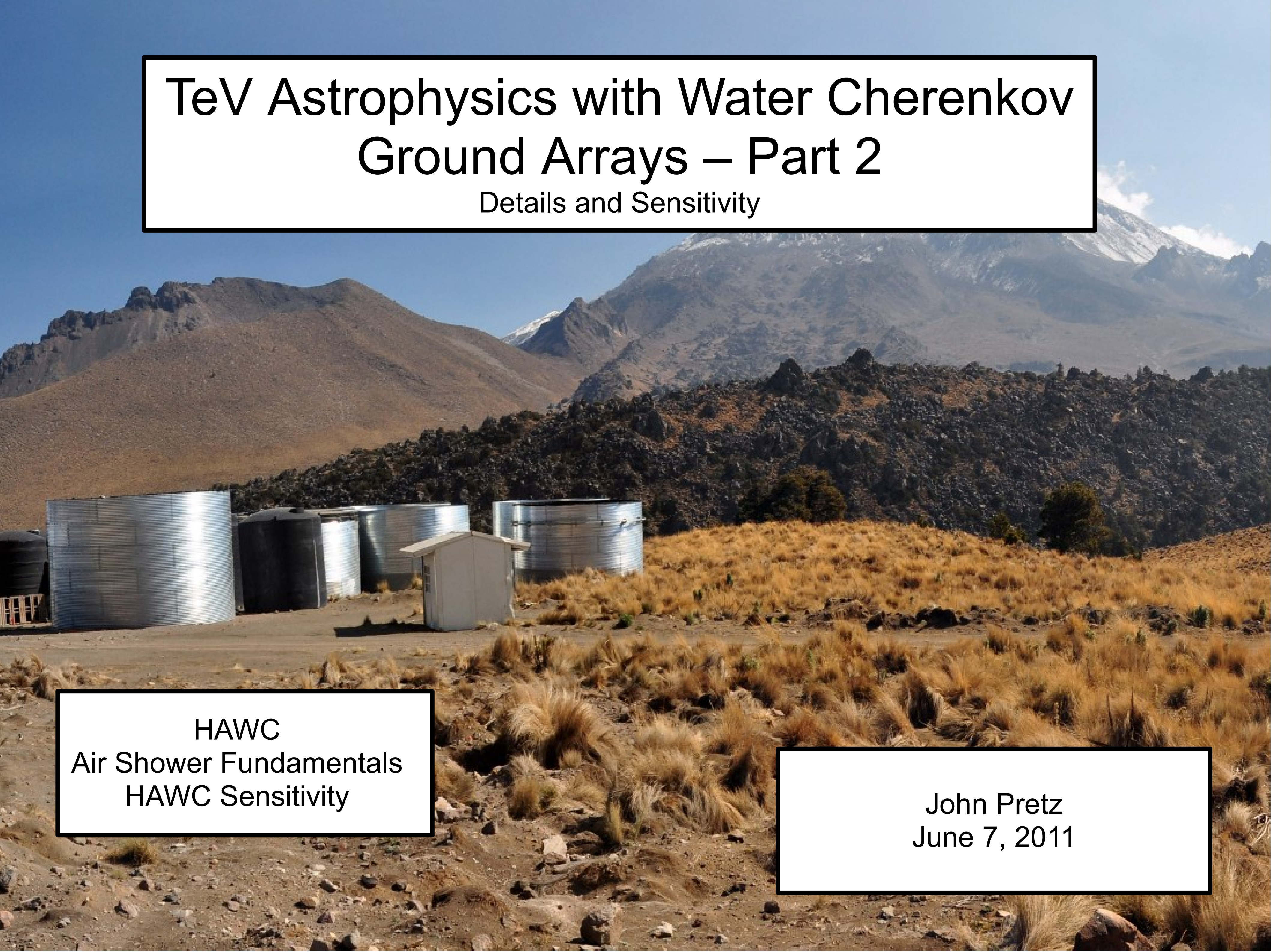
TeV Astrophysics with Water Cherenkov Ground Arrays – Part 2

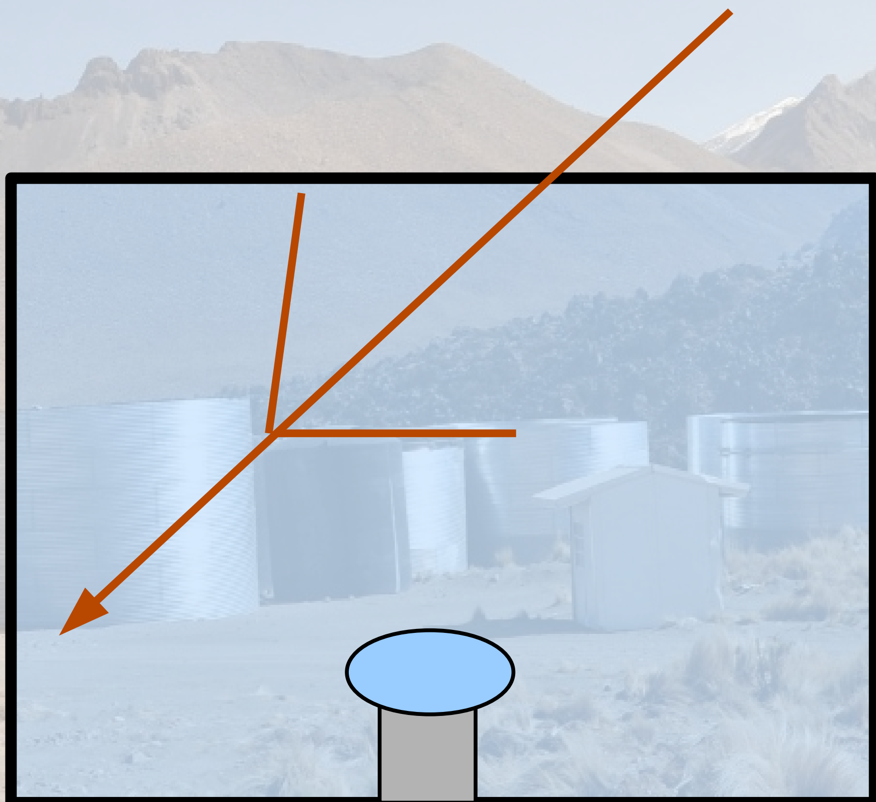
Details and Sensitivity

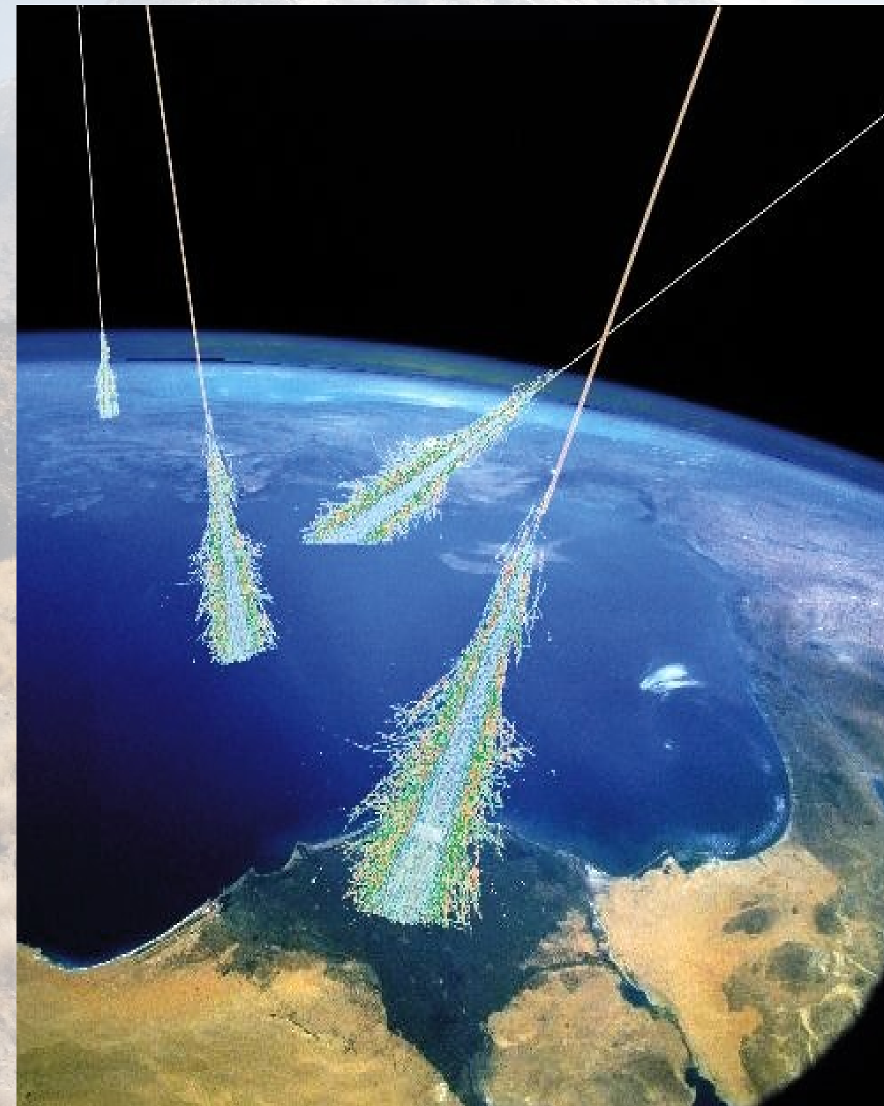


HAWC
Air Shower Fundamentals
HAWC Sensitivity

John Pretz
June 7, 2011

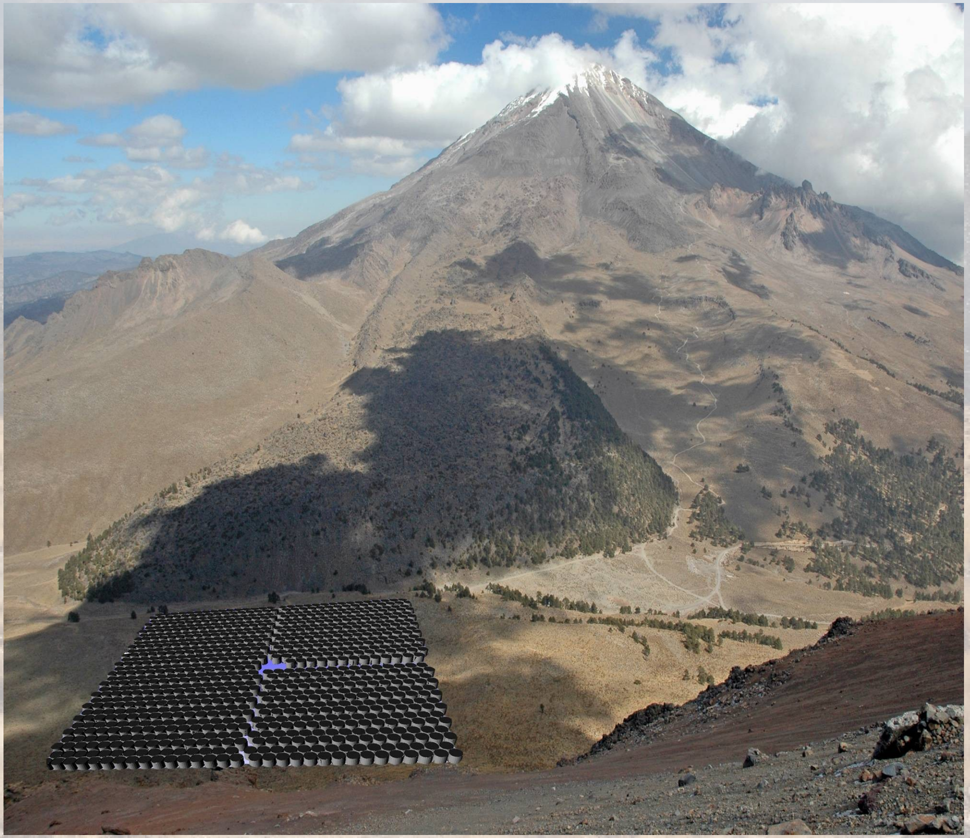
Water Cherenkov Detection of (gamma ray and cosmic ray) Air Showers





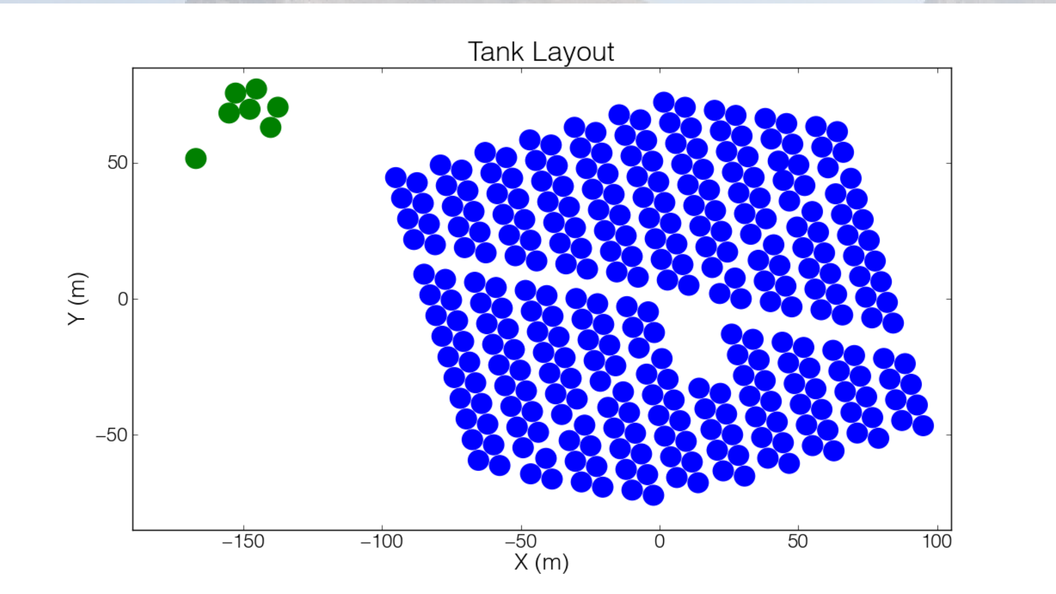
The High Altitude Water Cherenkov Experiment

- Move Milagro PMTs and front-end electronics to 4100 meter site at Sierra Negra, Mexico
- Existing infrastructure for Large Millimeter Telescope
- 2500 square meter area.
- 300 water tanks. 3 PMTs per tank.
  - 7.5 meter diameter
  - 4.0 meter water above PMTs
- Overall 15x sensitivity improvement over Milagro.
- See sources 225x faster.
  - See 1 Crab every day.



Water Cherenkov Detectors

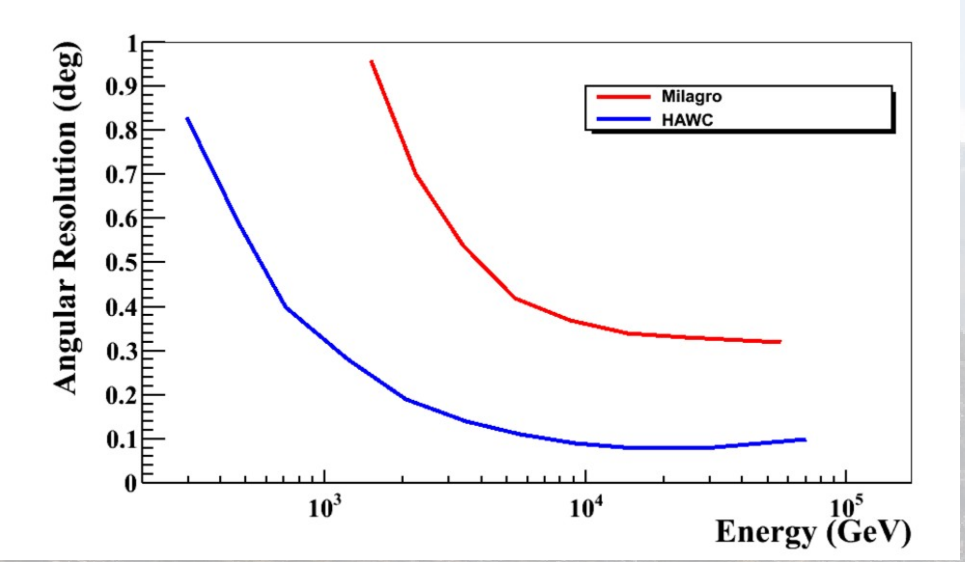
HAWC Improvements over Milagro

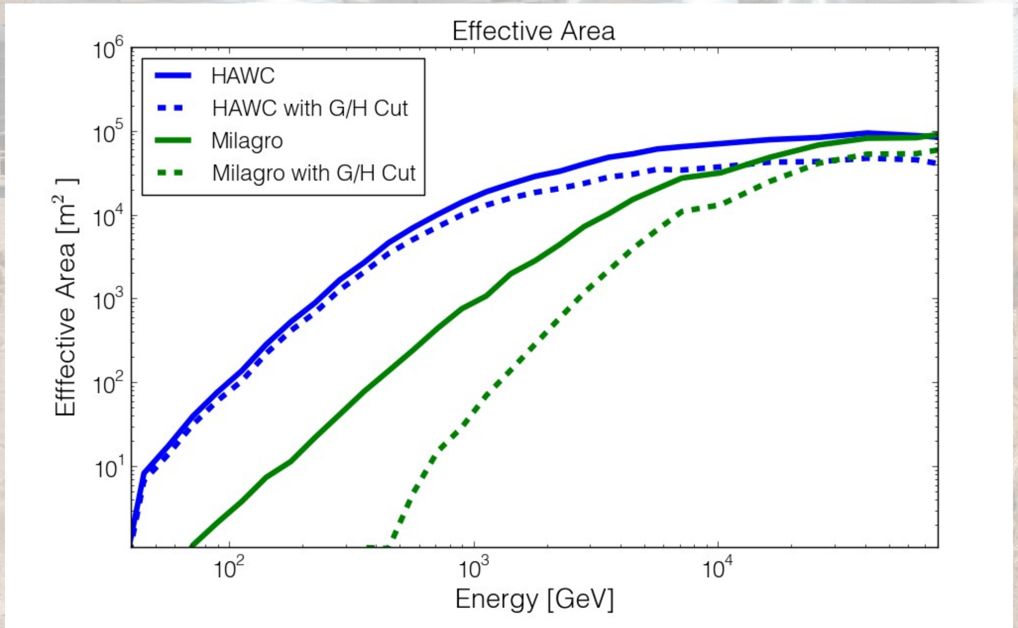


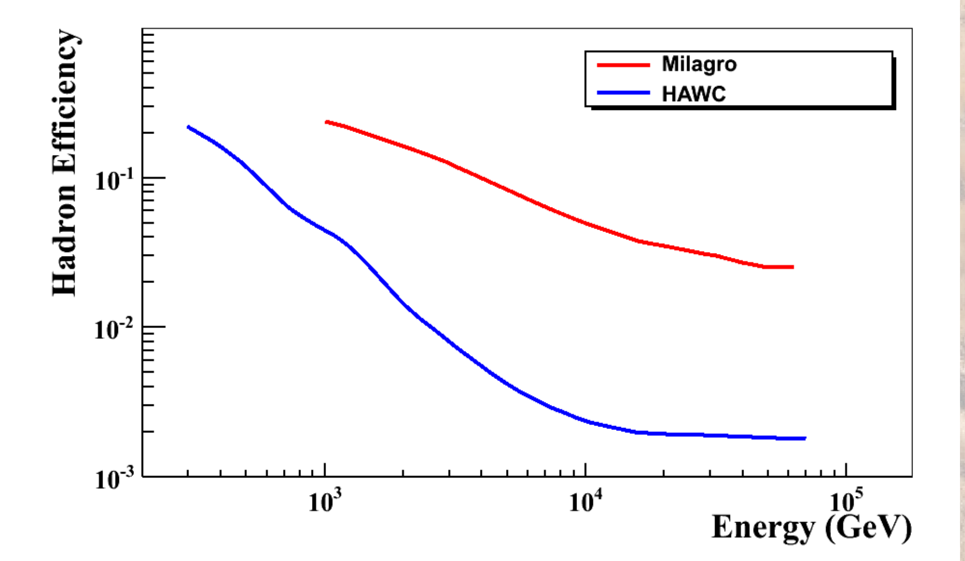
- Higher altitude. 4100 meters over 2600 meters.
- Larger triggering area. 22500 vs 4800 m^2.
- Larger area of muon discrimination. 22500 vs 4000 m^2.
- Overall 15x increase in sensitivity to a Crab-like source.
  - Observe Crab at 5 sigma in one day rather than several months.

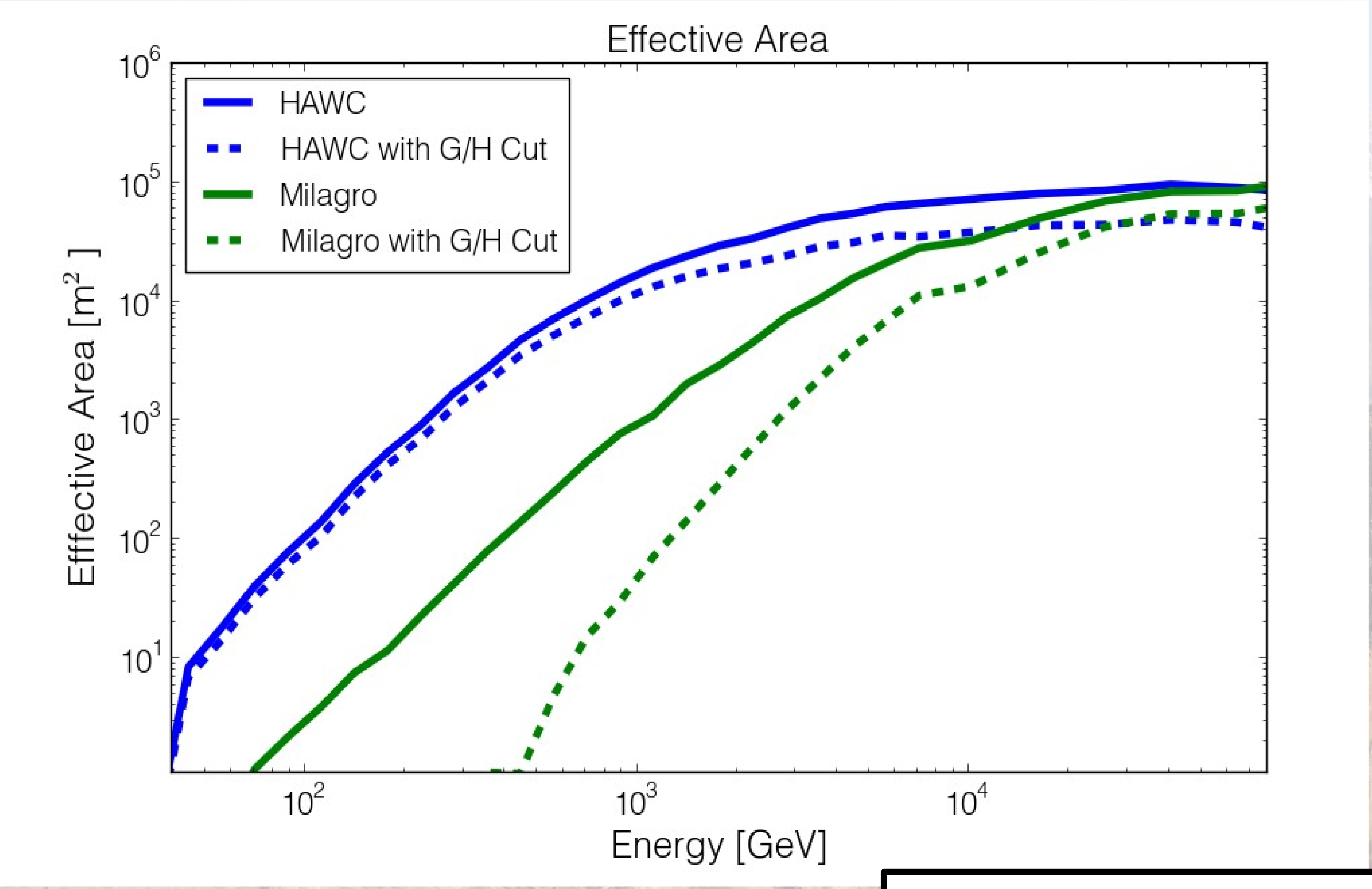
HAWC Improvements over Milagro

- Additional particles on the ground improves angular resolution.
- Additional area of “deep” muon detection area gives much better gamma/ hadron discrimination
- Higher altitude gives much higher low-energy response.





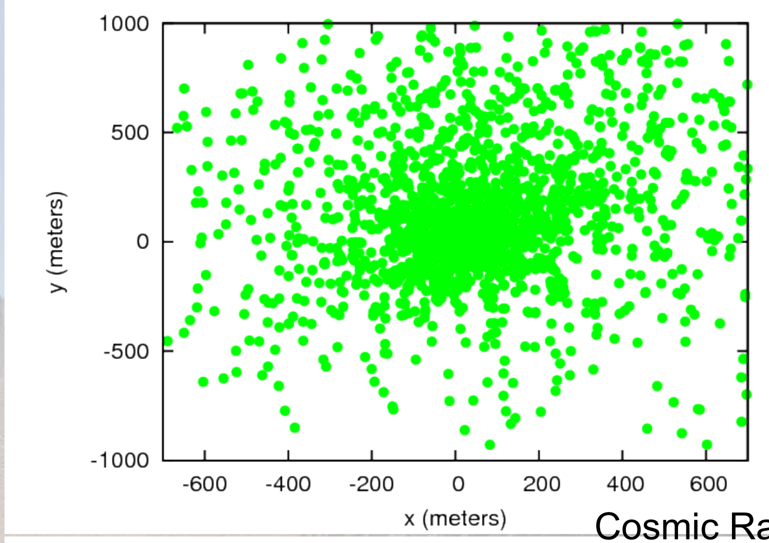


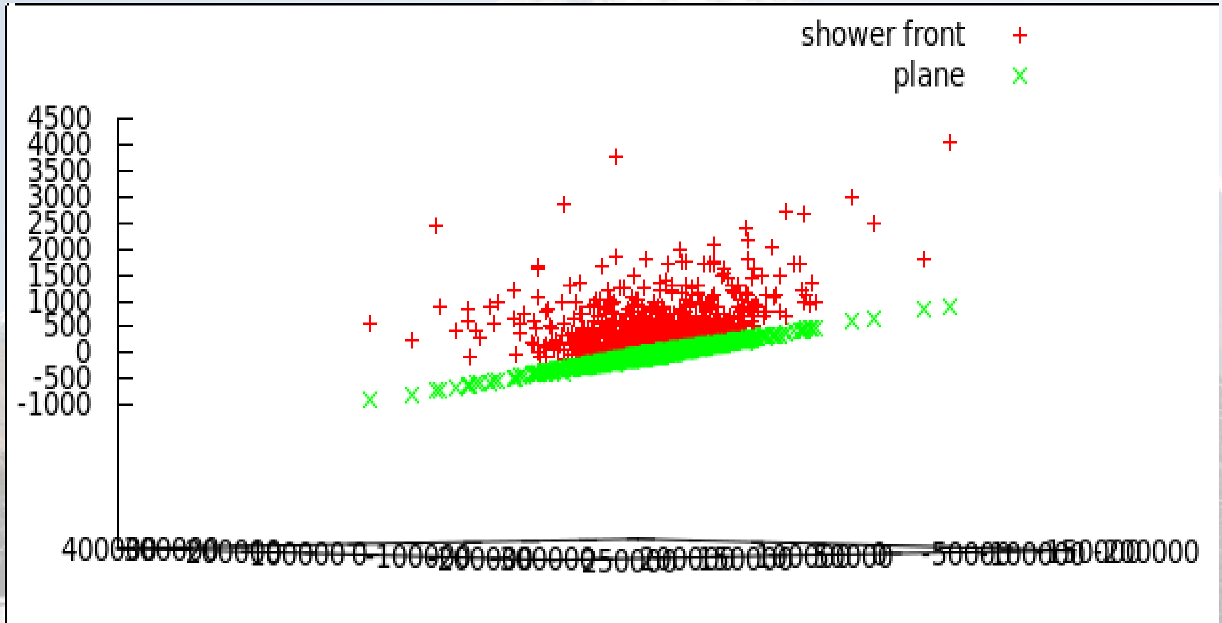


$$N_{events} = \int A_{eff}(E,\theta)\phi(E)dEdt$$

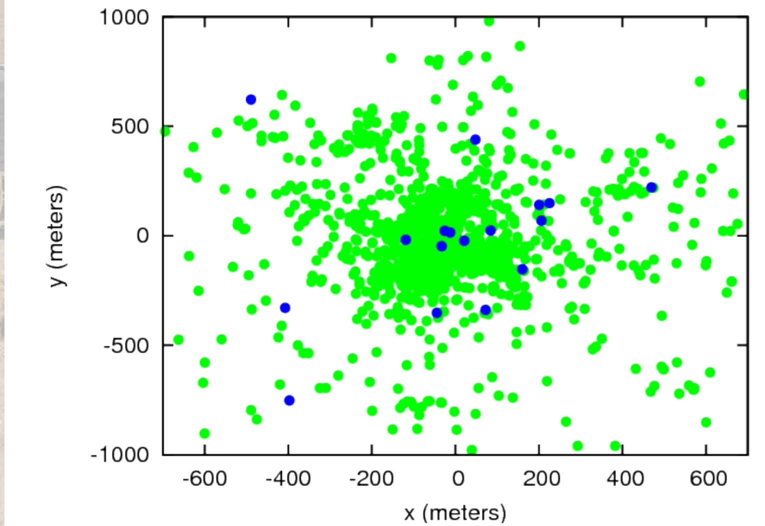
$$A_{eff}(E,\theta) = A_{thrown}\frac{N_{observed}(E,\theta)}{N_{thrown}(E,\theta)}$$

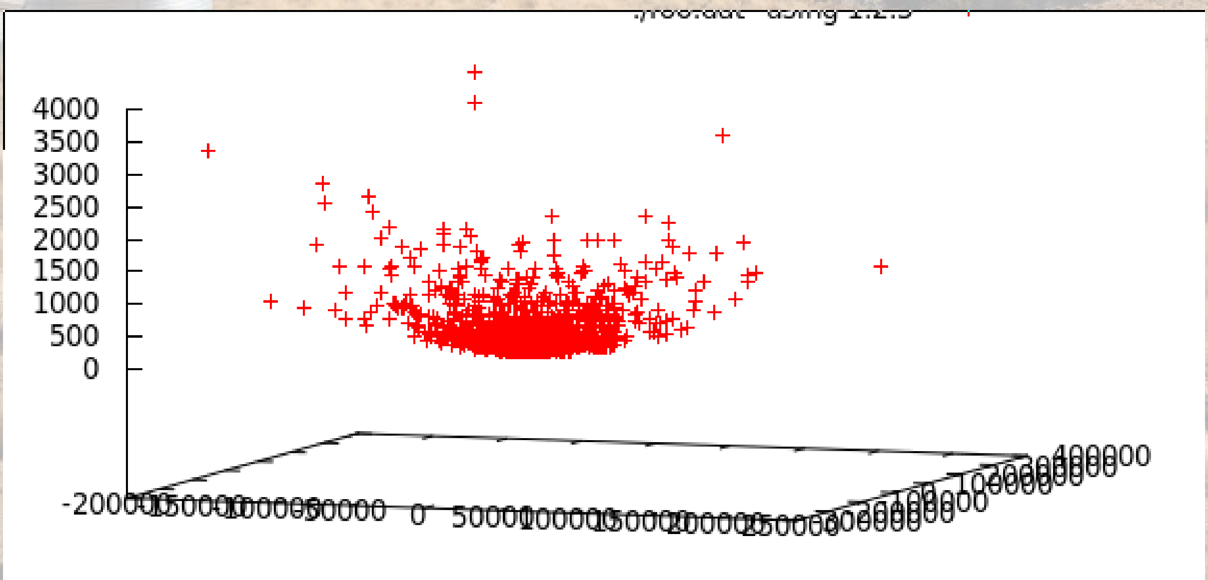
Gamma Ray





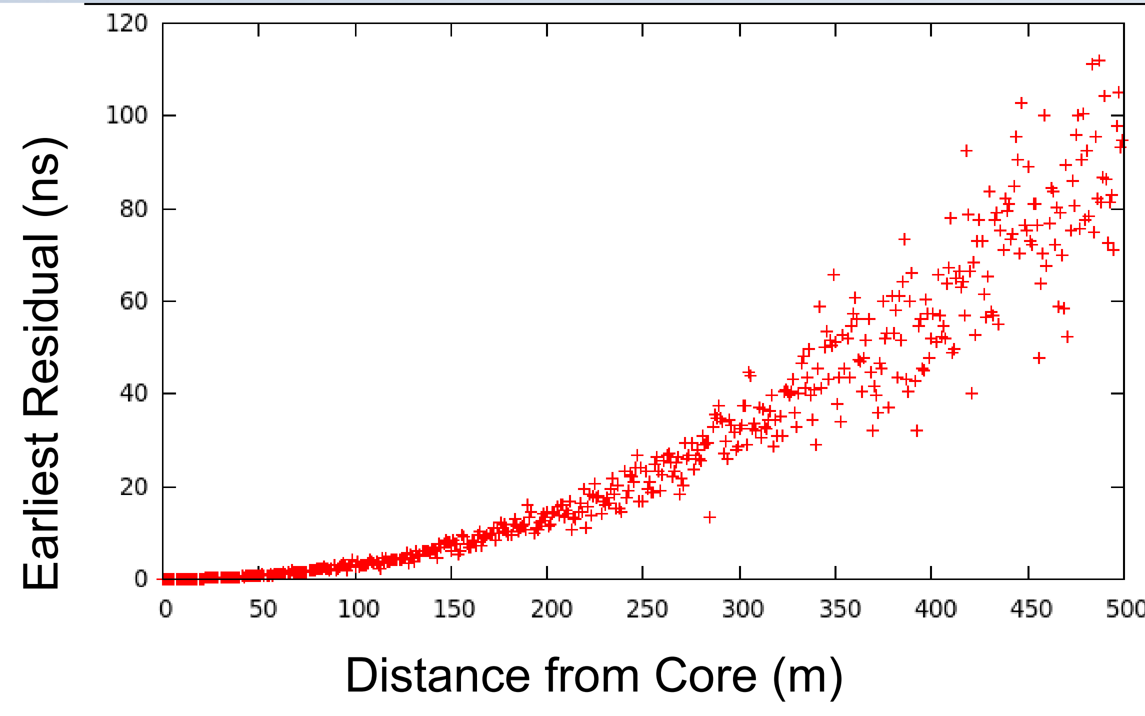
Cosmic Ray

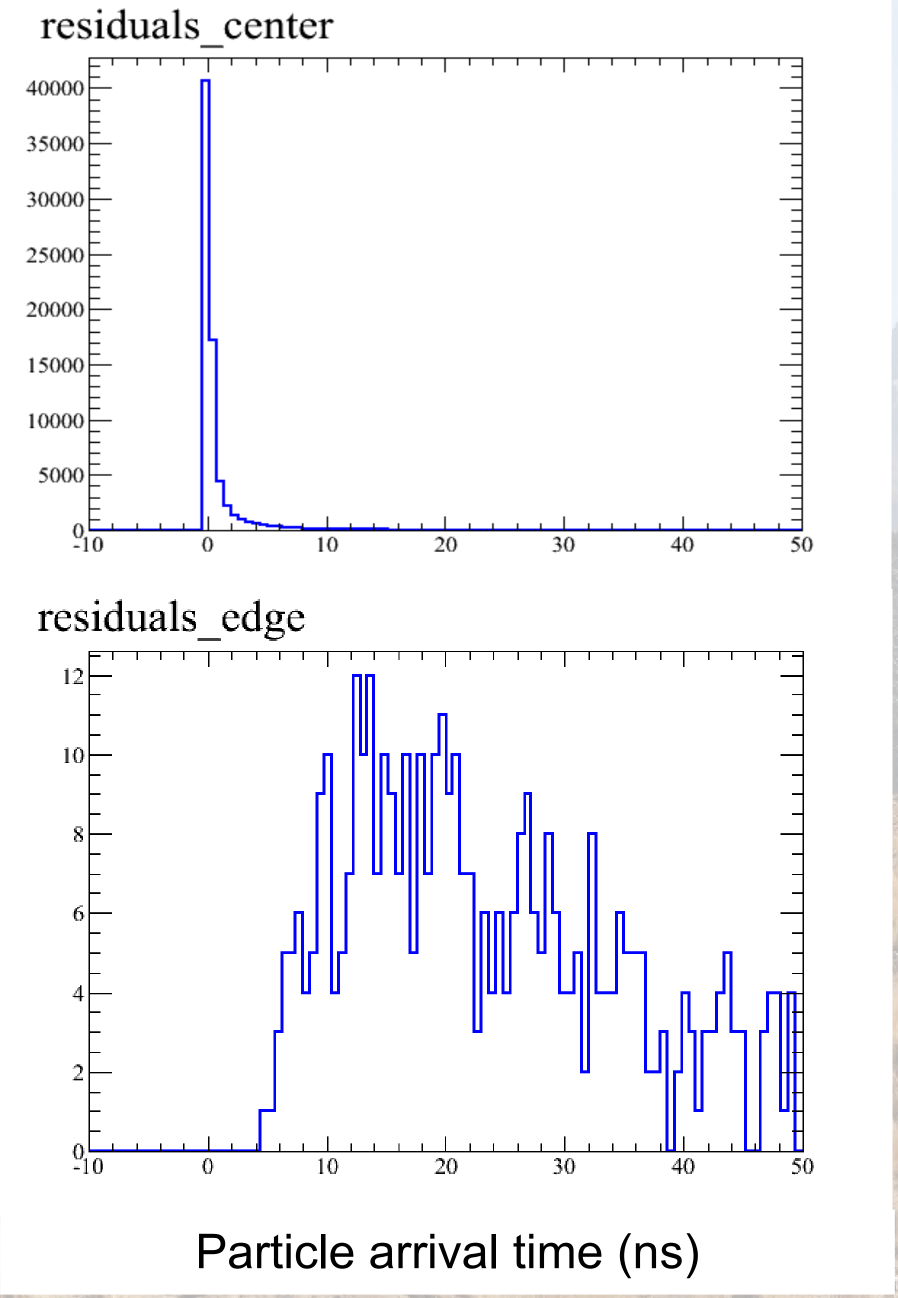




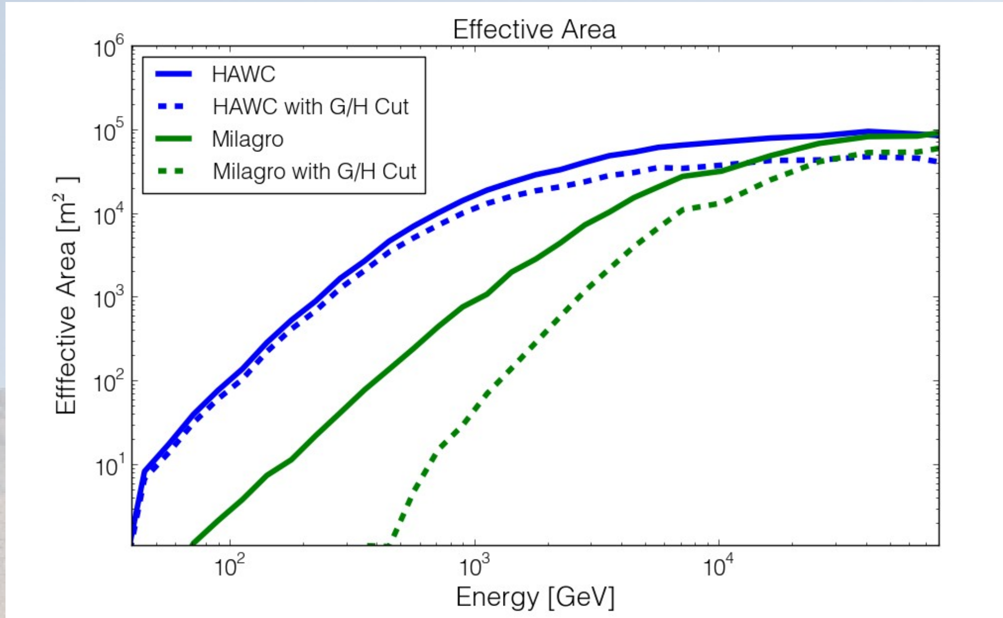
e± or gamma

μ±

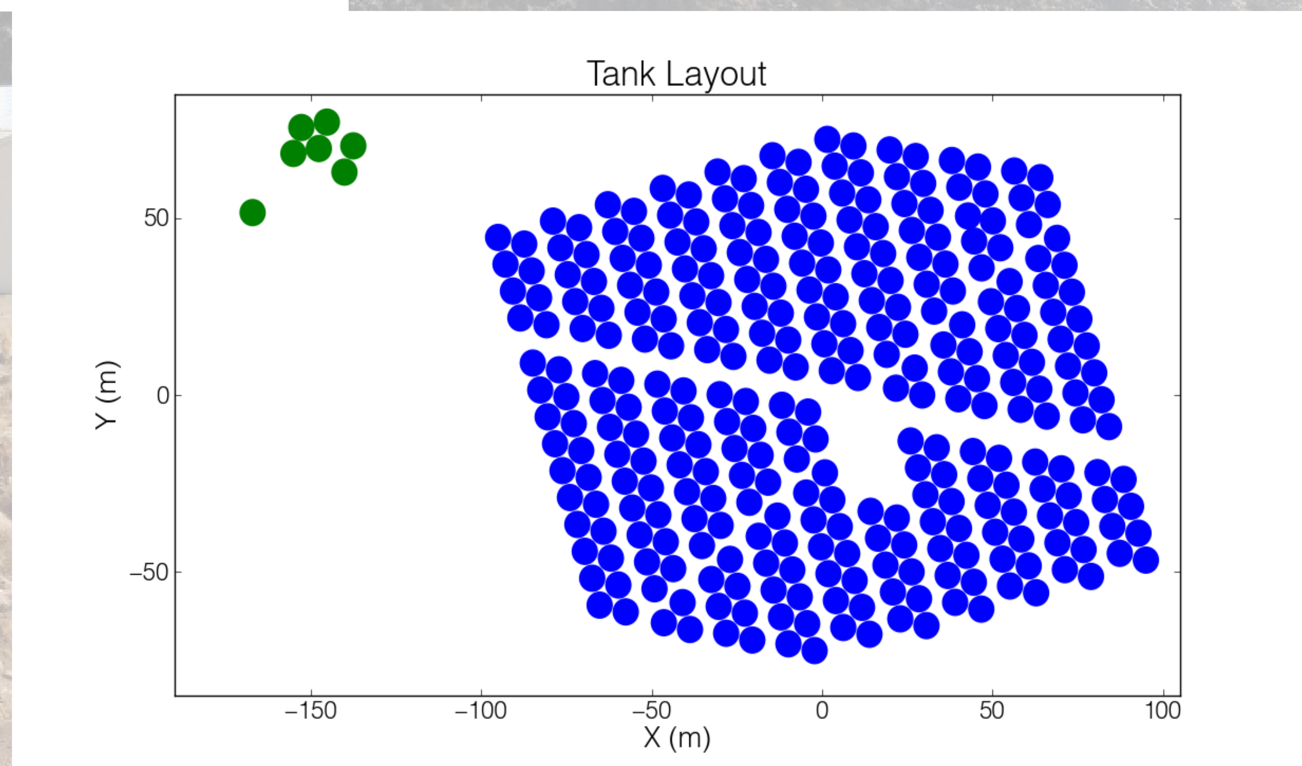


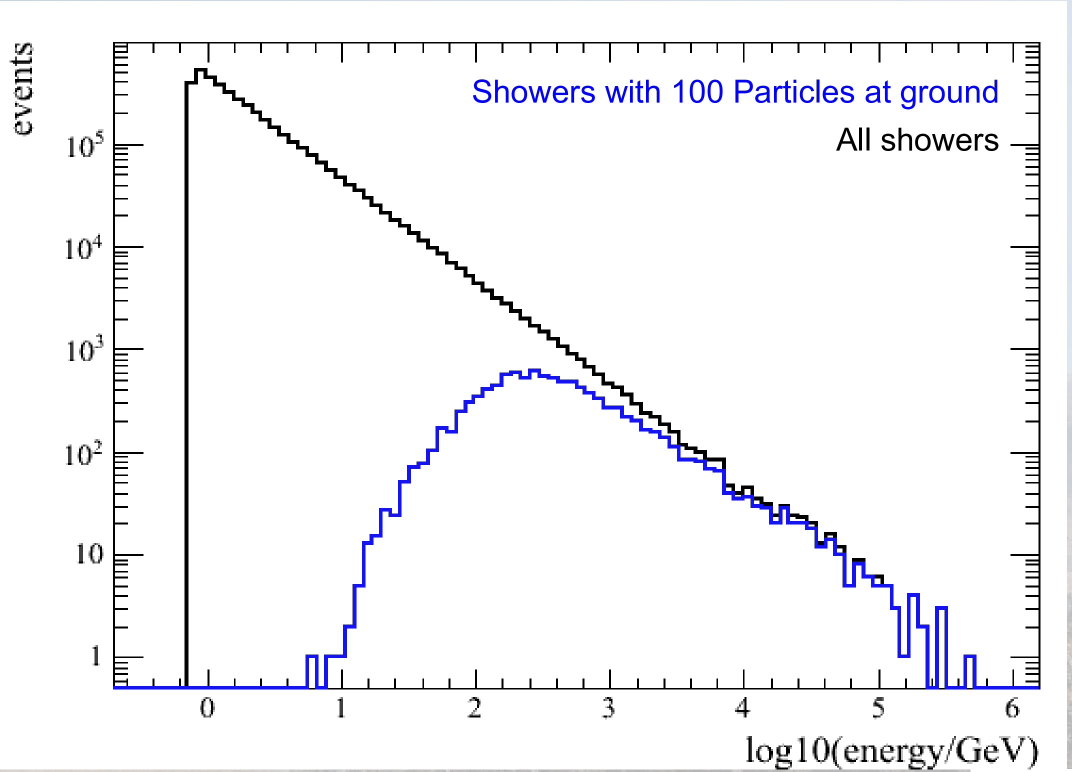


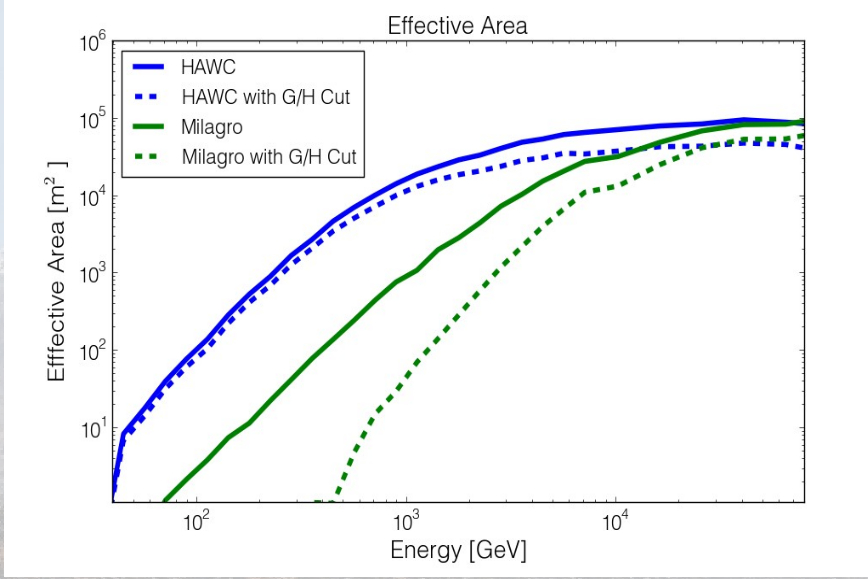
- Shower fronts are curved.
- Shower fronts are thick.
- 1 ns timing error over 50 meters results in 0.3 degree pointing error.



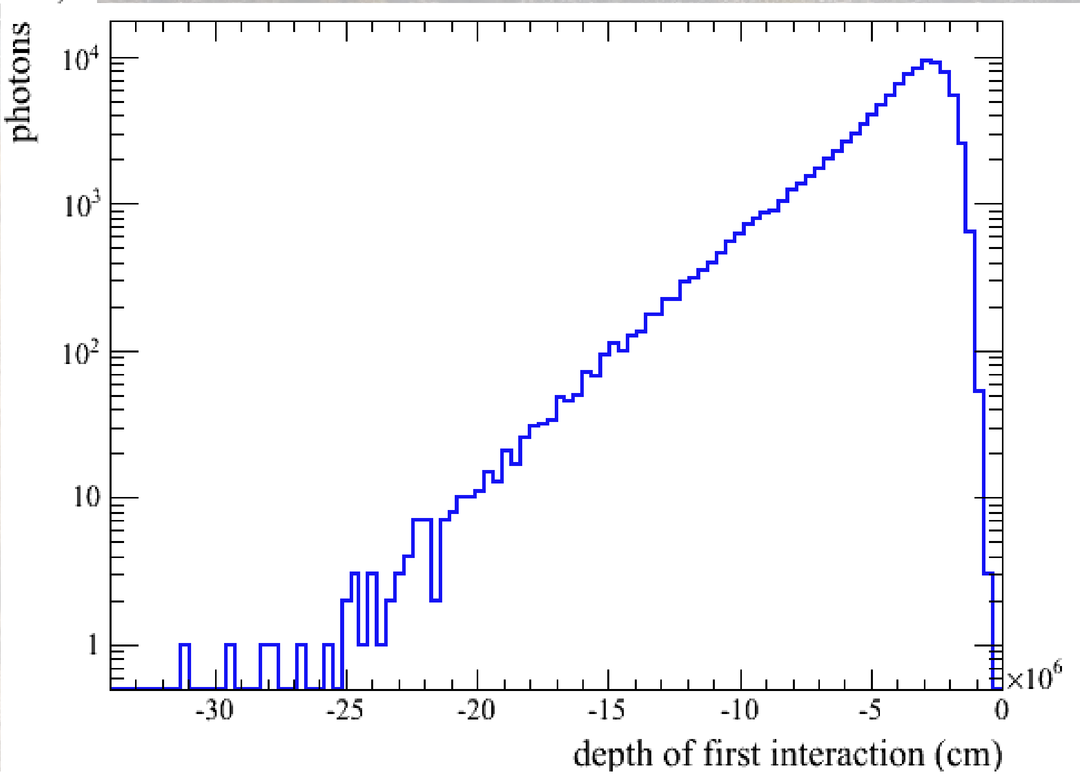
- Need to accurately resolve core location limits the high-energy area to the physical area of the array.







- Tendancy of low-energy showers to result in 0 ground level particles gives lower-than-geometric effective area.



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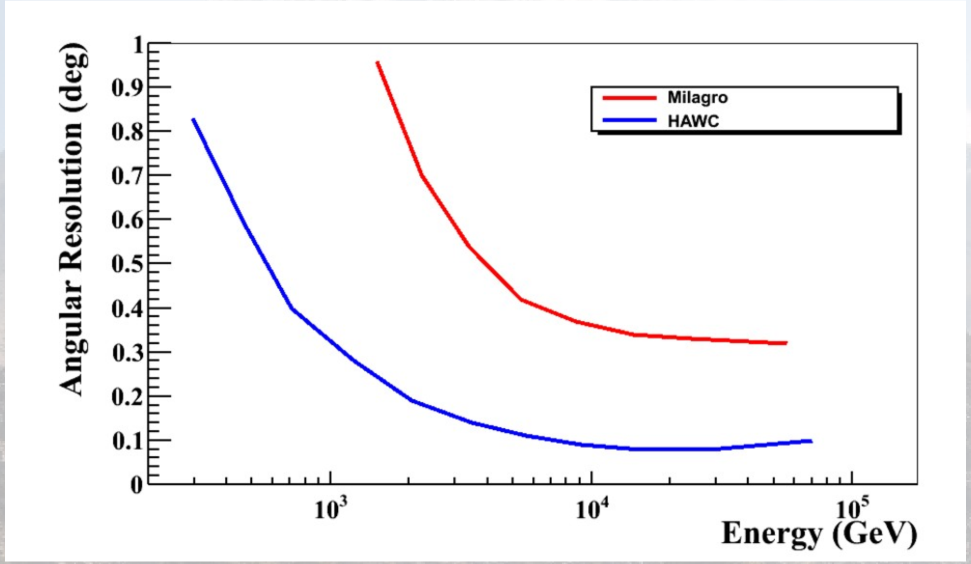
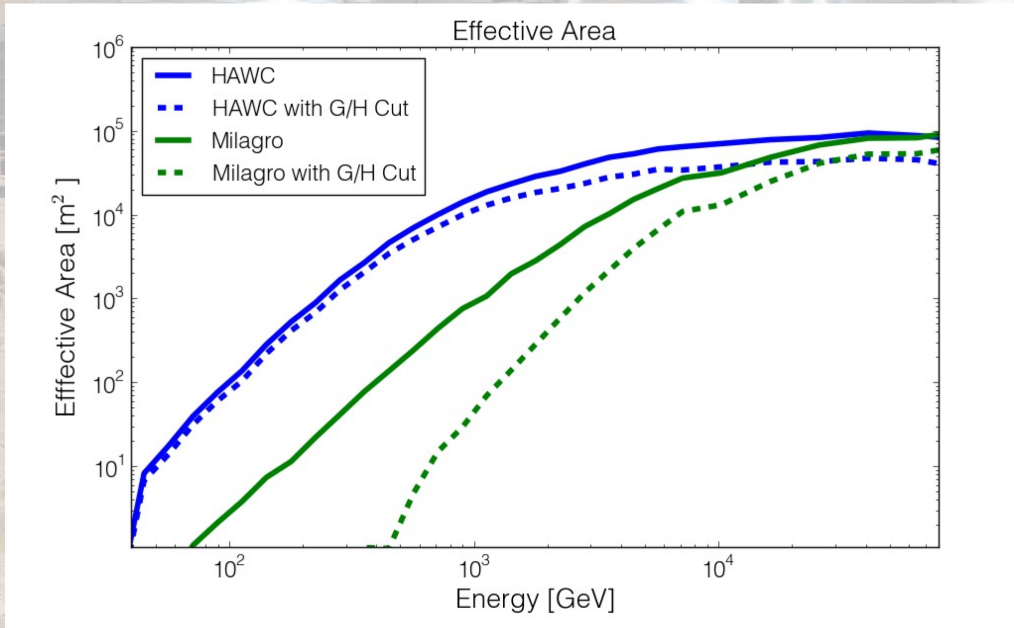
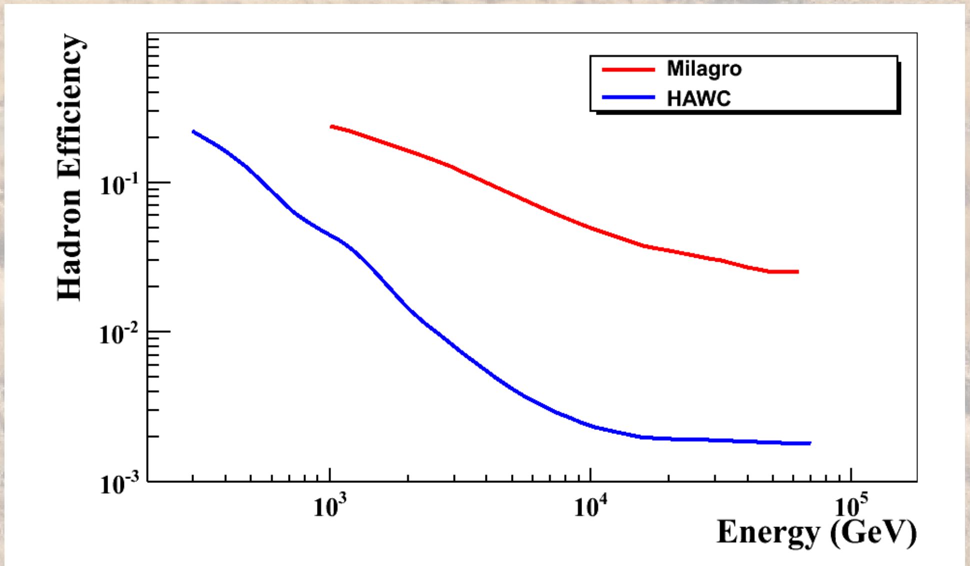
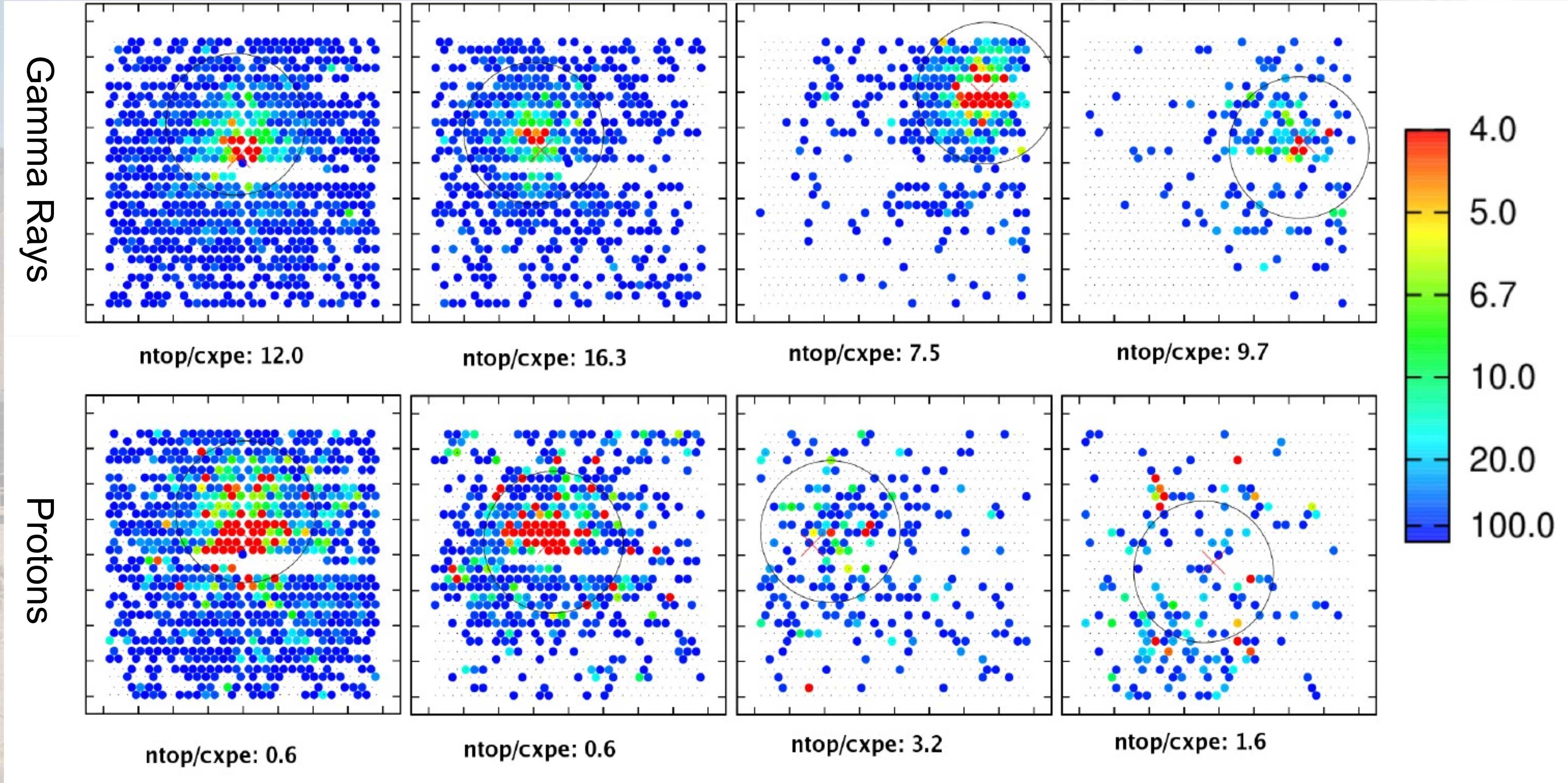






Gamma / Hadron Separation



Significance on the Crab

$$\Phi_{crab} = 3.45\text{x}10^{-11}\left(\frac{E}{\text{TeV}}\right)^{-2.63}\frac{\text{photons}}{\text{cm}^2\cdot\text{s}\cdot\text{TeV}}$$

$$\Phi_{proton} = 8.9\text{x}10^{-2}\left(\frac{E}{\text{TeV}}\right)^{-2.65}\frac{\text{protons}}{\text{m}^2\cdot\text{s}\cdot\text{TeV}\cdot\text{sr}}$$

- Assume 20000 square meter effective area over 1 TeV.
- Assume 5 hours transit time
- Assume a 0.5 degree bin on the sky ($2\text{x}10^{-4}$ sr)
- About 75 photons / 3900 protons before gamma / hadron separation
- Approximate 38 photons / 39 protons after gamma / hadron separation cuts.
- Bump up protons by 1.3 to account for other species of cosmic rays.
- About 5σ per day.

See HESS & ATIC Results

Summary and Outlook

- This summer: VAMOS prototype array (7 WCDs)
  - Hopeful detection of Moon Shadow
- Early next year: 30 WCDs and sensitivity comparable to Milagro.
- 300 WCDs in 2014.