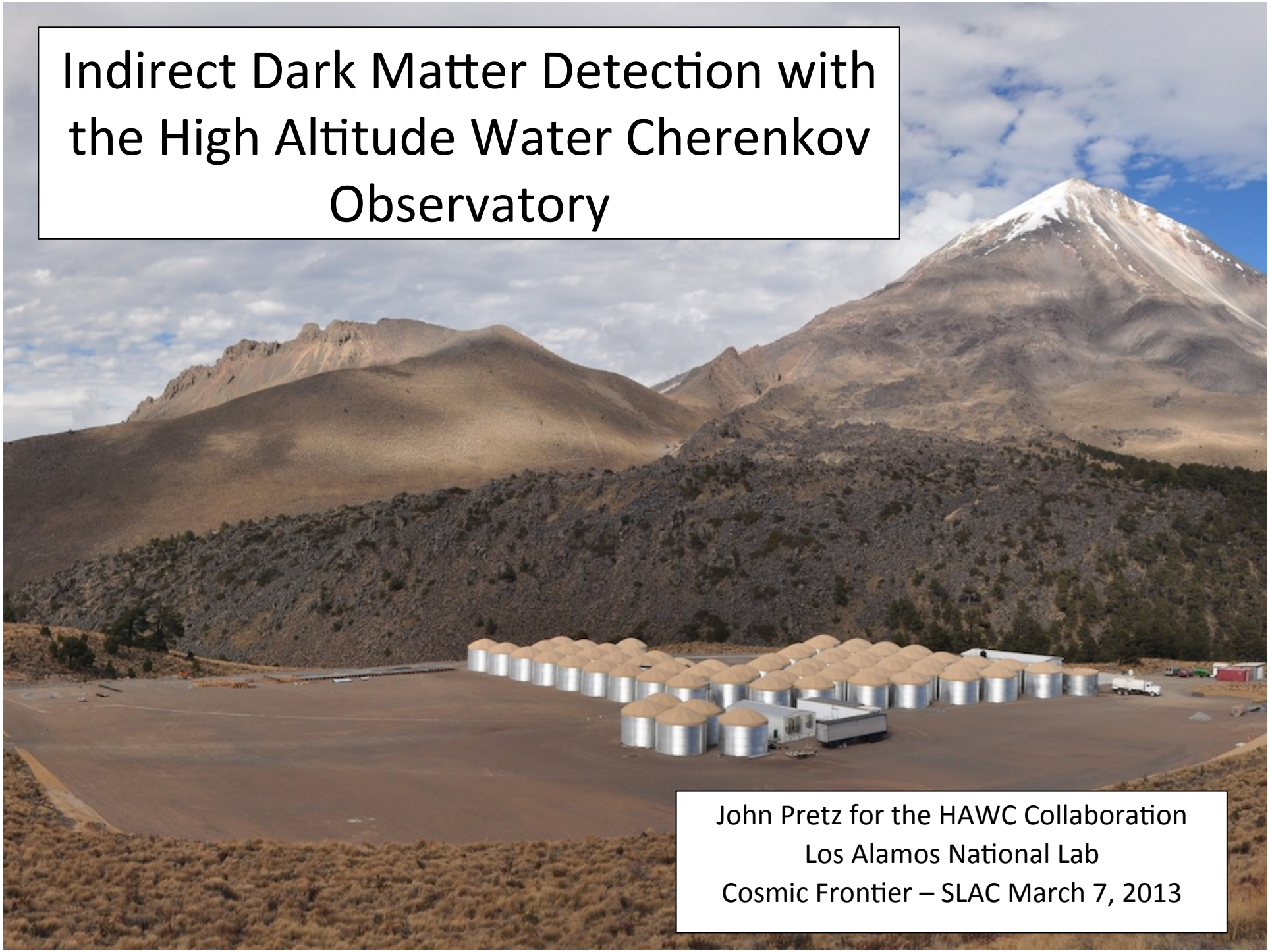
Indirect Dark Matter Detection with the High Altitude Water Cherenkov Observatory



John Pretz for the HAWC Collaboration
Los Alamos National Lab
Cosmic Frontier – SLAC March 7, 2013

HAWC Collaboration

USA:

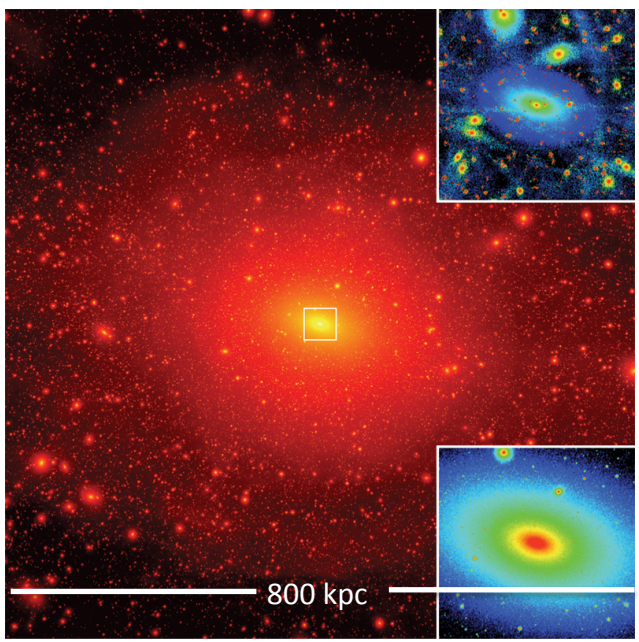
Los Alamos National Laboratory
University of Maryland
University of Utah
University of New Mexico
Michigan State University
Pennsylvania State University
NASA/Goddard Space Flight Center
University of New Hampshire
Georgia Tech
George Mason University
University of California, Irvine
Colorado State University
Michigan Technological University
University of Alabama
University of Wisconsin, Madison

Mexico:

Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE)
Universidad Nacional Autónoma de México (UNAM)
- Instituto de Astronomía
- Instituto de Física
- Instituto de Ciencias Nucleares
- Instituto de Geofísica

Universidad Autónoma de Chiapas
Universidad de Guadalajara
Benemérita Universidad Autónoma de Puebla
Universidad Michoacana de San Nicolás de Hidalgo
CINVESTAV
Universidad de Guanajuato
UGTO-IF
Universidad Autonoma del Estado de Hidalgo
Instituto Politecnico Nacional

Dwarf Spheroidal Galaxies and Indirect DM Signatures



Diemand et al. Nature. 454:735 (2009)

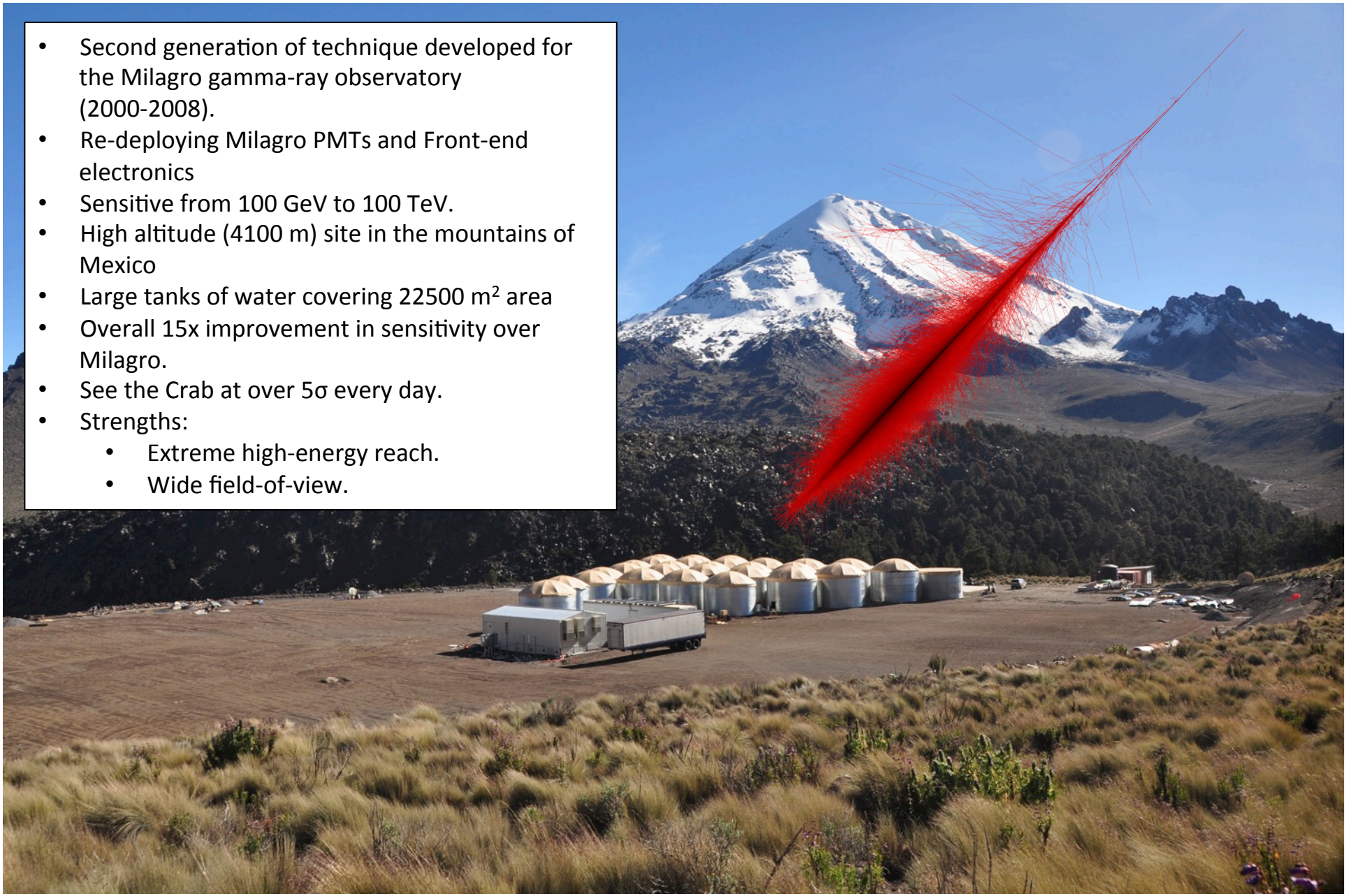
- Dark-matter-dominated satellites of our galaxy (Segue 1 has $M_\odot/L_\odot$ of 3400)
- Predicted by N-body simulations.
- Many (~10x) more predicted than observed.
  - Klypin et al. ApJ. 522:82 (1999)
  - Brooks et al. arXiv:1209:5394
- Essentially no astrophysical gamma-ray production.
- Limits on gamma-rays can limit DM interaction and decay occurrence.
- Standard formalism for computing gamma-ray spectrum (Evans et al PRD. 69:123501. (2004).):

$$\frac{d\Phi_\gamma}{dE}(\Delta\Omega, E) = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2\,m_\chi^2}\frac{dN_\gamma}{dE} \times \bar{J}(\Delta\Omega).$$

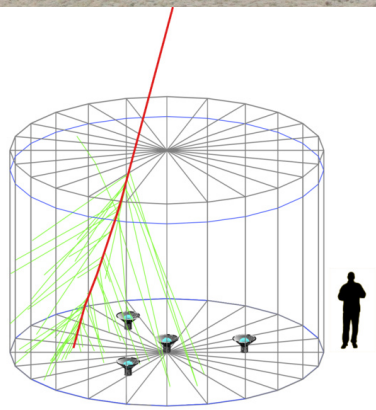
$$\bar{J}(\Delta\Omega) = \int_{\Delta\Omega} d\Omega \int_{s_{min}}^{s_{max}} \rho_\chi^2(r[s])ds$$

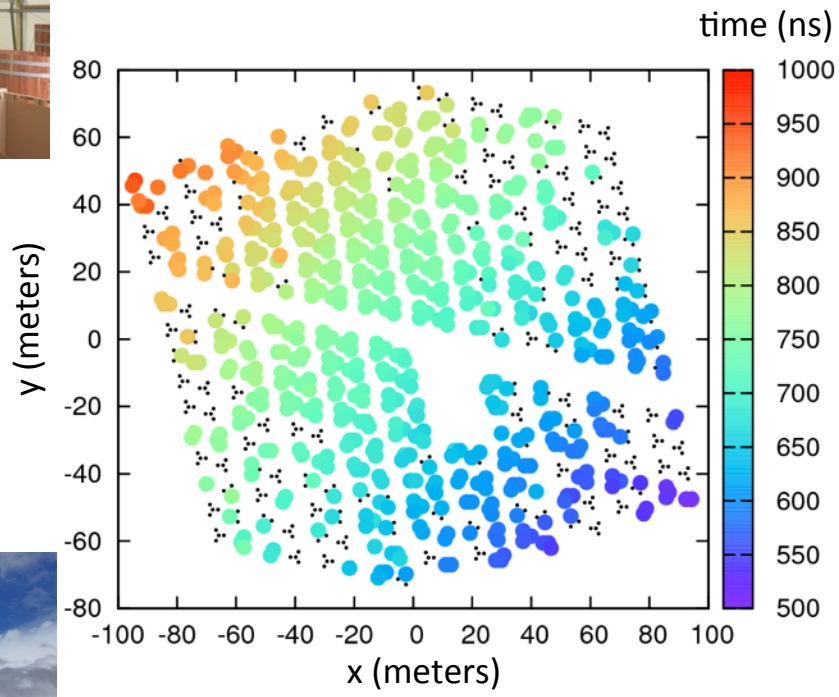
High Altitude Water Cherenkov Detector

- Second generation of technique developed for the Milagro gamma-ray observatory (2000-2008).
- Re-deploying Milagro PMTs and Front-end electronics
- Sensitive from 100 GeV to 100 TeV.
- High altitude (4100 m) site in the mountains of Mexico
- Large tanks of water covering 22500 m^2 area
- Overall 15x improvement in sensitivity over Milagro.
- See the Crab at over 5σ every day.
- Strengths:
  - Extreme high-energy reach.
  - Wide field-of-view.

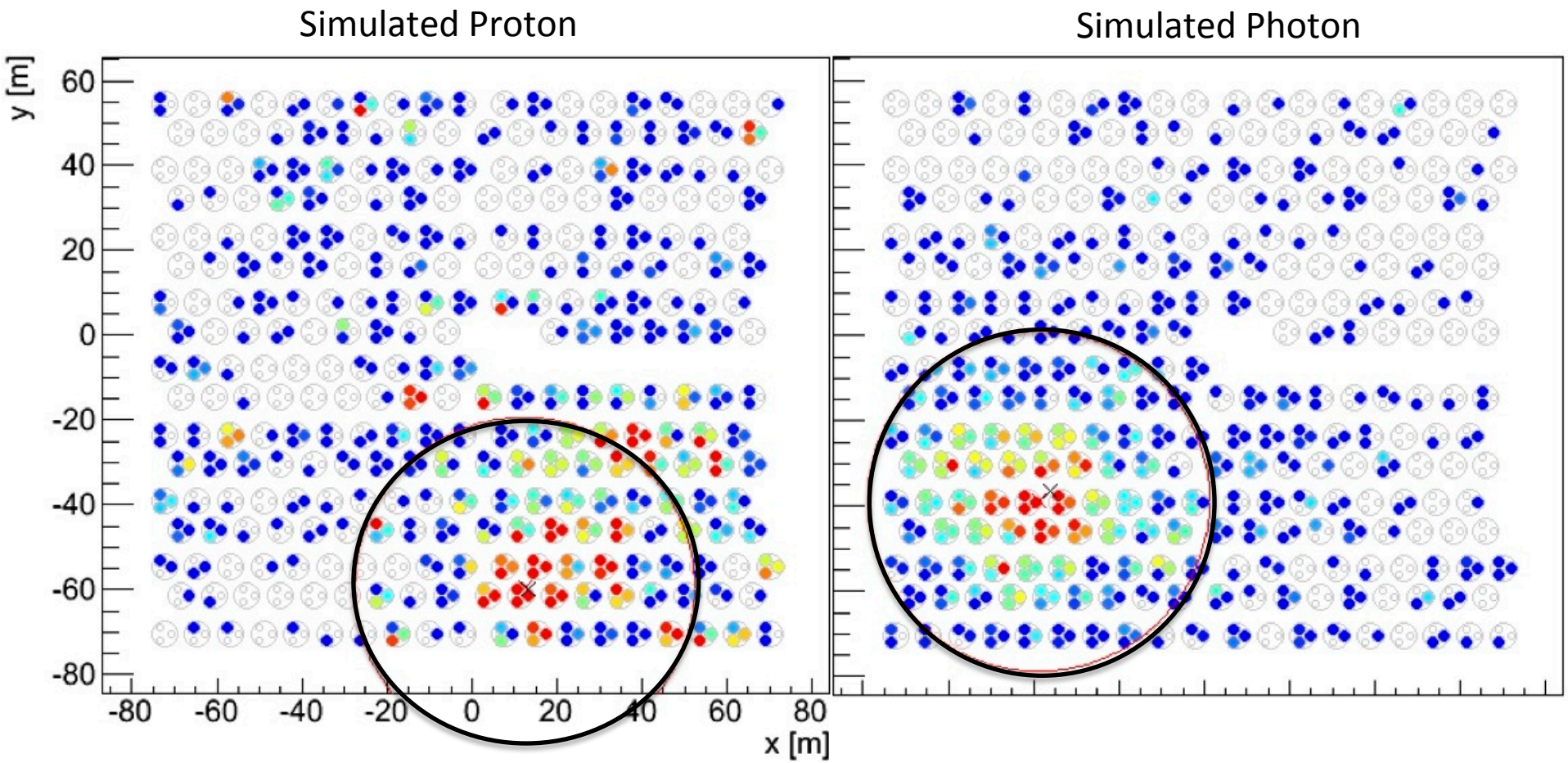


High Altitude Water Cherenkov Observatory

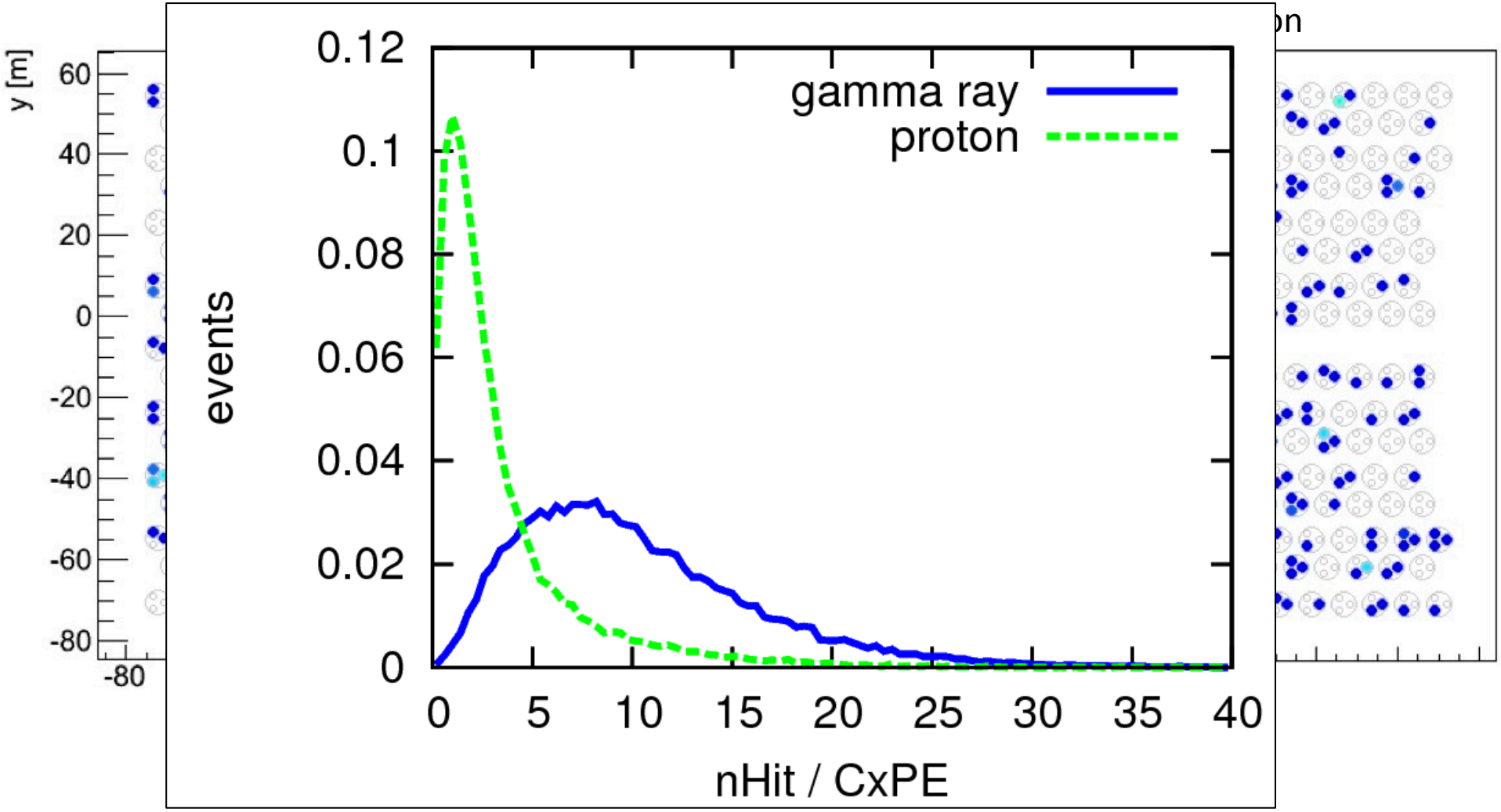




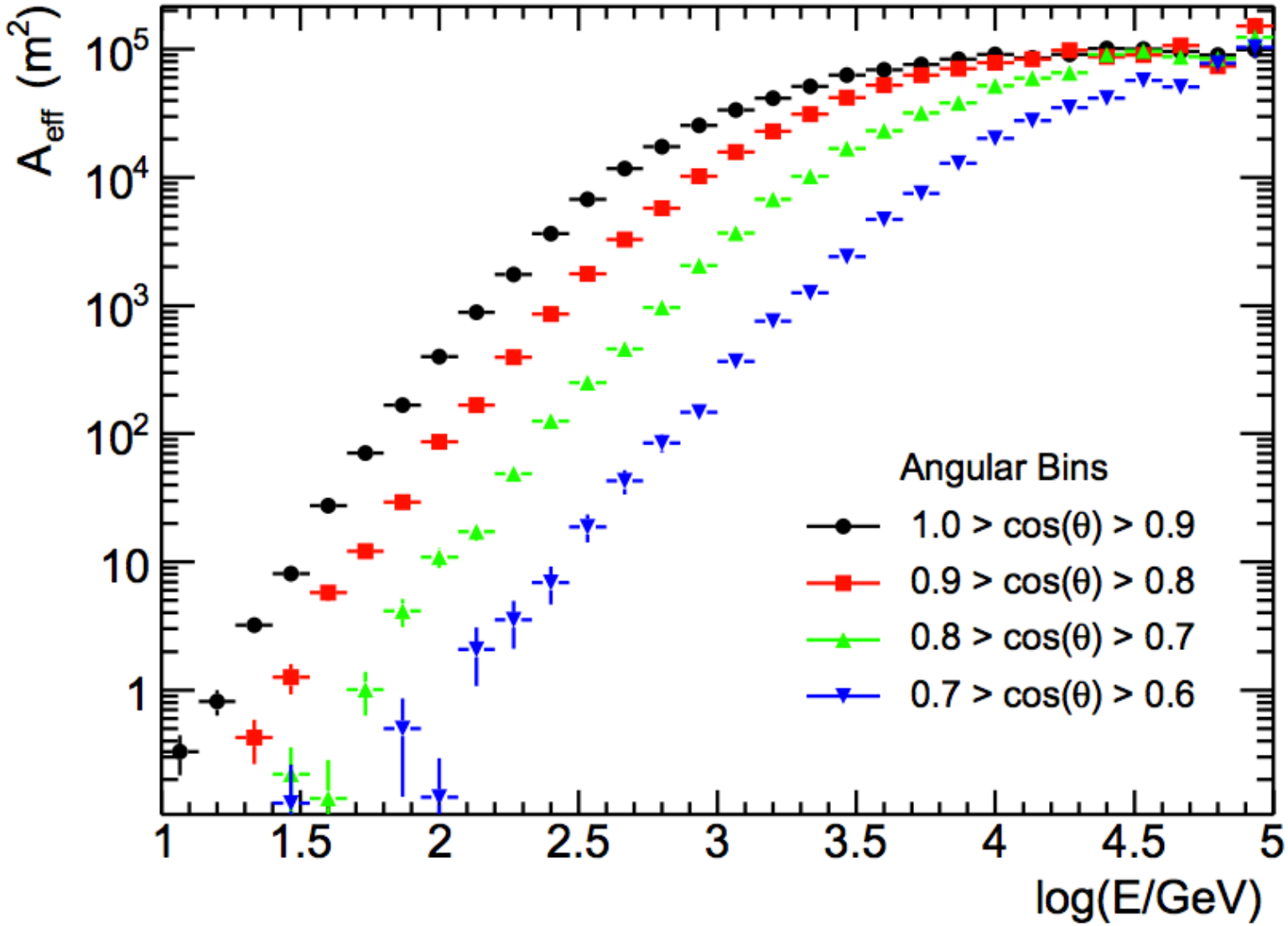
Photon / Hadron Discrimination



Photon / Hadron Discrimination

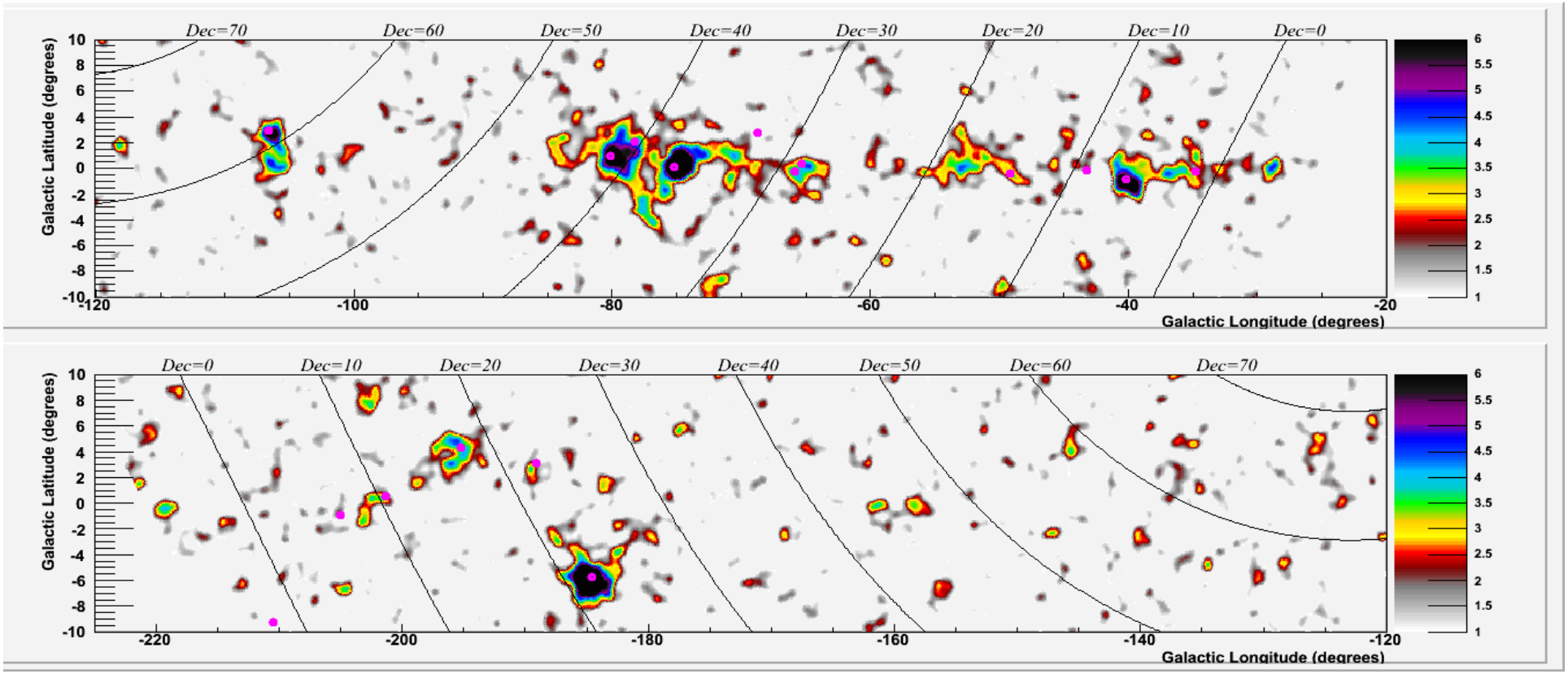


Effective Area



Astro. Part. Phys. 35:641 (2012)

Milagro 8-year Skymap

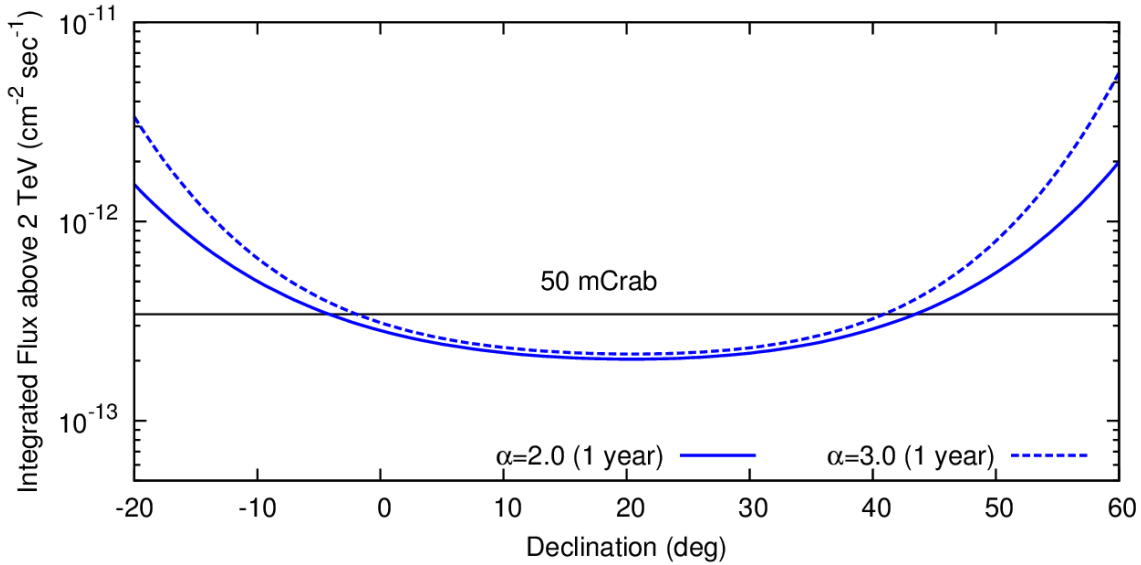


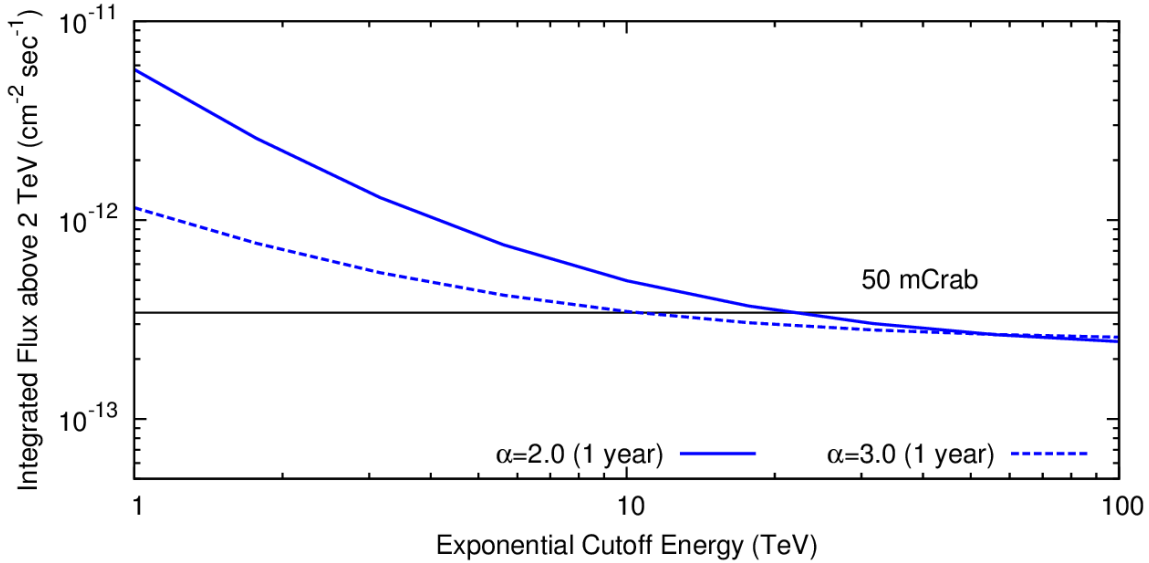
Milagro Collaboration: ApJ 700 (2009)

New TeV Sources.
GeV / TeV asociations are common.

HAWC-300 Sensitivity

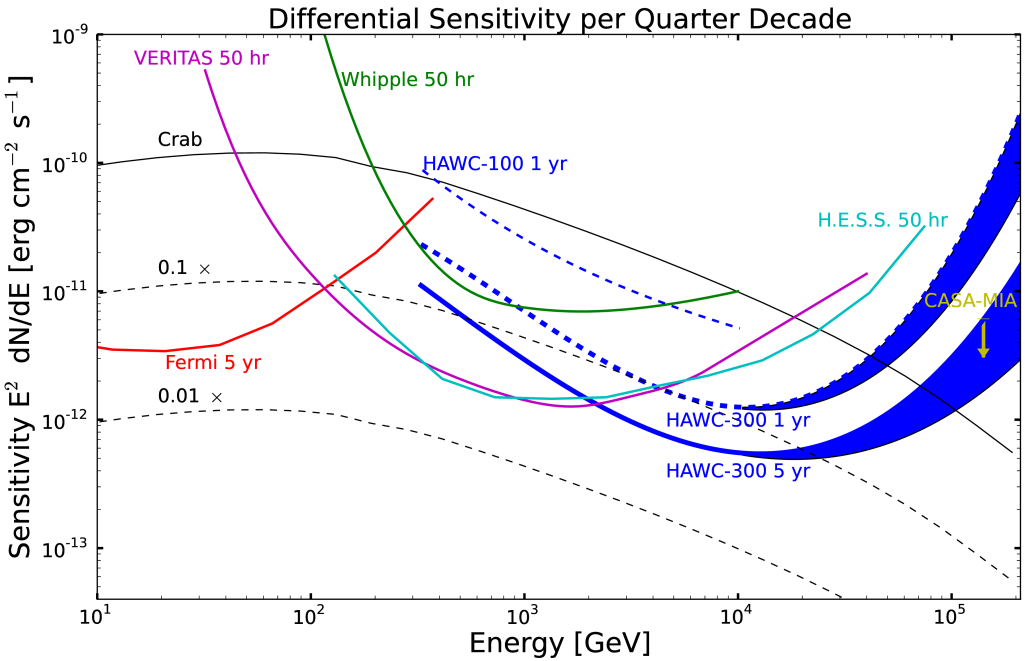
- Conservative estimate of sensitivity.
  - Simple cuts.
  - Sub-optimal high-energy cuts due to limited MC.
- Crab detected at >5σ in one day.
- 5×10^{-13} γ/cm^{-2} s^{-1} sensitivity (over 2 TeV) across 5 sr of the sky in 1 year.



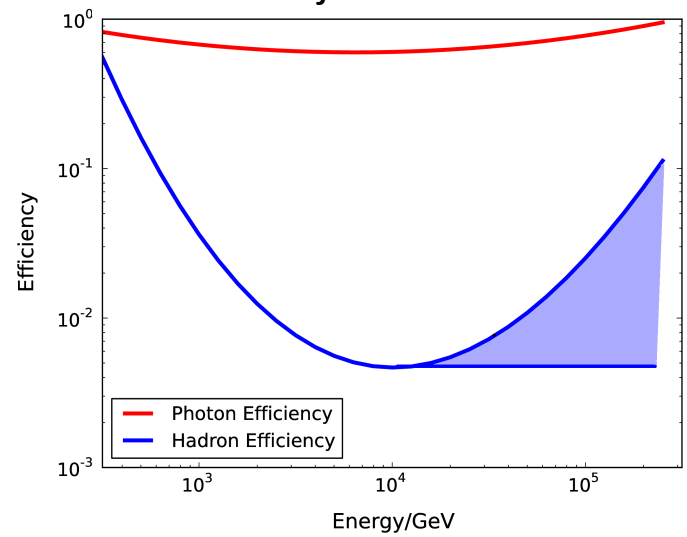


Preliminary….

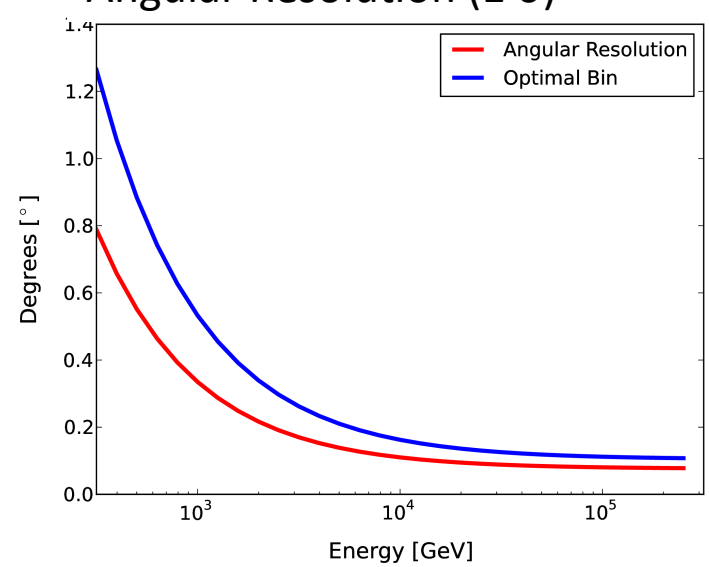
HAWC-300 Sensitivity



Hadron Rejection

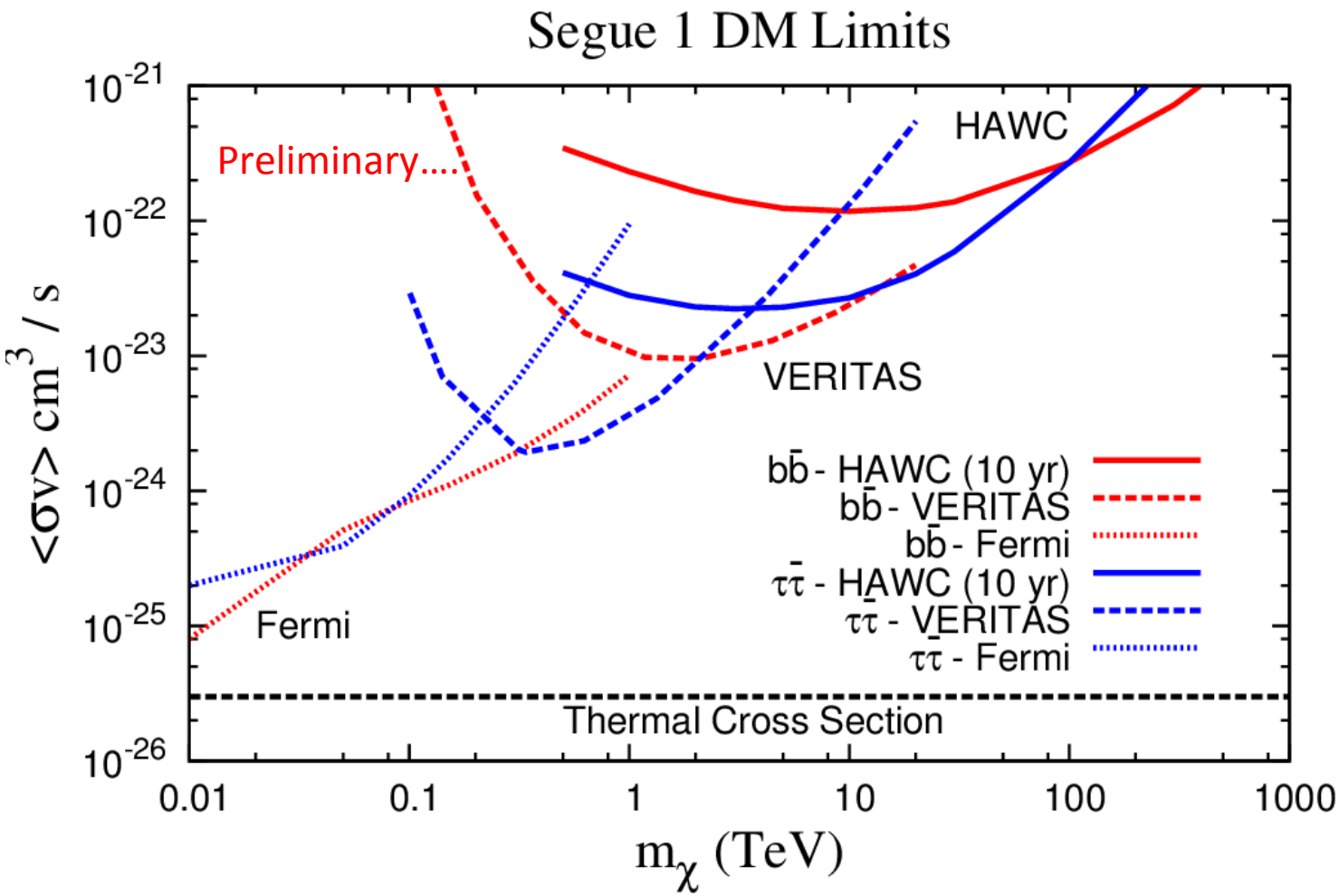


Angular Resolution (1 σ)



Preliminary….

Dark Matter Sensitivity



Fermi:
Ackermann et al. PRL 107:241302 (2011)

Spectra: P. Harding.

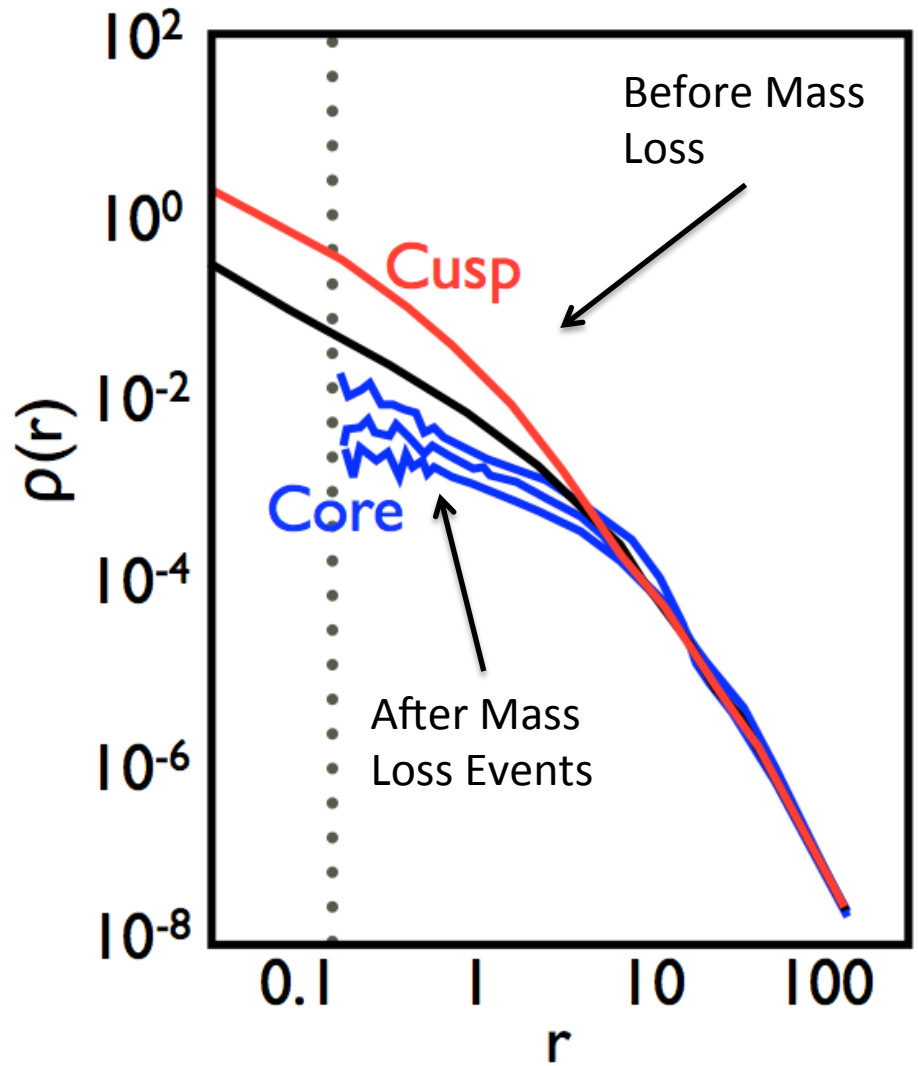
VERITAS:
Aliu et al. PRD 85:062001 (2012)

Galactic Center sensitivities forthcoming....

Missing Satellites "Dark" Dwarf Galaxies

- Cold DM simulations over-predict number of observed dwarf galaxies by as much as 10x (E.g. Klypin et al 1999)
- Resolution requires simulation of baryons.
- Presence of baryons:
  - Enhance the cuspiness of the center through adiabatic contraction (Gnedin et al. 2004)
  - Impulsive mass loss can flatten the center (Read & Gilmore 2003)

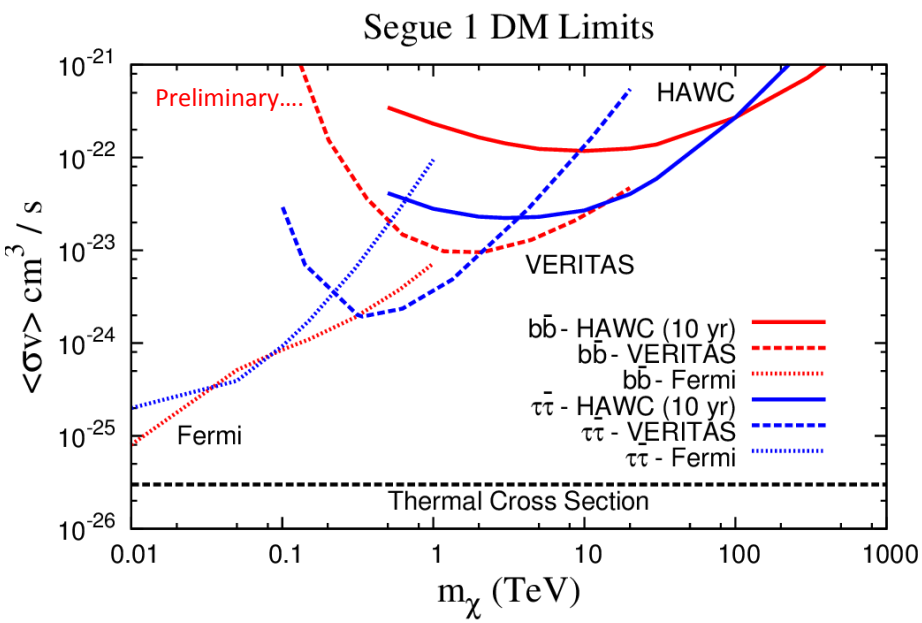
- *The best annihilation candidate may have no baryons.*



Read & Gilmore 2004; Navarro et al 1996

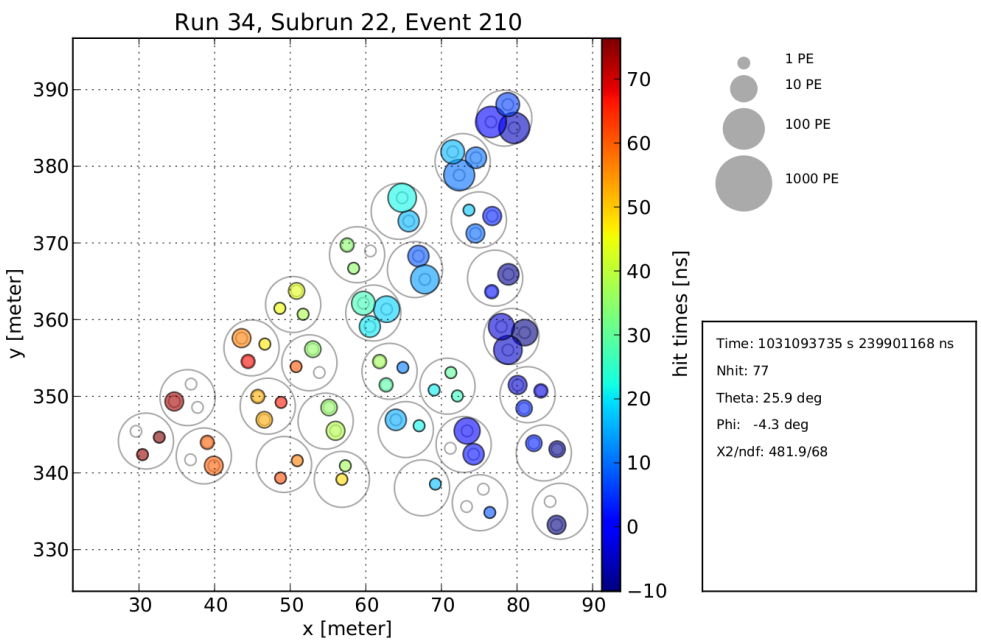
HAWC as a WIMP Instrument

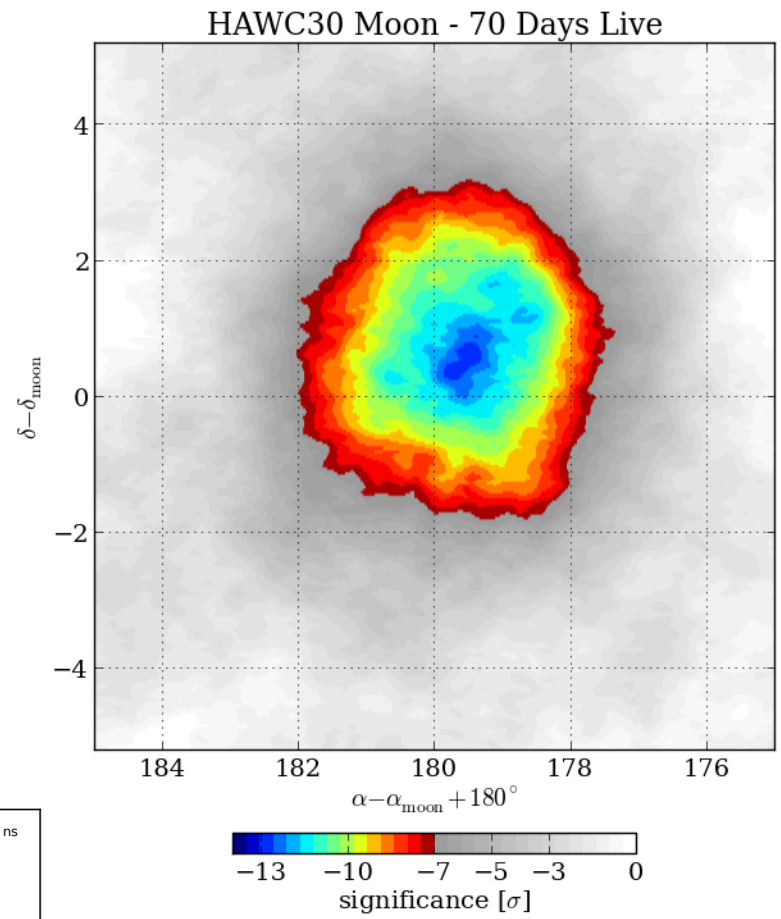
- High mass candidates (10-100 TeV and greater)
- Survey high-mass sky for DM objects unknown in other wavelengths.
- Improvement possible from stacking sources.
- Boosts of 10^3 to 10^4 get us to the thermal cross section.
- Wide-field enables study of Galactic DM profile (under study).



HAWC Status

- 10% of the array deployed and taking data (HAWC-30)
  - See the cosmic-ray shadow of the moon.
  - Good first agreement between data and simulation.
  - Roughly comparable to Milagro sensitivity.
- 30% of the array this summer.
  - Surpass Milagro sensitivity.
  - See the Crab in ~10 days.
- 100% in summer 2014.





Conclusions

- Identified dwarf-spheroidal galaxies provide a unique laboratory to search for dark matter interactions.
- HAWC's high-energy sensitivity (above 1 TeV) can be used to probe for dark matter annihilation in these objects.
- Unbiased sky survey can search for DM annihilation from galaxies with infinite mass-to-light ratio.
- Complementary limits to Fermi and IACTs.
- HAWC operations begin this summer with the instrument completed in summer 2014.

- Discovery is a real possibility.