



VERITAS Observations of the Galactic Center



A photograph showing two of the VERITAS telescopes at sunset. The telescopes are large, white, parabolic structures mounted on dark metal frames. They are silhouetted against a vibrant orange and yellow sky. In the background, there are dark hills and a few wispy clouds. The overall scene is dramatic and captures the beauty of scientific infrastructure in a natural setting.

Amanda Weinstein
for the VERITAS Collaboration



Overview

- Brief motivation
- Introduction to VERITAS
- Technical challenges
- Results
- Future work



- Ingredient 1: SM extension predicting a self-annihilating WIMP
- Ingredient 2: Channel that produces gamma rays

Annihilation Channel	Secondary Processes	Signals	Notes
$\chi\chi \rightarrow q\bar{q}, gg$	$p, \bar{p}, \pi^\pm, \pi^0$	p, e, ν, γ	
$\chi\chi \rightarrow W^+W^-$	$W^\pm \rightarrow l^\pm \nu_l, W^\pm \rightarrow u\bar{d} \rightarrow \pi^\pm, \pi^0$	p, e, ν, γ	
$\chi\chi \rightarrow Z^0Z^0$	$Z^0 \rightarrow l\bar{l}, \nu\bar{\nu}, q\bar{q} \rightarrow \text{pions}$	p, e, γ, ν	
$\chi\chi \rightarrow \tau^\pm$	$\tau^\pm \rightarrow \nu_\tau e^\mp \nu_e, \tau \rightarrow \mu, W^\pm \rightarrow p, \bar{p}, \text{pions}$	p, e, γ, ν	
$\chi\chi \rightarrow \mu^+\mu^-$		e, γ	Rapid energy loss of μ s in sun before decay results in sub-threshold ν s
$\chi\chi \rightarrow \gamma\gamma$	Z^0 decay	γ	Loop suppressed
$\chi\chi \rightarrow Z^0\gamma$		γ	Loop suppressed
$\chi\chi \rightarrow e^+e^-$		e, γ	Helicity suppressed
$\chi\chi \rightarrow \nu\bar{\nu}$		ν	Helicity suppressed (important for non-Majorana WIMPs?)
$\chi\chi \rightarrow \phi\phi$	$\phi \rightarrow e^+e^-$ internal/final state brems inverse Compton γ 's	e^+	New scalar field with $m_\chi < m_\phi$ to explain large electron signal and avoid overproduction of p, γ

$$\frac{dF(E, \hat{n})}{dEd\Omega} = \int d\ell \ell^2 r(\ell \hat{n}) \frac{dN_\gamma(E)}{dE} \frac{1}{4\pi\ell^2}$$

$$= \frac{\langle \sigma v \rangle}{8\pi M^2} \frac{dN_\gamma(E)}{dE} \int d\ell \rho^2(\ell \hat{n})$$

Particle Physics Astrophysical Factor

- Ingredient 3: Sufficient local DM density



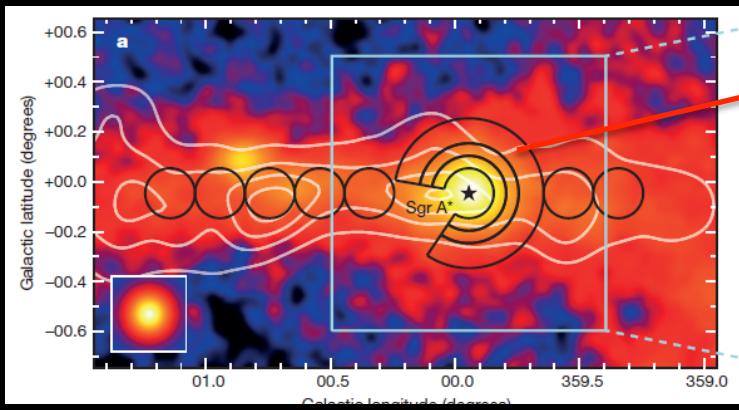
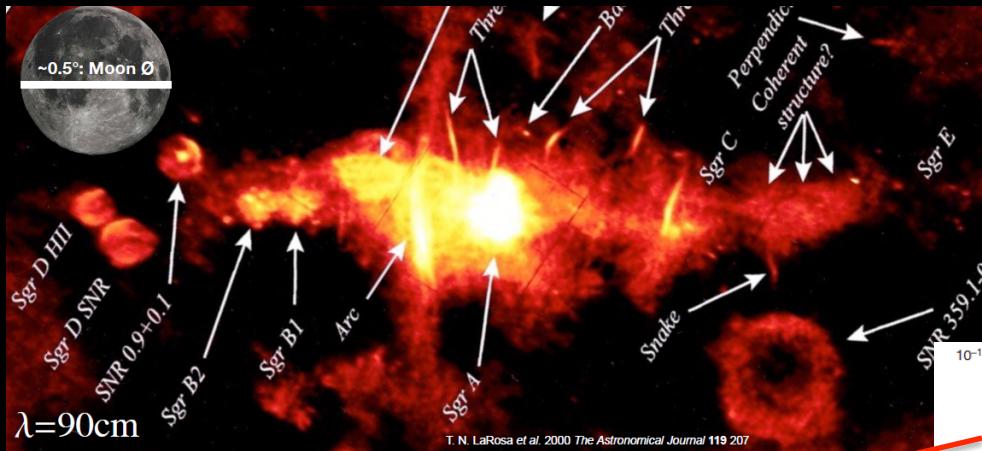
Dark Matter continued

<u>Target</u>	<u>Advantages</u>	<u>Disadvantages</u>
Galactic Center	Close by, lots of DM	Large γ BG
Fermi-LAT UIDs	Possibly local, known gamma-ray sources	Unknown distance, nature
Galaxy Clusters	-Largest DM concentrations in universe	-very distant (weak signal) -very extended -possible γ BG
Dwarf Galaxies	-High Mass/Light -No likely γ BG	DM distribution can be very uncertain

Motivation II: Astrophysics

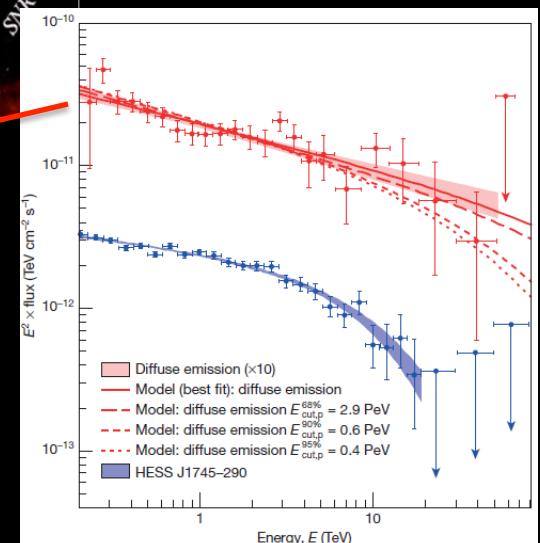


- Abundant VHE gamma-ray emission in region from interesting astrophysical sources
 - Includes bright VHE γ -ray source probably associated with black hole central engine (Sgr A*), diffuse emission from CR interactions with ISM
- Understanding this emission also critical to dark matter studies using the GC

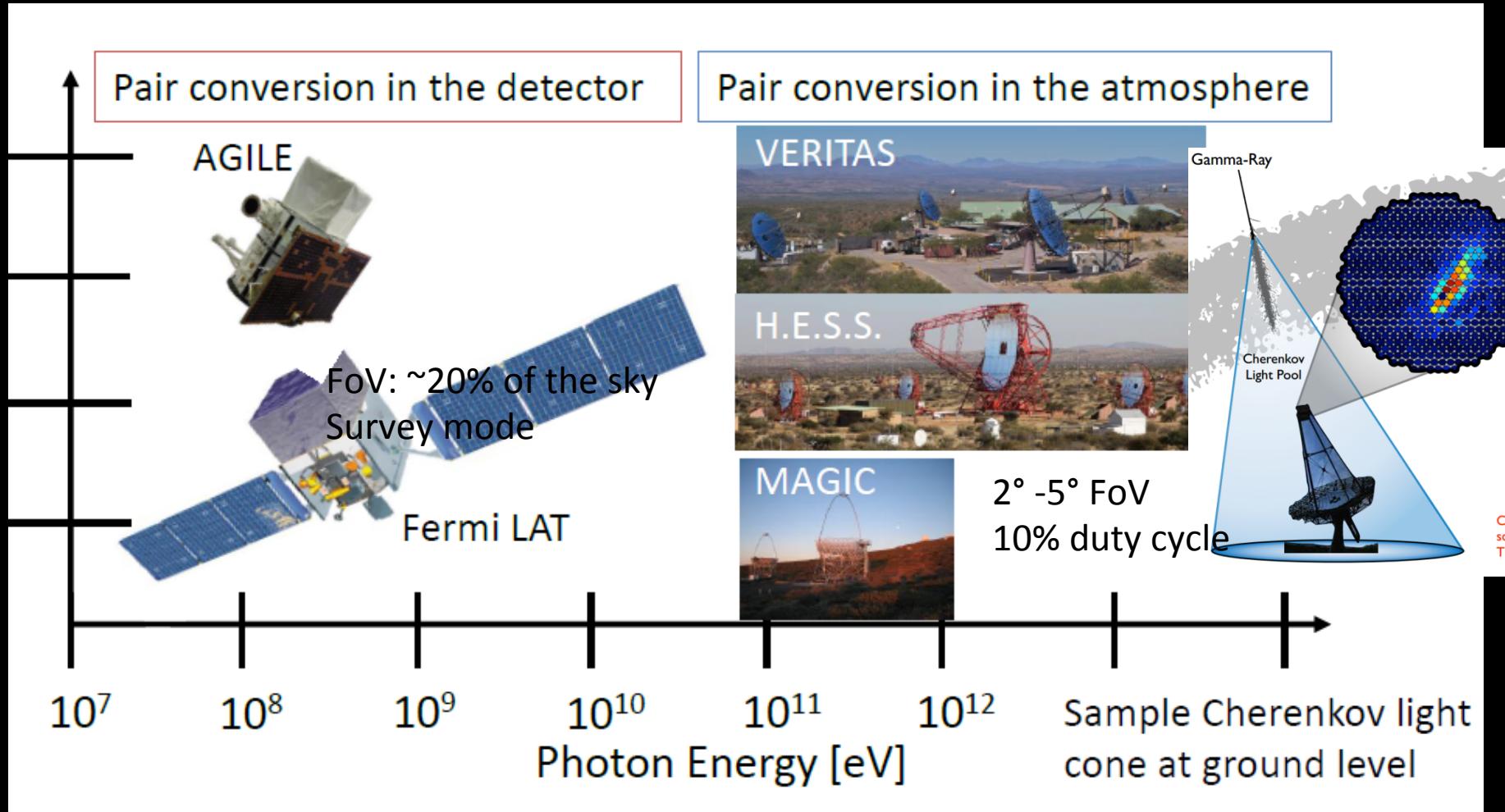


[doi:10.1038/nature17147](https://doi.org/10.1038/nature17147)

ICHEP 2016



Gamma-ray Detectors

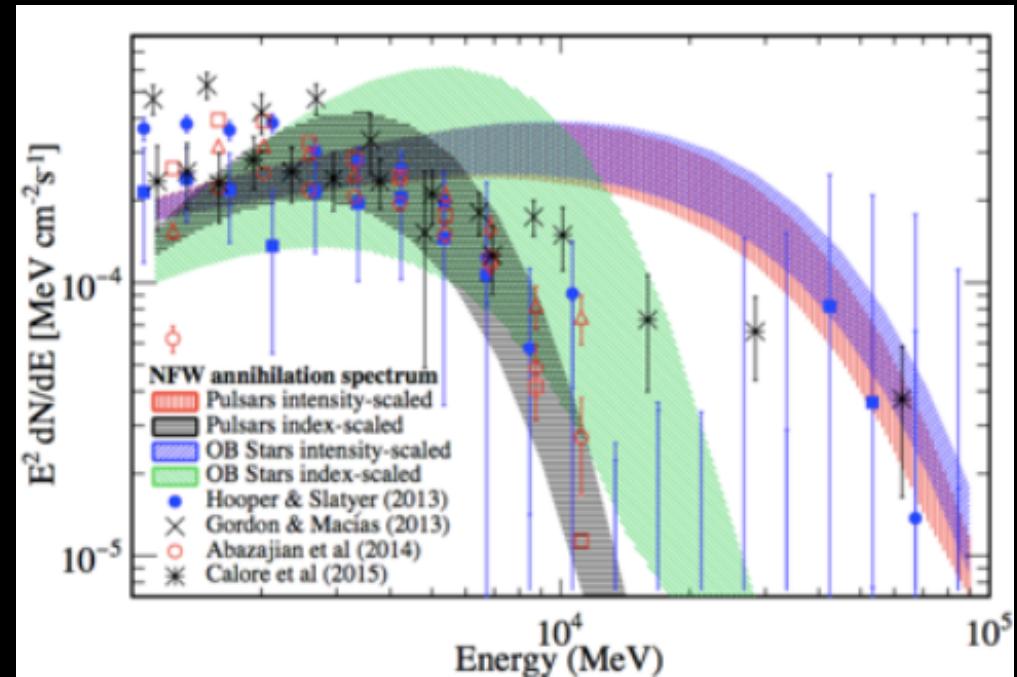


Adapted from Hays, ICRC 2015

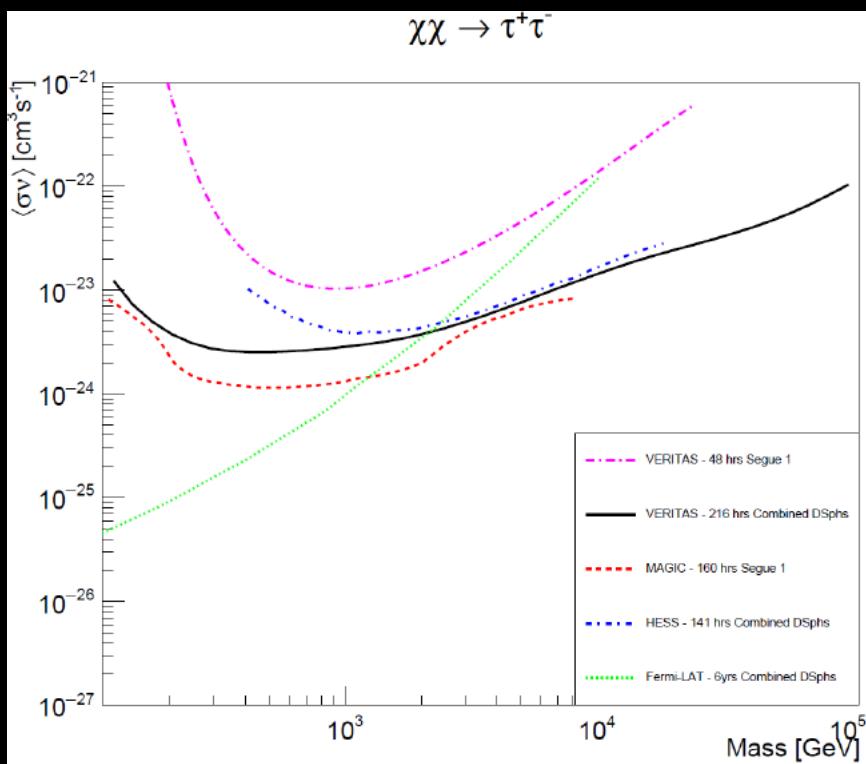
Complementarity of experiments



- Different combinations of experiments and targets are more or less constraining for different models and channels
- IACT observations have window to constrain high-mass WIMPs



And for low-mass WIMP case,
DM-free region to constrain “messy”
astrophysics!



Fermi-LAT excess @ GC; fits DM profile, ~ 50 GeV
WIMP or pulsars?

The VERITAS Instrument



Specifications:

- Energy range: ~85 GeV to ~30 TeV (post upgrade)
- Energy resolution ~ 20%
- Angular resolution (68% containment): $<0.1^\circ$ at 1 TeV, 0.14° at 200 GeV
- Source location accuracy: <50 arcseconds



Sensitivity:

- 1% Crab in < 30 hrs
- 10% Crab in < 30 min

Yearly observing (good weather):

- Dark time ~800 hours
- Moonlight ~400 hrs additional

Instrument design:

- Four 12-m imaging atmospheric Cherenkov telescopes
- 499-pixel cameras (3.5° FoV)
- FLWO, Mt. Hopkins, Az (1268 m)



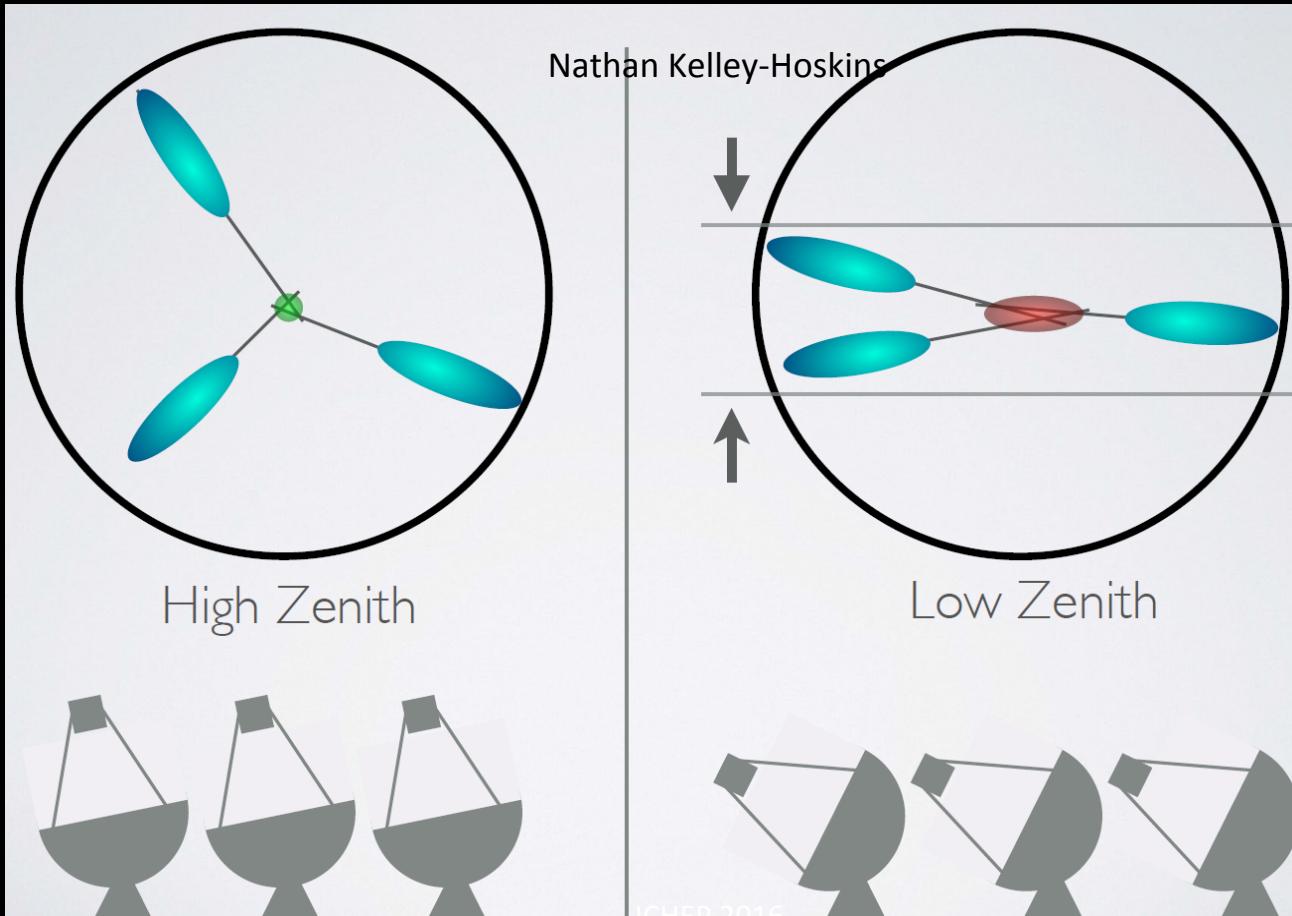
Supported by: NSF/DOE/Smithsonian,
NSERC(Canada)



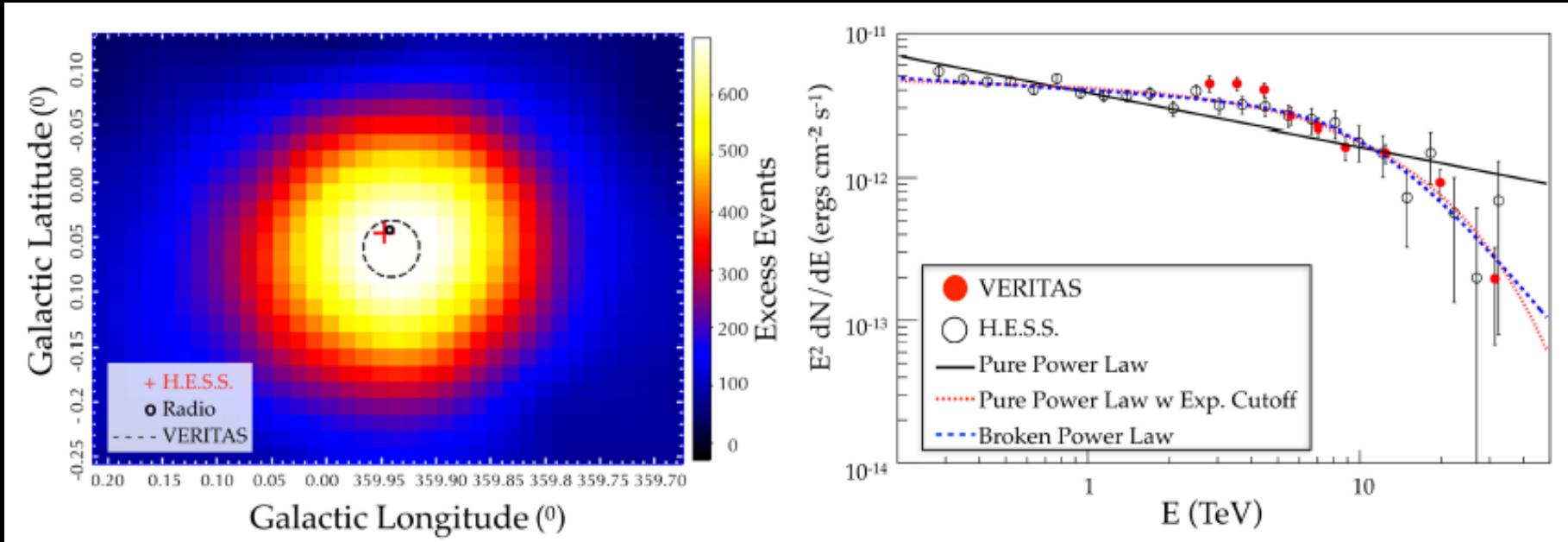
VERITAS on GC: 2010-2014



- ~85 hours of data taken at large zenith angles
- LZA requires specialized *disp* method to recover angular resolution
- Energy threshold also rises to ~2 TeV



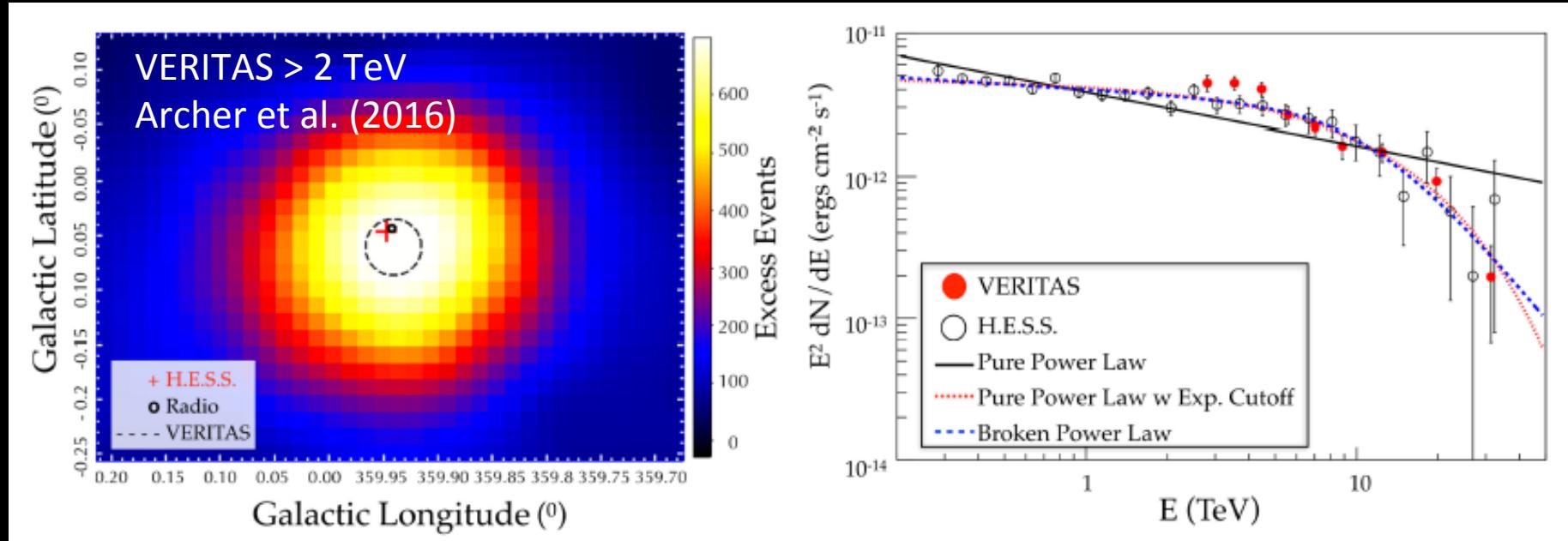
VERITAS on Sgr A*



- Accounting for the diffuse emission challenging:
 - This study extracts full spectrum from direction of Sgr A* (dominated by bright point source)
 - Yields results that are consistent with alternative approach (Viana et al. 2013)
- Combined H.E.S.S.-VERITAS spectrum statistically rich

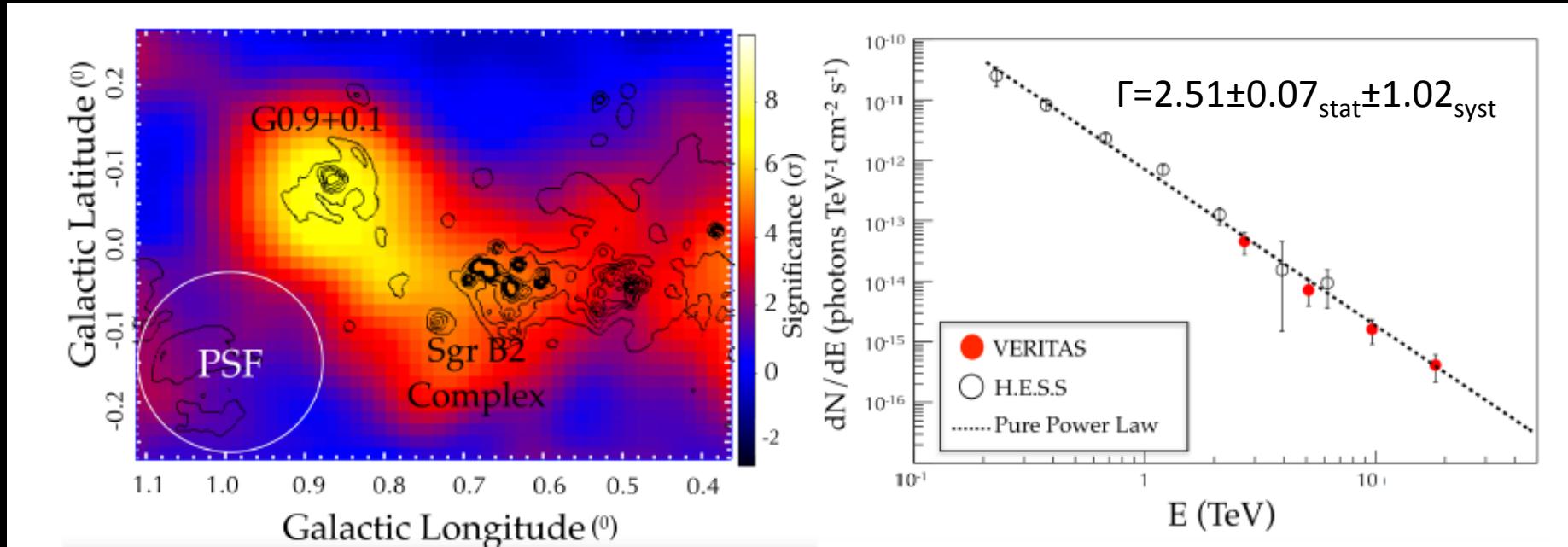


VERITAS on Sgr A*



Model	N_0 ($\text{cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}$)	Γ_1	Γ_2	E_{break} or E_{cut} (TeV)	$\frac{\chi^2}{n.d.f.}$
Power Law	$2.36 (\pm 0.05) \times 10^{-12}$	2.37 ± 0.02	N/A	N/A	148/32
Exp. Cutoff Power Law	$2.82 (\pm 0.08) \times 10^{-12}$	2.05 ± 0.04	N/A	12.1 ± 1.6	35/31
Smoothly Broken Power Law	$2.55 (\pm 0.07) \times 10^{-12}$	2.14 ± 0.04	4.39 ± 0.39	12.1 ± 1.7	32/30

Power-law (PL) with exp. cutoff, smoothly broken PL favored over pure PL

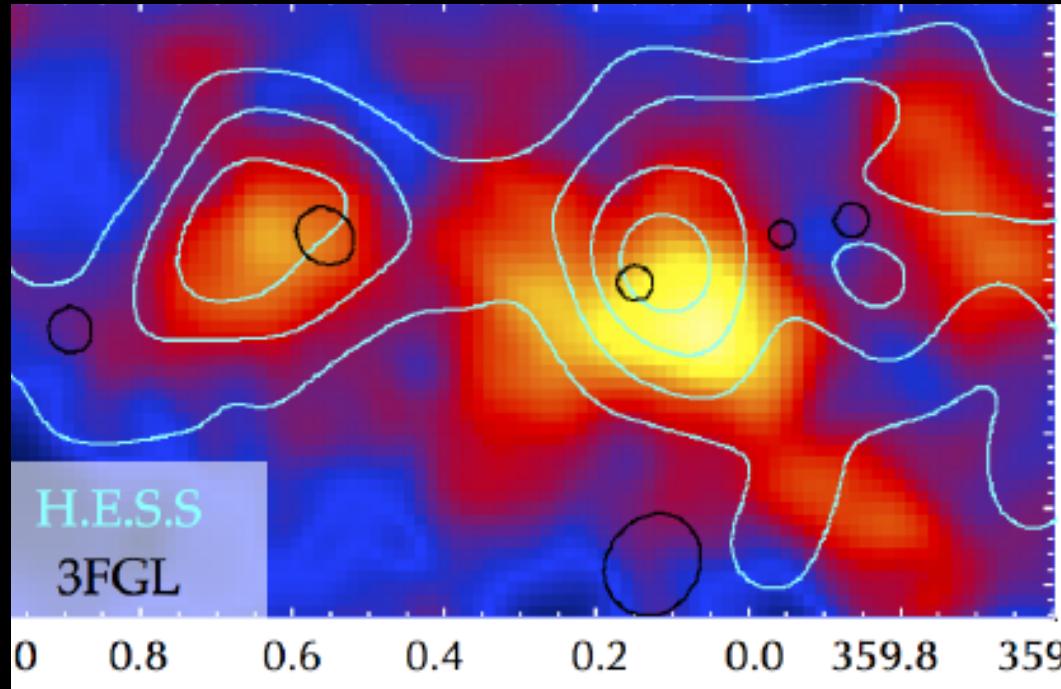


- Composite radio SNR (bright PWN core, extended radio shell)
- H.E.S.S., VERITAS centroids consistent with each other and radio core
- Joint VERITAS-H.E.S.S. spectrum fits well to a pure power-law with no break up to 20 TeV

Residual Diffuse emission



VERITAS > 2 TeV
Archer et al. (2016)



- H.E.S.S. observes diffuse gamma-ray emission along the galactic ridge above 300 GeV (within central 3° of plane)
 - Correlates with dense molecular cloud regions
 - May contain unresolved point sources, DM component
- VERITAS: subtracting out Sgr A* and G0.9+0.1 reveals similar emission structure above 2 TeV



Local enhancements

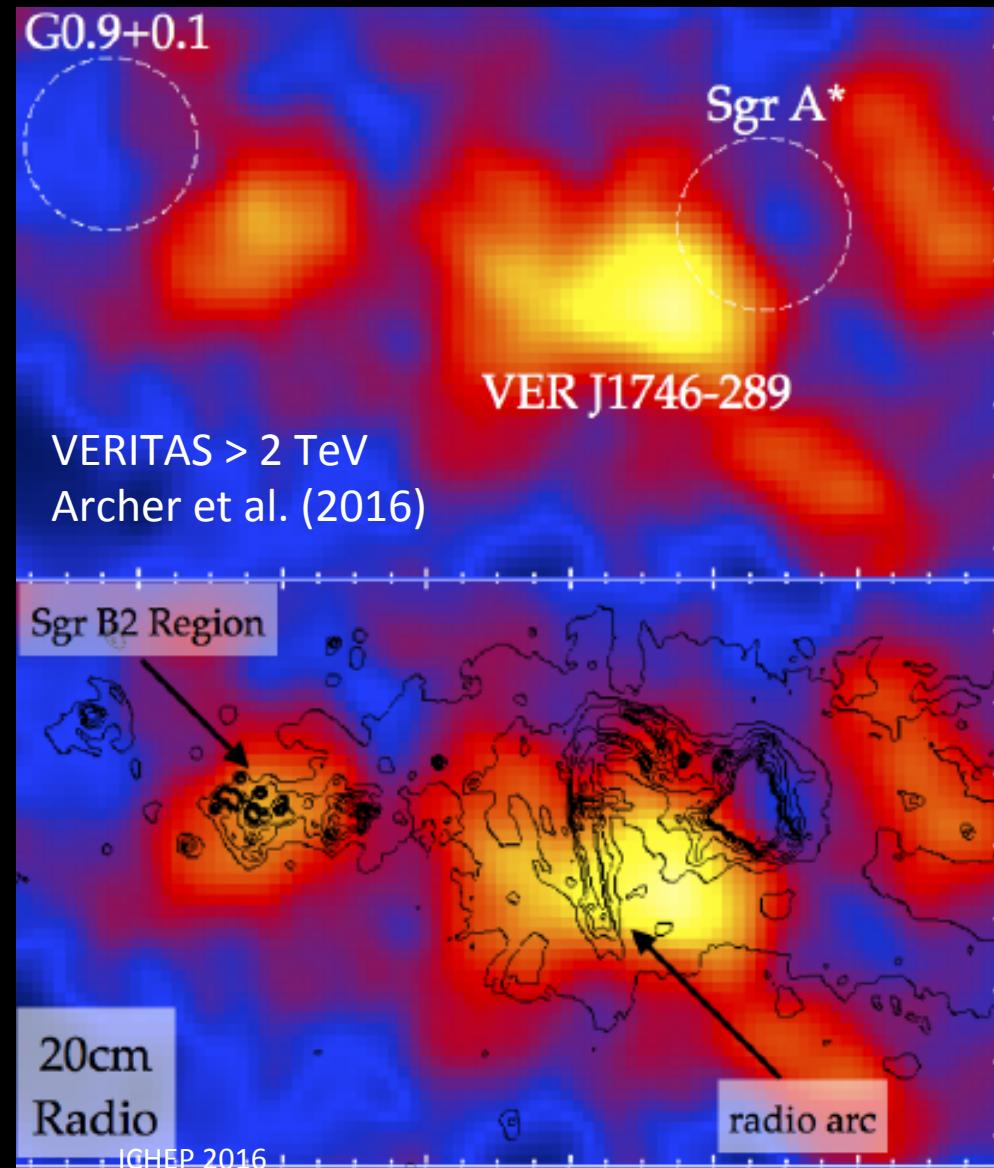


- Sgr B2 below detection threshold (4.1 σ post-trials)
- Second enhanced above threshold at $\sim 7\sigma$: VER J1746-289

- Marginally extended
- Position:

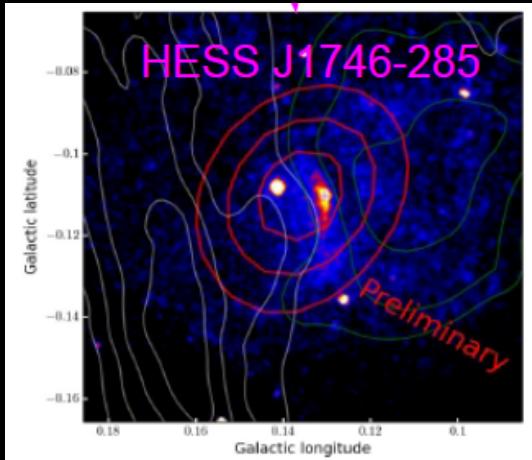
$$l = 0.86^\circ \pm 0.015^\circ_{stat} \pm 0.013^\circ_{sys},$$

$$b = 0.067^\circ \pm 0.02^\circ_{stat} \pm 0.013^\circ_{sys}$$

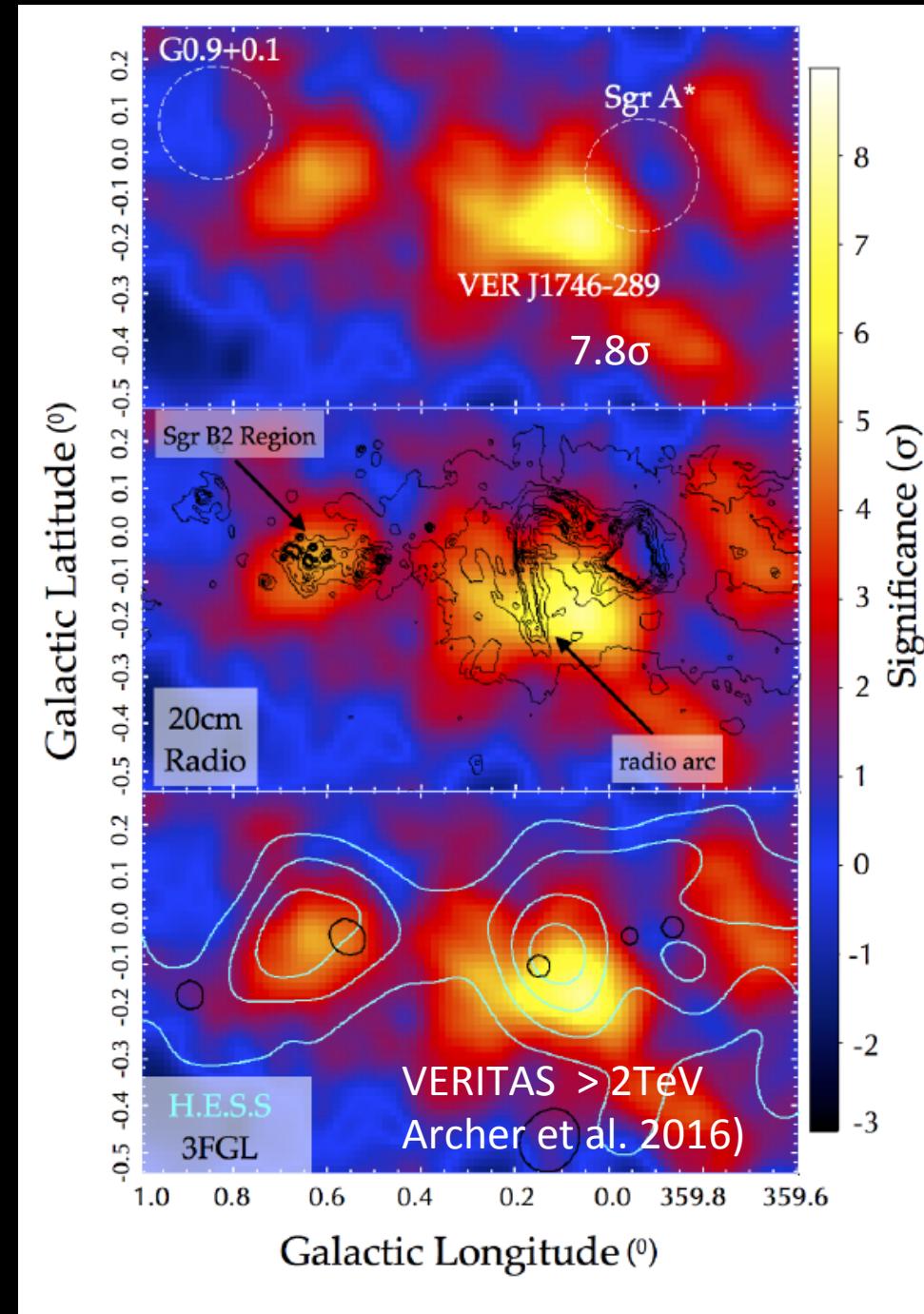




- H.E.S.S. sees point source that corresponds to radio arc
- VER J1746-289 a combination of PWN detected by H.E.S.S. and diffuse emission?

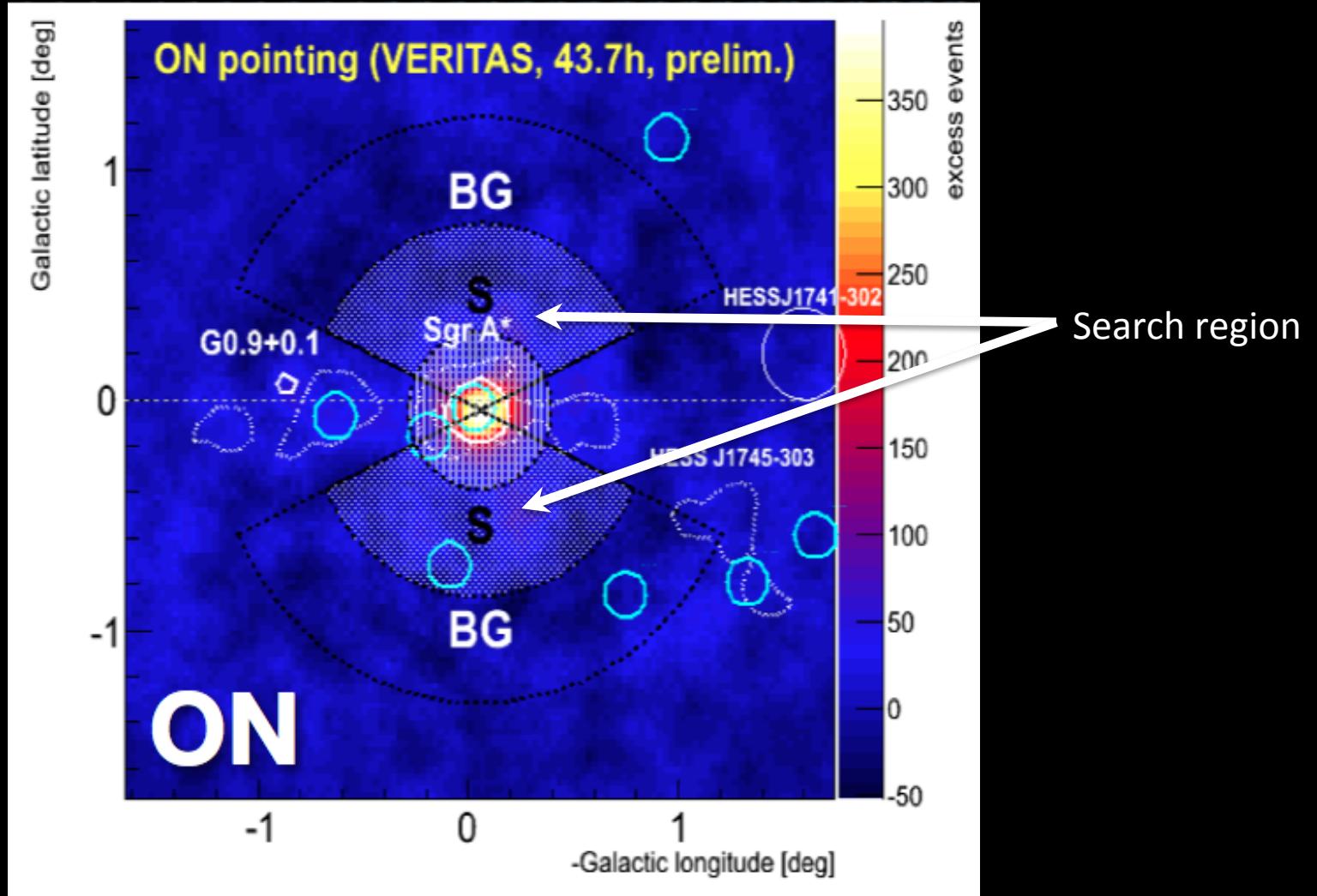


8/4/2016



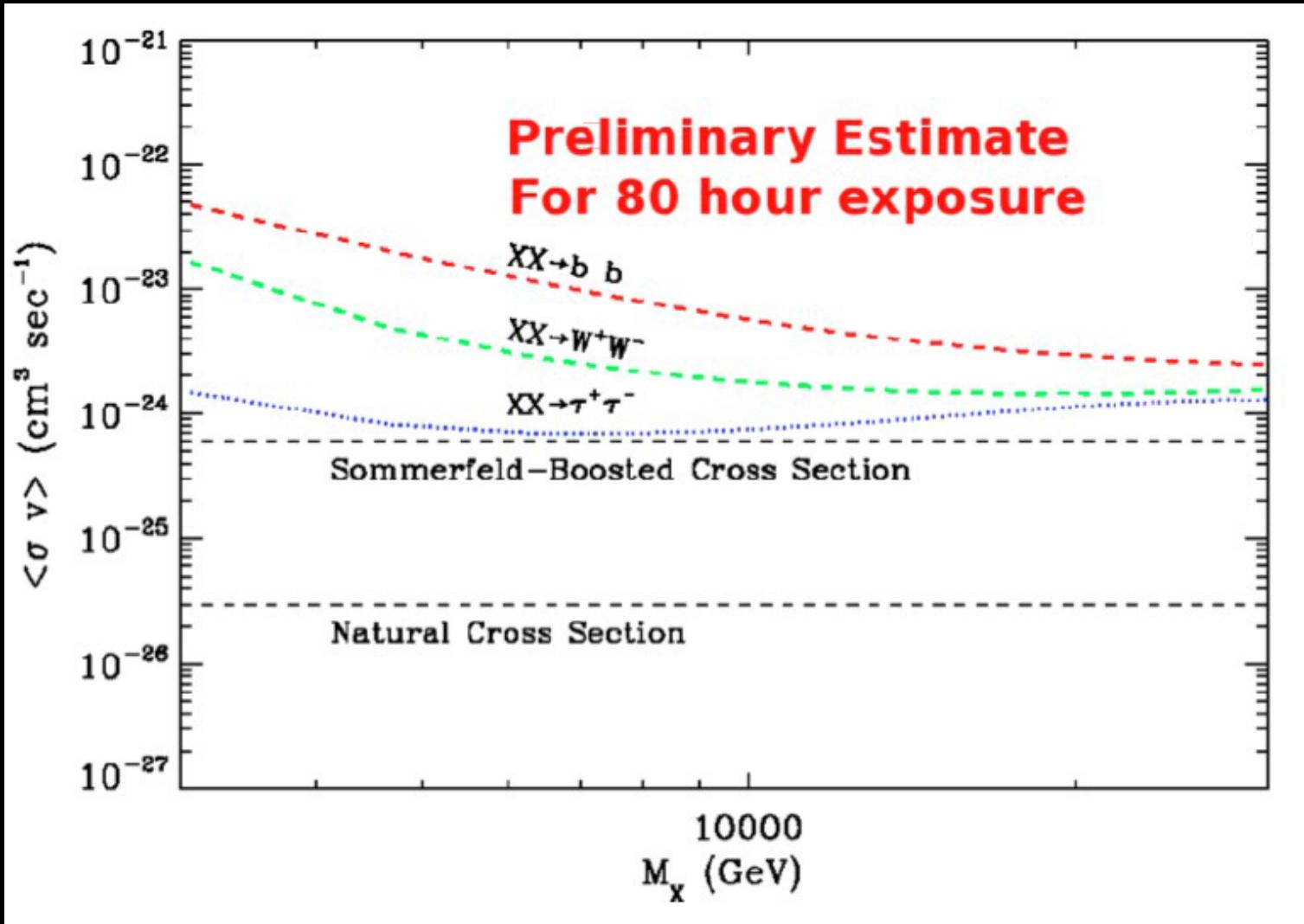


Planned DM search region





Potential DM Reach





Future plans

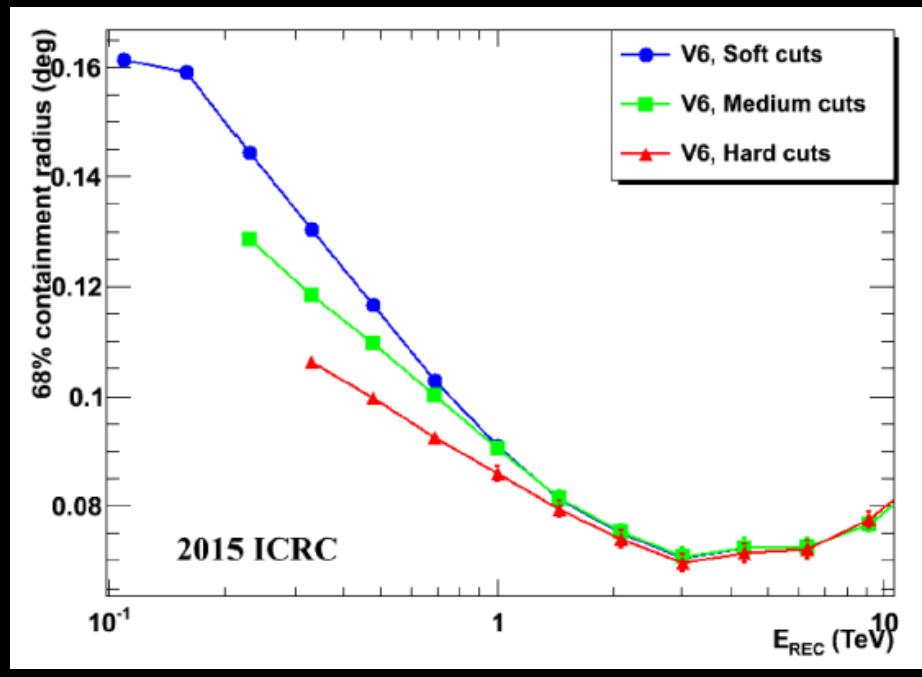
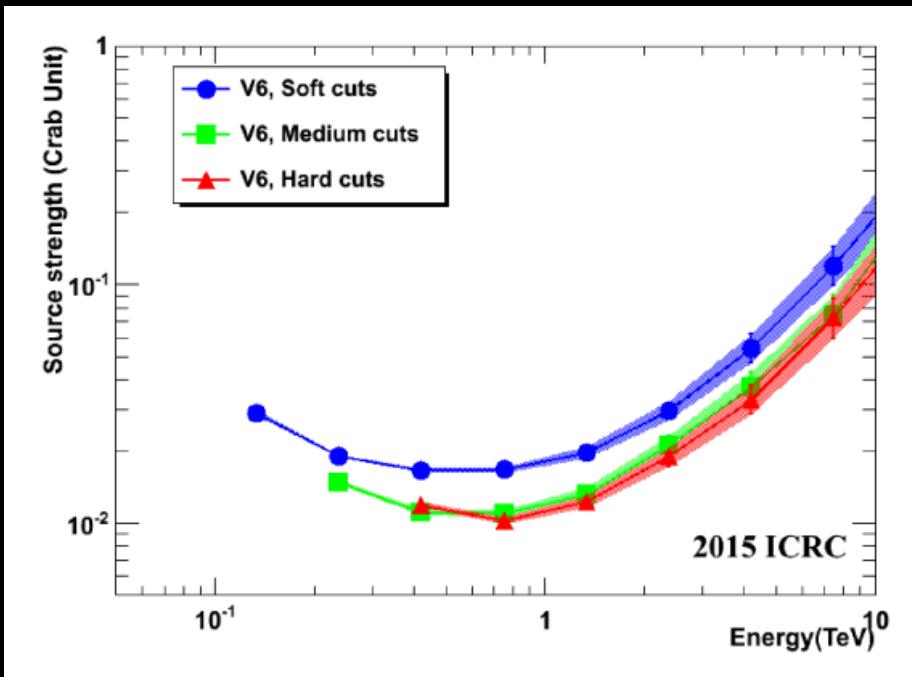
- Continued observations
 - Monitor central engine for variability in the TeV
 - Deepen exposure and sensitivity
- More sophisticated analysis
 - Disentangling different components of the complex emission near the GC is key to astrophysics and DM studies
 - Likelihood methods are better suited to separating out multiple components and at combining results with data from other instruments (e.g. Fermi)



BACKUP

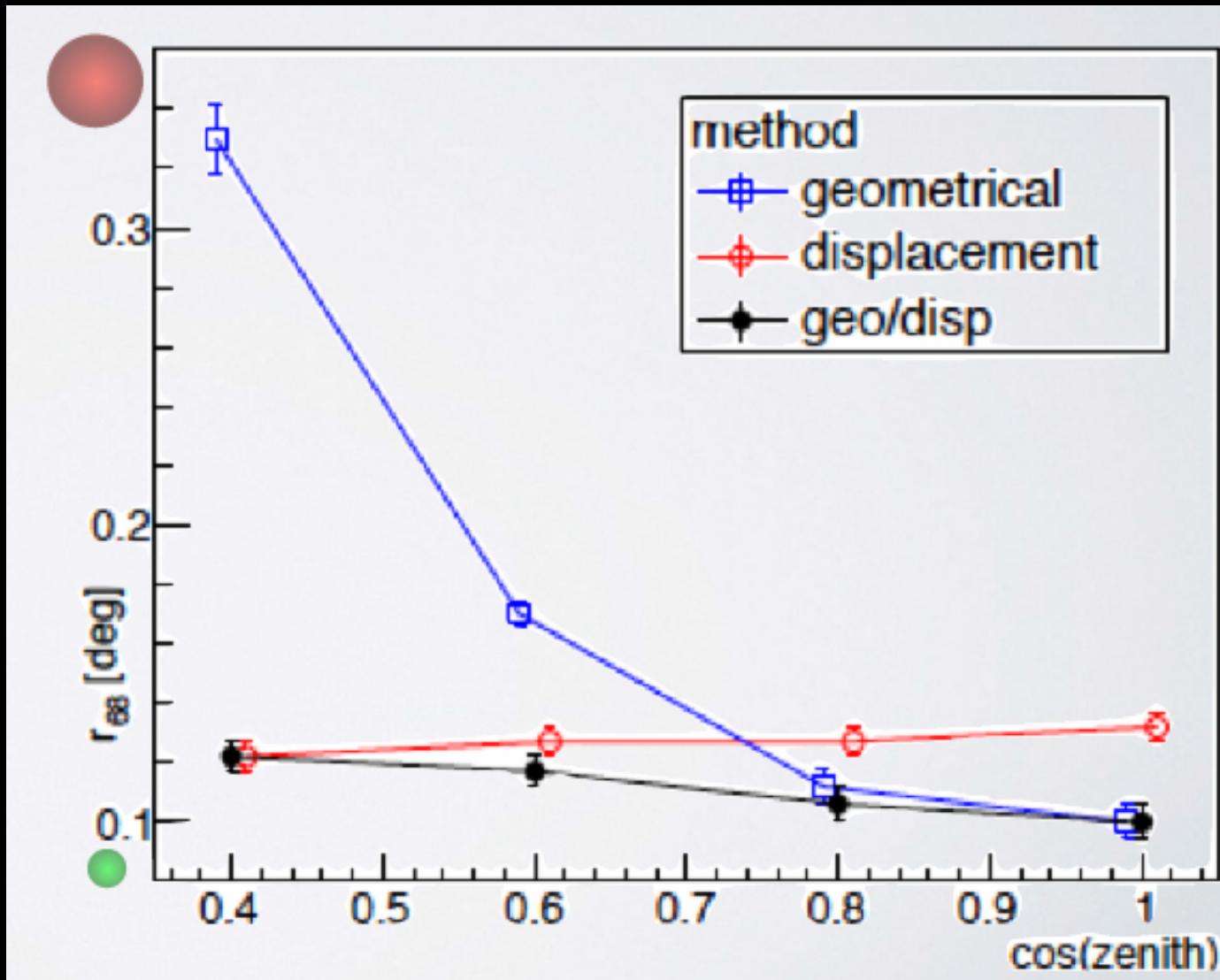


Nominal VERITAS Performance





Performance at Large Zenith Angles



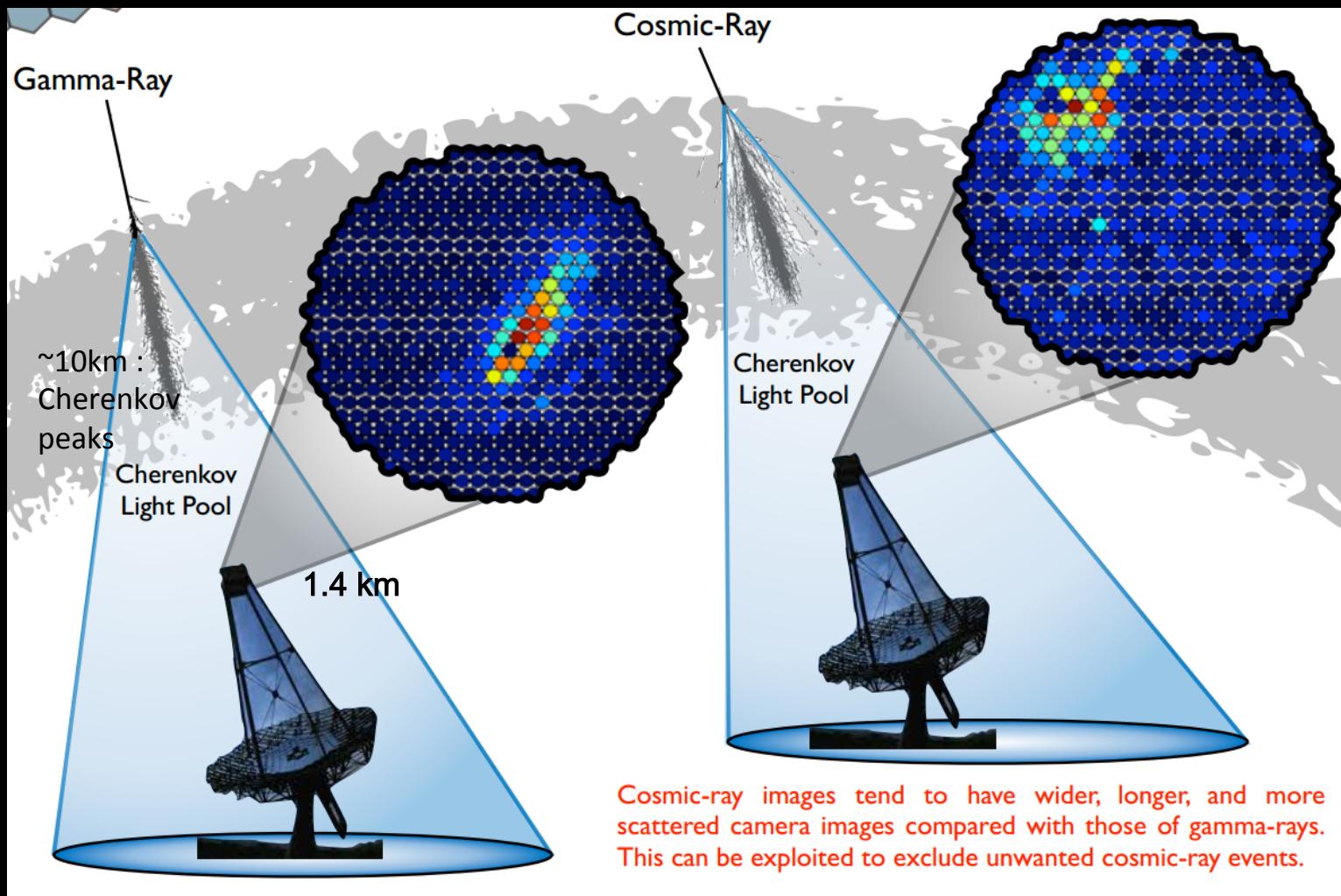


Atmospheric Cherenkov Telescopes



~0.01-100 TeV

Electromagnetic calorimetry with the atmosphere



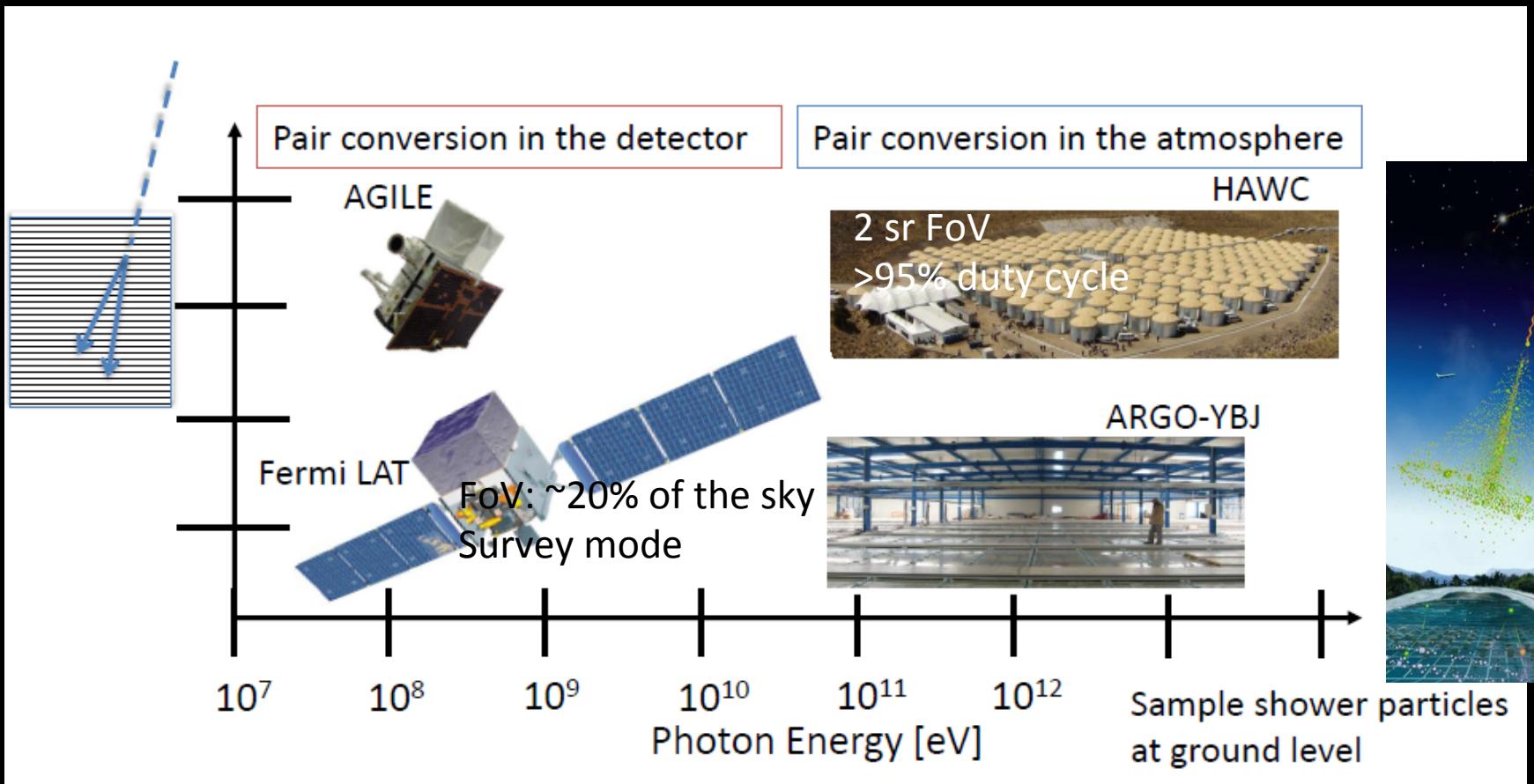
Collection area $\sim 10^5 \text{ m}^2$

8/4/2016

Cherenkov radiation produced by relativistic secondary particles ICHEP 2016



Gamma-ray Detectors I



Adapted from Hays, ICRC 2015

