Feasibility of an Air Cherenkov Array as an Atmospheric Neutrino Veto

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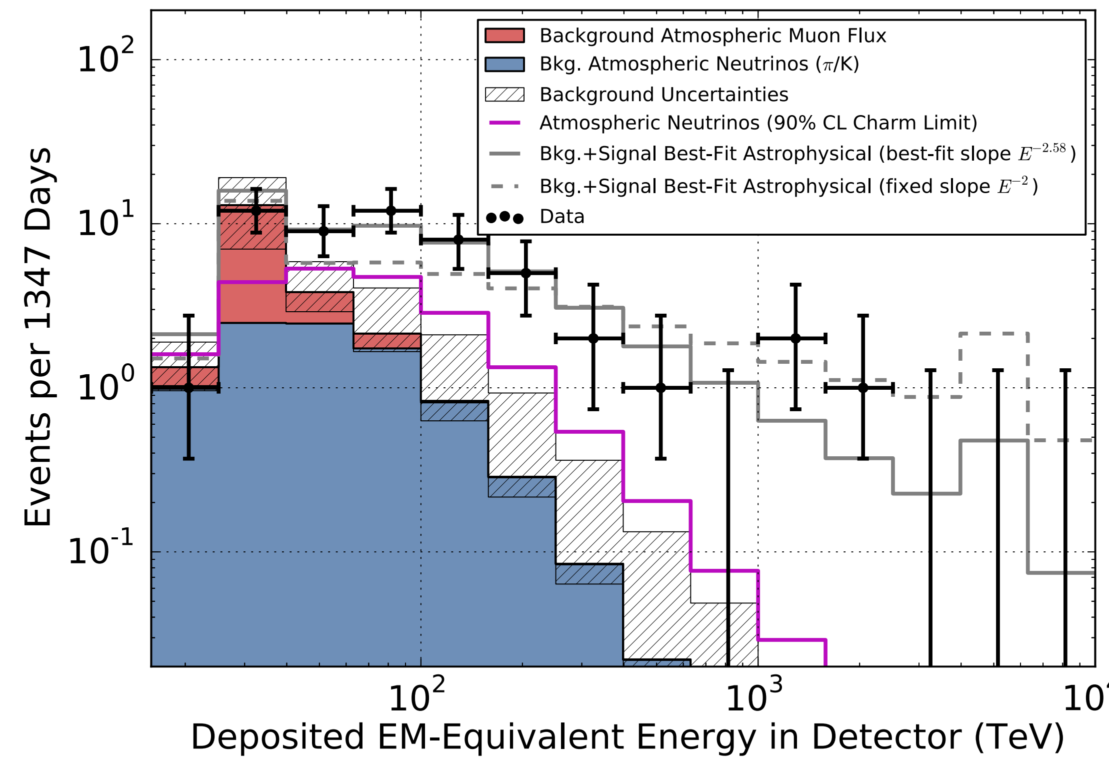
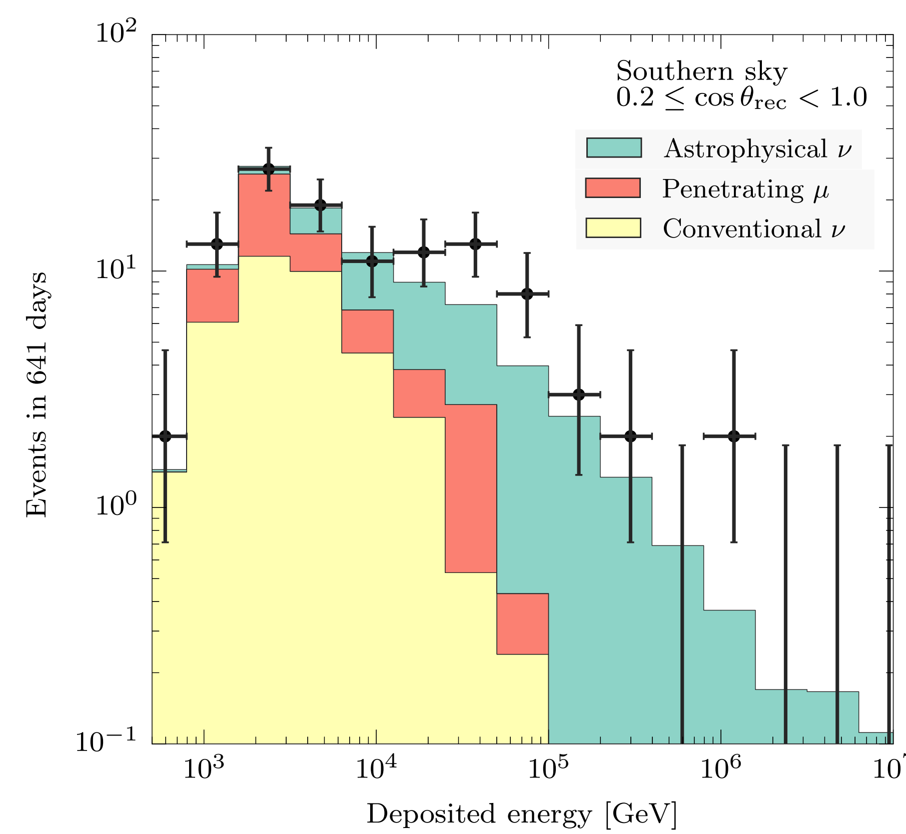
Astrophysical Neutrino Spectrum

arXiv:1510.05223, *Phys. Rev.* D91, 022001 (2015)

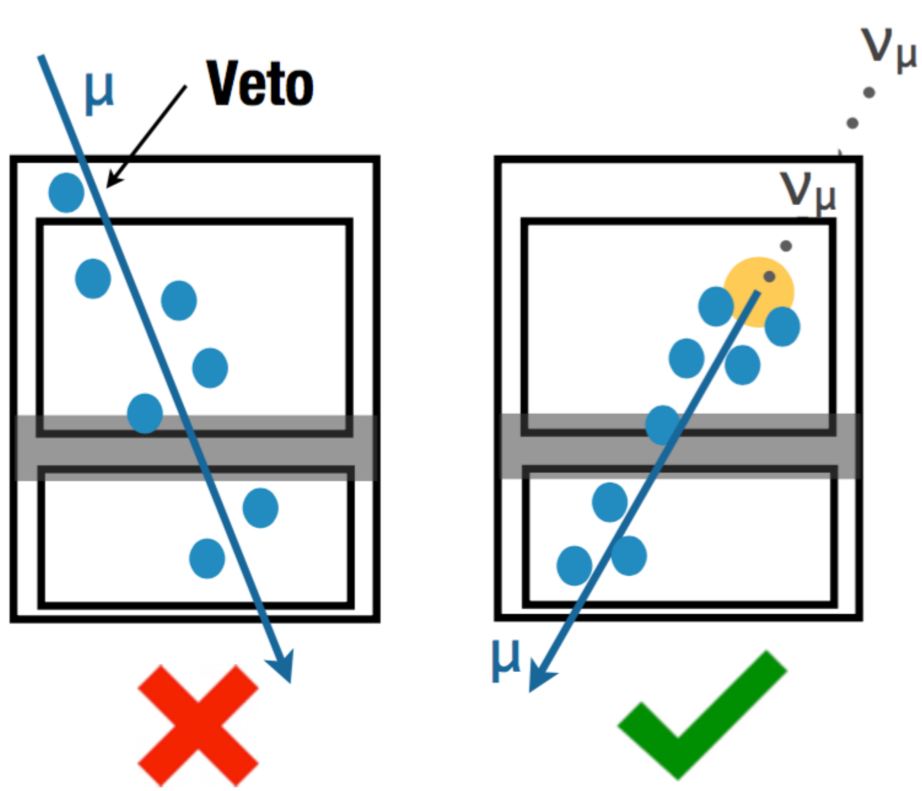
- Growing evidence the astrophysical neutrino spectrum does not follow a simple power law
  - Multiple populations of sources, complex source dynamics,…?
- Atmospheric neutrinos limit the observable energy range
  - Something interesting at a few 10's of TeV?
  - Low energy behavior important for understanding relationship to extragalactic gamma ray background

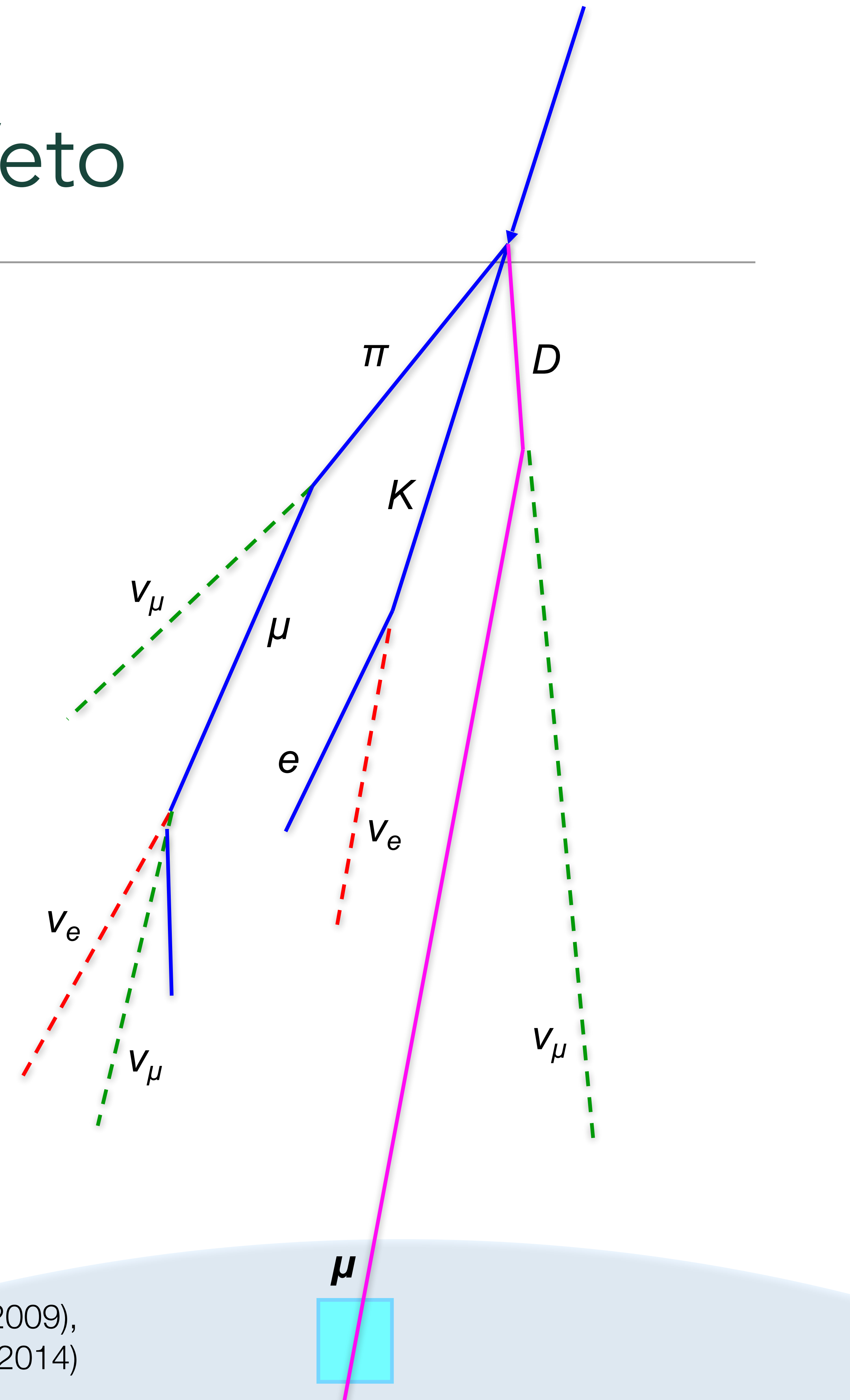




Atmospheric Neutrino Veto

- Atmospheric neutrinos are a foreground to neutrino telescopes
- Can be vetoed by detecting the neutrinos' parent air showers



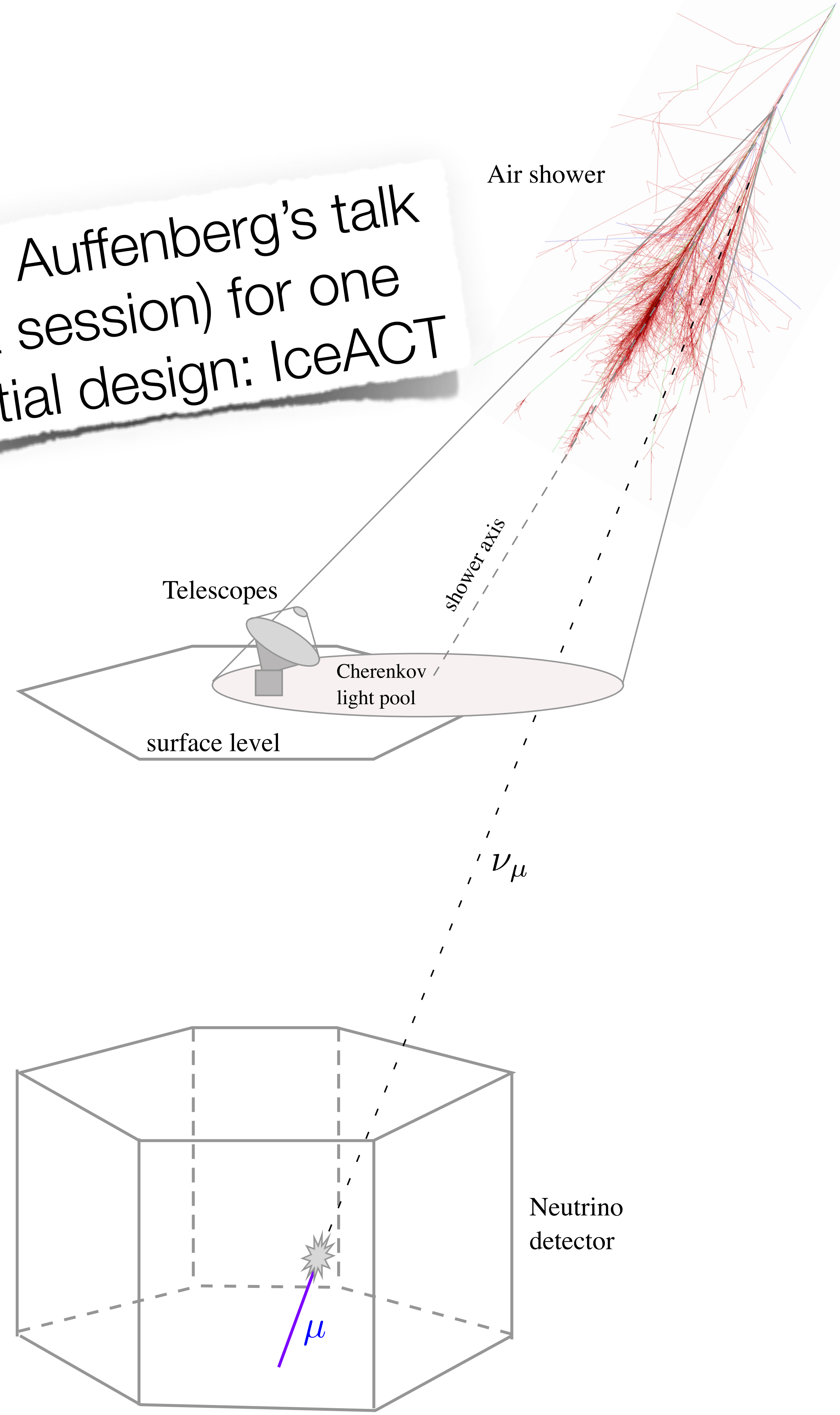


Schönert, Gaisser, Resconi and Schulz, *Phys. Rev*. D79, 043009 (2009), Gaisser, Jero, Karle and van Santen, *Phys. Rev*. D90, 023009 (2014)

Air Cherenkov Veto

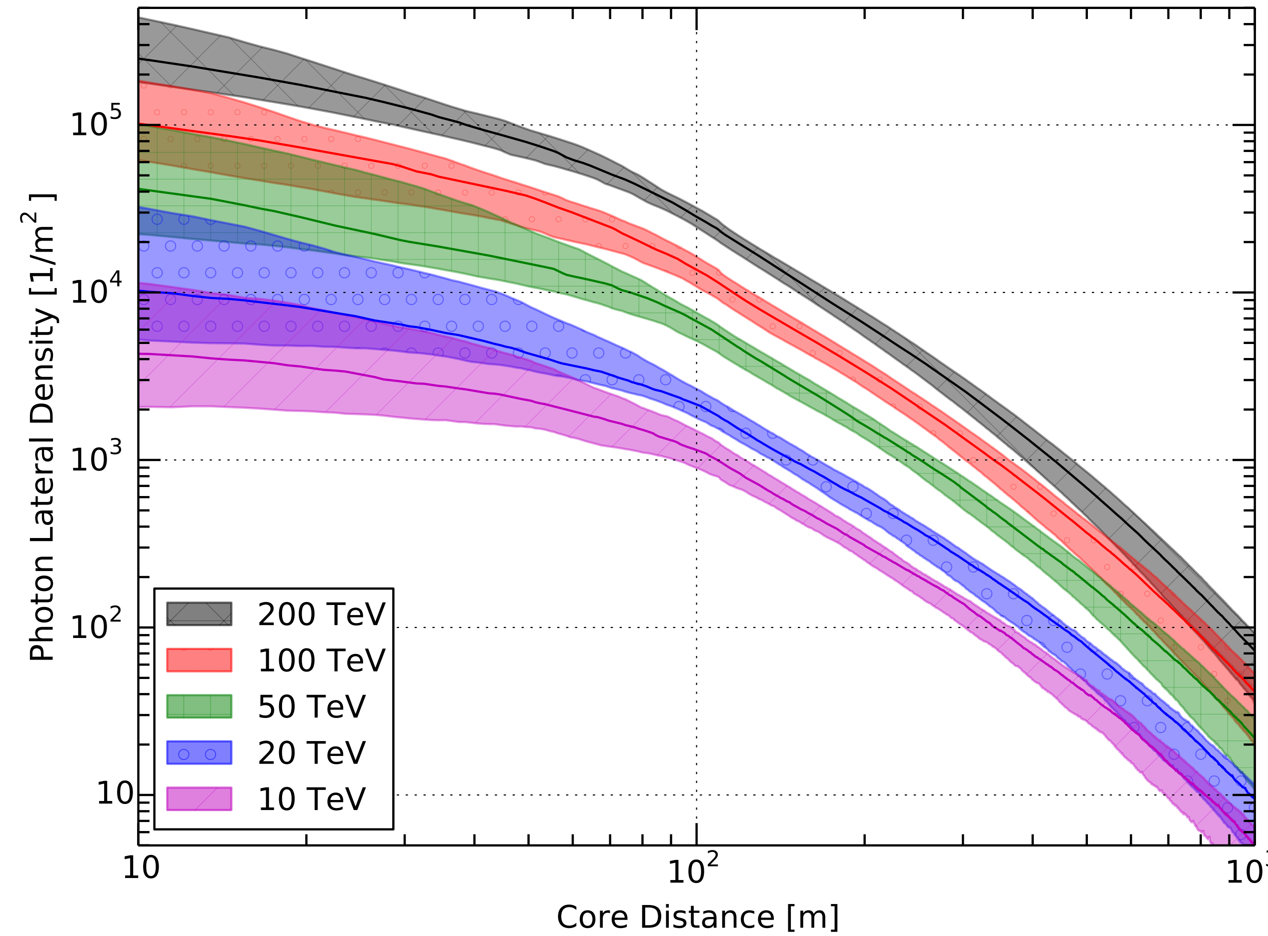
- Muon detectors under 1.5 km overburden not the most obvious way to detect air showers
  - Alternatively, look for particles reaching the surface or Cherenkov photons emitted by the shower
- Inexpensive Cherenkov detectors offer intrinsic directionality and low threshold, light pool extends for hundreds of meters
  - Main drawbacks are restricted duty cycle, background stability

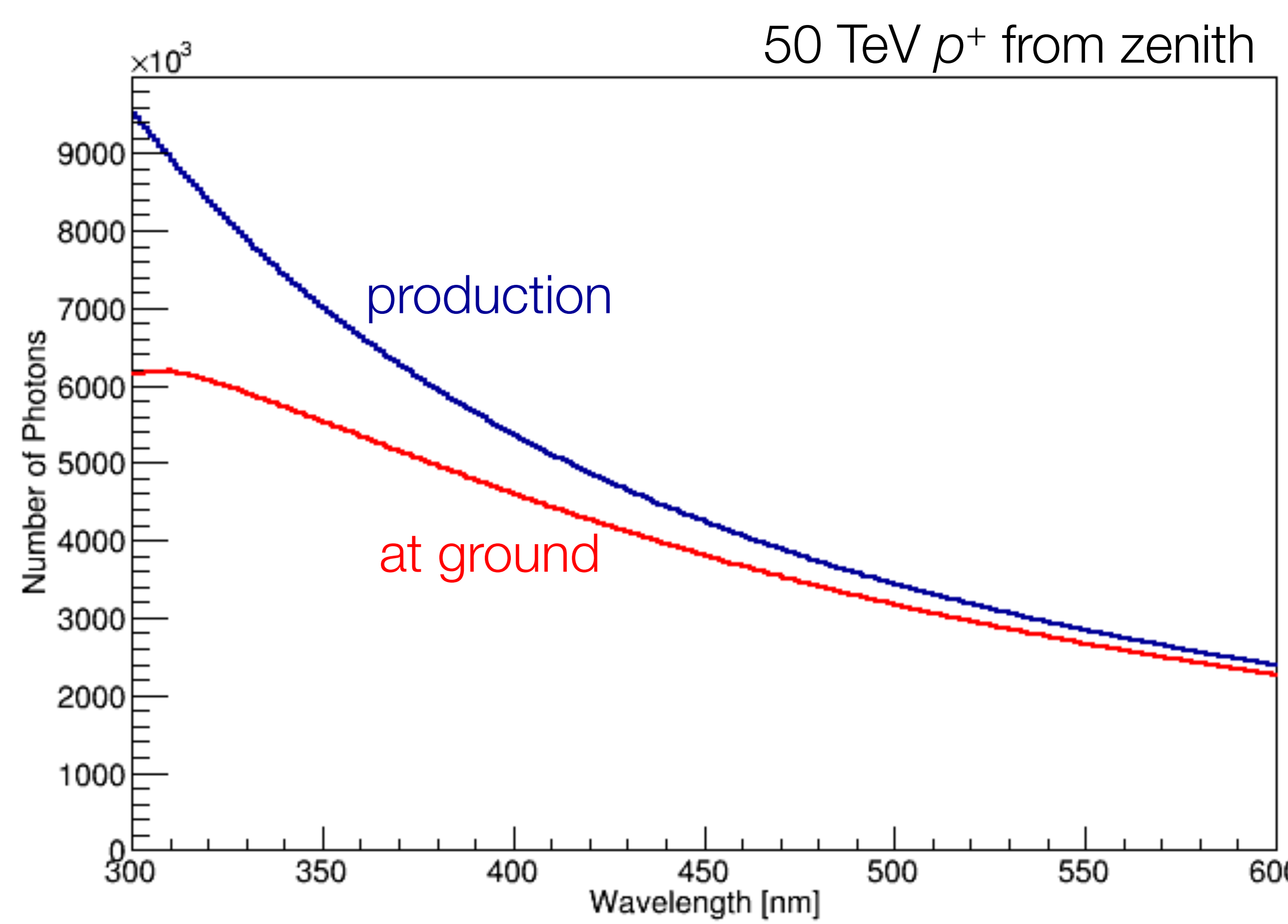
See J. Auffenberg's talk (next session) for one potential design: IceACT



Cherenkov Emission

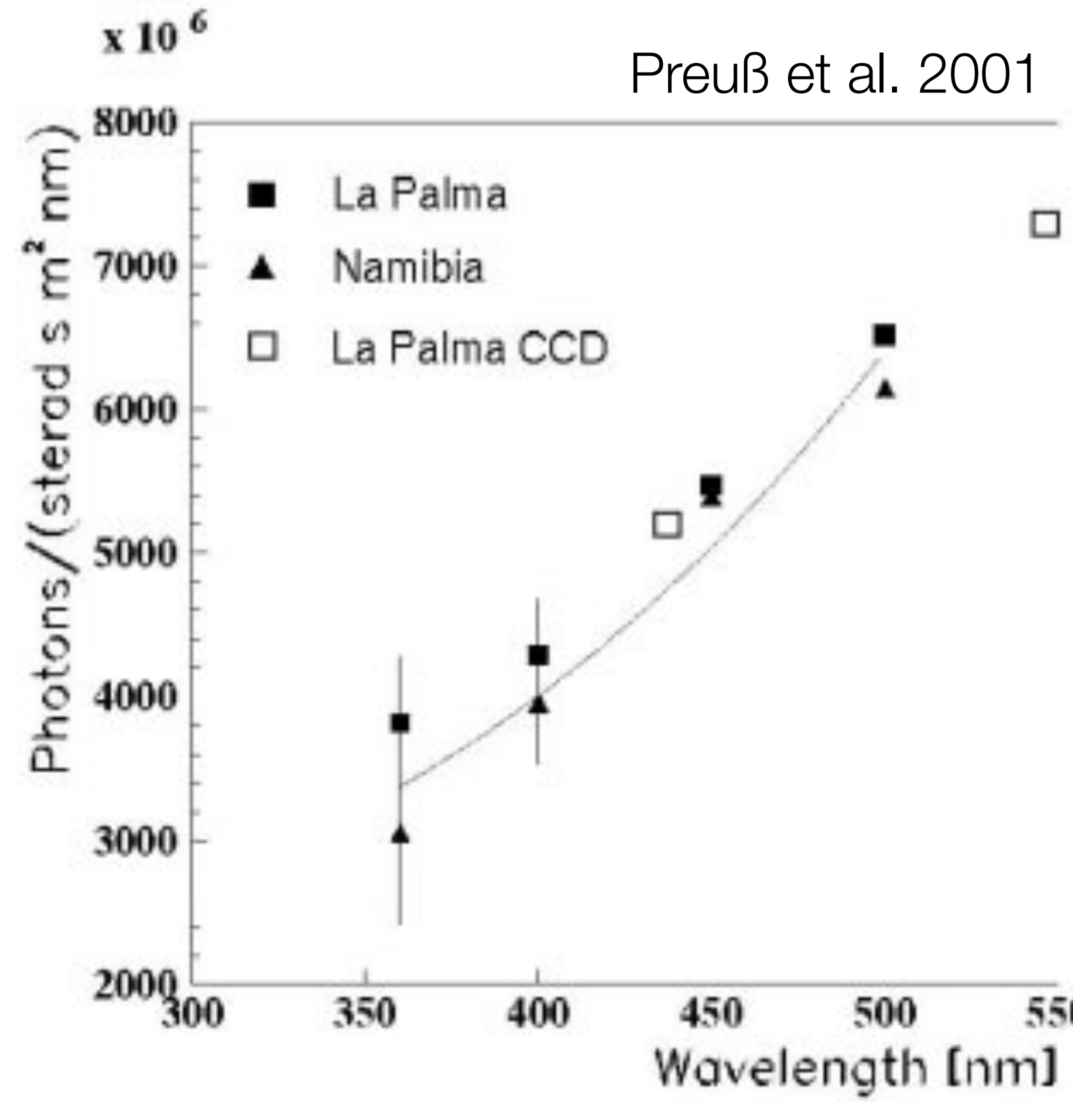
- Photon density falls off more rapidly beyond ~100 m from shower axis
  - Shower-to-shower variation is larger in the center, density is more consistent at edges
- Photon spectrum flattened somewhat by atmospheric attenuation
  - Weakly dependent on energy and zenith (to 60°) → ignore for now
- Arrive in a fast pulse: 20 ns window collects ~75% of photons even at edges of light pool





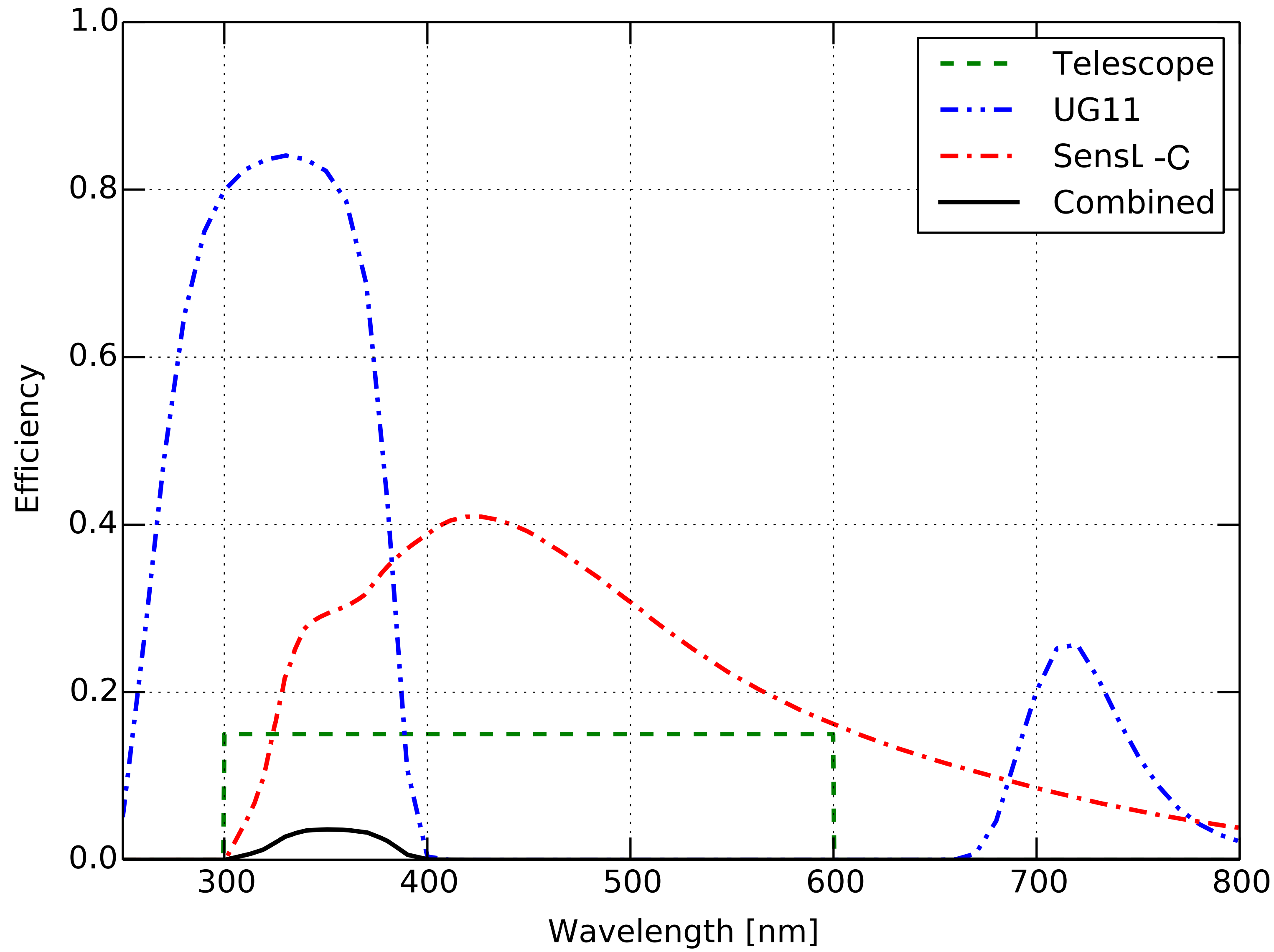
Background Light

- Night sky background
  - Using a model from La Palma/Namibia (should be conservative for South Pole)
  - Roughly follows $\lambda^{3.5}$ spectrum
- Dark counts
  - Dark rate of SensL-C SiPM is 200 Hz/mm^2 at -30°C (highest recorded SP winter temp.)
  - For a 61-pixel camera with 6 mm x 6 mm SiPMs: <1% probability of a single dark count in a 20 ns trigger window → ignore
- Aurora australis
  - Emission primarily in lines (notch filter?) – not believed to be show-stopper in *U* or *B* bands, but still under investigation



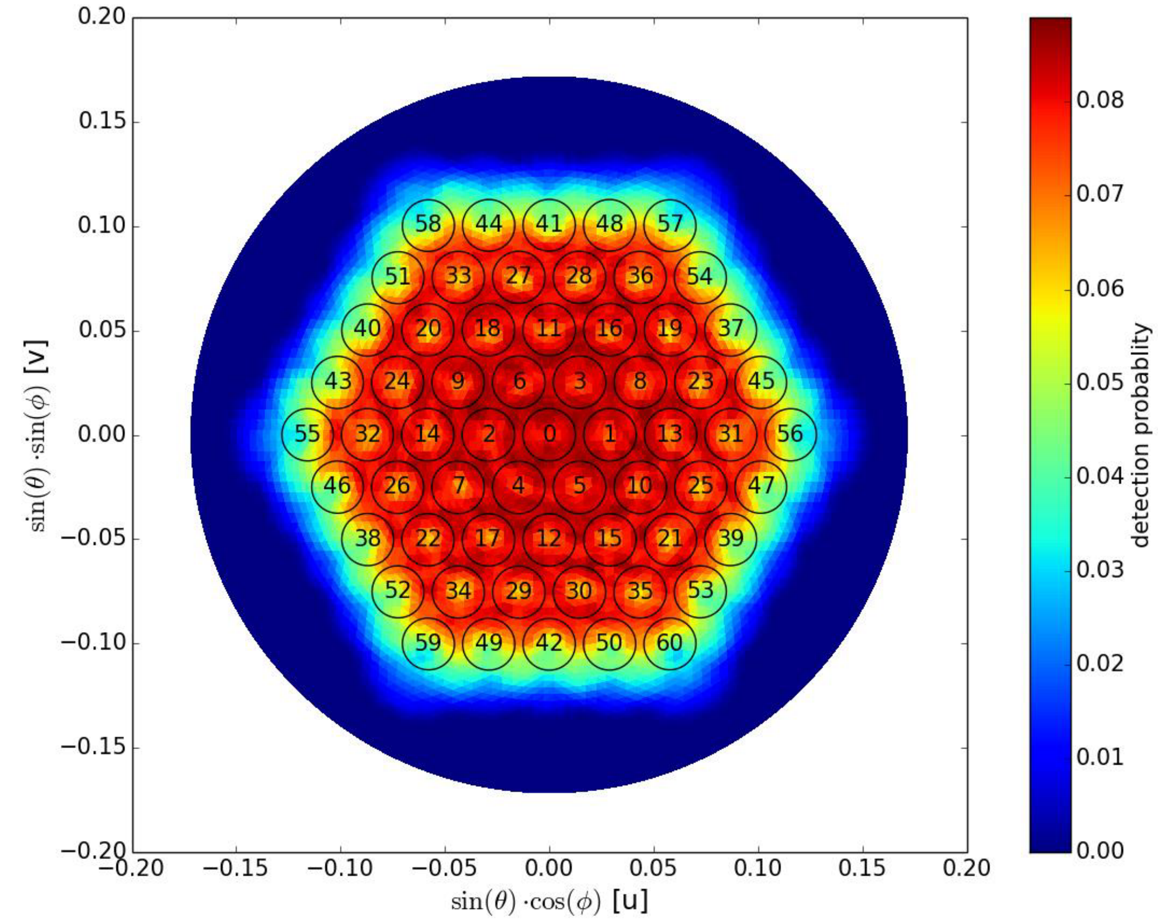
Photon Detection Efficiency

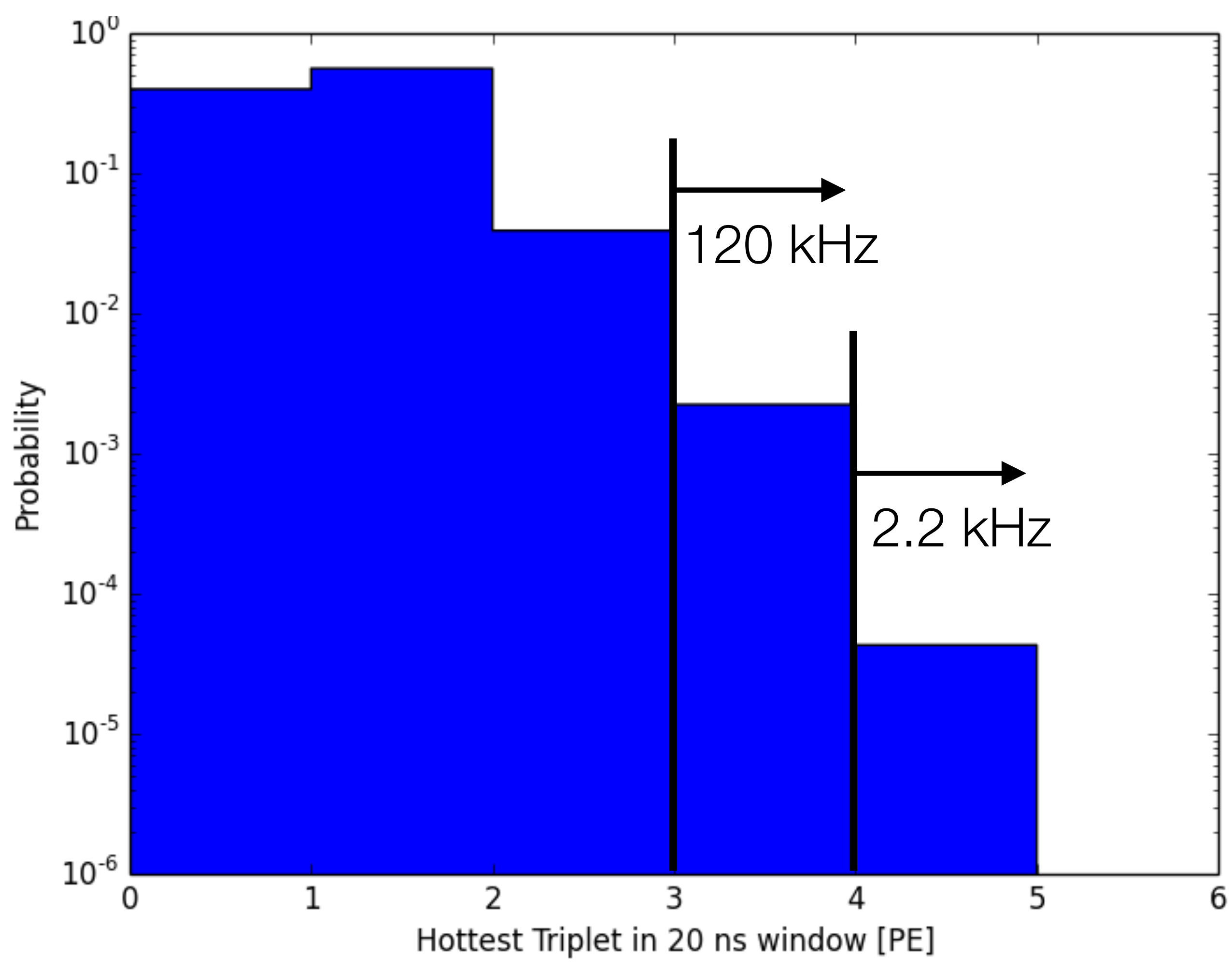
- Assumed optical efficiency of telescope (lens, geometry, camera plane instrumentation, etc.): 15%
- SiPM collection efficiency
  - SensL-C assumed for now
  - New J model, better in UV?
- UG11 glass filter to cut out long wavelengths
  - Extends lower than sensitivity of currently assumed SiPM model
  - Inclusion under study



Straw Man Trigger

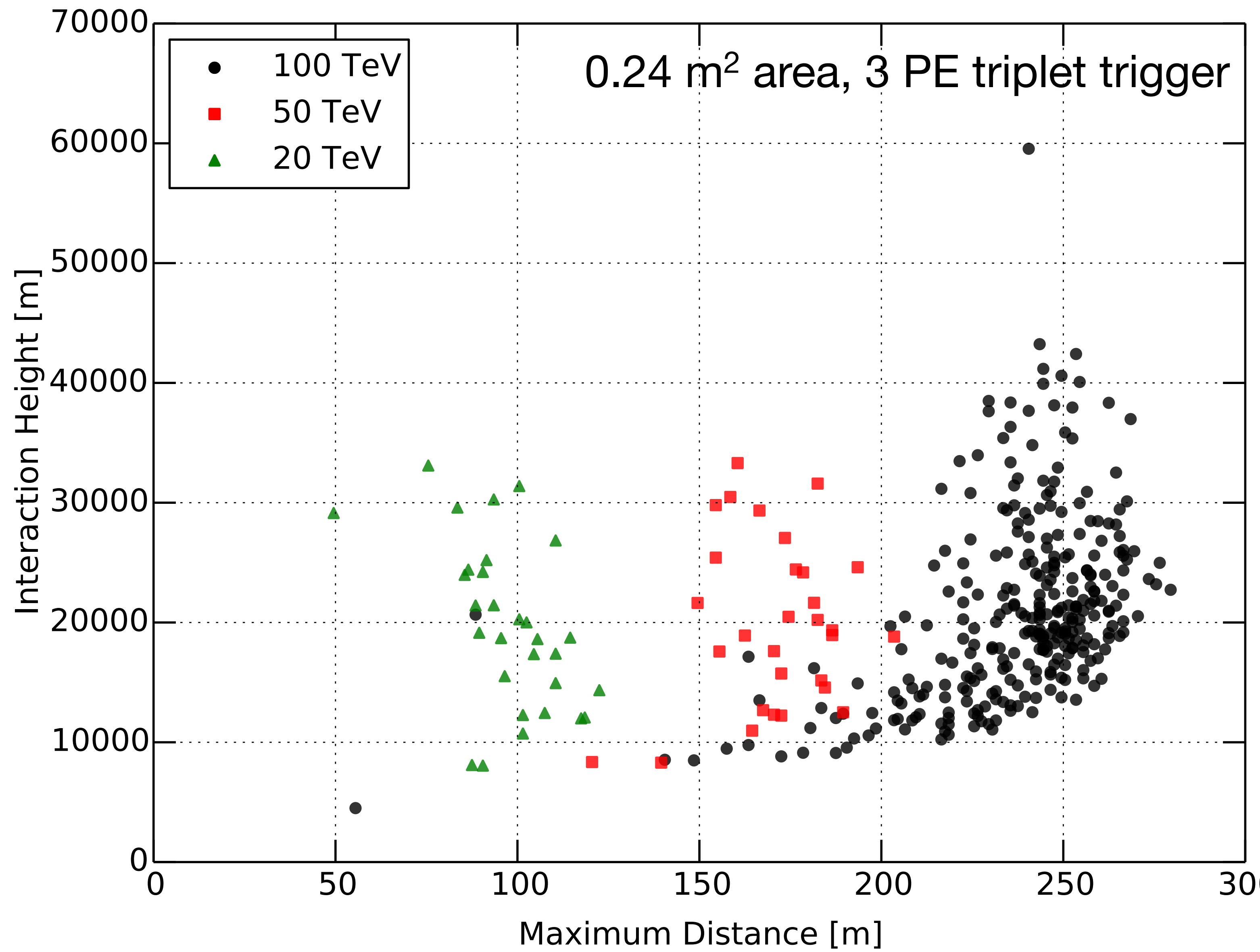
- Envision buffering trigger primitives for few seconds, readout only for IceCube trigger coincidence
- NSB background rate 6.36 x 10^{-2} PE pixel^{-1} $(20\ \text{ns})^{-1}$ m^{-2} after efficiencies
- Toy MC of a coincidence trigger for an IceACT-like telescope: Q_{tot} in 20 ns in three neighboring pixels
    - Threshold of ≥3 PE gives 0.2% accidentals → ~120 kHz rate
    - Threshold of 4 PE gives accidental trigger chance of ~4 x 10^{-5} → ~2.2 kHz





Shower Detection Distance

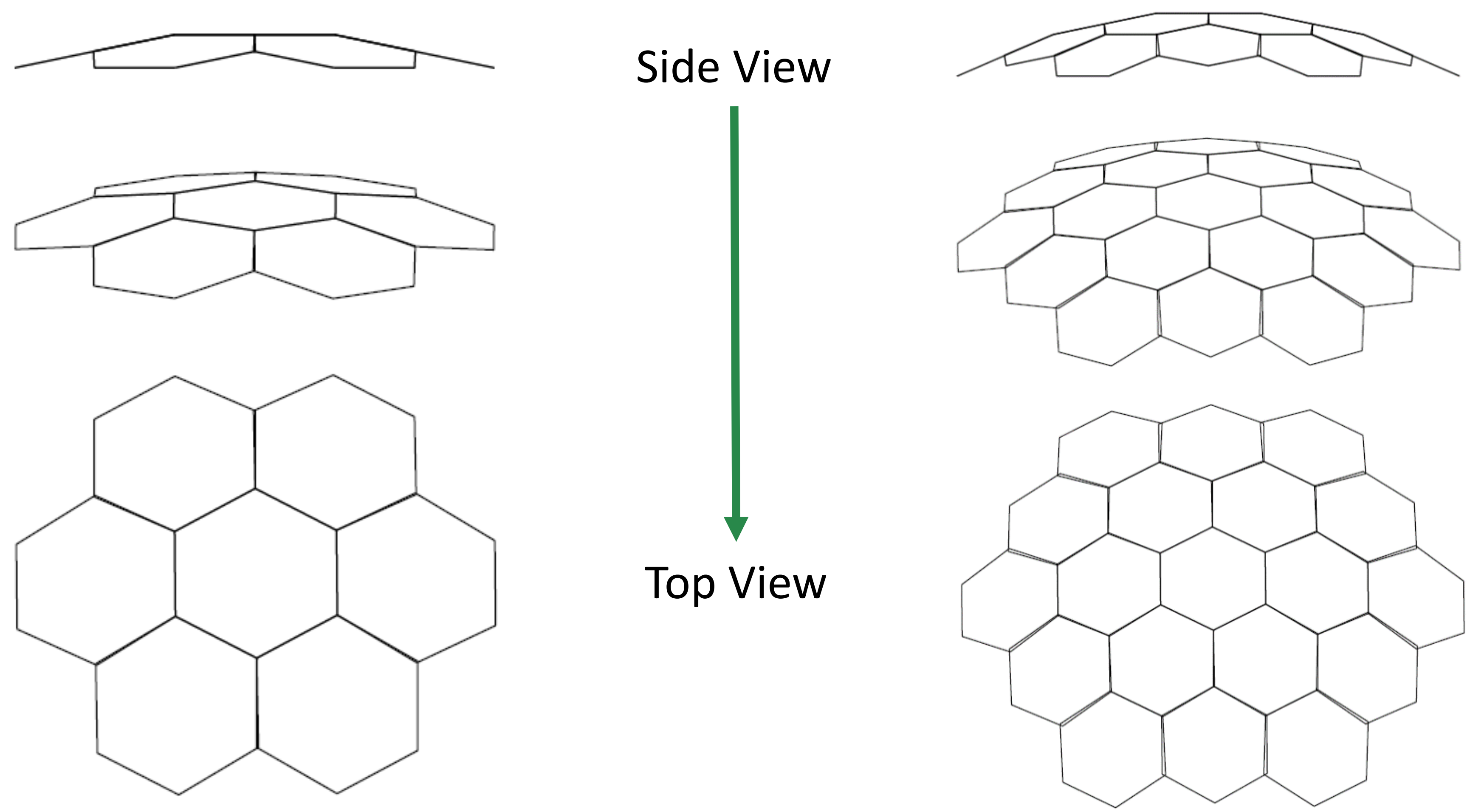
- Simulated vertical proton showers at three energies with Corsika
  - Most missed showers penetrate too deeply, Cherenkov light pool doesn't have time to spread out
  - Vertical protons are therefore worst case
- ~99% of 100 TeV showers detectable out to 150 m
  - Corresponds to ~30 TeV atmospheric neutrinos



Multi-Telescope Stations

18° FOV FROM ZENITH
7 telescopes per station

30° FOV FROM ZENITH
19 telescopes per station



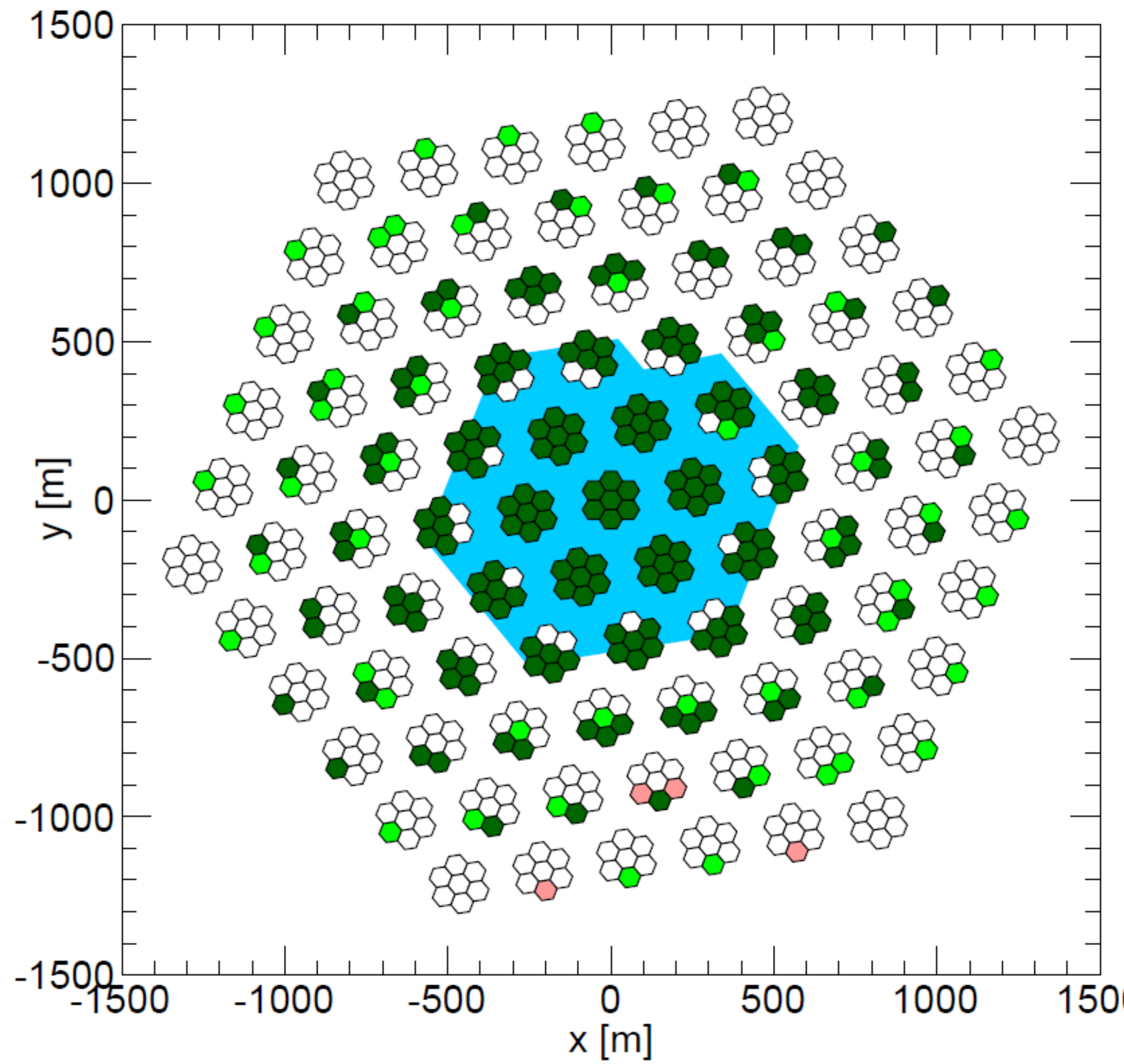
- Envision stations with multiple small telescopes in a fly's-eye arrangement

A Possible Air Cherenkov Veto Array

18° FOV from zenith

How many DOMs seen	Number of Telescopes
n > 50	196
10 < n ≤ 50	53
0 < n ≤ 10	4
n = 0	384

~250 telescopes required to cover 18° from zenith (~700 for 30°)

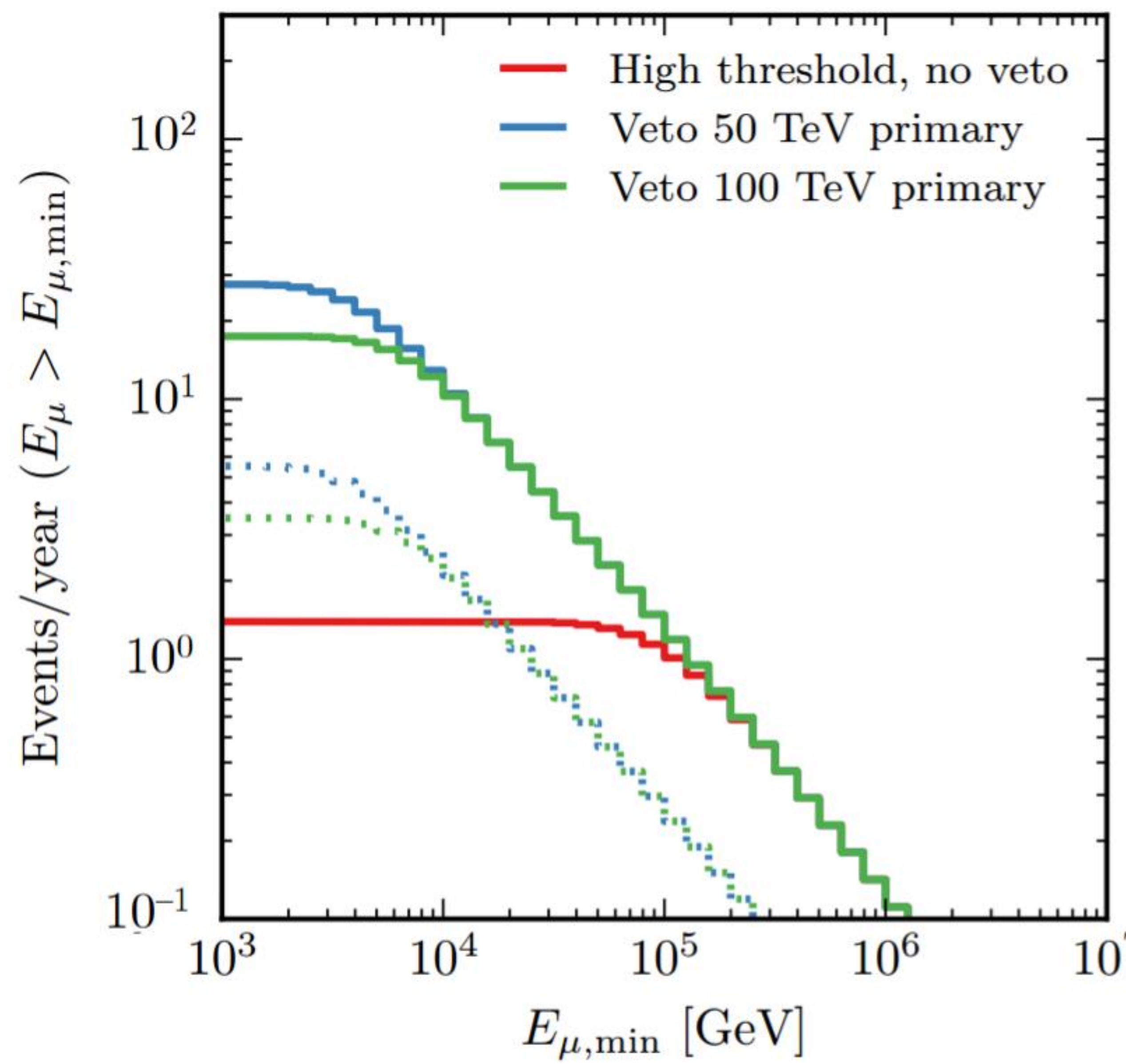


- Per-telescope cost estimate ~10,000€ (plus cables, etc.)
- Also investigating a ring array for Galactic Center → comparable # telescopes

Impact on Neutrino Astronomy

- Preliminary measurements from South Pole indicate ~20% duty cycle is possible

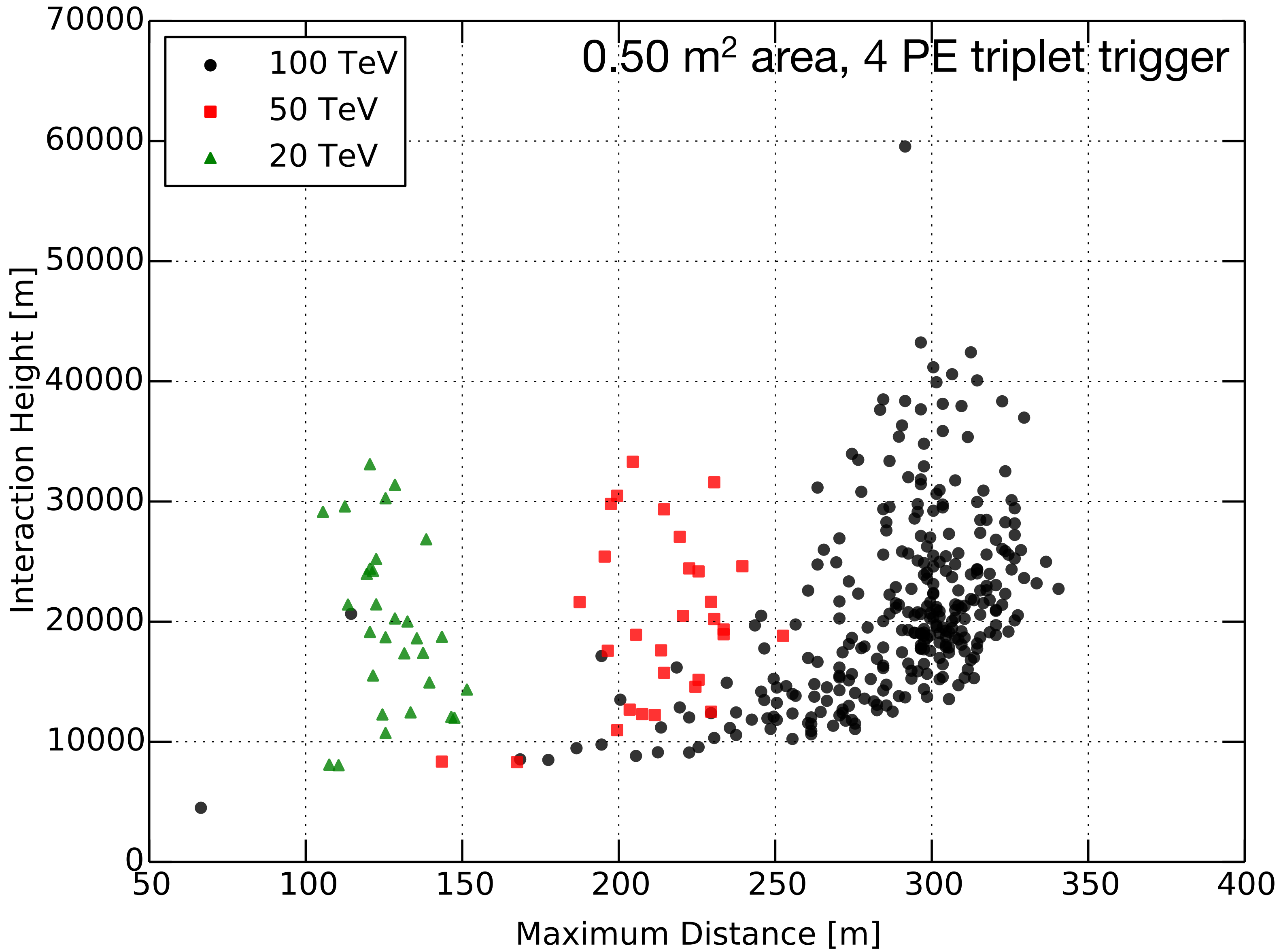
- For a source in the field of view with $dN/dE \sim E^{-2.5}$ spectrum, factor of 2-3 increase in through-going muon rate
  - Assumes step-function efficiency, needs to be refined



- Could also increase fiducial volume for starting events (now only 40%)

Larger Telescopes?

- Assume telescope collection area of 0.50 m^2 (~2x IceACT)
  - Crudest approach: two IceACTs
  - Different SiPMs might increase collection with better S/N
- ~99% of <u>50</u> TeV showers detectable out to 150 m
  - Alternatively, could increase spacing, but tail of penetrating showers is tough



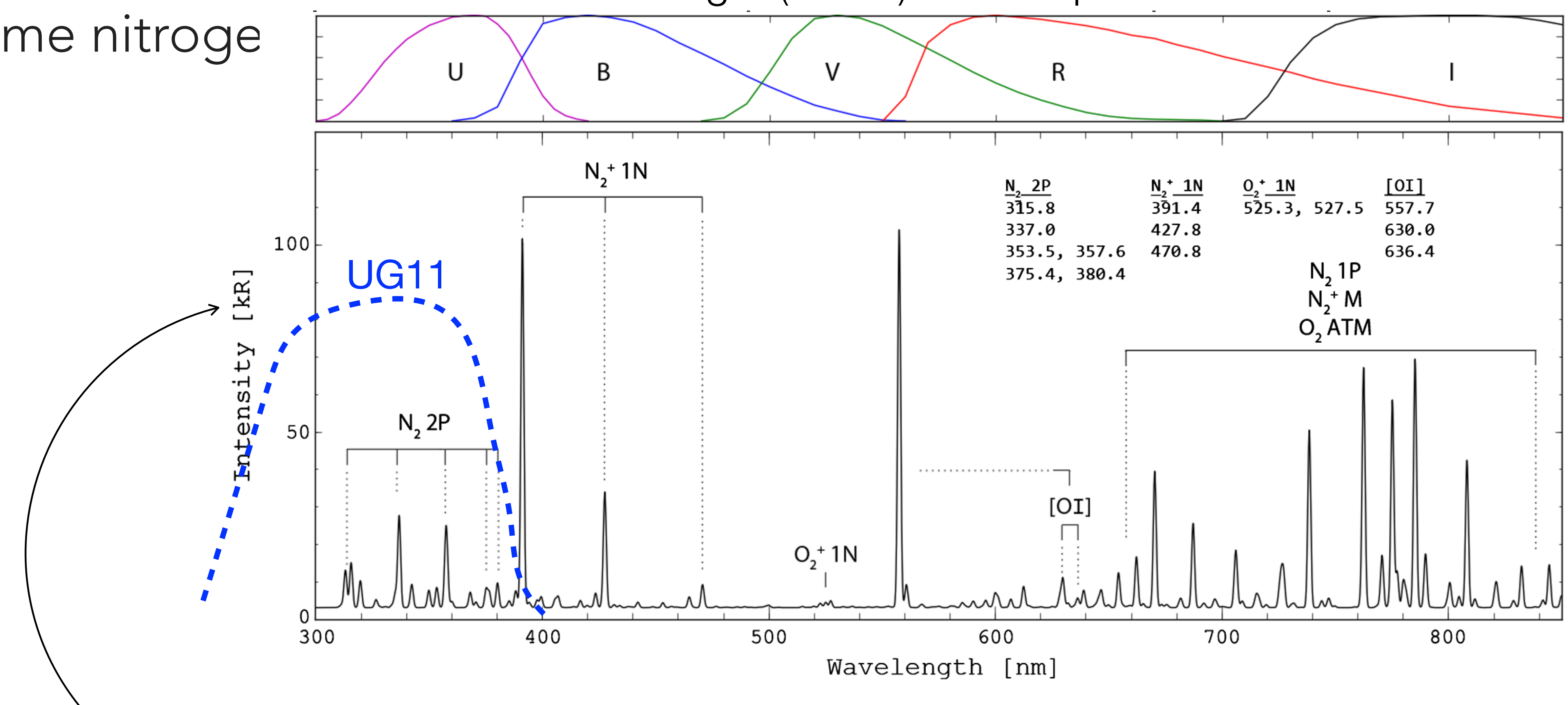
Outlook

- Preliminary studies indicate air shower detection with inexpensive air Cherenkov detection is promising
  - Primary cosmic ray threshold of 50-100 TeV seems possible → corresponds to neutrino veto threshold around 20-30 TeV
  - Critical energy range for investigating Galactic sources, lower-energy behavior of IceCube astrophysical neutrino flux
- Potential to increase rate of through-going neutrino-induced muons by a factor of several for a source in the field of view
- Reasonable sky coverage appears possible at several M$ cost scale (MRI)
- Full detector simulation, characterization of background levels and environmental issues at site now underway

Aurora Australis

- Some nitroge

bright (IBC III) aurora spectrum: Sims et al. 2012

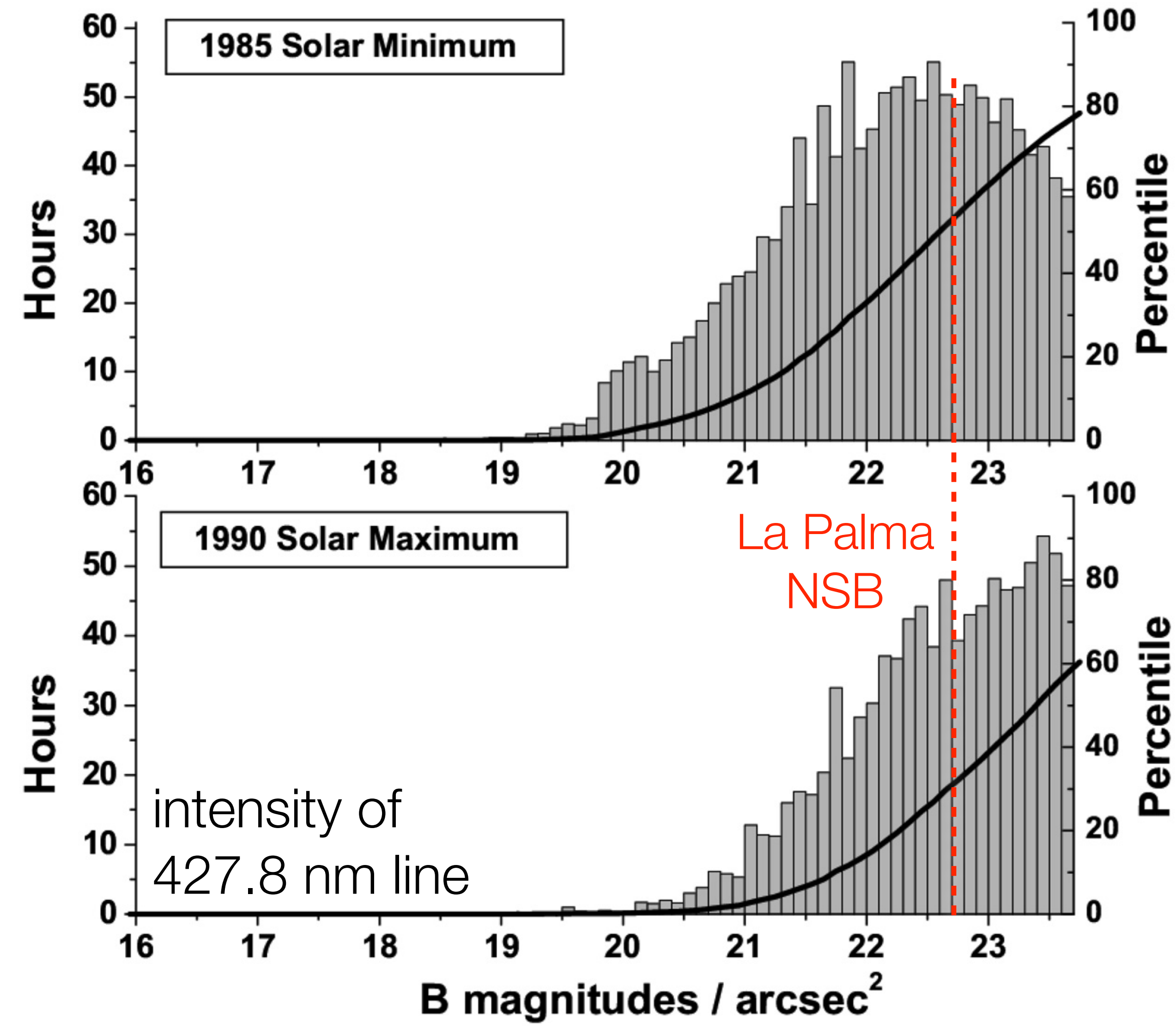


1 kR = 8×10^{11} photons m^{-2} s^{-1} sr^{-1}
= 27.5 photons m^{-2} ns^{-1} in IceACT

Aurora Australis

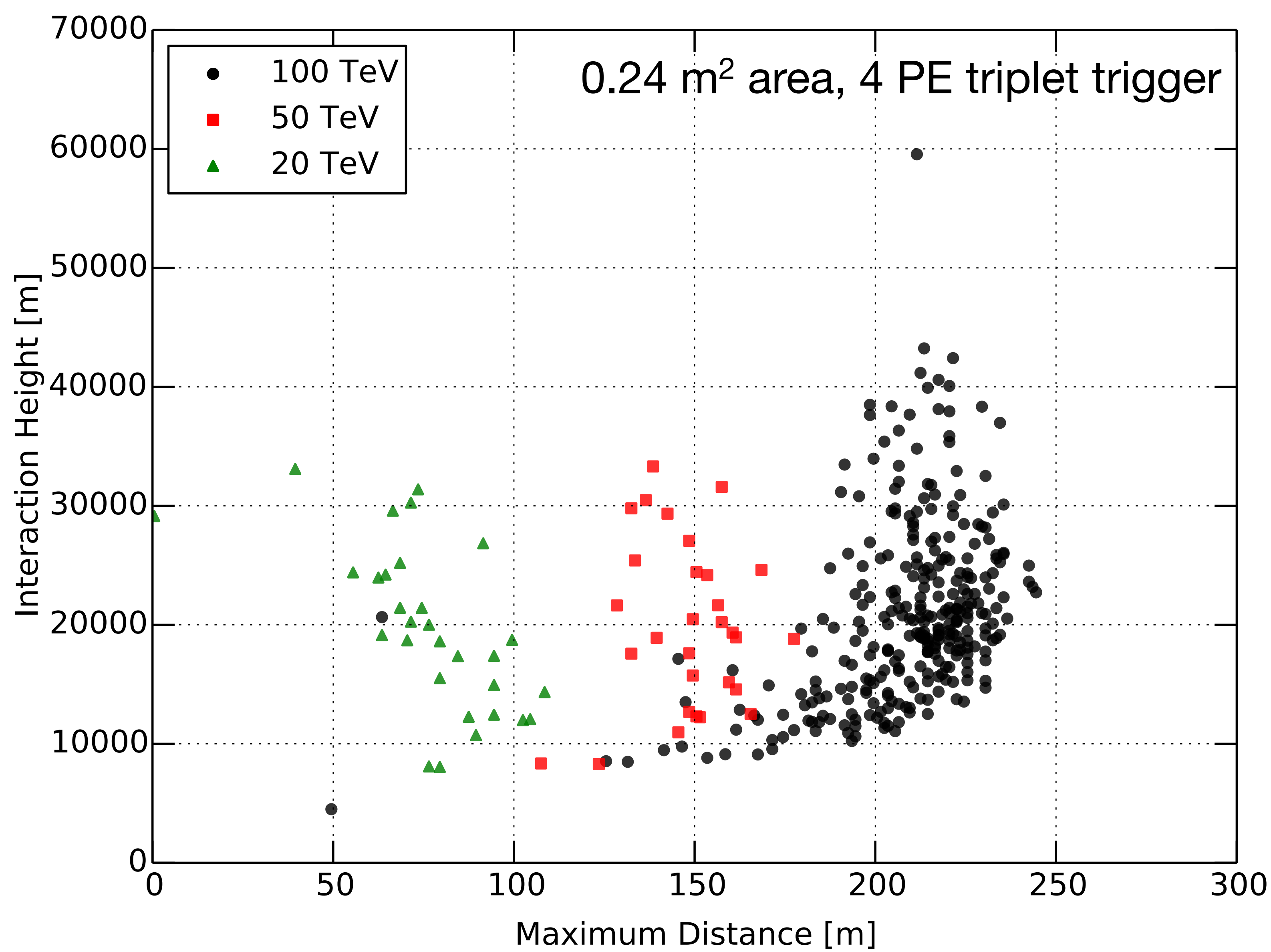
- 90th percentile of 428 nm line intensity reported by Dempsey (SP) is factor of 2.5-6.3 above assumed *B* band NSB
    - 6x assumed NSB rate would give MHz rate at 4 PE threshold
- Sims et al. (Dome A) report similar median but 4x lower 90th percentile during 2009 solar maximum
- Haven't found any *U* band data – better to rely on our own *in situ* measurements

SP aurorae: Dempsey et al. 2004



Shower Detection with Increased Threshold

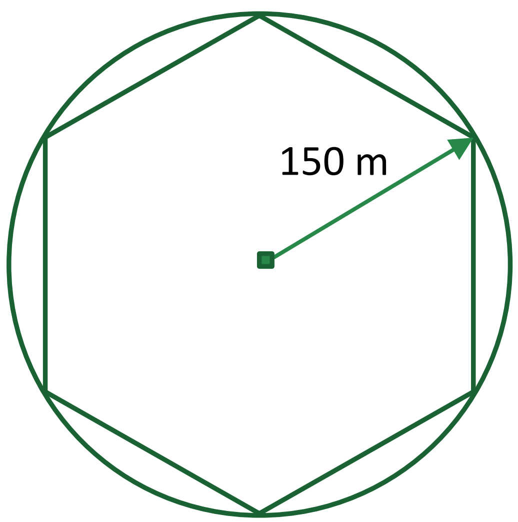
- Assume higher threshold required to reduce rate in electronics
  - For NSB alone, 4 PE triplet rate ~2200 Hz
- ~97% of 100 TeV showers still detected out to 150 m
  - Probably 99% after accounting for overlap in station grid



Station Layout

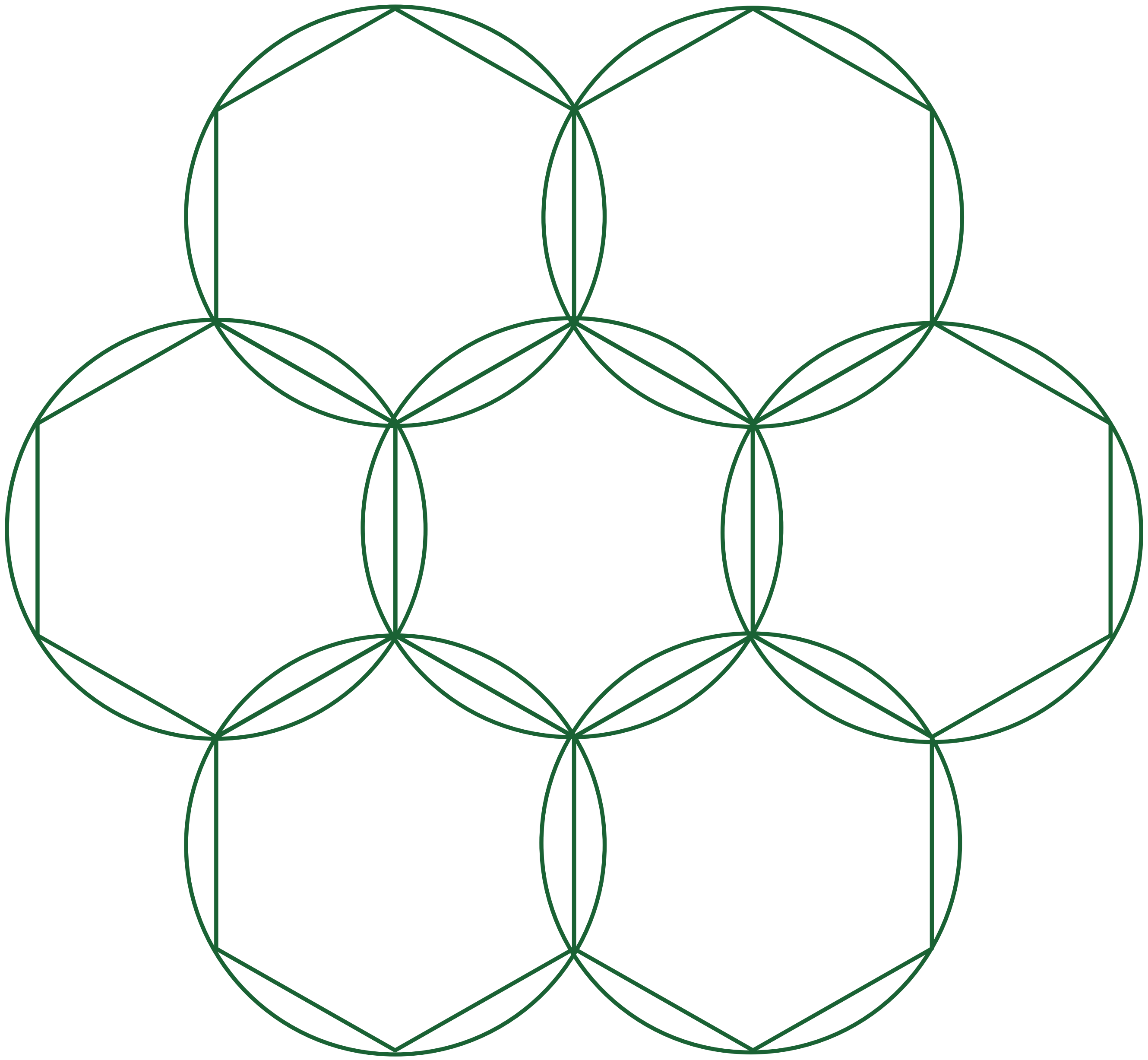
Know we want stations with radius of 150 meters.

Create a grid of hexagons that can be inscribed in a circle of radius 150 m.



Stations are located at the center of the hexagons/circles.

Showers near 150 m from stations may be seen by more than one station → "detectable by one telescope" criteria may be overconservative.

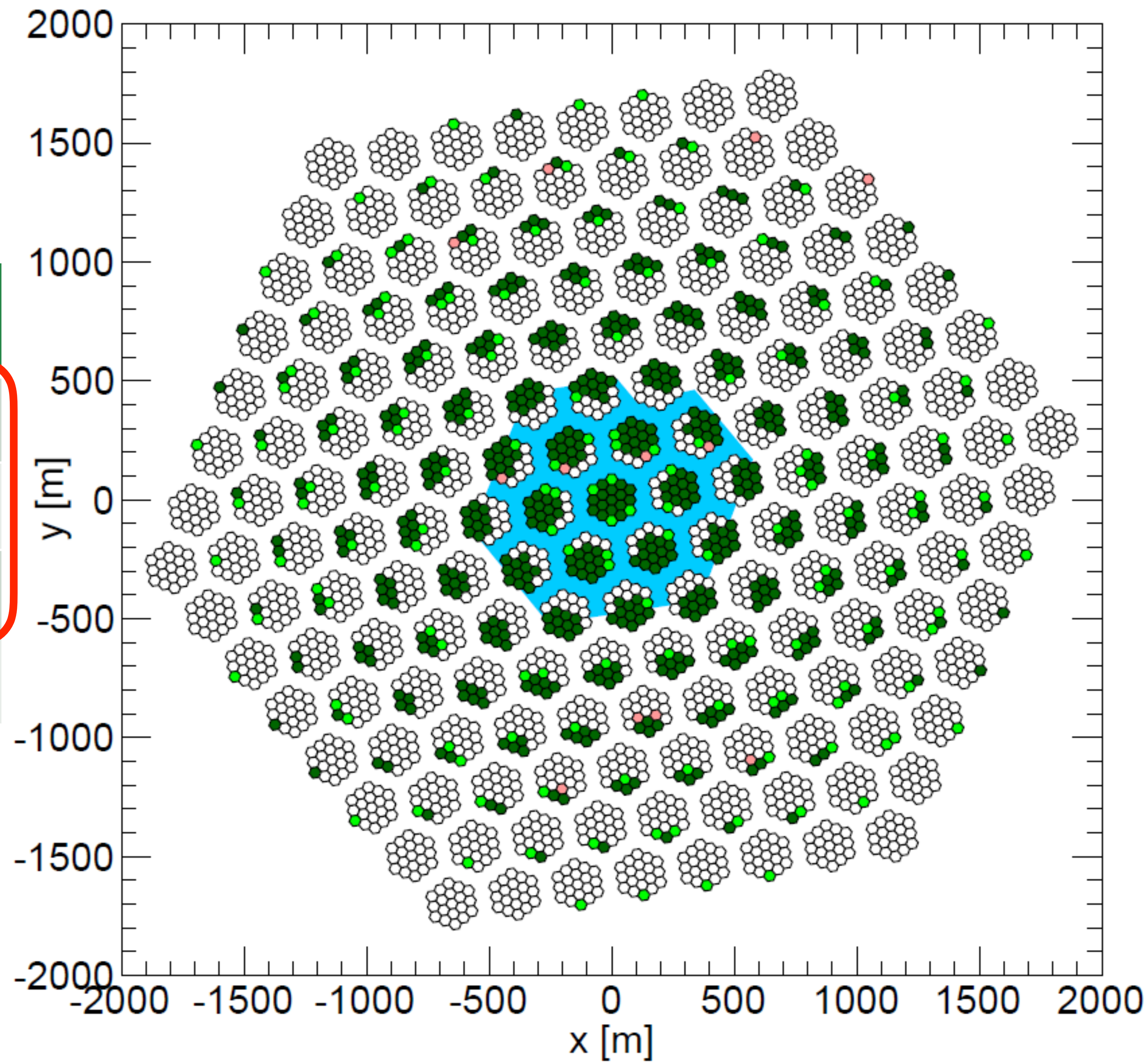


Large Overhead Array

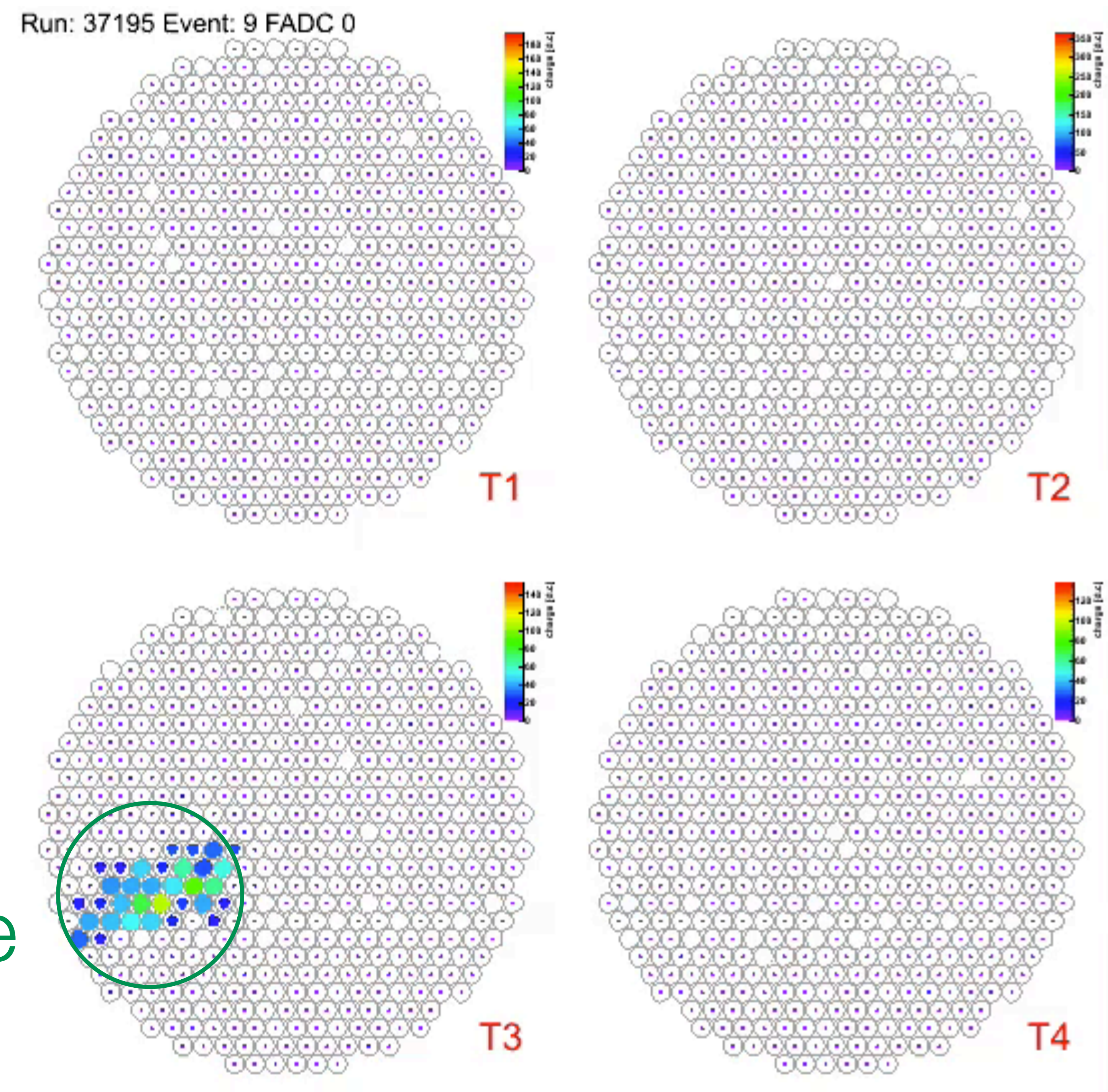
30° FOV from zenith

How many DOMs seen	Number of Telescopes
n > 50	563
10 < n ≤ 50	148
0 < n ≤ 10	12
n = 0	2488

~700 telescopes required to cover 30° from zenith



Camera Comparison: VERITAS vs. IceACT



IceACT pixel size