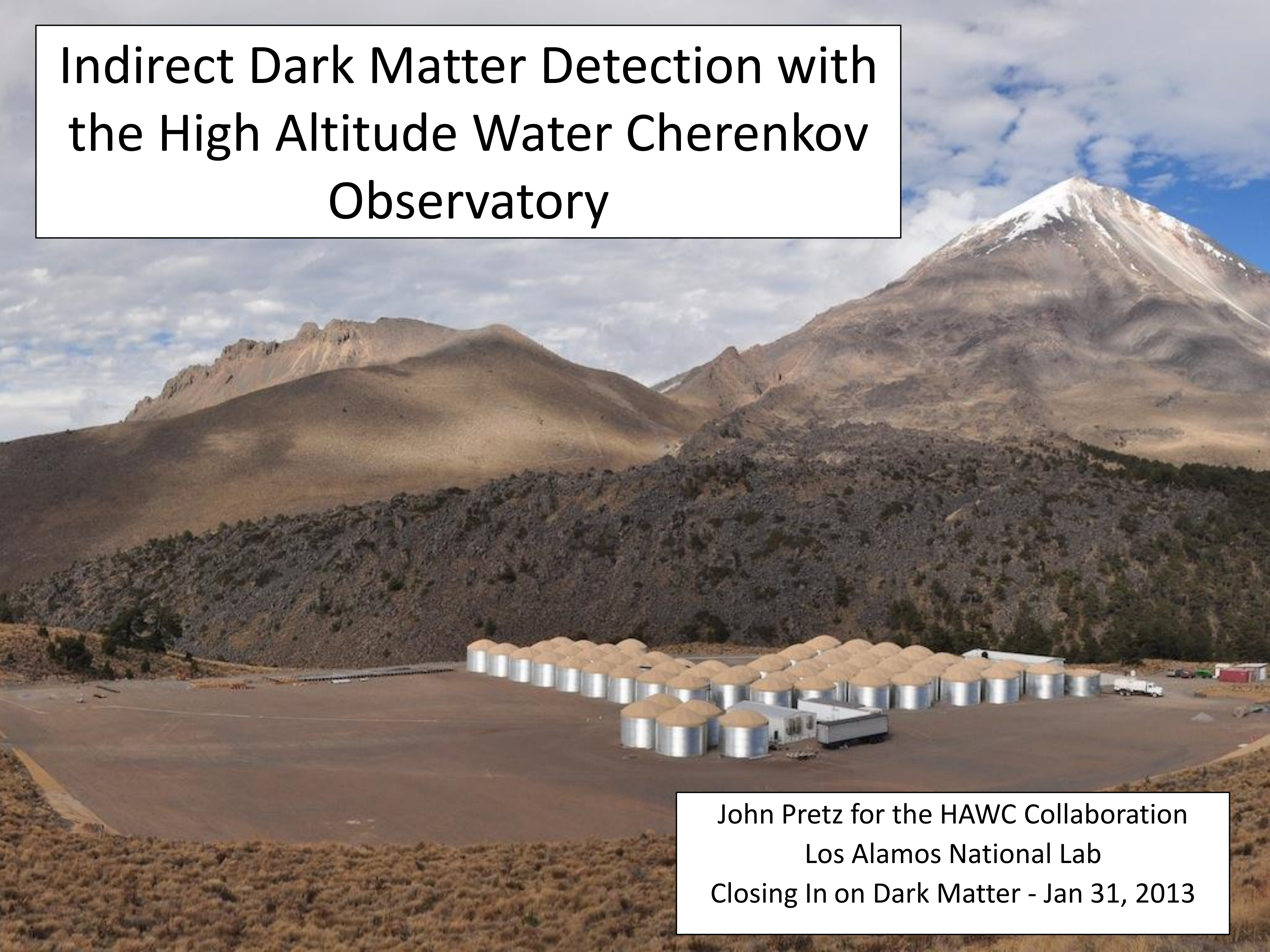
Indirect Dark Matter Detection with the High Altitude Water Cherenkov Observatory



John Pretz for the HAWC Collaboration
Los Alamos National Lab
Closing In on Dark Matter - Jan 31, 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

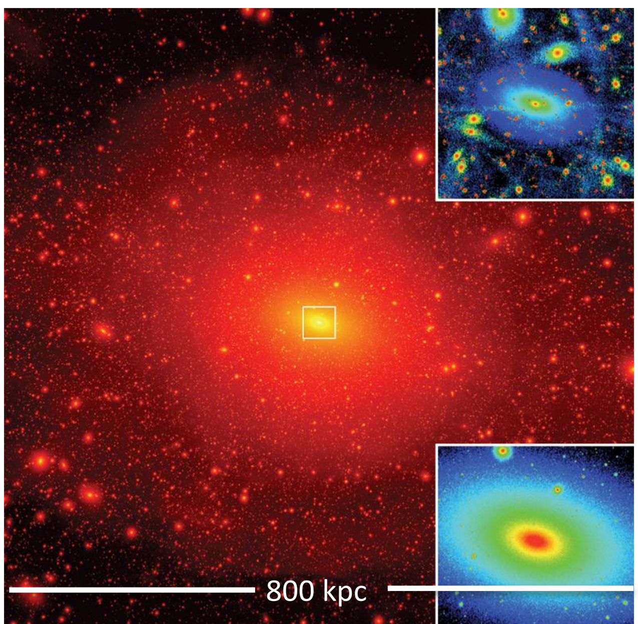
Universidad Autónoma de Chiapas
Universidad de Guadalajara
Benemérita Universidad Autónoma de Puebla
Universidad Michoacana de San Nicolás de Hidalgo
CINVESTAV
Universidad de Guanajuato
UGTO-IF
Universidad Autonoma del Estado de Hidalgo
Instituto Politecnico Nacional

Dwarf Spheroidal Galaxies and Indirect DM Signatures

- 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).):

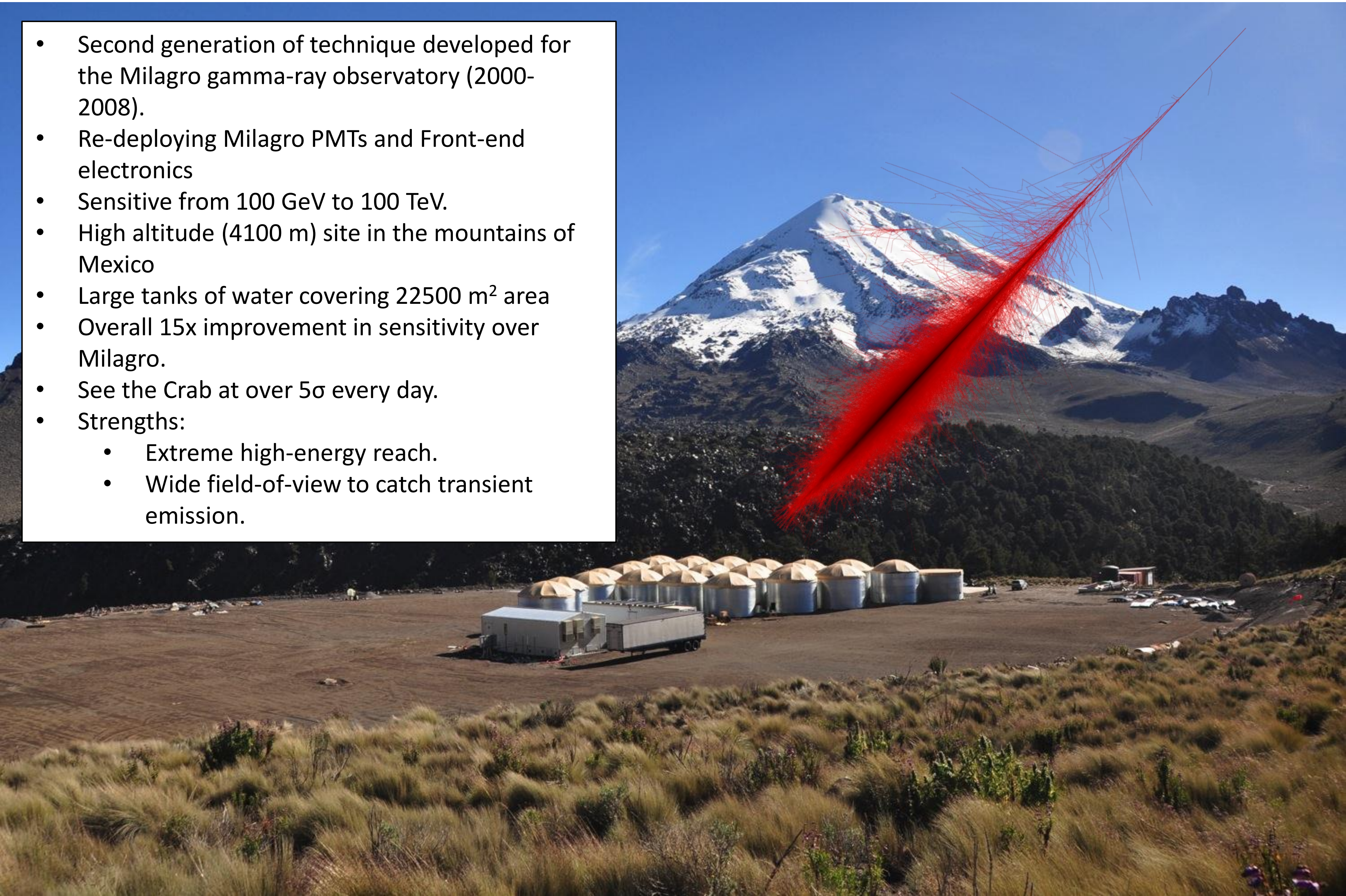
$$\frac{d\Phi_\gamma}{dE}(\Delta\Omega, E) = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2\,m_\chi^2}\frac{dN_\gamma}{dE} \times \bar{J}(\Delta\Omega).$$

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



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

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 to catch transient emission.

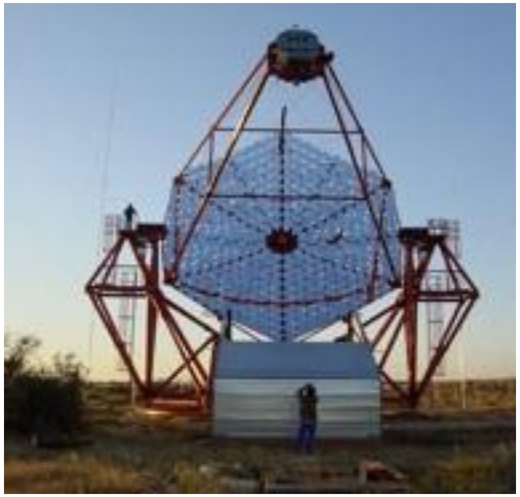
Comparison of Gamma-Ray Detectors

<u>Low Energy Threshold</u>
EGRET/Fermi

Space-based (Small Area)
"Background Free"
Large Duty Cycle/Large Aperture

Sky Survey (< 10 GeV)
AGN Physics
Transients (GRBs) < 100 GeV

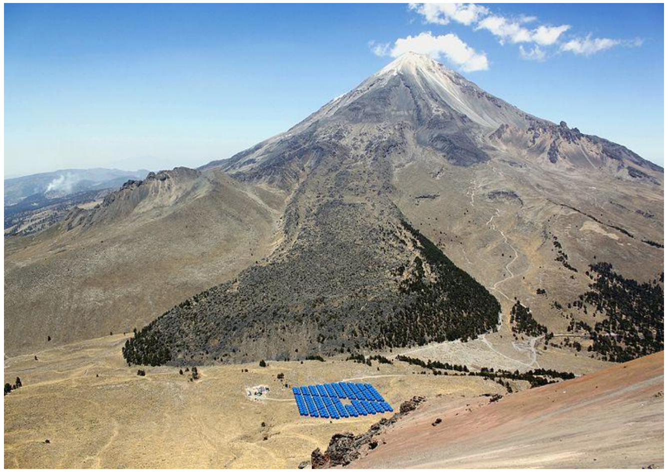
<u>High Sensitivity</u>
HESS, MAGIC, VERITAS, CTA



Large Effective Area
Excellent Background Rejection
Low Duty Cycle/Small Aperture

High Resolution Energy Spectra
Studies of known sources
Surveys of limited regions of sky at a time

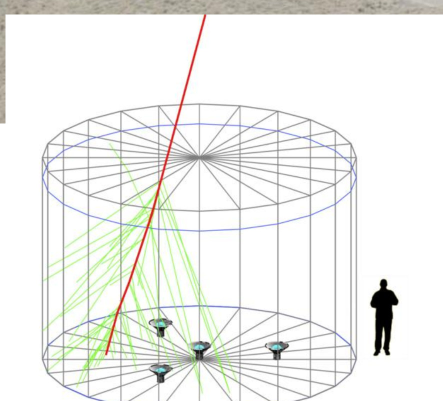
<u>Large Aperture/High Duty Cycle</u>
Milagro, Tibet, ARGO, HAWC

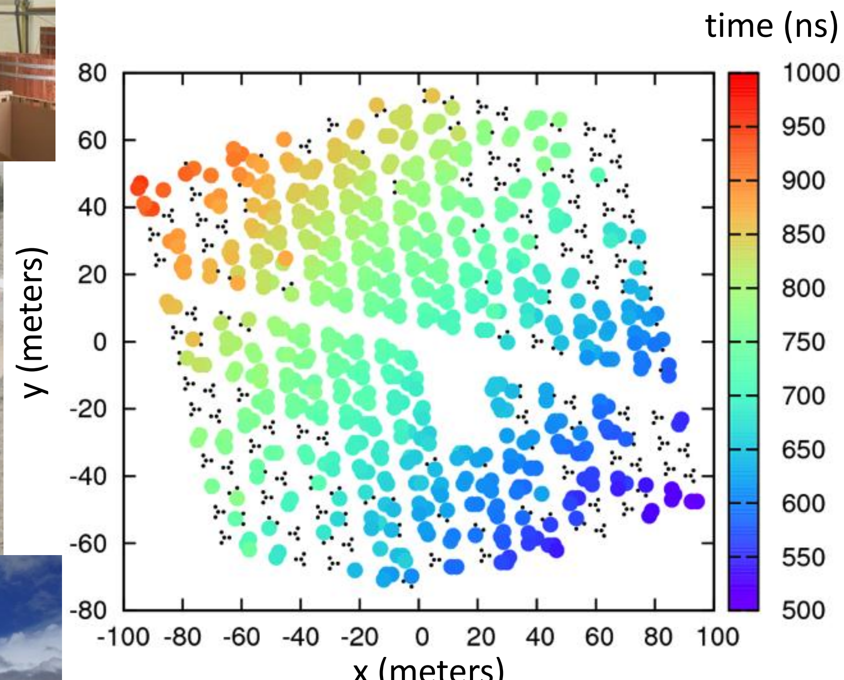


Moderate Area
Good Background Rejection
Large Duty Cycle/Large Aperture

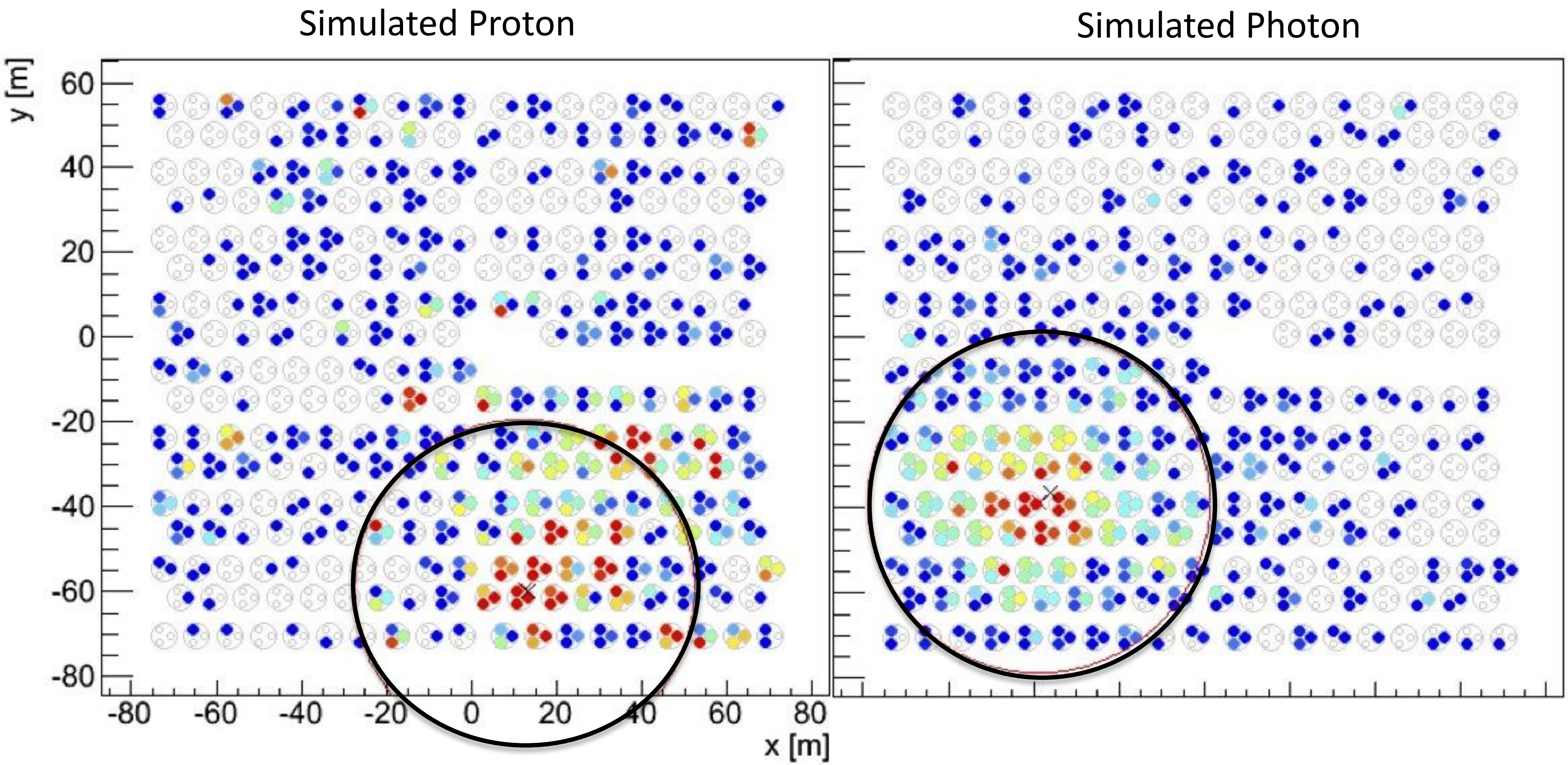
Unbiased Sky Survey
Extended sources
Transients (GRB's)
Solar physics/space weather

High Altitude Water Cherenkov Observatory

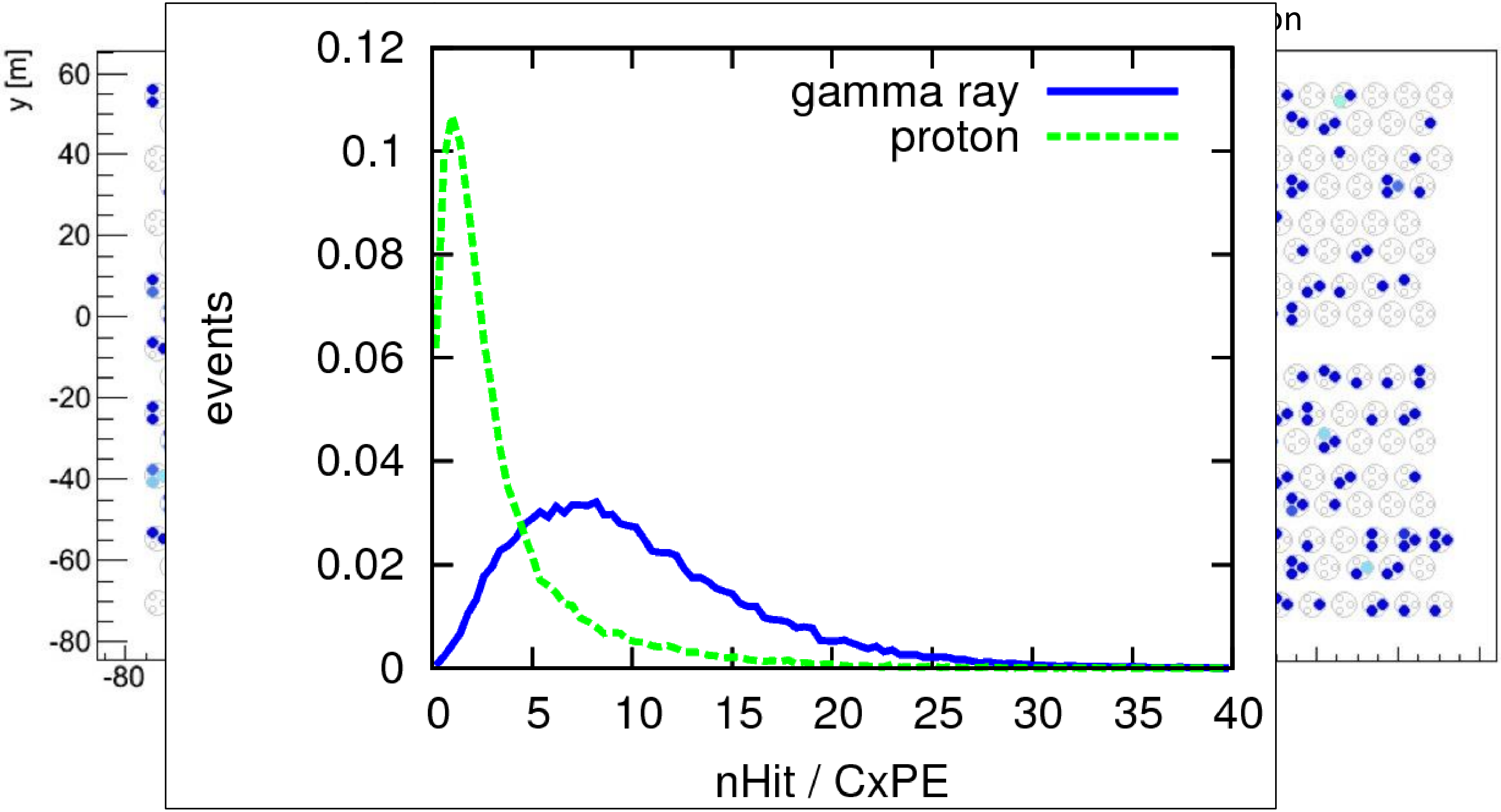




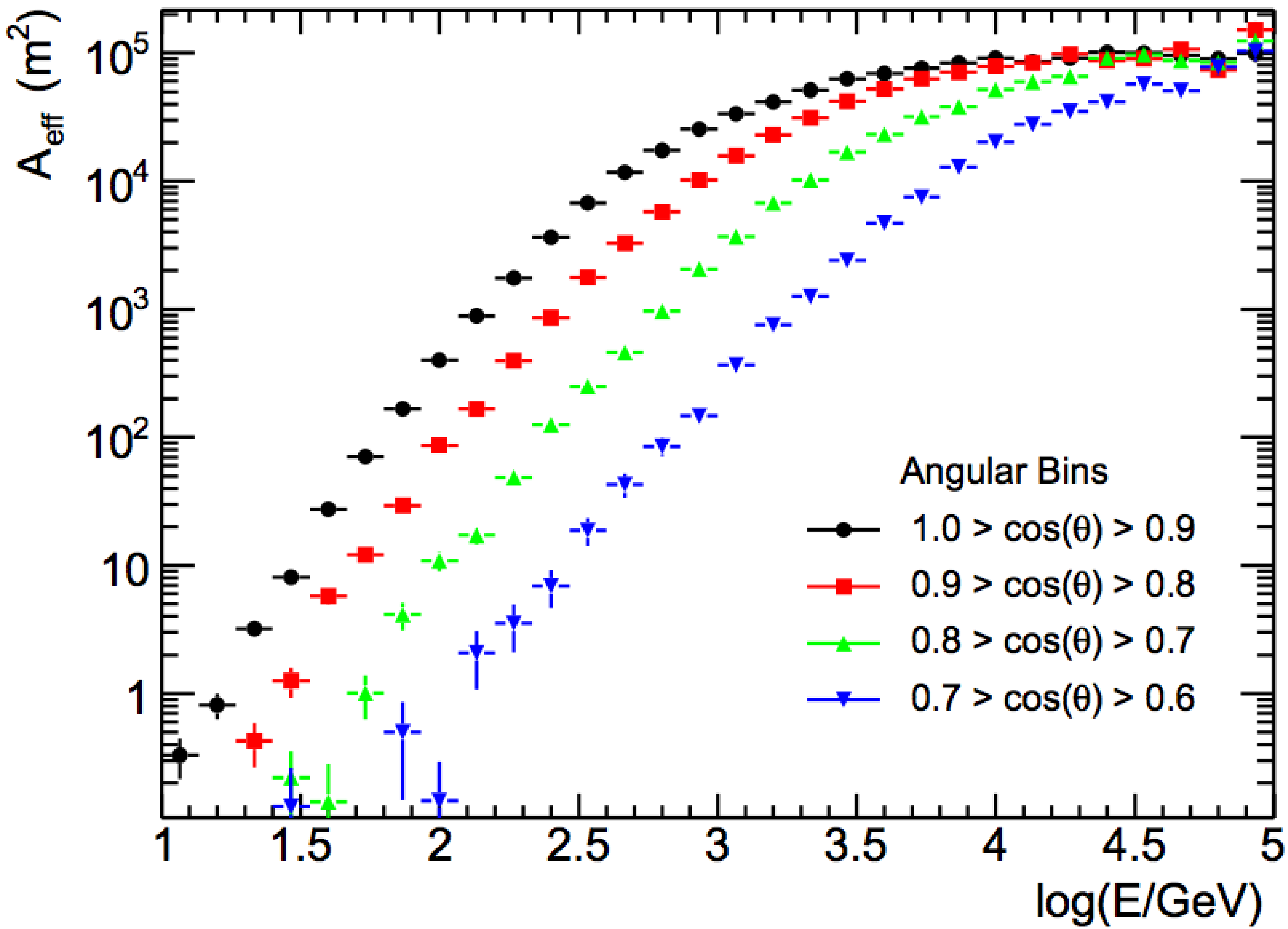
Photon / Hadron Discrimination



Photon / Hadron Discrimination

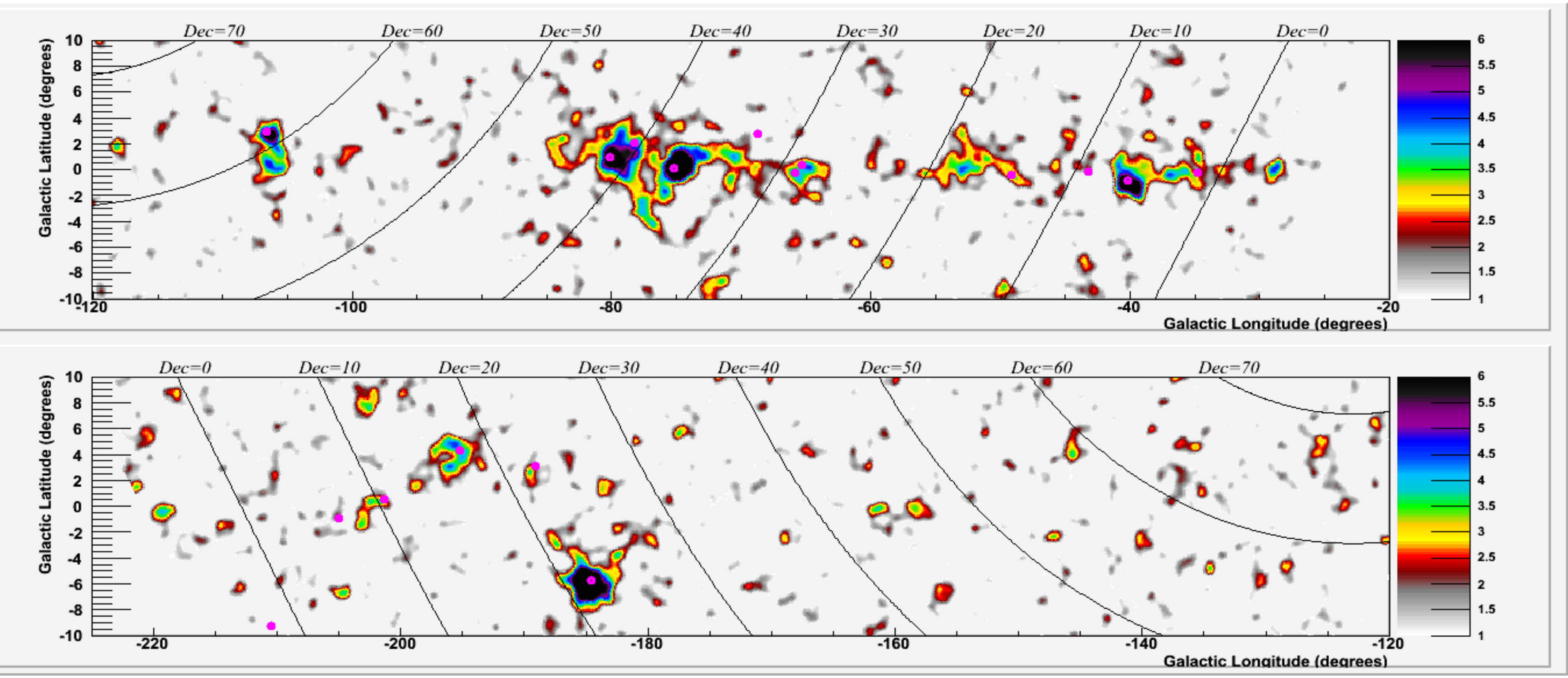


Effective Area



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

Milagro 8-year Skymap

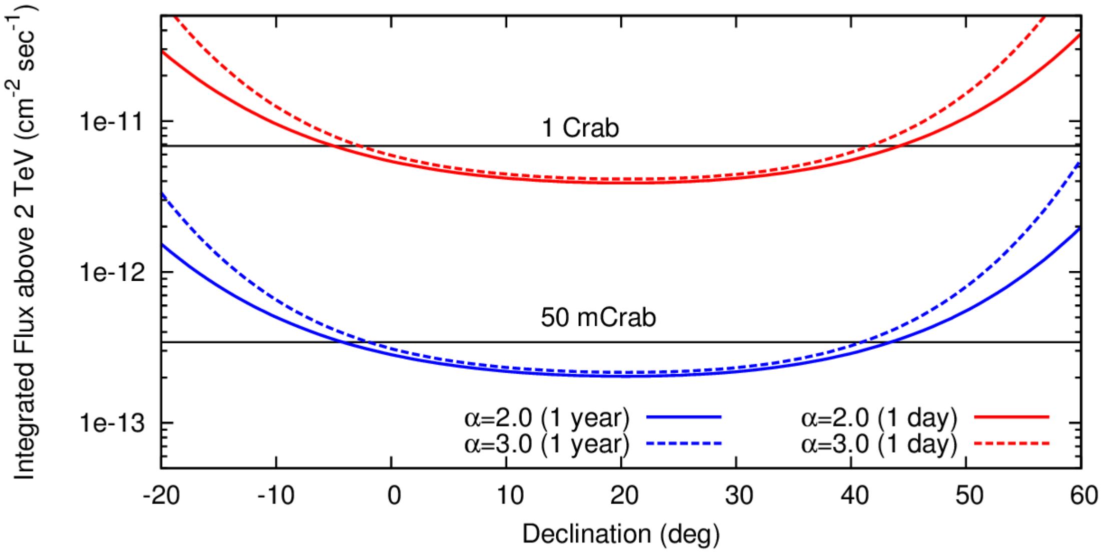


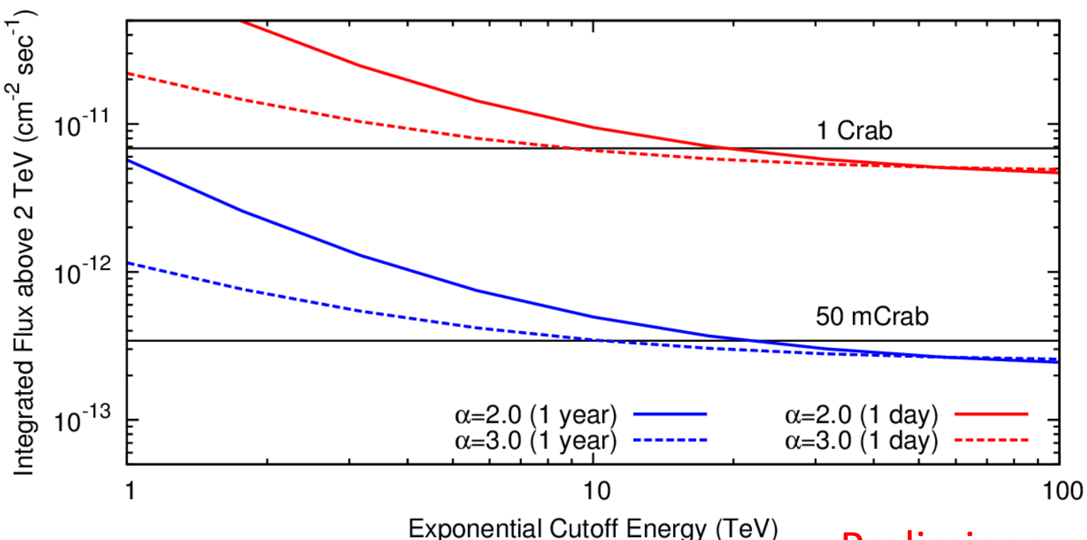
New TeV Sources.
GeV / TeV asociations are common.

Milagro Collaboration: ApJ 700 (2009)

HAWC-300 Sensitivity

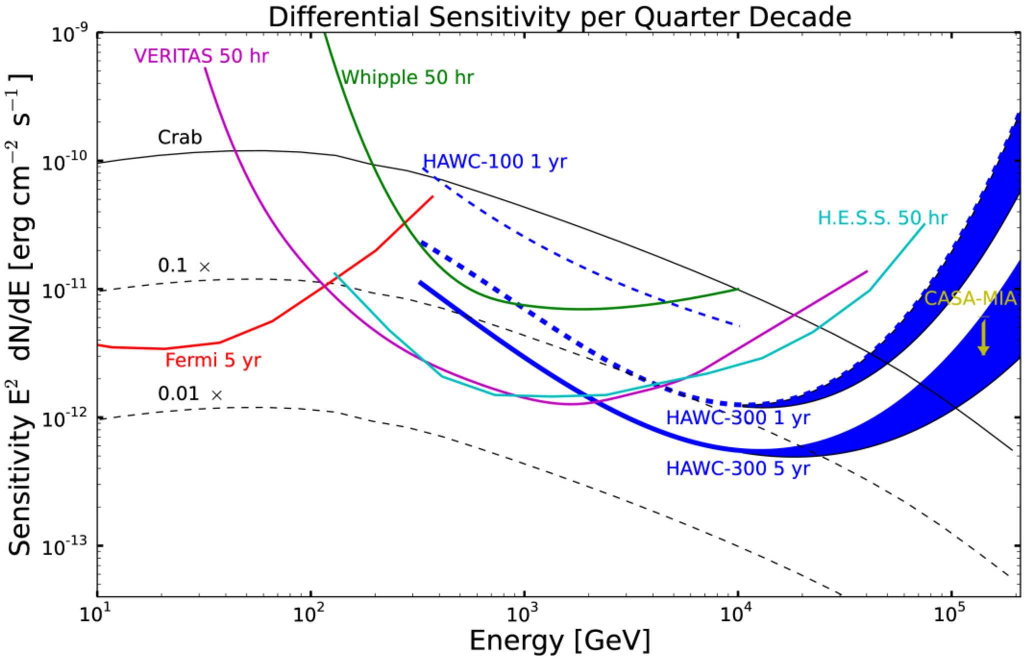
- Conservative estimate of sensitivity.
  - Simple cuts.
  - Sub-optimal high-energy cuts due to limited MC.
- Crab detected at >5σ in one day.
- 5×10^{-13} γ/cm^{-2} s^{-1} sensitivity (over 2 TeV) across 5 sr of the sky in 1 year.



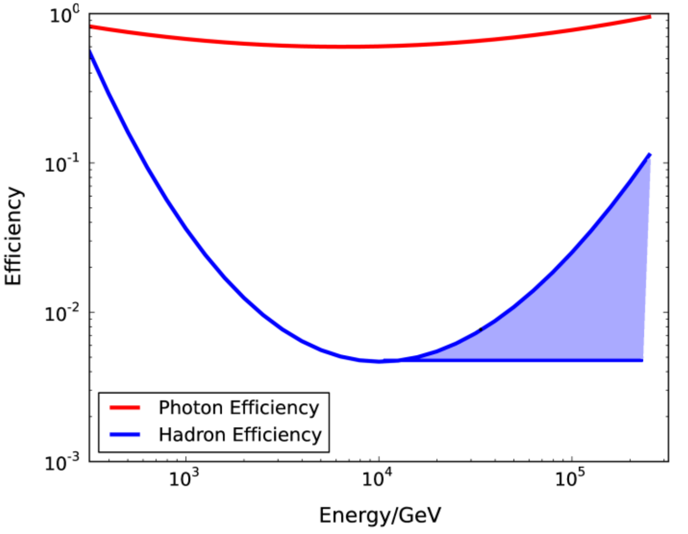


Preliminary....

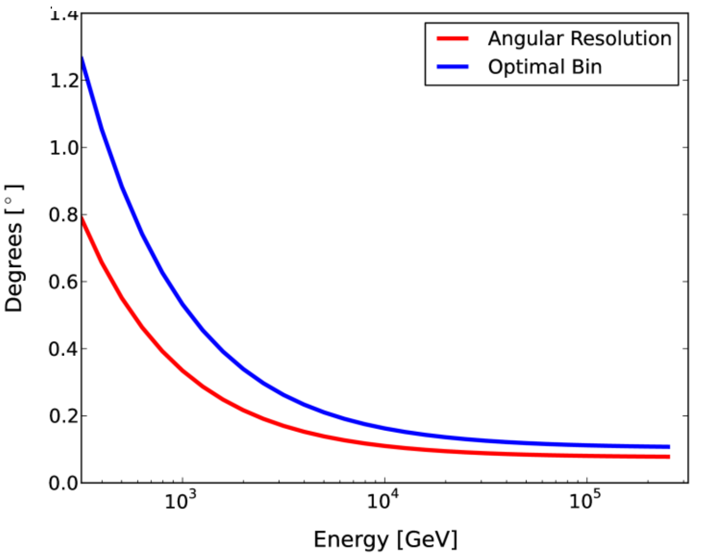
HAWC-300 Sensitivity



Hadron Rejection

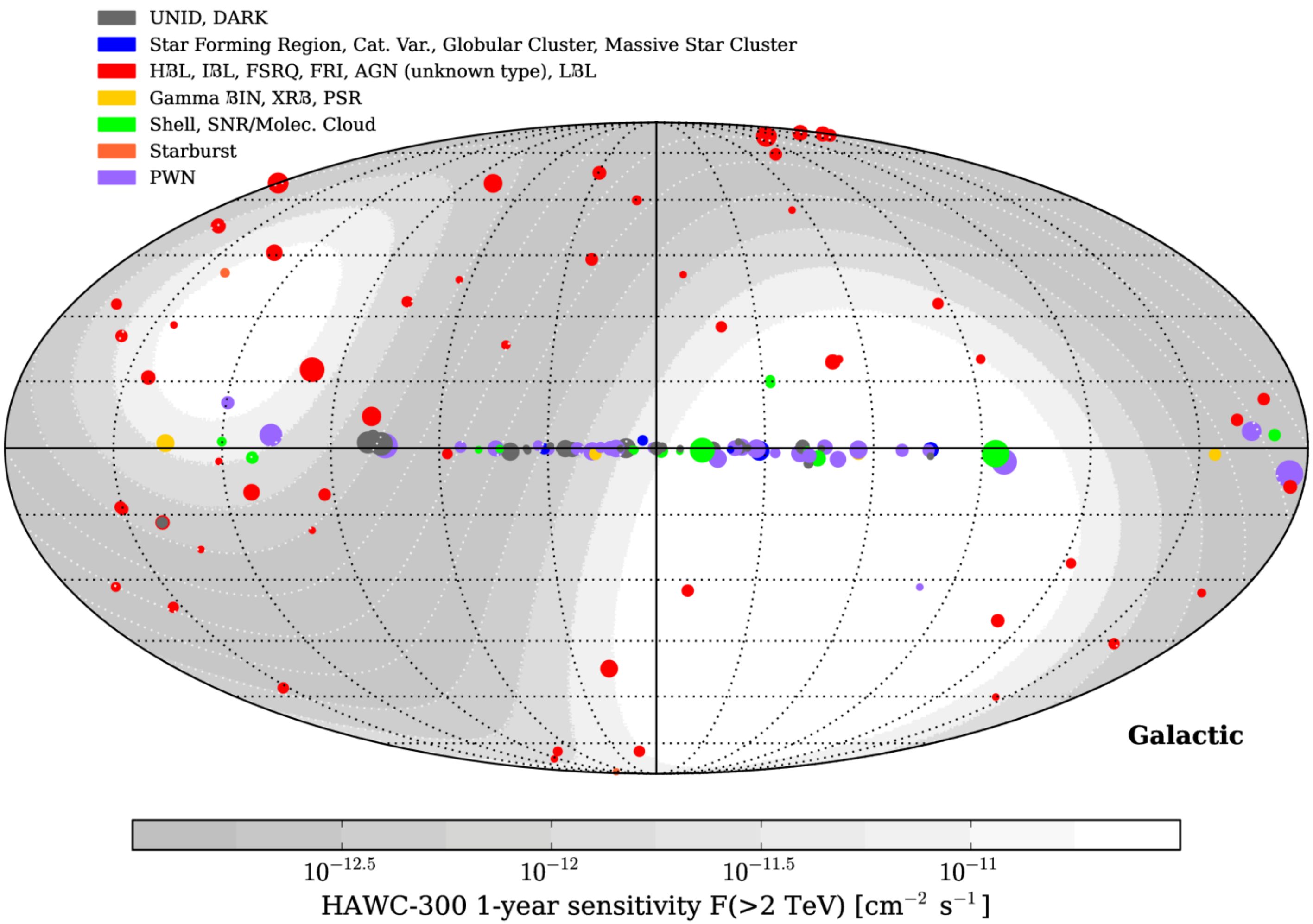


Angular Resolution (1 σ)



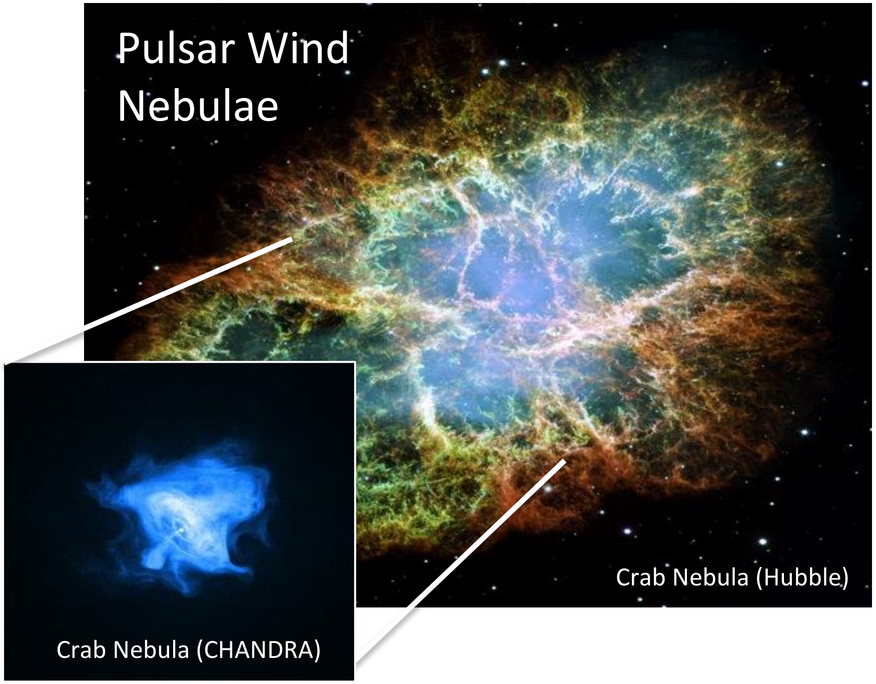
Preliminary….

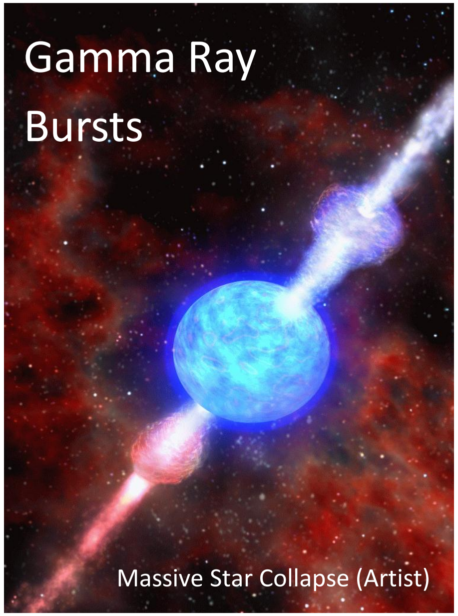
HAWC-300 Sensitivity

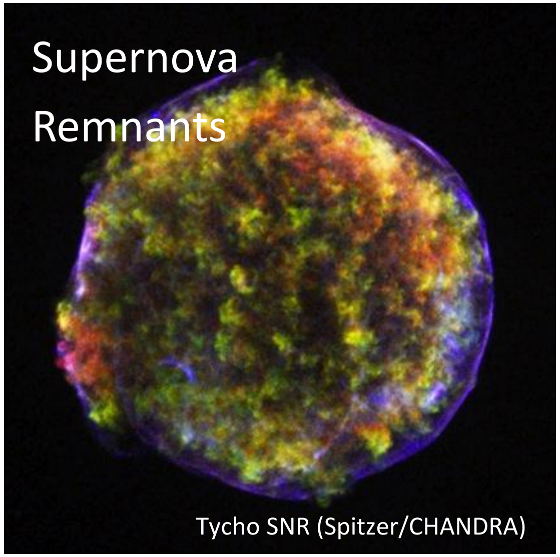


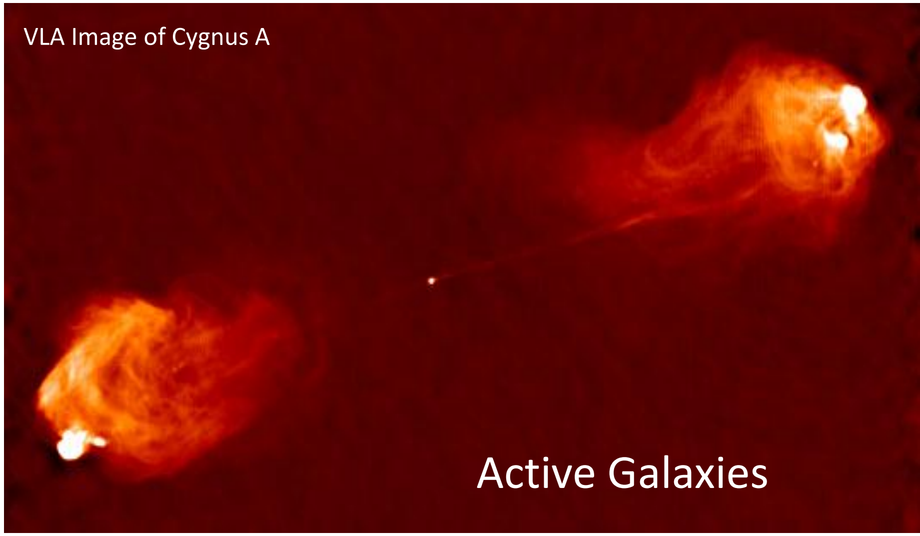
Preliminary....

Sources We Study

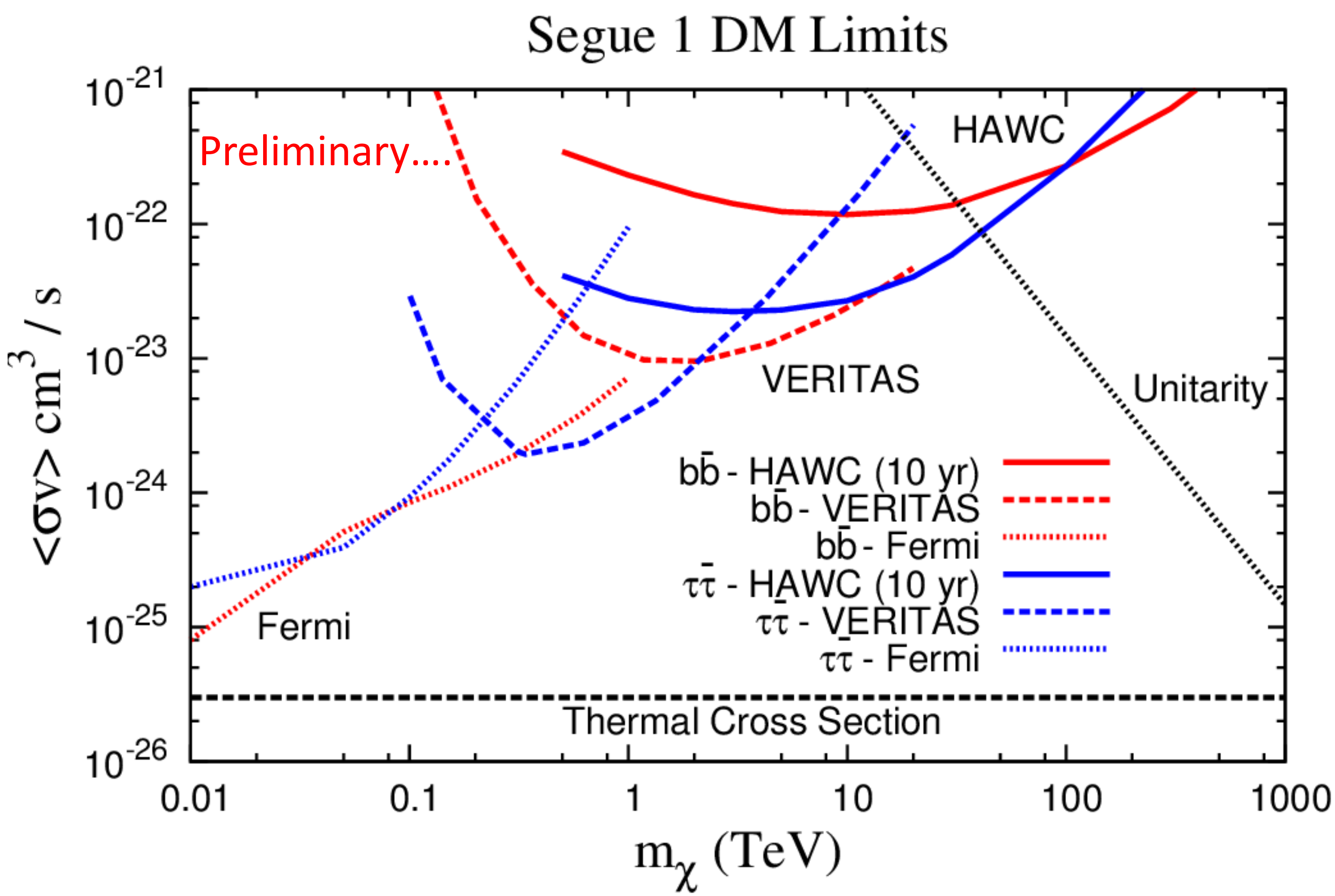








Dark Matter Sensitivity



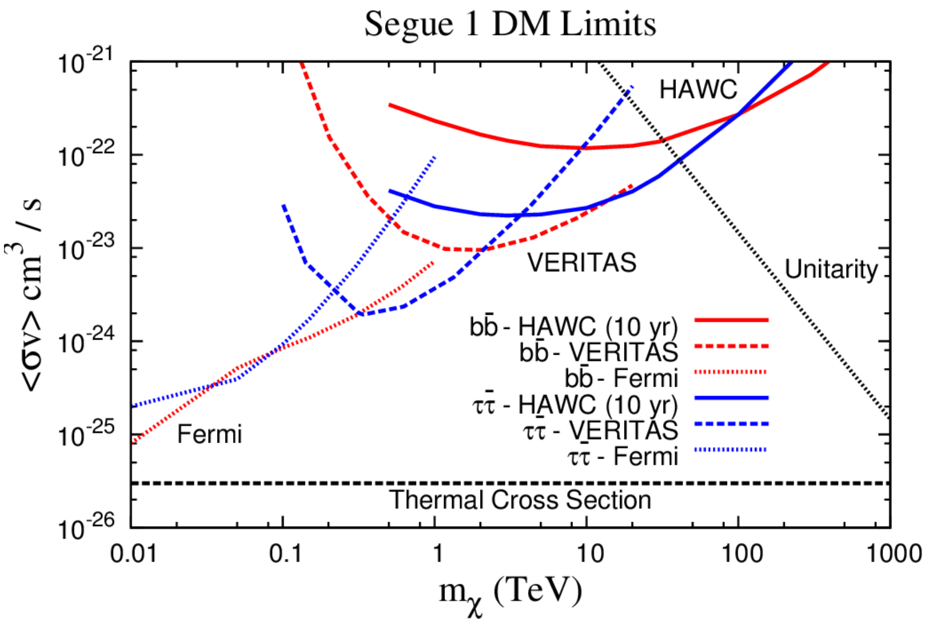
Spectra: P. Harding.
Fermi:
Ackermann et al. PRL 107:241302 (2011)

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

Unitarity:
Griest et al. PRL 64:615. (1990)
Hui PRL 86:3467 (2001)
Harding. UMD Ph.D. thesis (2012)

HAWC as a WIMP Instrument

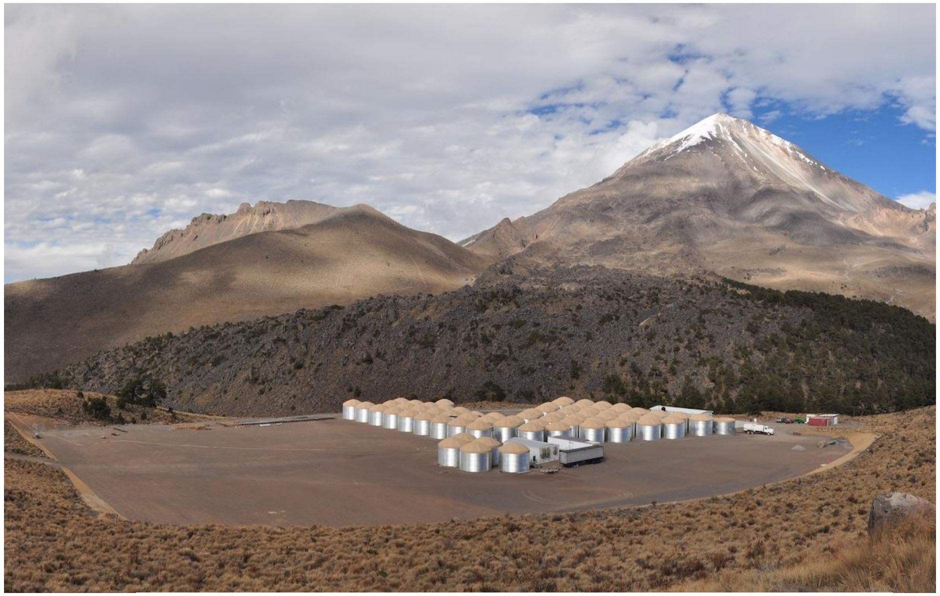
- High mass candidates.
- Survey high-mass sky for DM objects unknown in other wavelengths. Seems the dimmer dSph provide the best targets.
- Improvement possible from stacking sources.
- Unitarity arguments against extremely high masses. Surmountable (Profumo, PRD 72:103521, 2005) Probing some of the highest-mass possibilities.
- Boosts of 10^3 to 10^4 get us to the thermal cross section.
- Wide-field enables study of Galactic DM profile (under study).

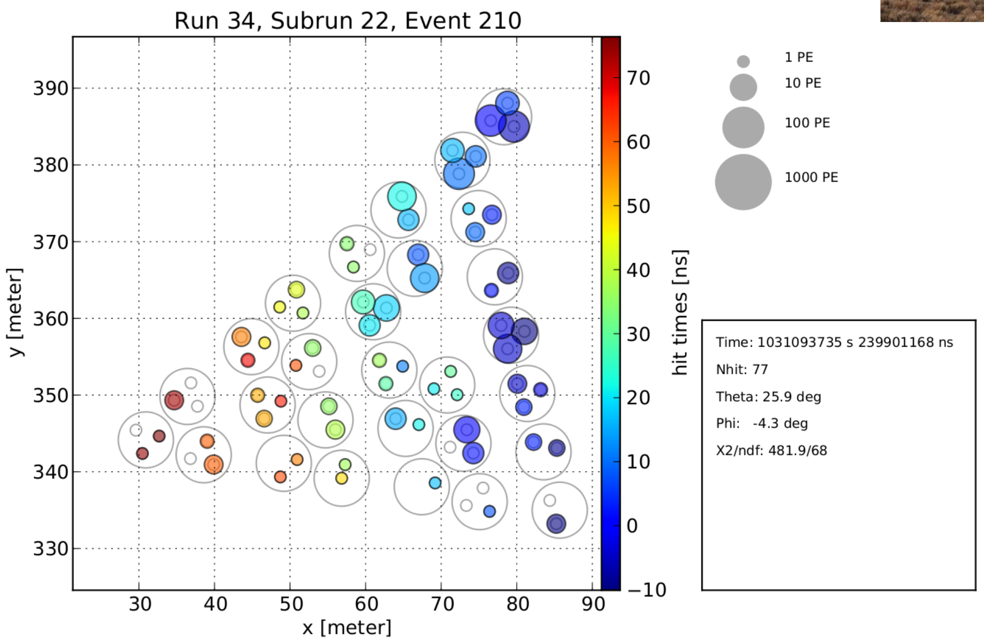


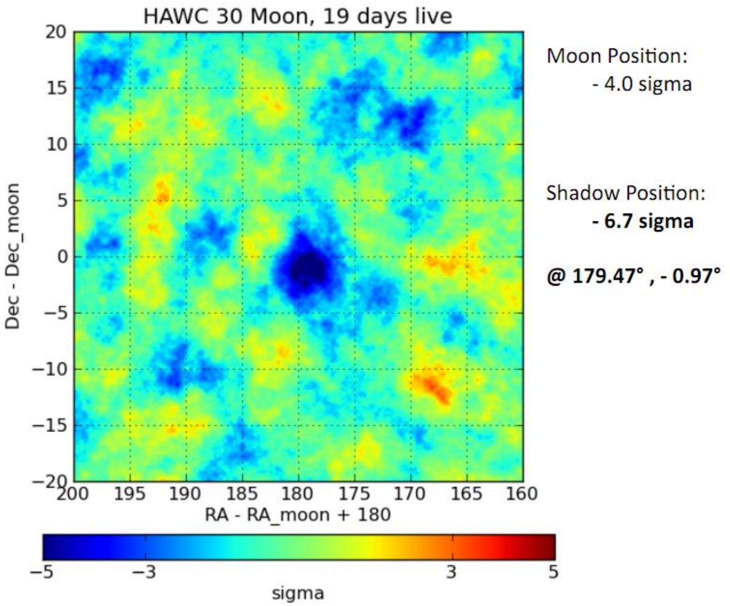
Preliminary….

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. Discovery is possible.
- HAWC operations begin this summer with the instrument completed in summer 2014.