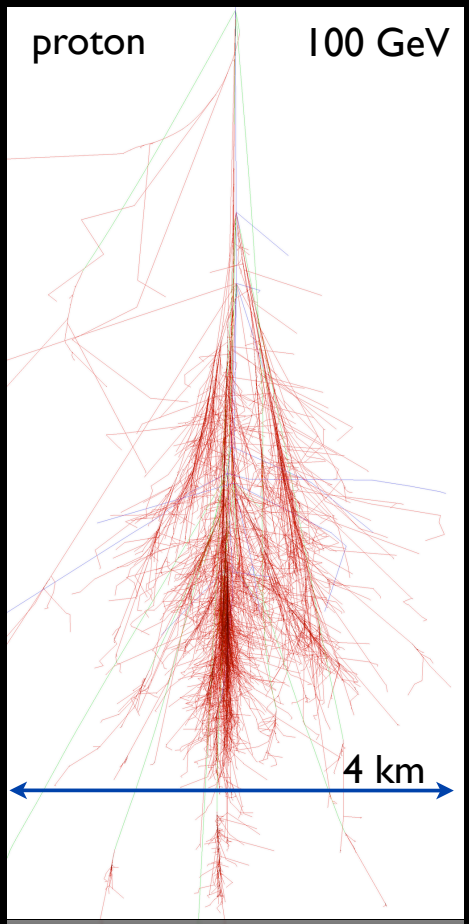
Roles of All-Sky Instrument

- Present
  - Galactic Survey at high energies
  - ~100 TeV survey (with outriggers)
  - Extended objects (PWN, Diffuse emission)
  - Extragalactic survey
  - Extragalactic transients (AGN, GRBs)
- Future (with CTA)
  - Extragalactic survey
  - Extragalactic transient (AGN, GRBs)

Extensive Air Showers

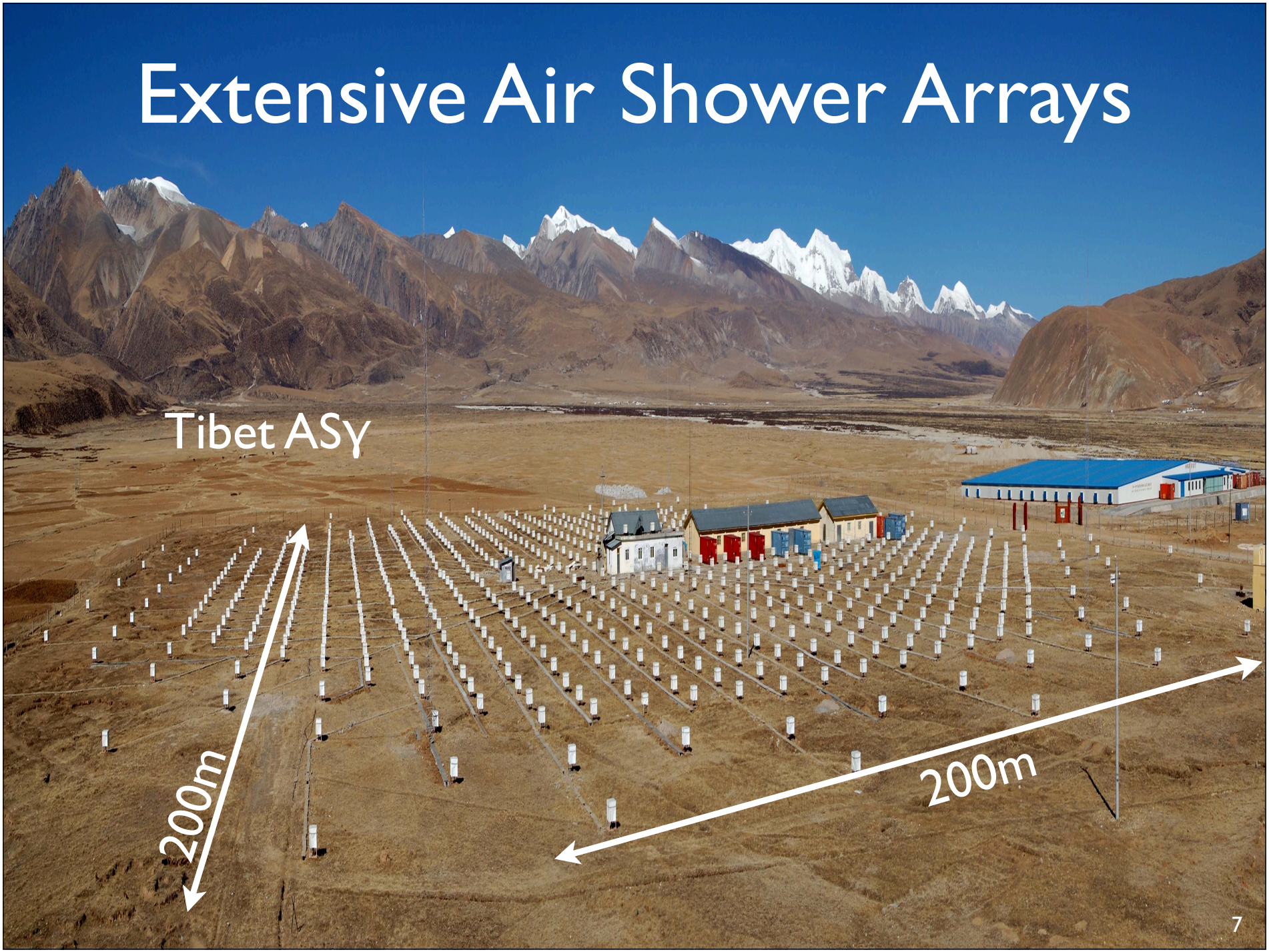


- γ showers almost purely e-m and relatively compact
- Hadronic showers contain muons (~30/TeV)
- Both have core of energetic particles
- Ground-based VHE telescopes must distinguish protons from photons

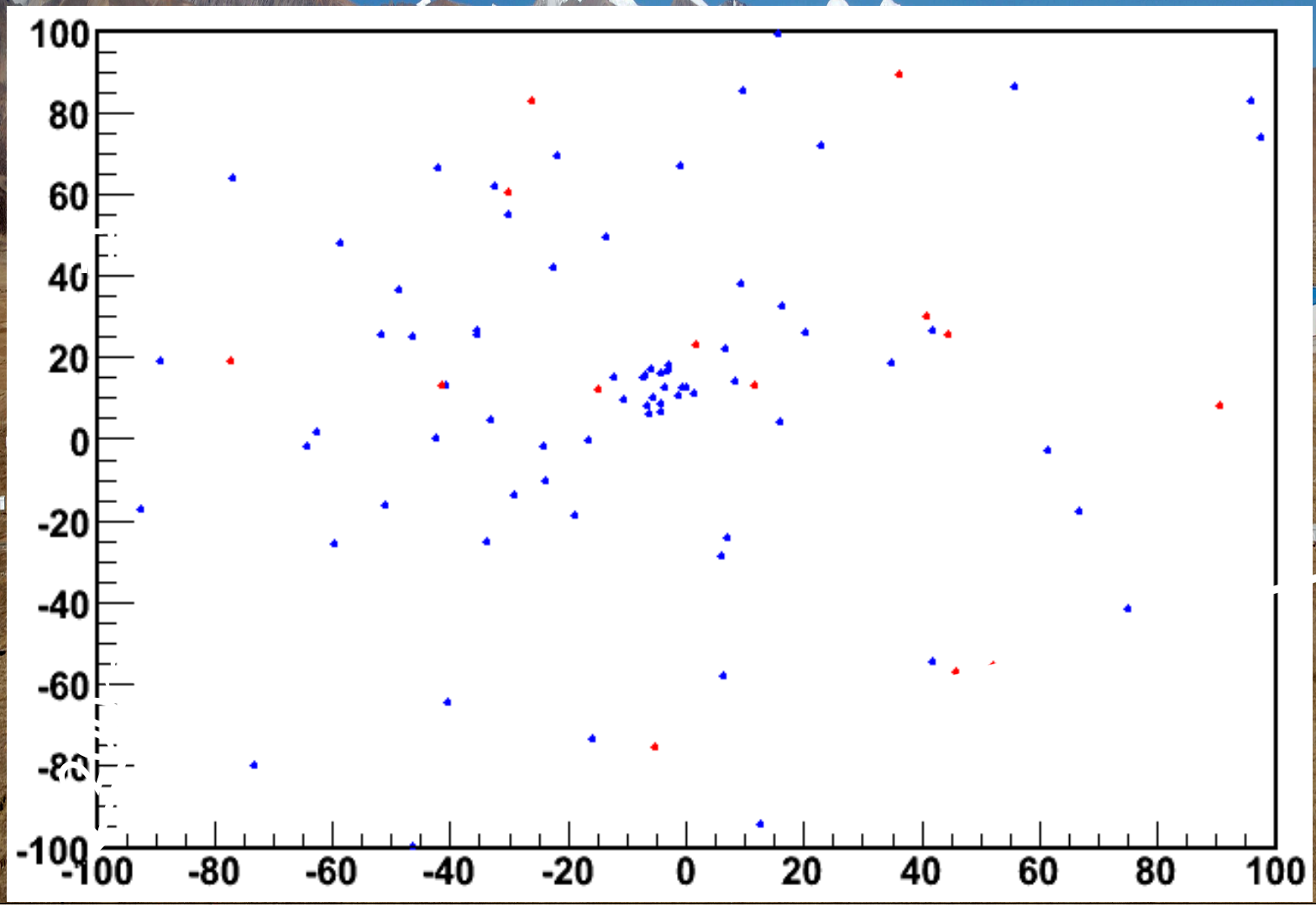


F. Schmidt, "CORSIKA Shower Images", http://www.ast.leeds.ac.uk/~fs/showerimages.html

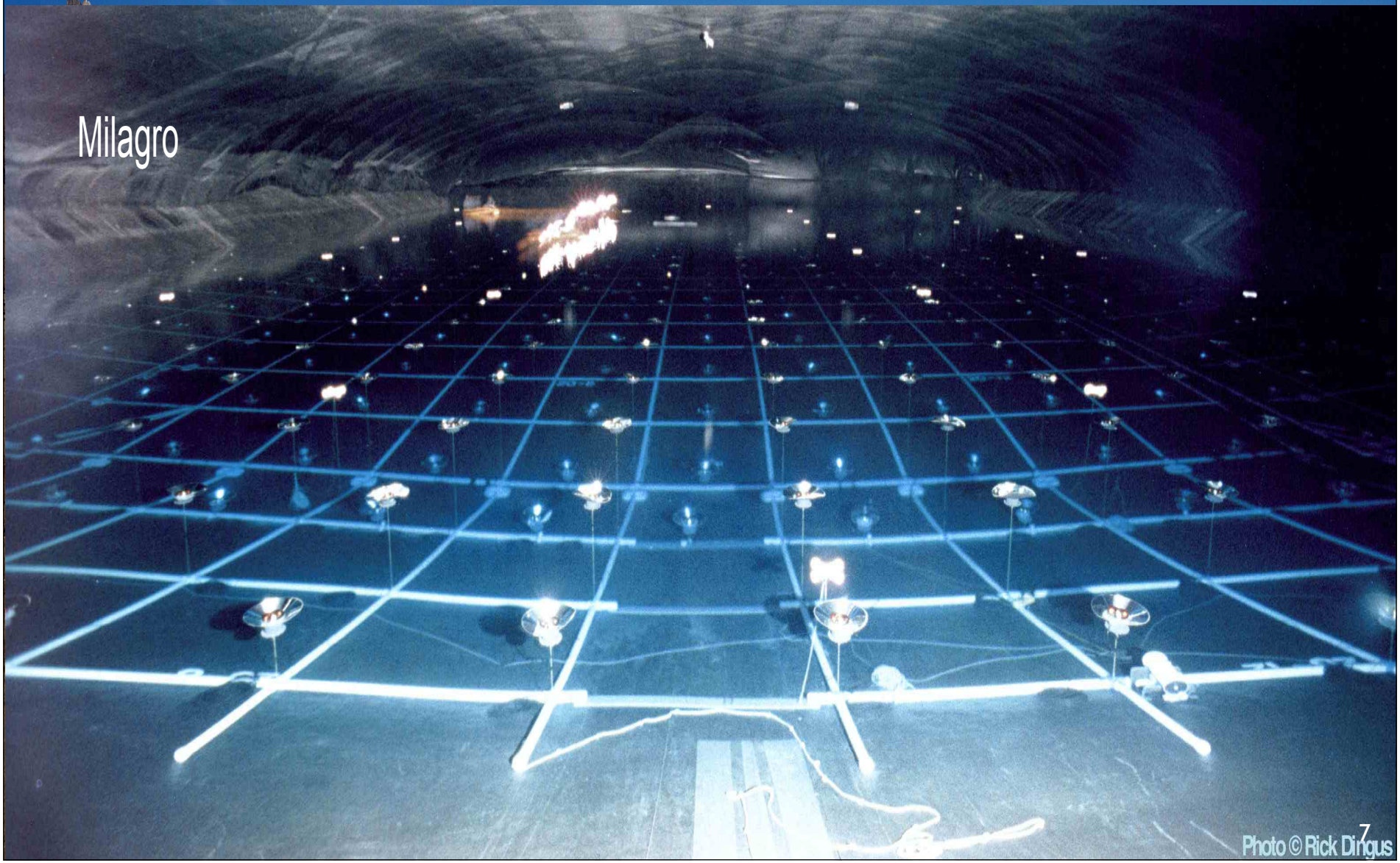
Extensive Air Shower Arrays



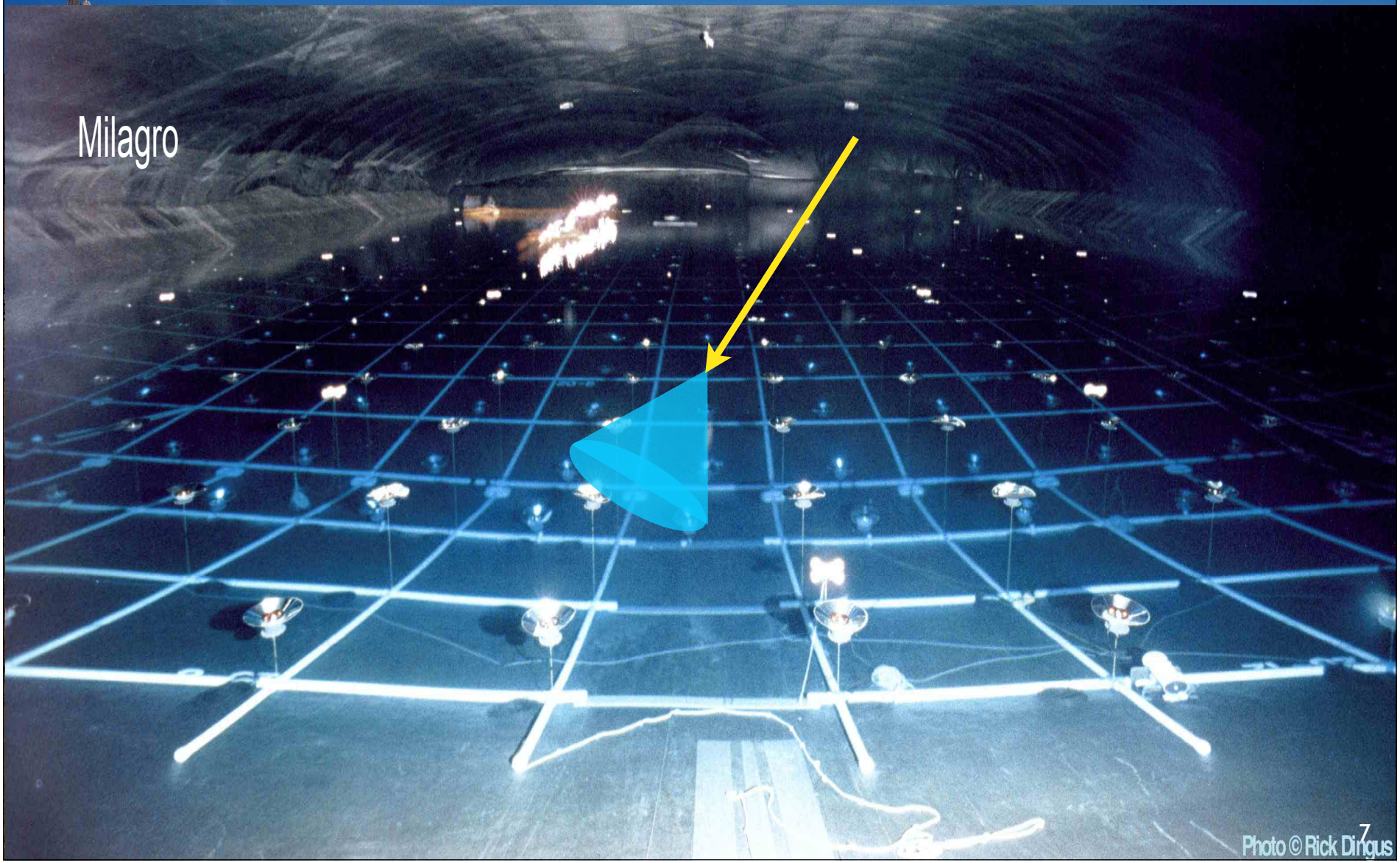
Extensive Air Shower Arrays



Extensive Air Shower Arrays

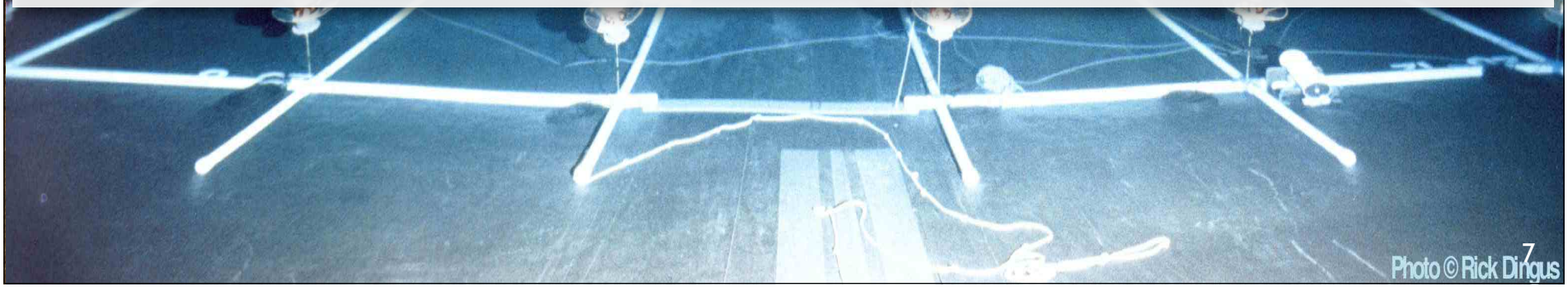


Extensive Air Shower Arrays

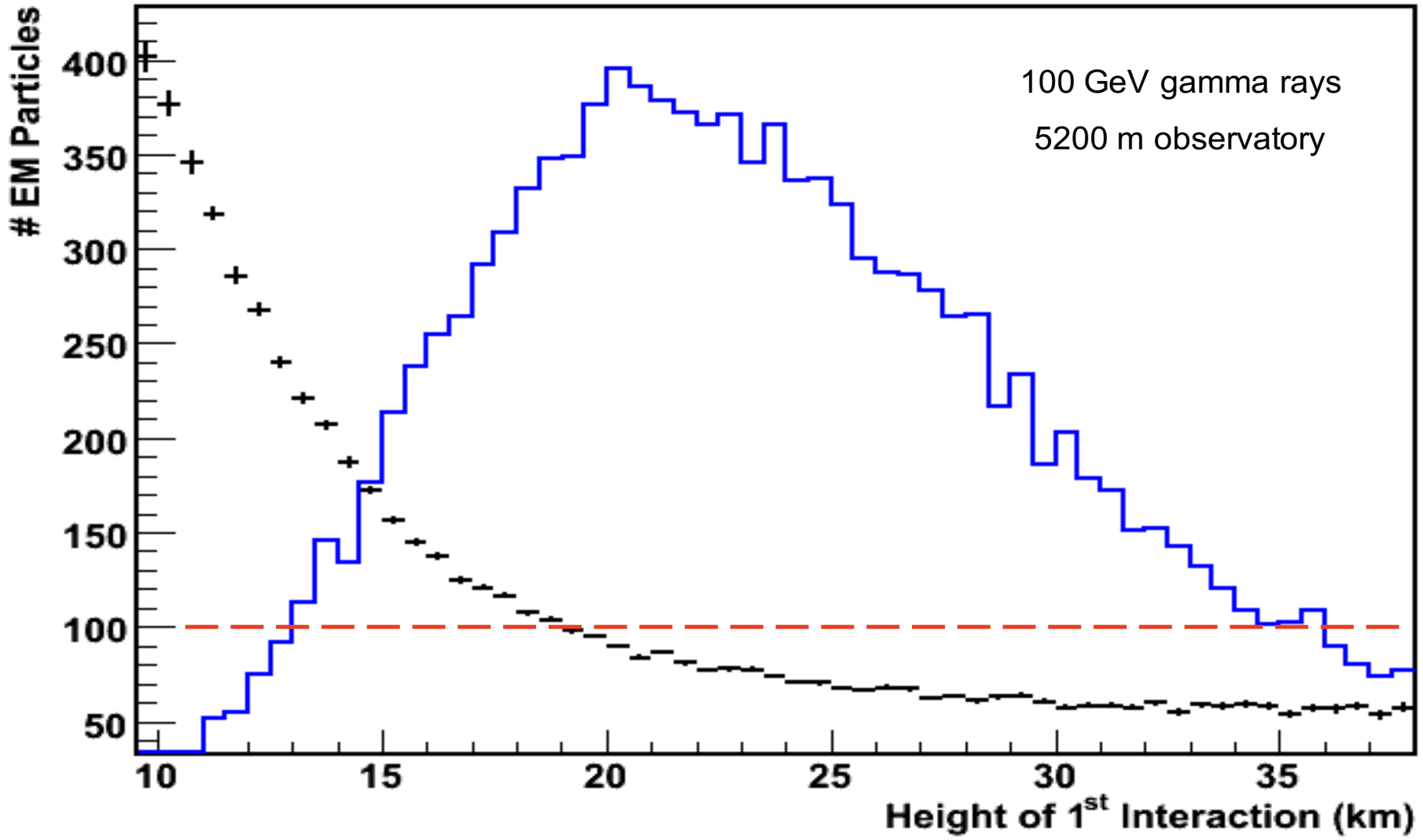


Extensive Air Shower Arrays

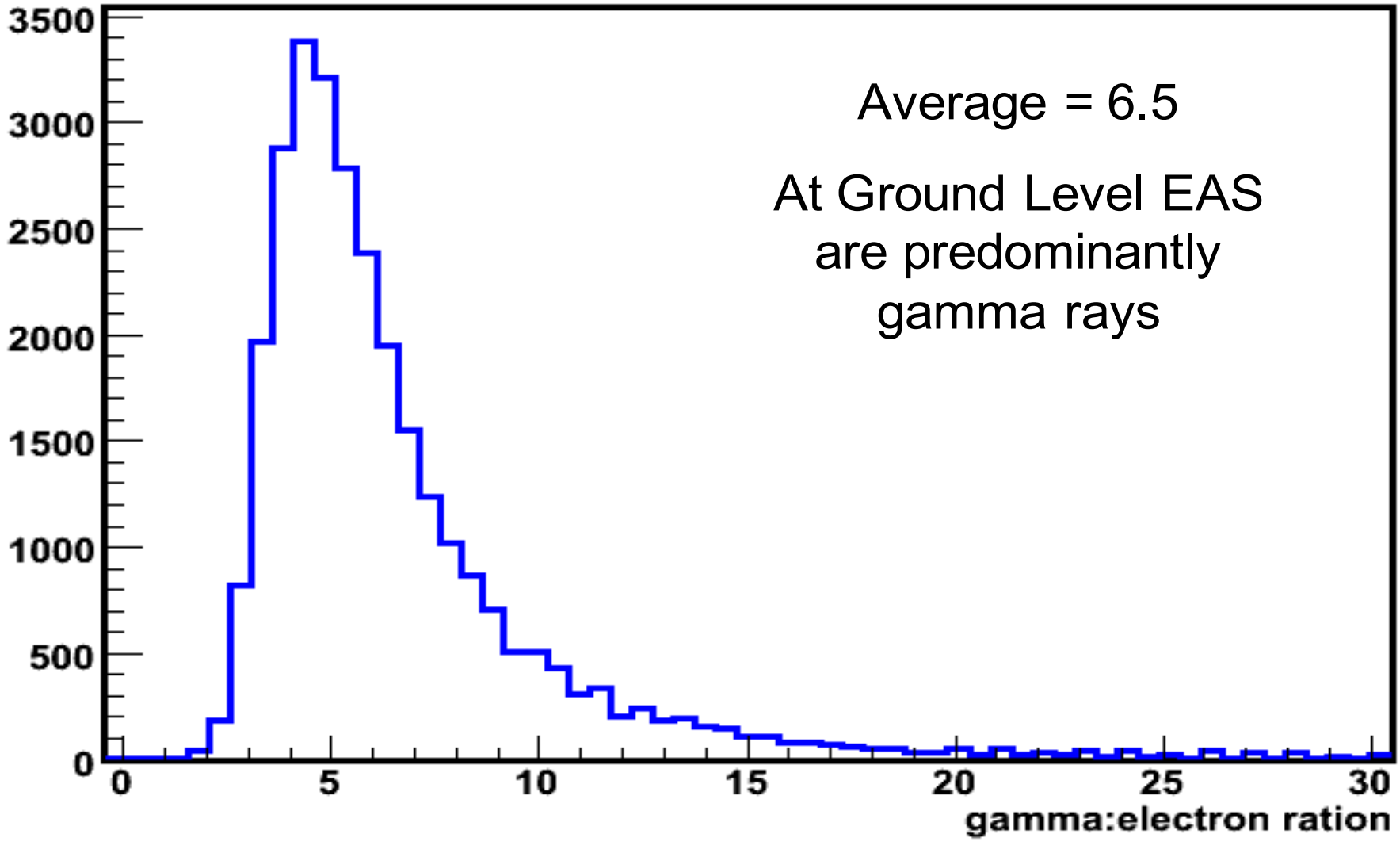
- Detect particle that survive to ground level
- Scintillation detector arrays sparsely instrument the ground <2% coverage
- Water detectors (or RPC carpet) can densely sample the shower particles (~50% particles detected)
- Water will also convert gamma rays to electrons/positrons (gamma rays dominate the particles on ground ~6:1)
- Deep water detector (≳4m) can serve as muon detector



Shower Fluctuations



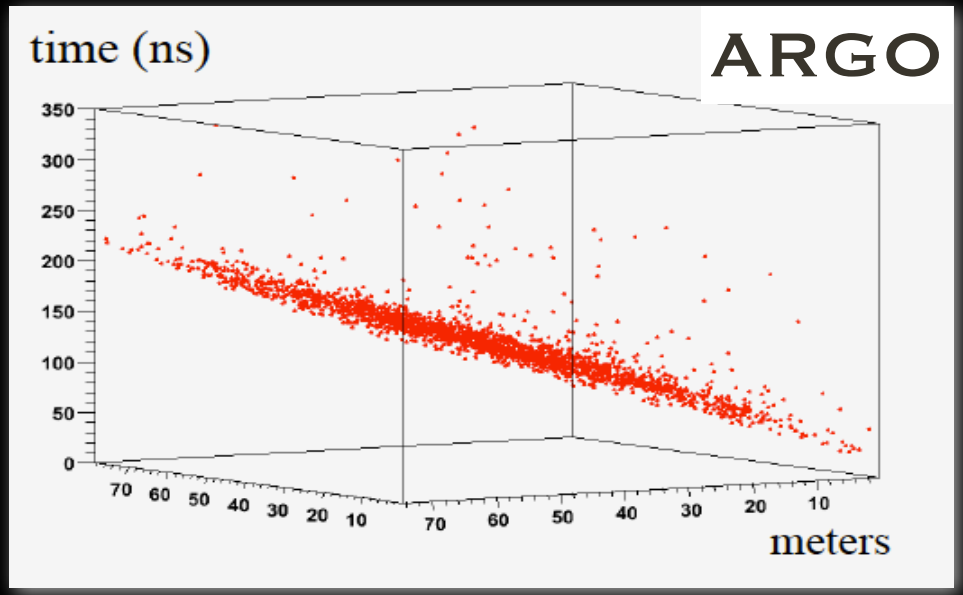
Shower Composition



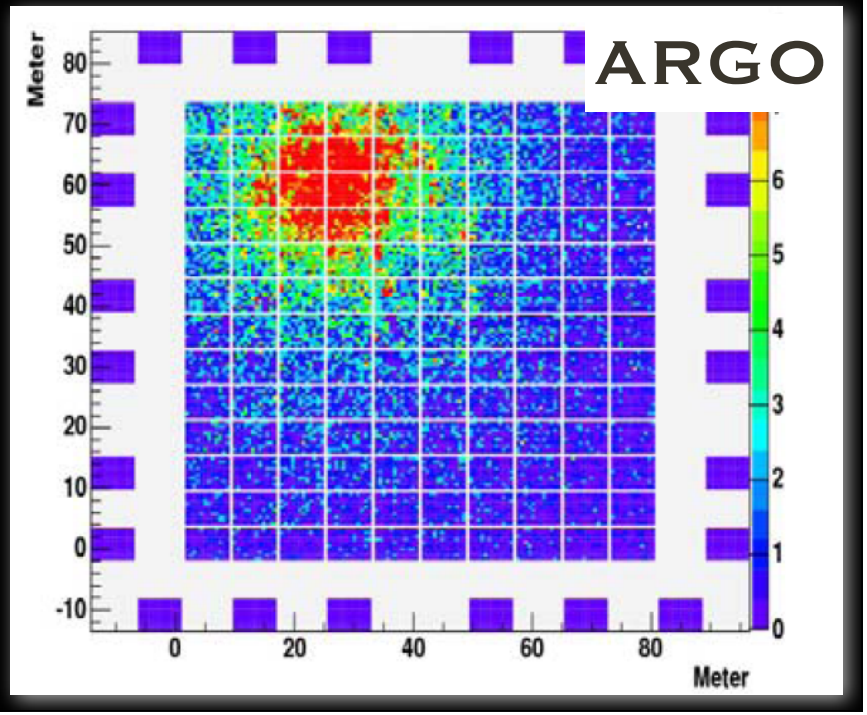
Average = 6.5

At Ground Level EAS are predominantly gamma rays

Angular and Energy Reconstruction

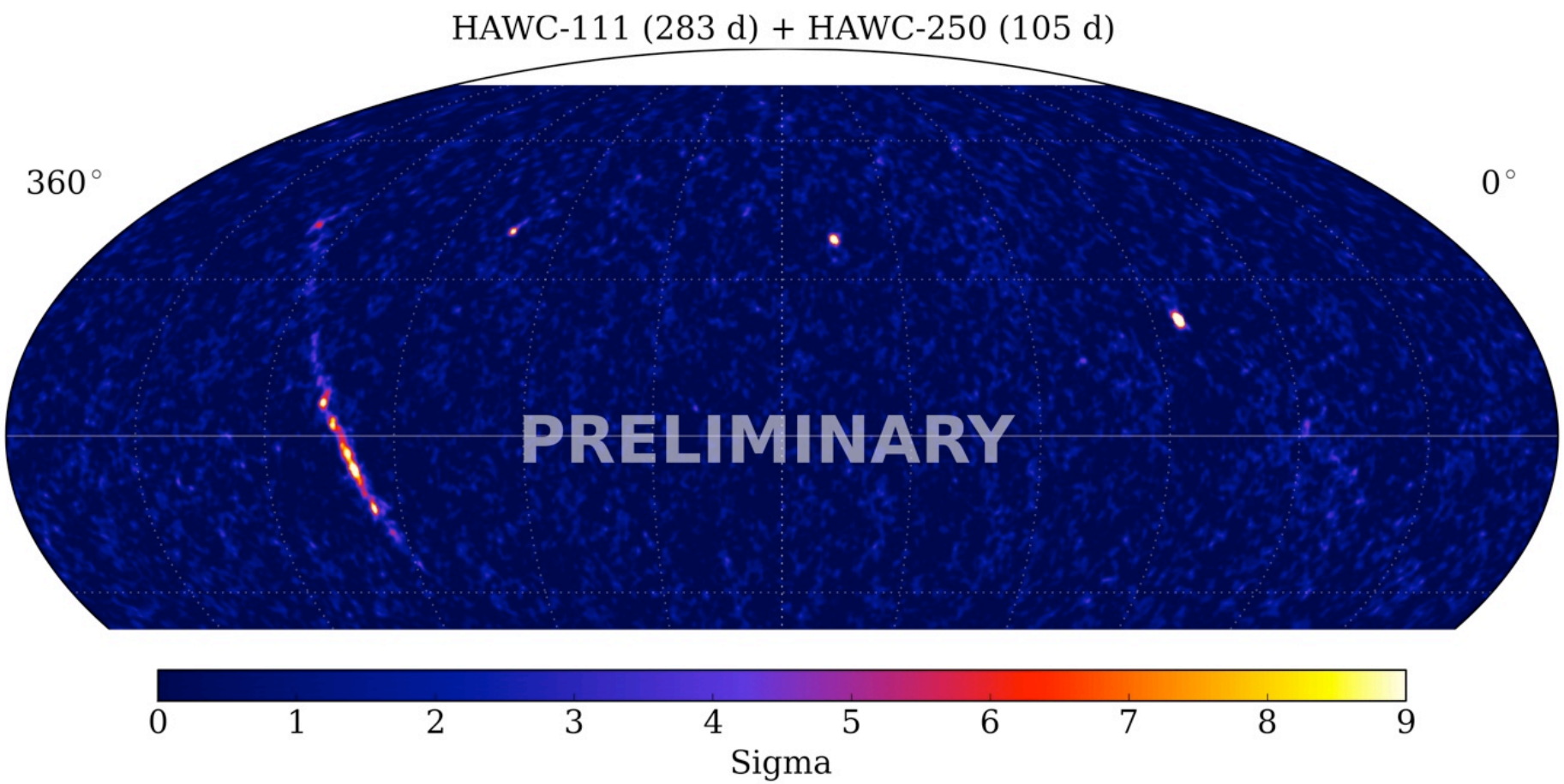


Direction via timing
(~ns timing yields 0.2°-1° resolution)

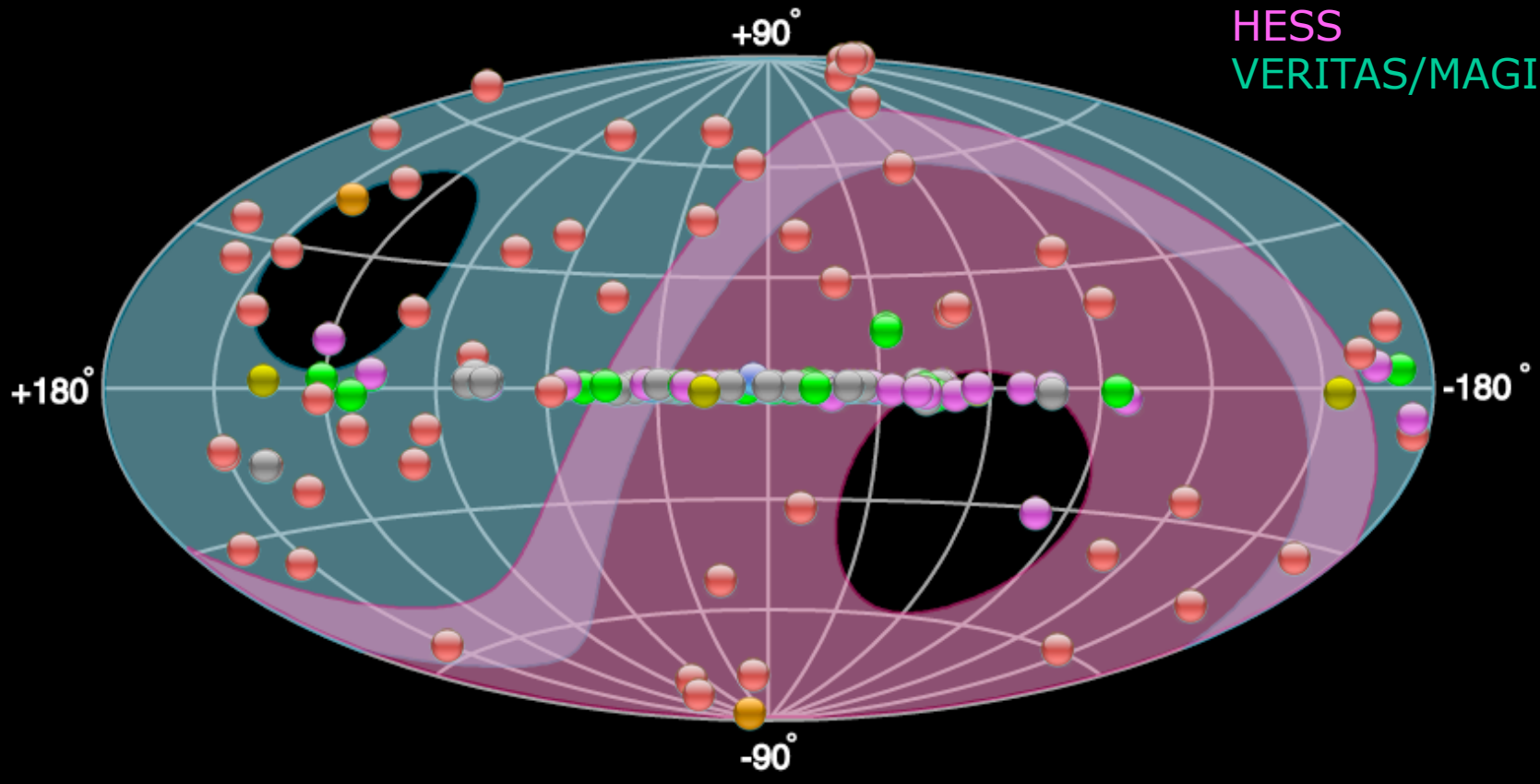


Primary energy via energy at ground
(shower fluctuations dominate resolution ~40%)

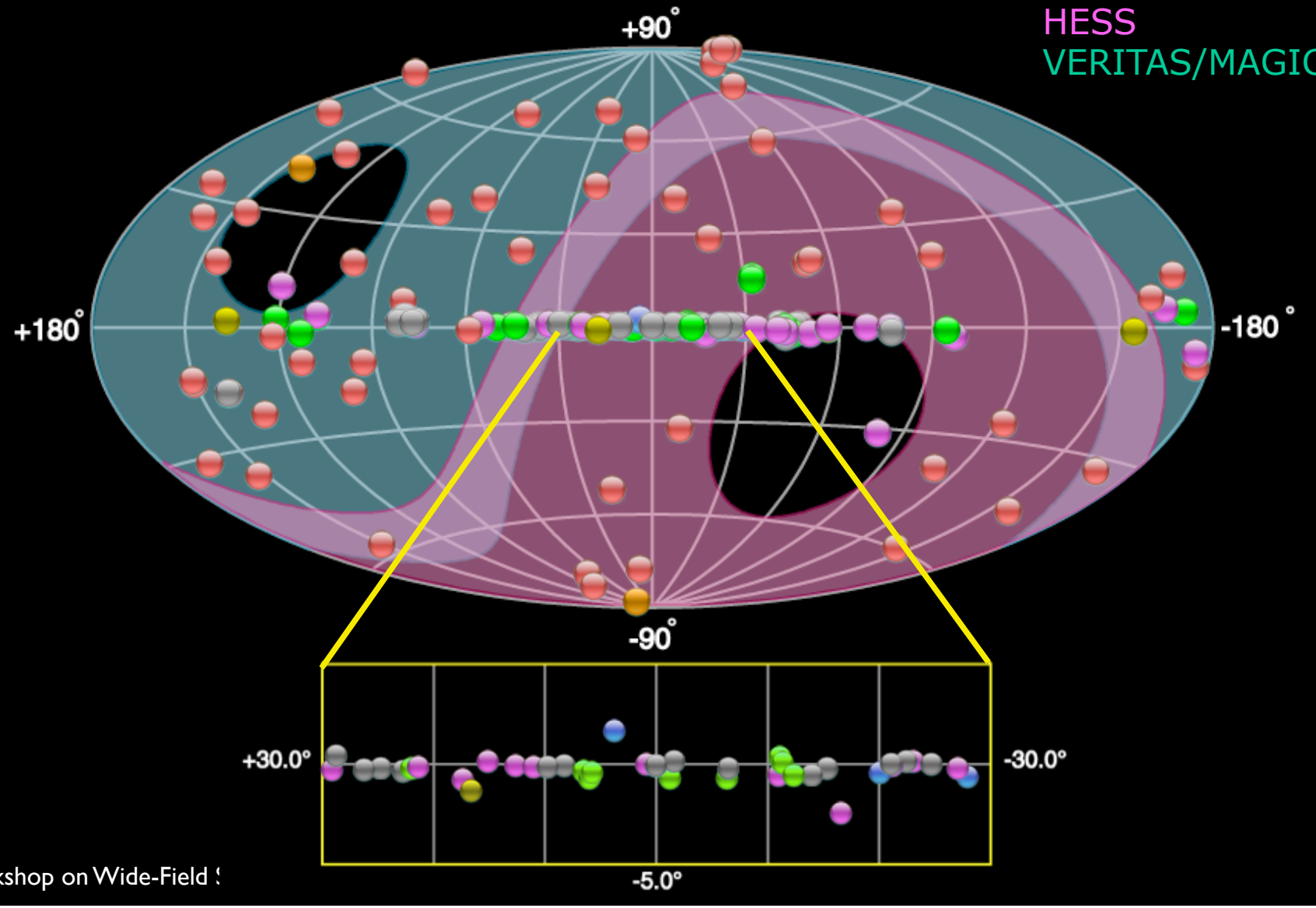
HAWC Sky


HAWC-111 (283 d) + HAWC-250 (105 d)
360°
0°
PRELIMINARY
0
1
2
3
4
5
6
7
8
9
Sigma

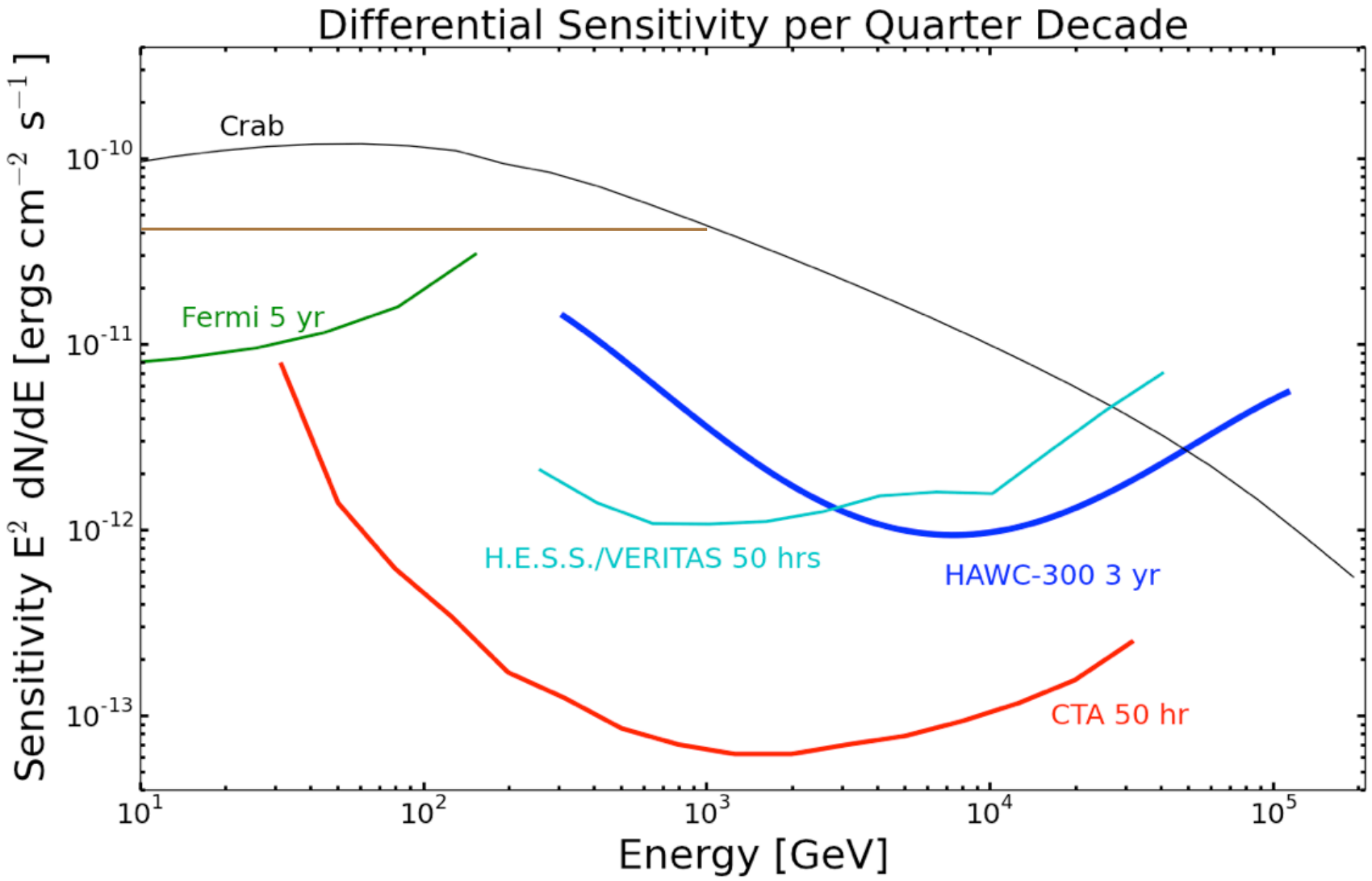
TeV Sky



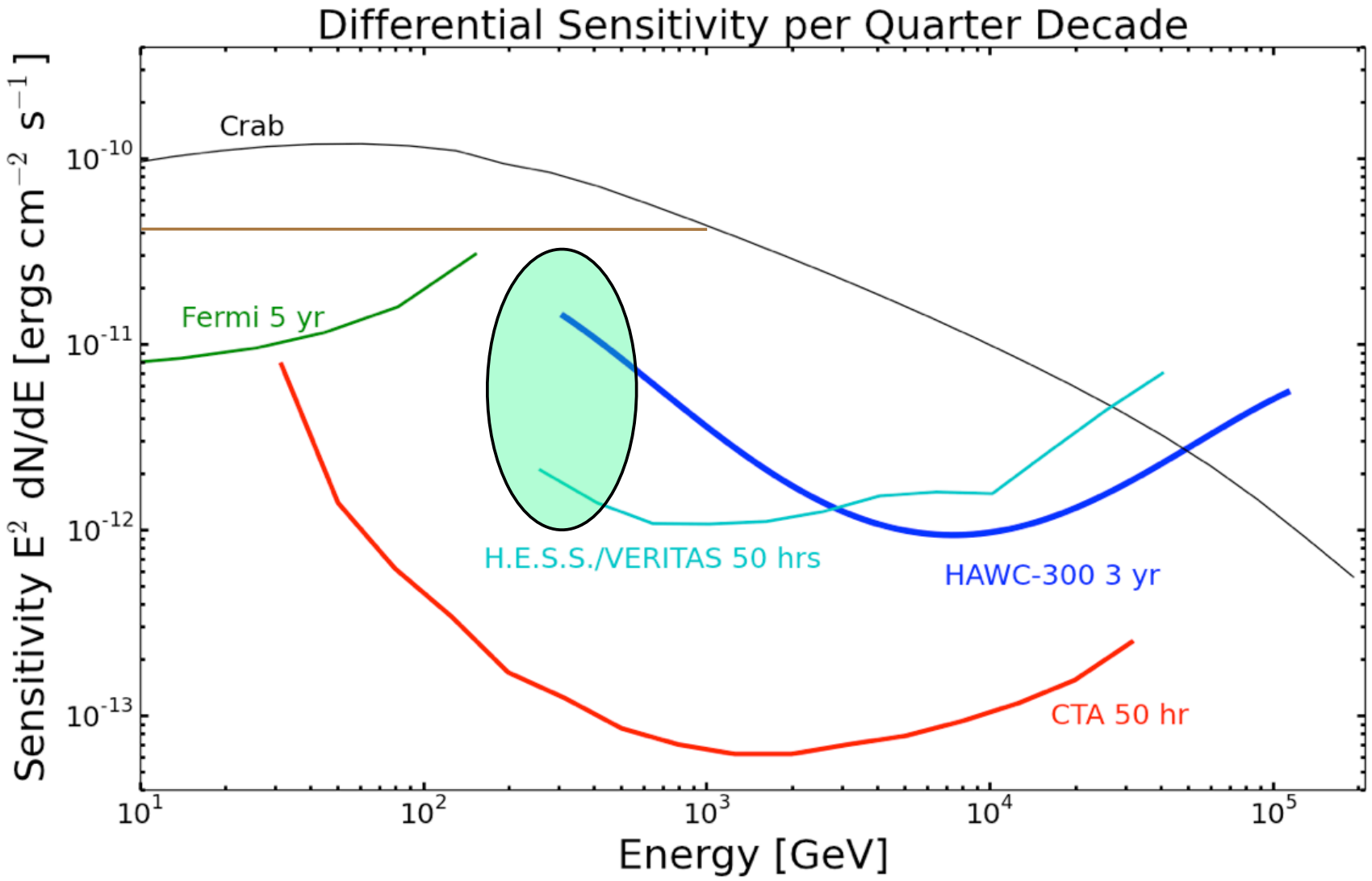
TeV Sky



CTA and HAWC


Differential Sensitivity per Quarter Decade
Sensitivity E^2 dN/dE [ergs cm^{-2} s^{-1}]
Energy [GeV]
Crab
Fermi 5 yr
H.E.S.S./VERITAS 50 hrs
HAWC-300 3 yr
CTA 50 hr
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^1
10^2
10^3
10^4
10^5

CTA and HAWC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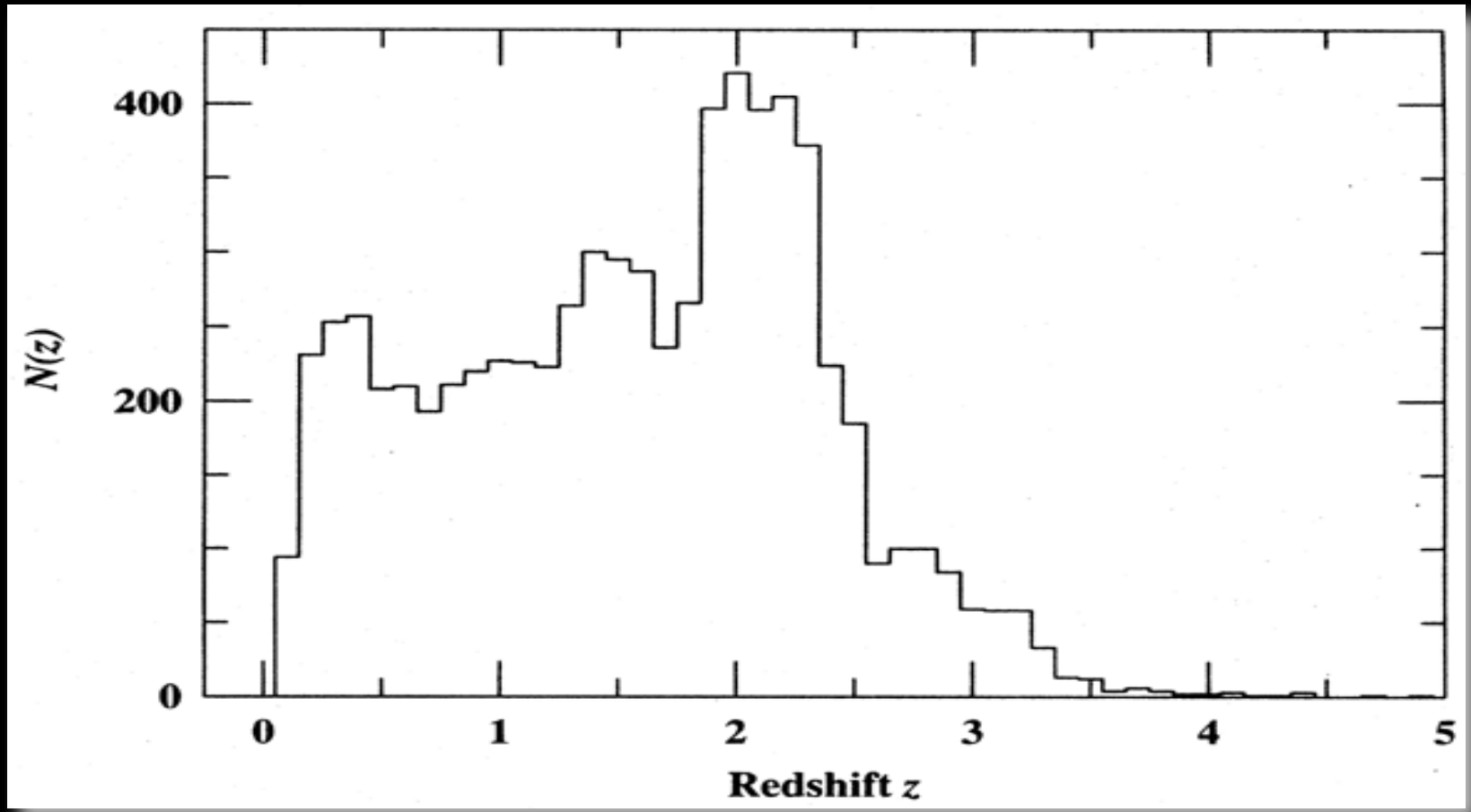
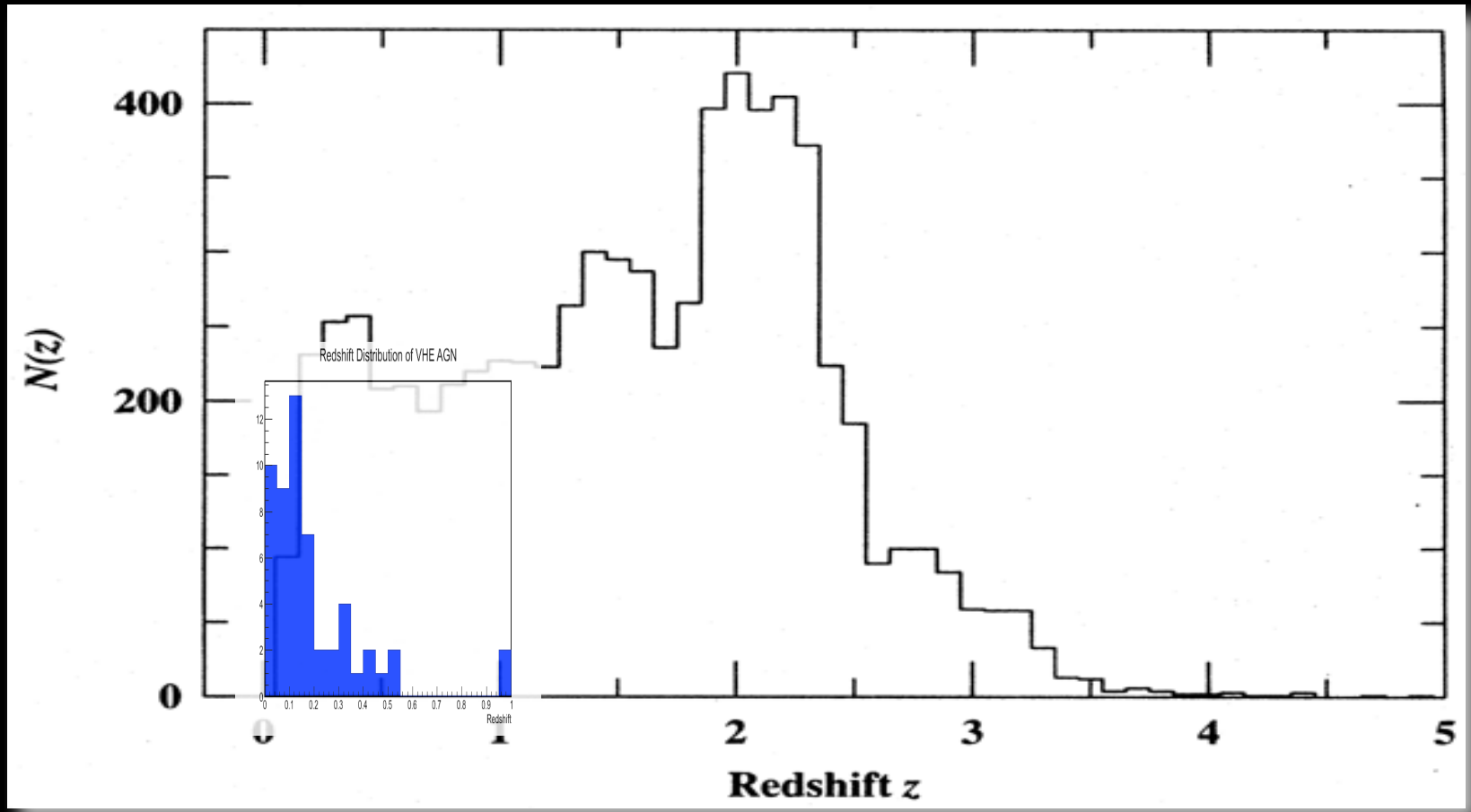
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

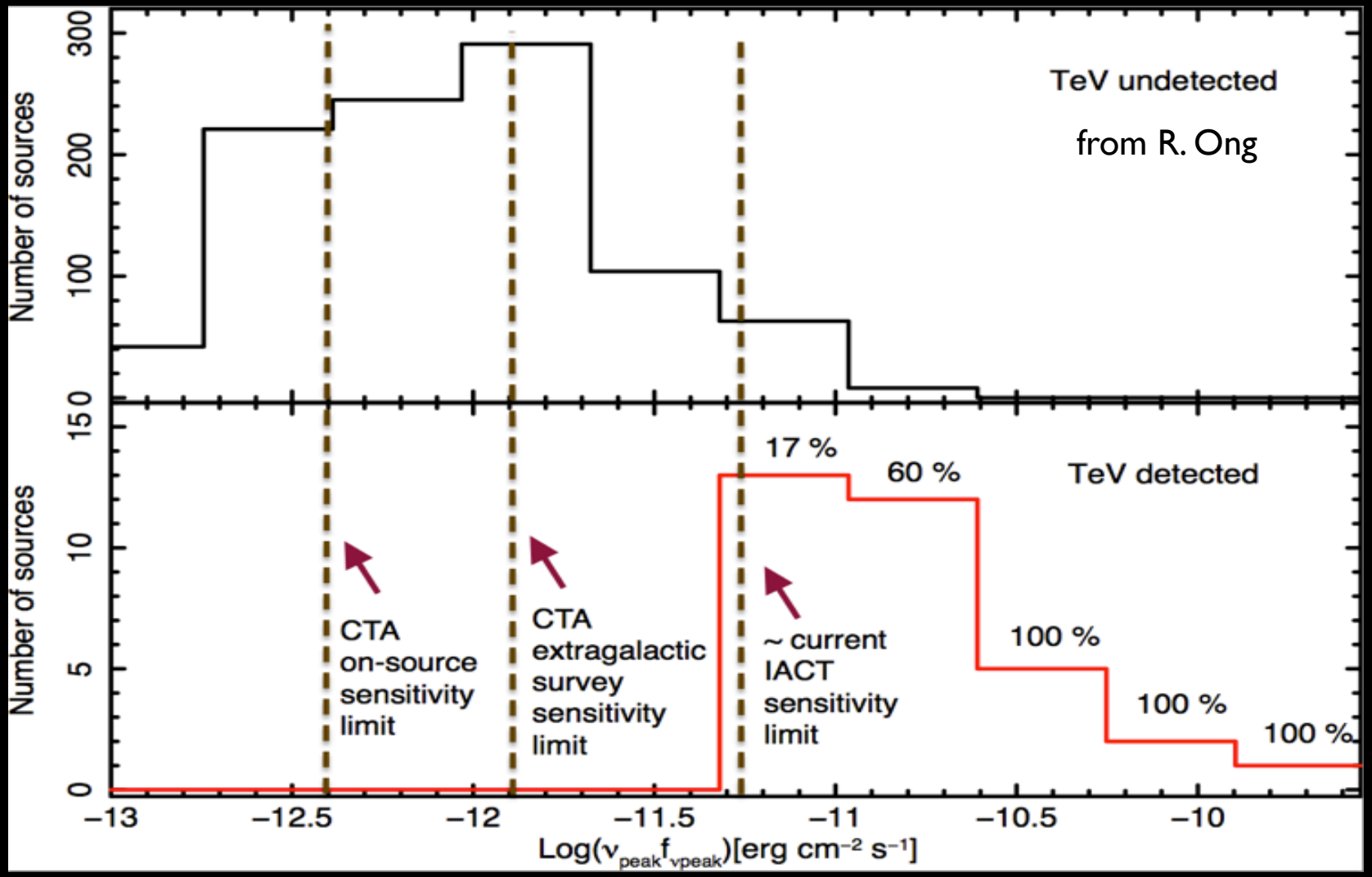
AGN Redshift Distribution



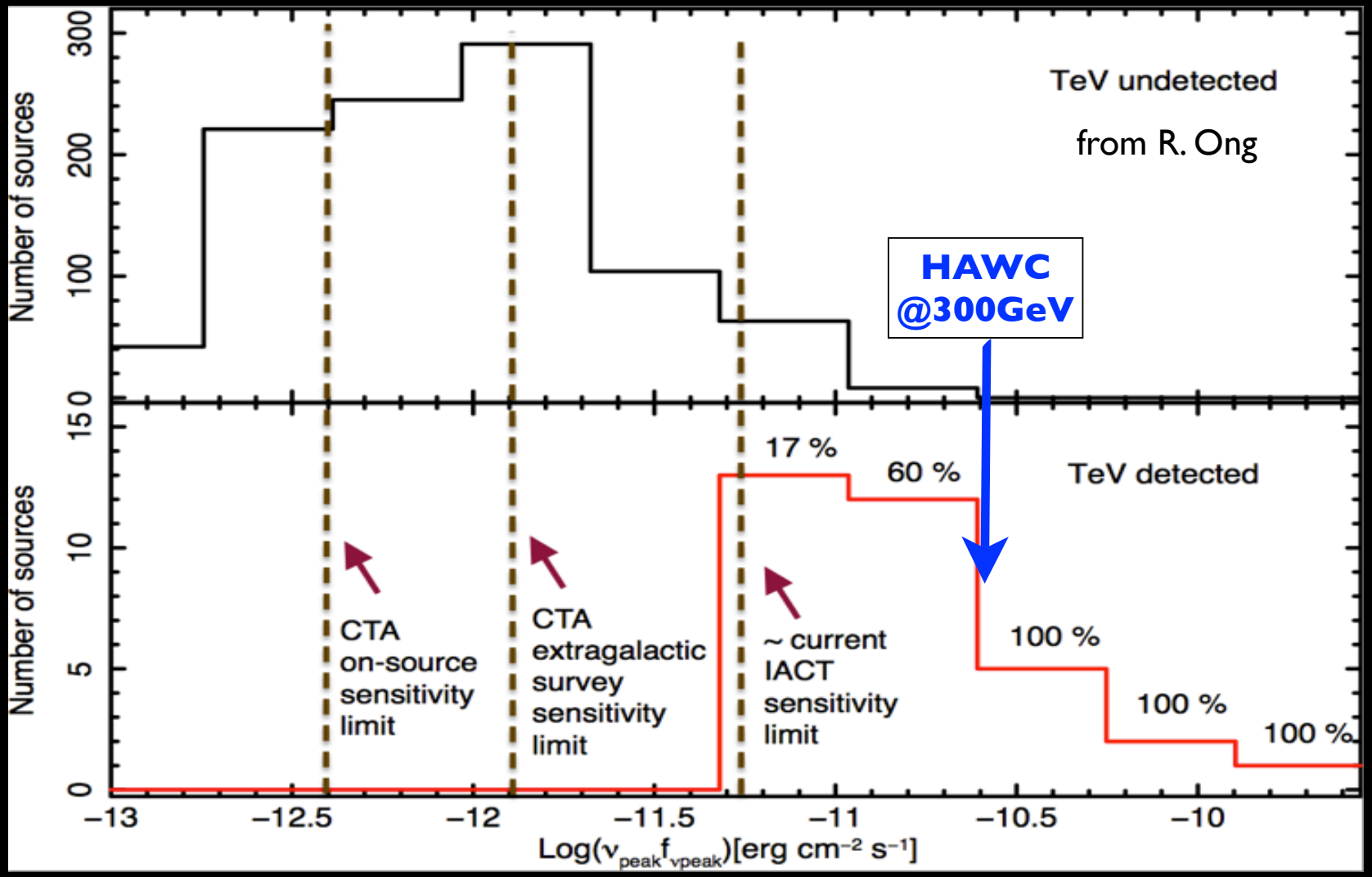
AGN Redshift Distribution



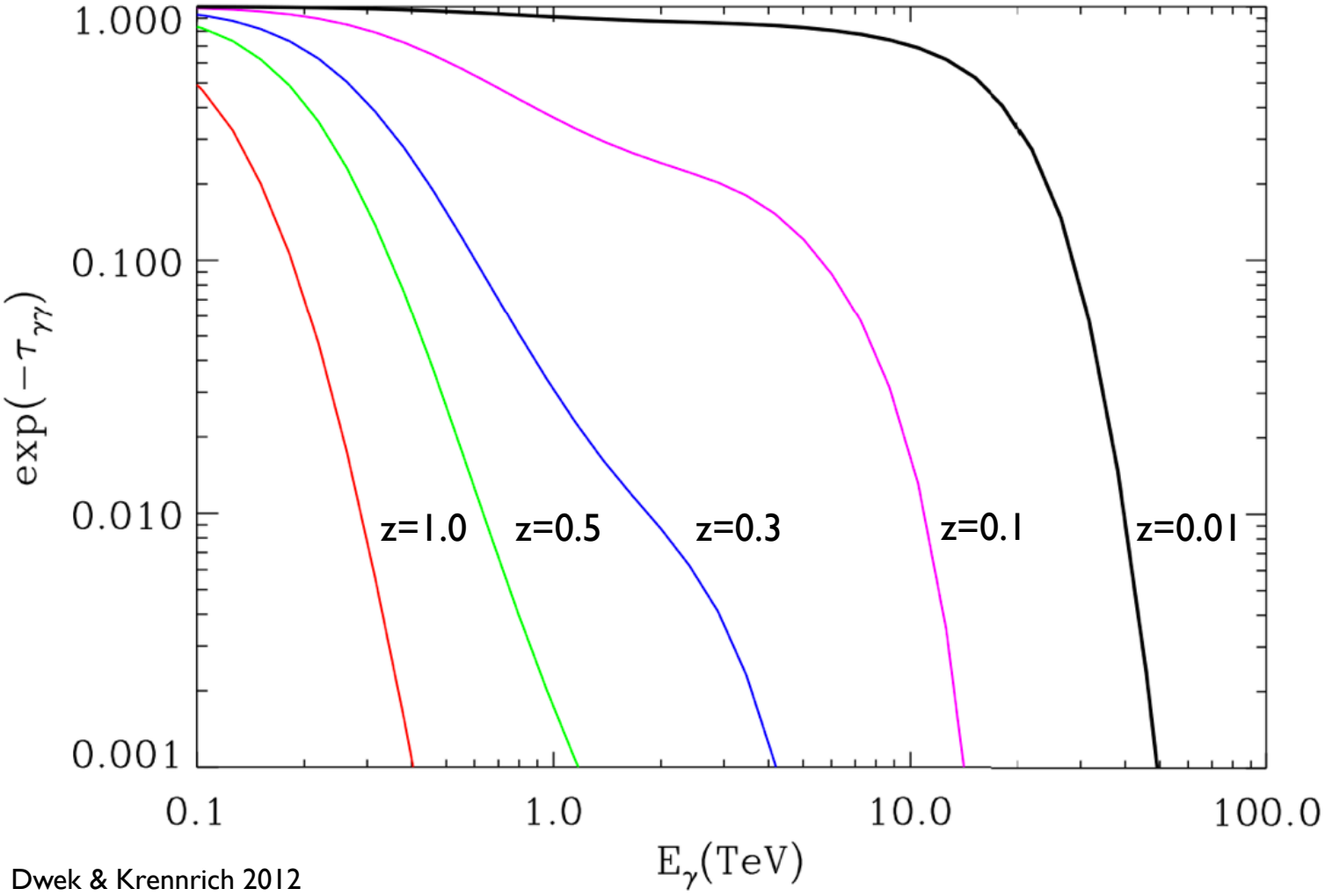
Extragalactic Survey



Extragalactic Survey

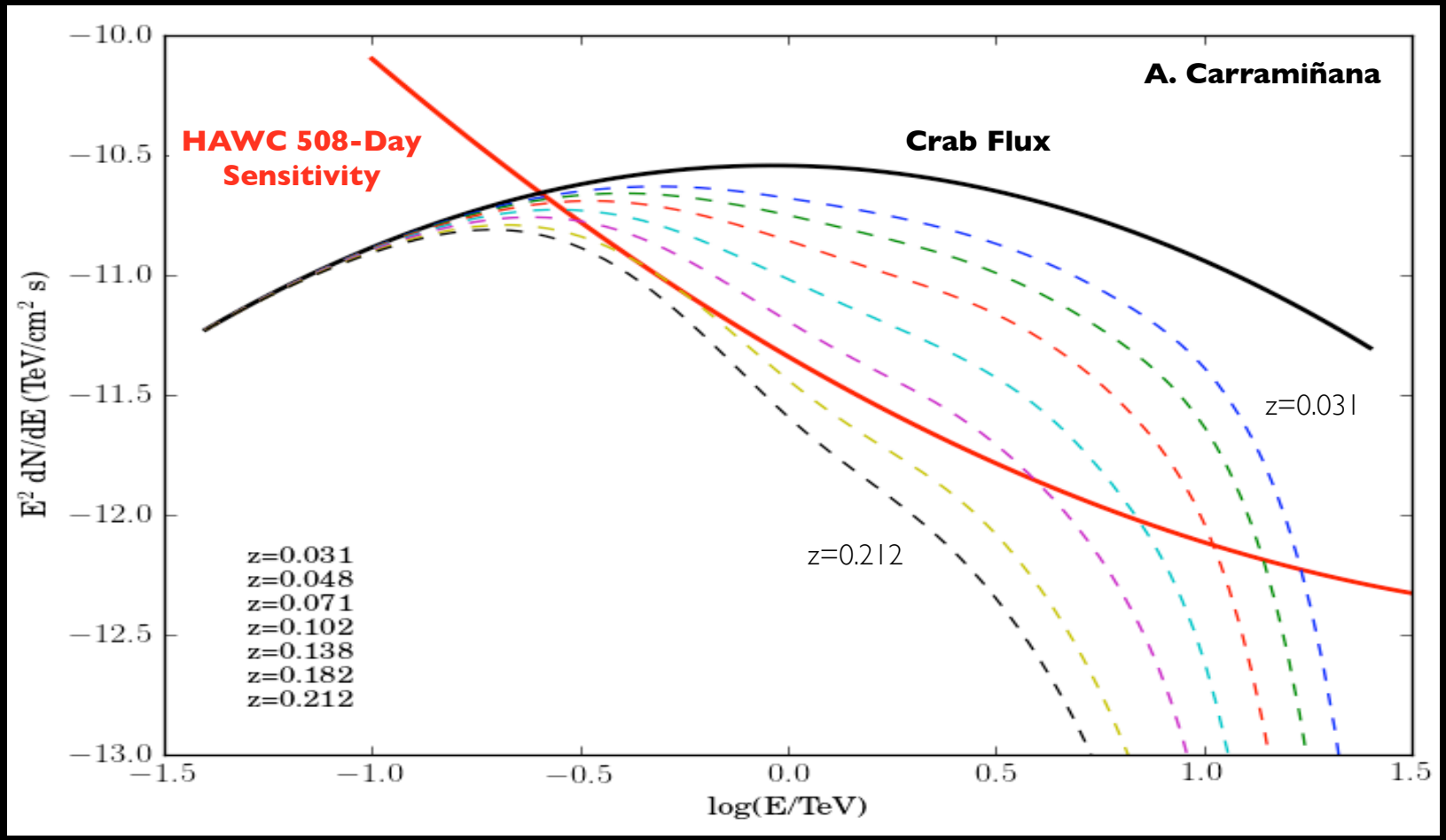


Spectral Distortion



Dwek & Krennrich 2012

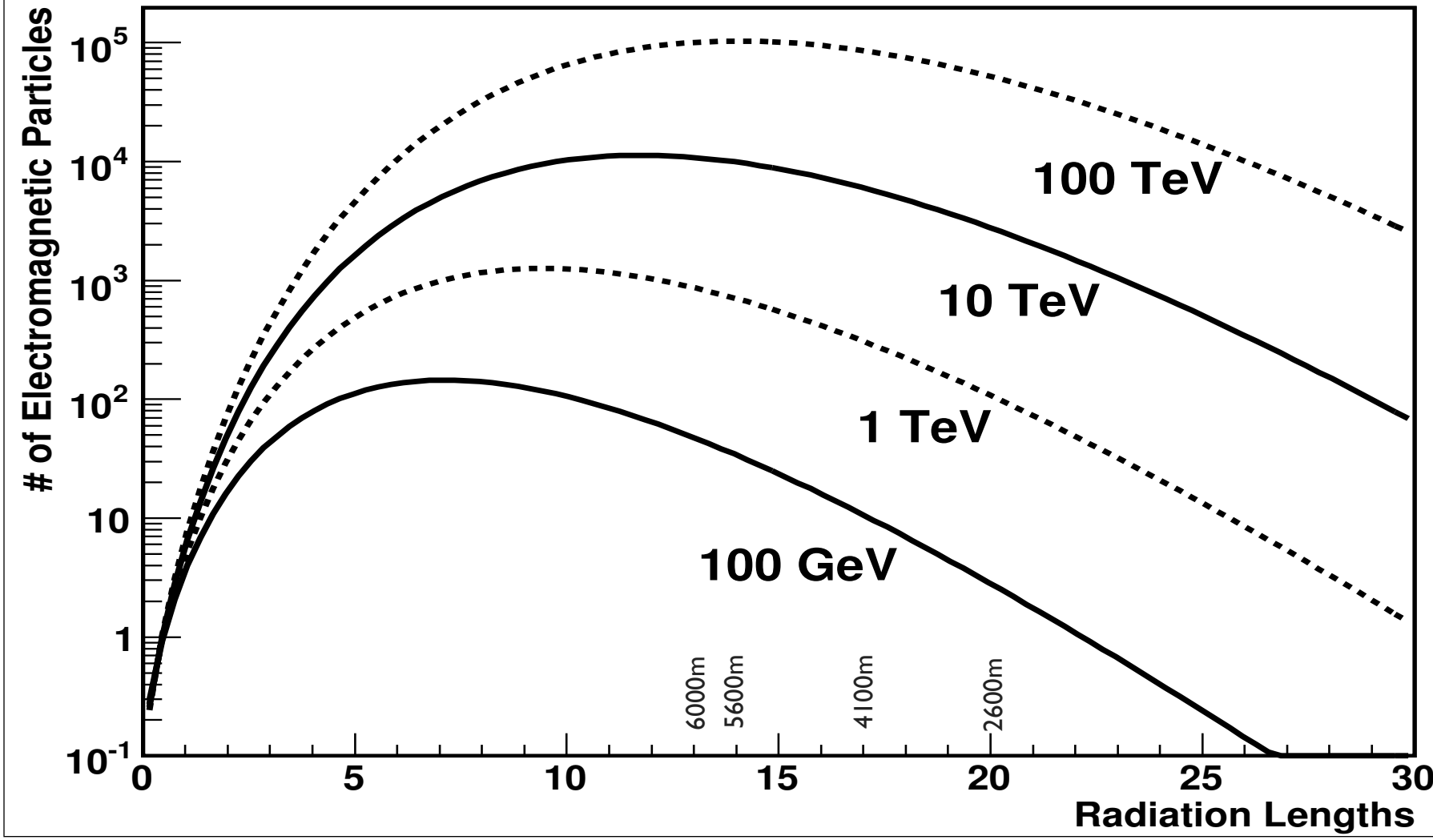
EBL Absorption



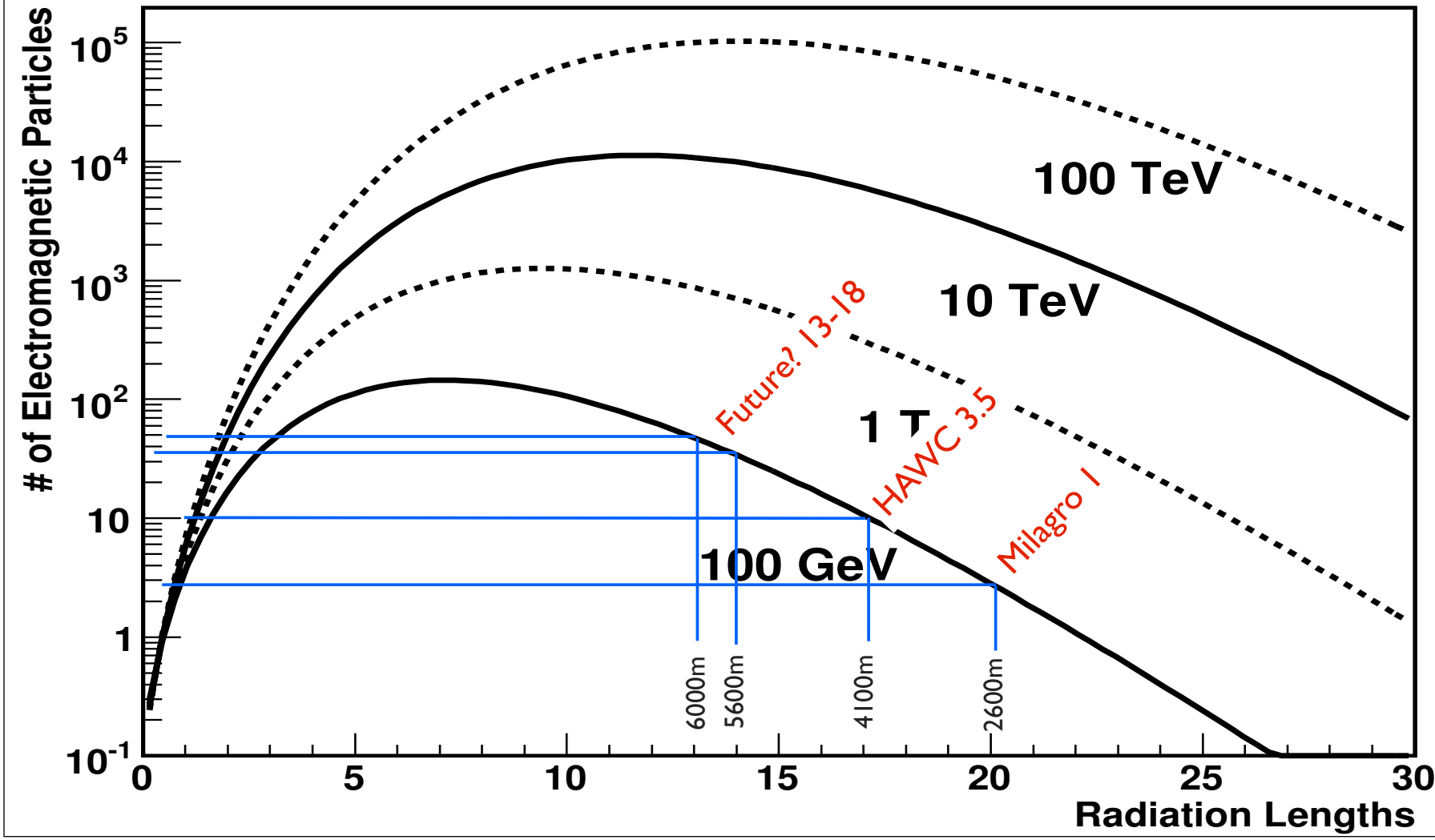
CTA and HAWC

- HAWC sensitivity well matched to current generation of IACTs (VERITAS, H.E.S.S., and MAGIC)
- To be useful to CTA we need:
  - ~10x greater sensitivity
  - Detection of transients
  - Requires significantly lower energy threshold
  - Southern hemisphere site
- Is this possible?

Extreme Altitude Array



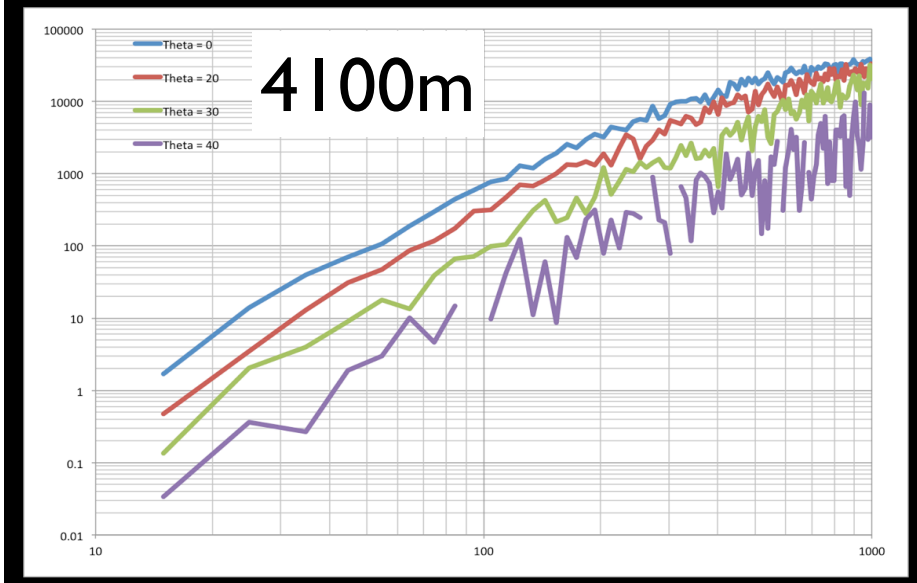
Extreme Altitude Array

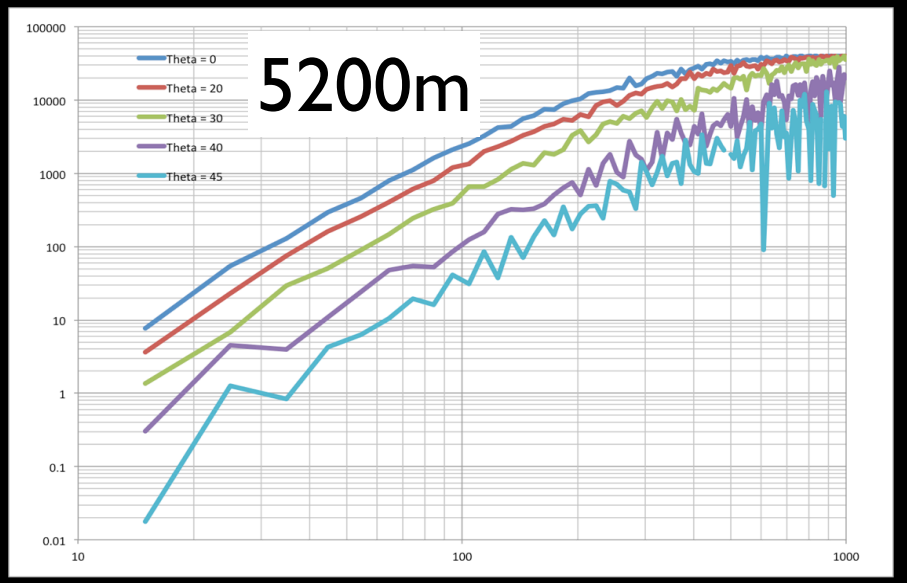


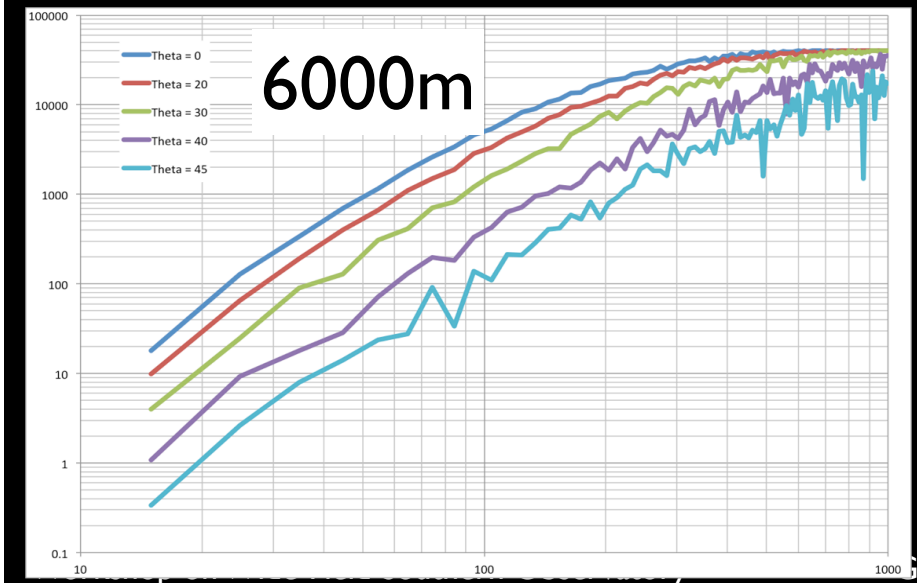
Extreme Altitude Study

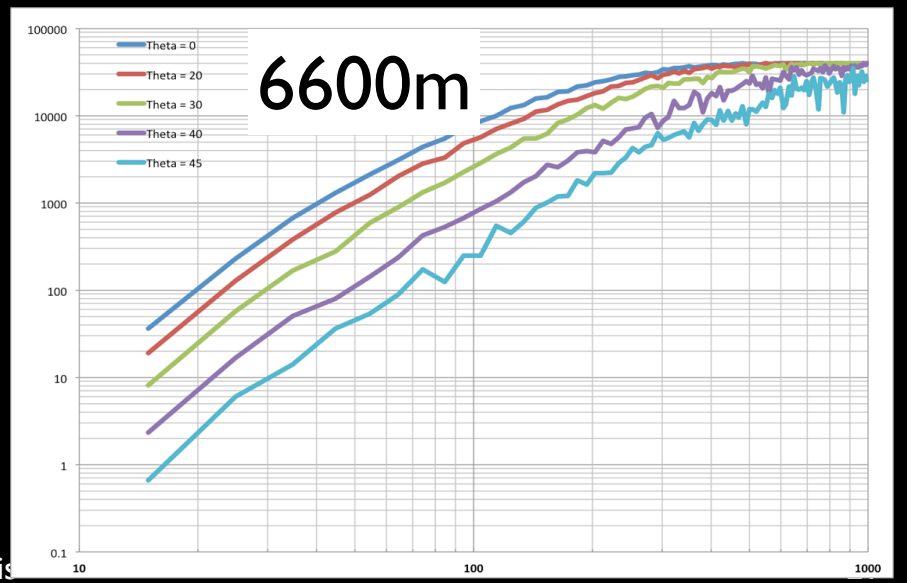
- Assume a 30 x 30 tank array with 3m separation (8100 m^2 total area)
- Each tank 1.5m deep x 3m diameter (dense pack)
- Single 10" high QE PMT at bottom looking up
  - 0.25 PE/MeV
  - 0.10 PE/MeV in HAWC
- Trigger on 30 (of 900) tanks
- No noise in simulation
- Test altitudes of 4100m (HAWC), 5200m, 6000m, 6600m
- Gamma rays from 10 GeV to 1 TeV ($E^{-2.3}$ spectrum)
- Protons from 10 GeV to 1 TeV ($E^{-2.7}$ spectrum)
- No background rejection used

Results: Effective Area



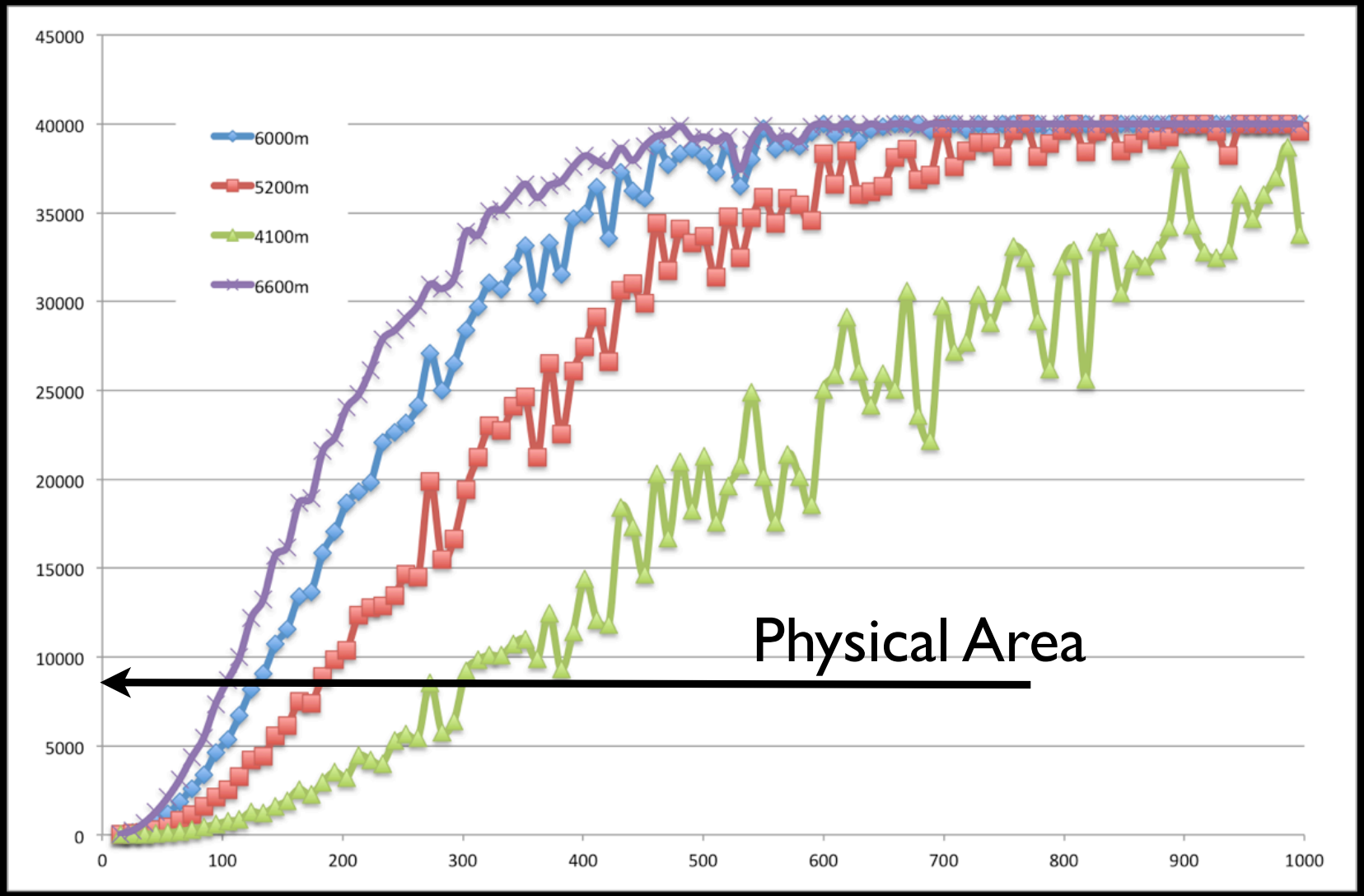




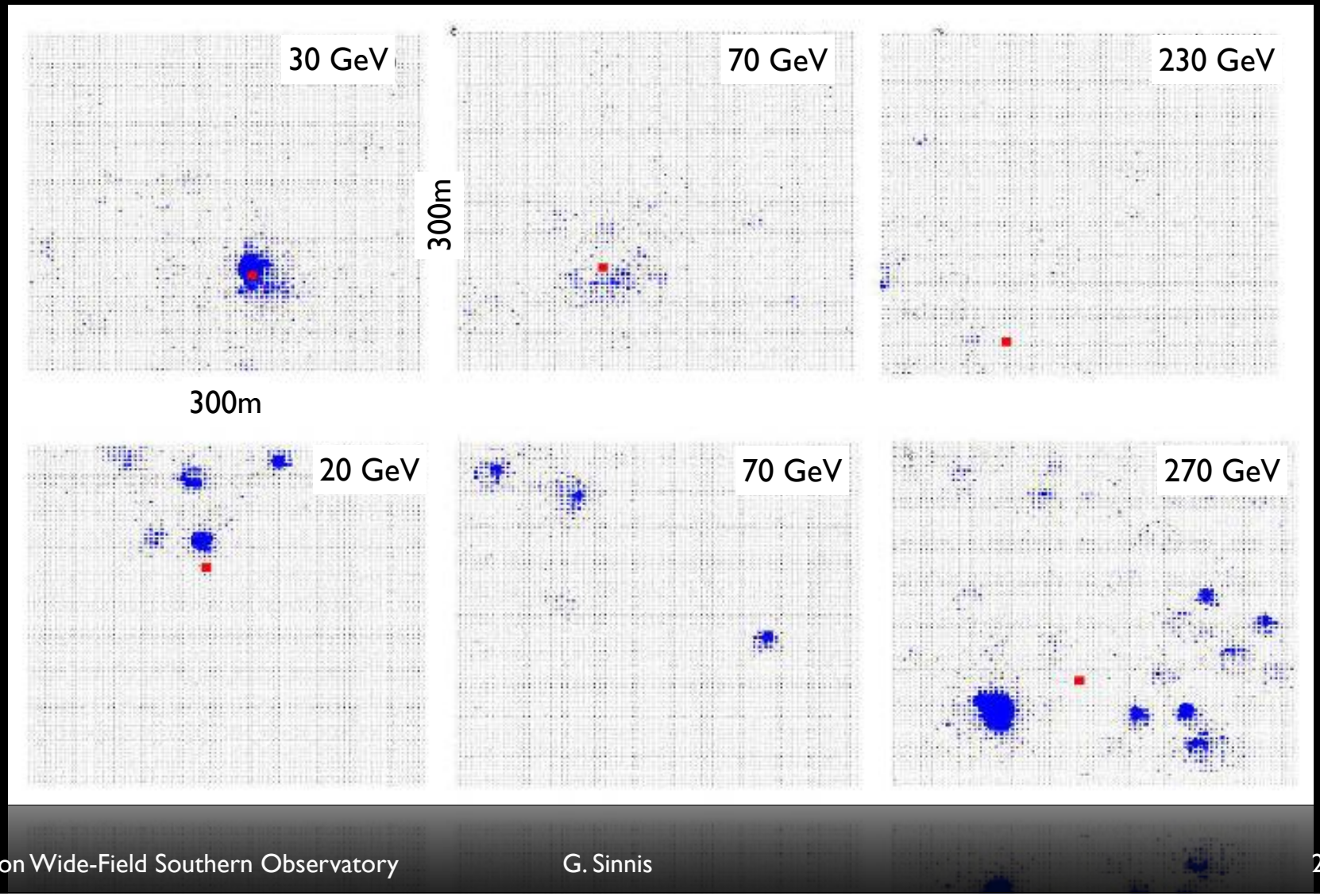


G. Sinnis

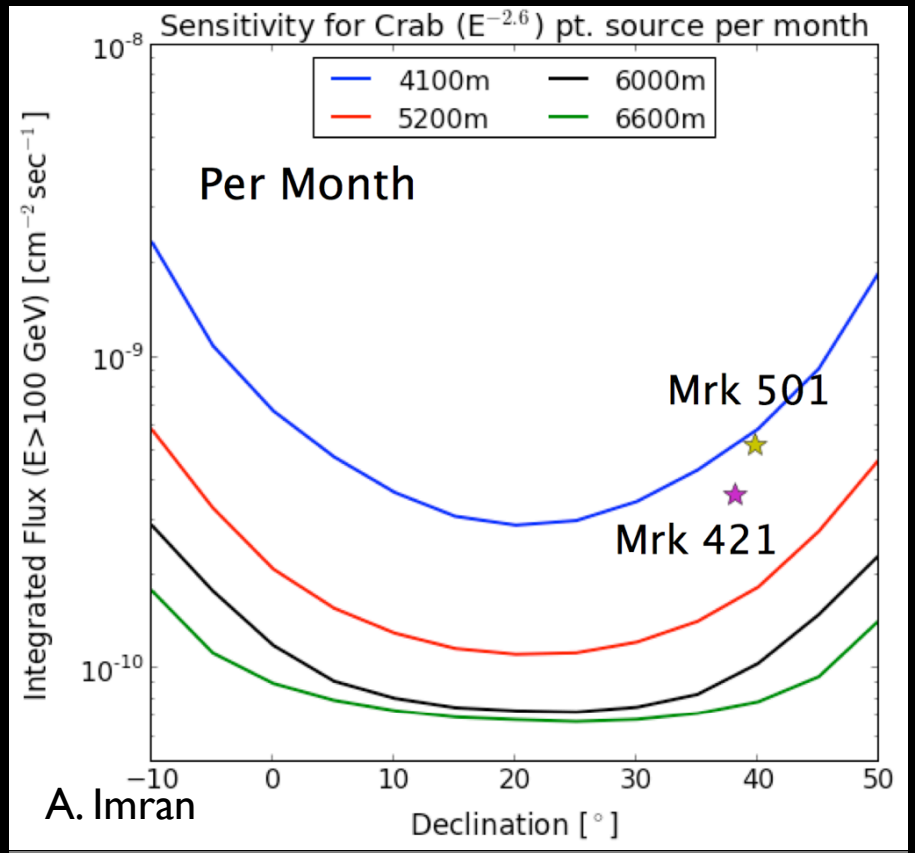
Results: Effective Area



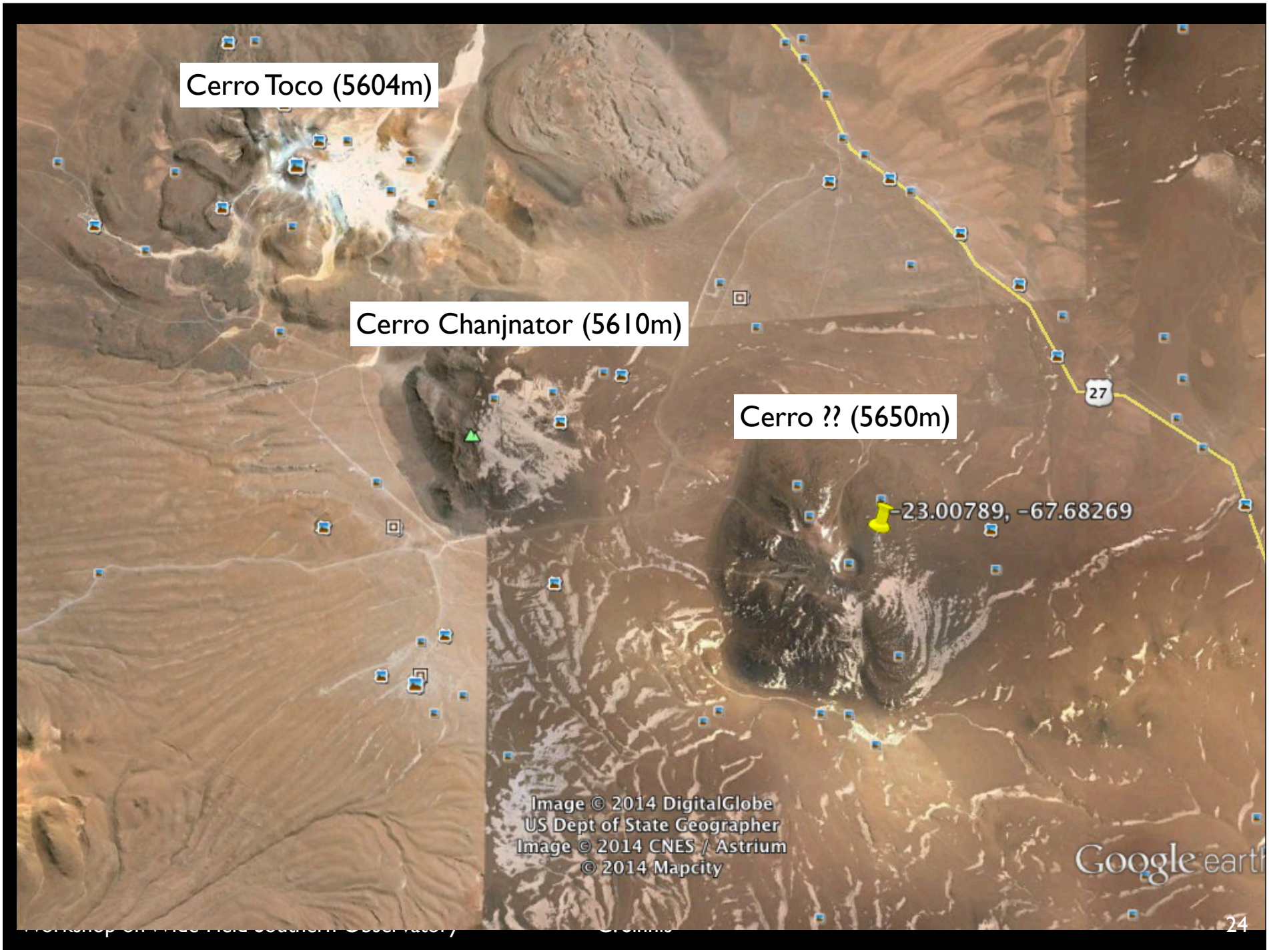
Background Rejection

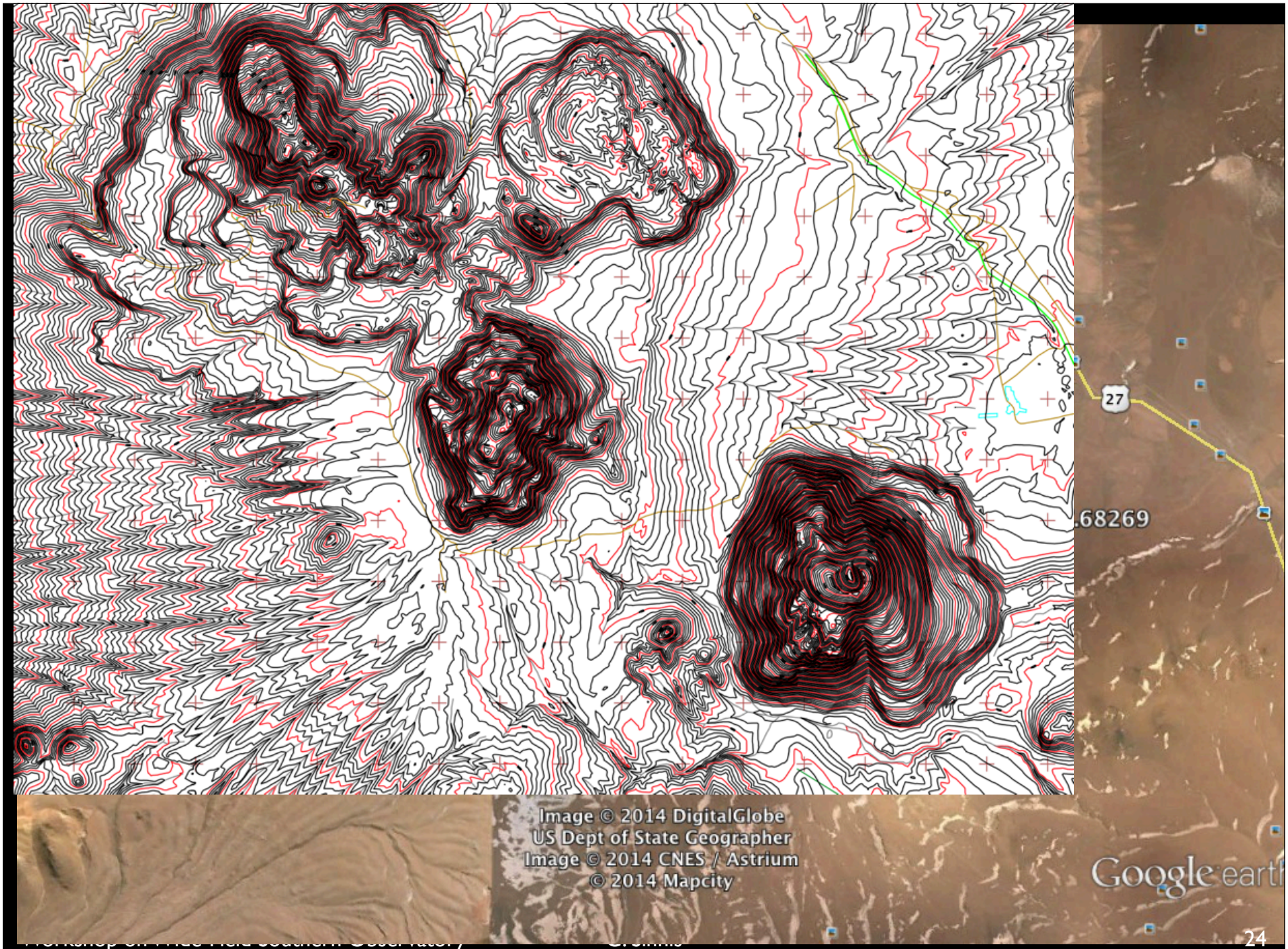


Results: Sensitivity



- An array at 6000m is ~5x more sensitive than the same array at 4100m
- >10x area at 100 GeV
- Larger improvement for extragalactic sources
- AGN and GRBs are strength of extreme altitude array
- 5-10x GRB detection capability of HAWC (I. Taboada)


Cerro Toco (5604m)
Cerro Chanjnator (5610m)
Cerro ?? (5650m)
-23.00789, -67.68269
27
Image © 2014 DigitalGlobe
US Dept of State Geographer
Image © 2014 CNES / Astrium
© 2014 Mapcity
Google earth


27
68269
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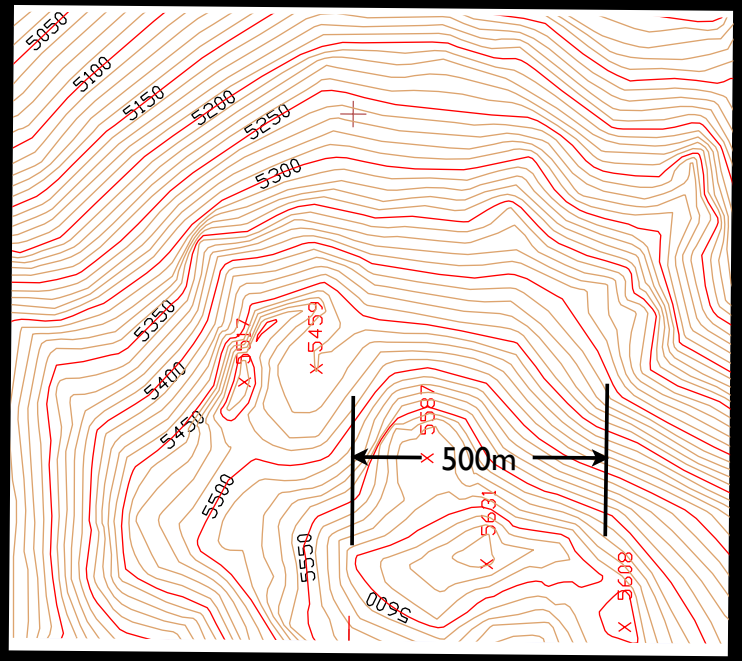
Google earth

Possible Sites
Chajnantor Science Preserve



Cerro Chajnantor
Location of CCAT
S 22° 59' 8.3"
W 67° 44' 25.0"
5611 m asl

Cerro ??
S 23° 0' 28.5"
W 67° 41' 8.0"
5650 m asl

Possible Sites
Chajnantor Science Preserve

Cerro Chajnantor
Location of CCAT
S 22° 59' 8.3"
W 67° 44' 25.0"
5611 m asl

Cerro ??
S 23° 0' 28.5"
W 67° 41' 8.0"
5650 m asl

Remaining Questions

- Is a background rejection capability necessary? And if so is it possible?
- Proper modeling of low-energy response of an array
  - realistic noise model - including correlations
- Realistic sensitivity to AGN flaring and GRBs - what can we expect to see?
- Is this sufficient to justify construction of an all-sky southern observatory

Summary

- HAWC has successfully detected a large number of Galactic sources - huge success!
- CTA will survey the Galaxy and will be sensitive to extended sources
- The extragalactic sky has (for the most part) eluded HAWC's sensitivity
- A future southern observatory must achieve a significantly lower energy threshold: $\lesssim$200 GeV
- Altitude will be the dominant factor - assuming a dense sampling array, sensitive to gammas and electrons.
- Work is needed to determine the necessary altitude
- 5600m seems to be the highest available location
- Scientific justification has not yet been established

Cerro Chajnantor

The CCAT site is an immense asset that the team wants to fully utilize. At 5600 meters above sea level in the Atacama Desert in northern Chile, the transparency of the atmosphere is unique. The