Dark Matter Searches using Dwarf Galaxies with HAWC

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11 August 2017

Located at 97.5° W, 18.9 ° N (Parque Nacional Pico de Orizaba) at 4100m

300x 7.3 m diameter, 5 m height tanks, 3x 8" R5912 PMTs and 1x 10" R7081-HQE PMT

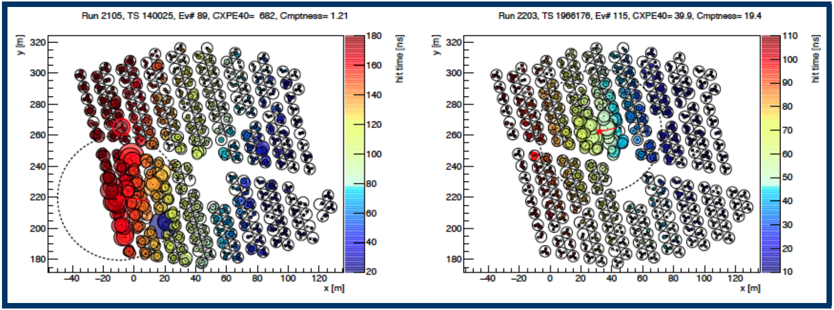
in total: 55kT of water (110 B747s, 160M water bottles) - 3900 truck trips

covers 22000 m^2, total length of coaxial cables: ~180km

24kHz trigger rate, 2TB of data per day, 95% livetime

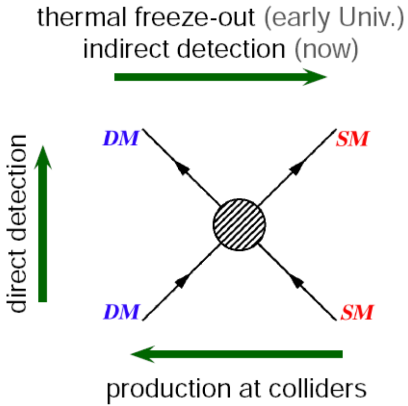
- The event rate: 20 kHz [data rate of ~0.02 GB/s (2 TB/day)]
- Crab Nebula: 400 photons/day, Background: 15000 cosmic rays/second

Lots of background, Efficient Background rejection required

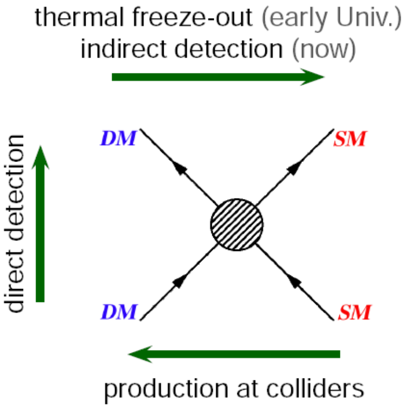


[arXiv:1701.01778]

Dark Matter Detection



Dark Matter Detection

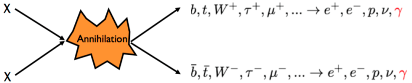


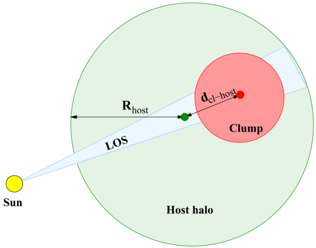
Dark Matter - Indirect Detection

Particle Physics | Astrophysics

$$\frac{d\phi}{dE}_{annihilation} \propto \frac{<\sigma v>}{M_\chi^2} \quad \frac{dN}{dE} \quad \int d\Omega \int_{l.o.s.} \rho^2 dx$$

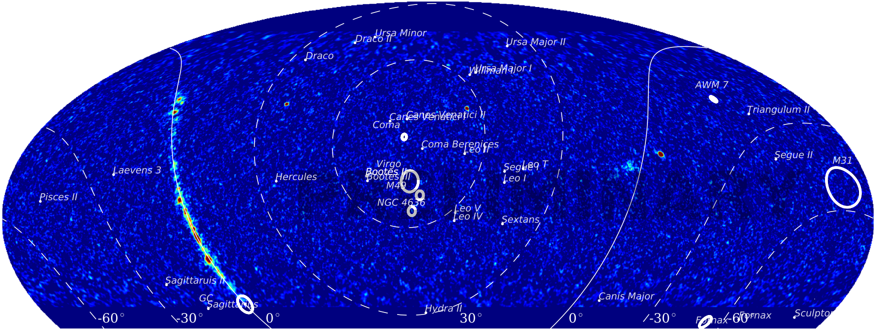
$$\frac{d\phi}{dE}_{decay} \propto \frac{1}{\tau M_\chi} \quad \frac{dN}{dE} \quad \int d\Omega \int_{l.o.s.} \rho dx$$





- Particle Physics part by PYTHIA8
- Astrophysics Part (J- and D- factors) by CLUMPY and references

HAWC
High Altitude Water Cherenkov Gamma-Ray Observatory



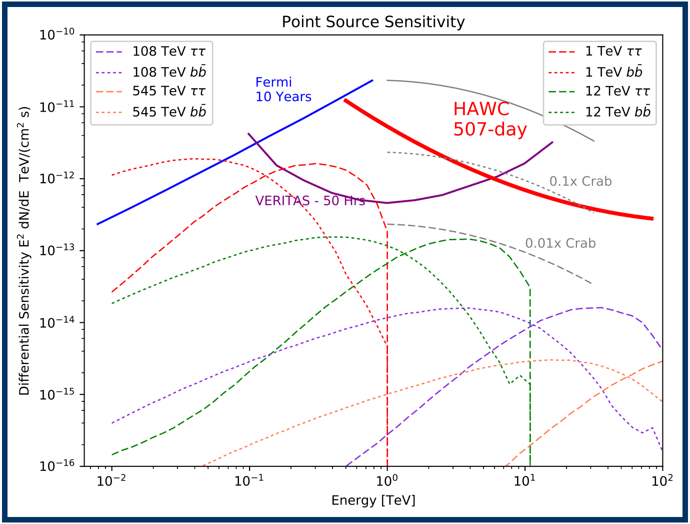
Potential sources to look for dark matter signature

J- and D- factors (1)

Source	RA (deg)	Dec (deg)	log10[J(θ)] ($GeV^2 cm^{-5} sr$)	log10[D(θ)] ($GeV^2 cm^{-2} sr$)	θ_{max} (deg)
Bootes 1	210.05	14.49	18.47	18.45	0.47
CanesVenatici I	202.04	33.57	17.62	17.55	0.53
CanesVenatici II	194.29	34.32	17.95	17.69	0.13
Coma Berenices	186.74	23.90	19.32	18.71	0.31
Draco	260.05	57.07	19.37	19.15	1.30
Hercules	247.72	12.75	16.93	16.89	0.28
Leo I	152.11	12.29	17.57	18.05	0.45
Leo II	168.34	22.13	18.11	17.36	0.23
Leo IV	173.21	-0.53	16.37	16.48	0.16
Segue 1	151.75	16.06	19.66	18.64	0.35
Sextans	153.28	-1.59	17.96	18.48	1.70
Triangulum II[*]	33.33	36.18	20.44	18.42	0.12
Ursa Major I	158.72	51.94	19.67	19.04	0.53
Ursa Major II	132.77	63.11	18.66	17.78	0.43
Ursa Minor	227.24	67.24	19.24	18.13	1.37

From different realizations of profile parameters, mean values were calculated. (from Geringer-Sameth et al., 2015)
([*] from arxiv:1603.08046v2)
NFW profile was used as Dark Matter density profile.
Sources are considered as point sources.

(Fermi-VERITAS-)HAWC Sensitivity



annihilation values are calculated for Segue 1, $<\sigma v>=10^{-23}$

HAWC scanned for 1-100 TeV M_χ

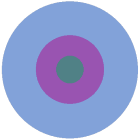
Systematics on the Limits

HAWC Systematics

- Signal passing rate
- Measured number of photo-electrons (PEs) based on simulations
- Simulated PMT charge and the charge from actual data
- Uncertainty associated with the angular resolution

~50% uncertainty [arxiv:1701.01778]

Astrophysical systematics



outer blue: 1.0° HAWC PSF
inner green: 0.2° HAWC PSF
J and D factor integration angle: ~0.5° [purple]

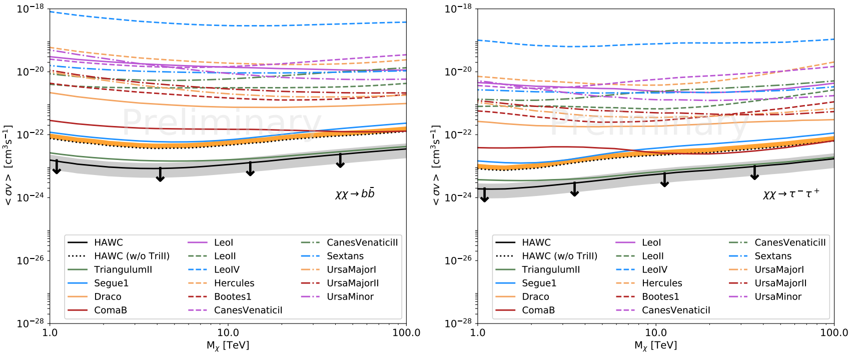
– J and D factor Integration angles kept constant, but HAWC PSF changes with energy.

– Physical constraint by DM profile yields **one sided uncertainty**

— 42% uncertainty for annihilation cross-section limits

— 38% uncertainty for decay lifetime limits

Dark Matter Annihilation (Upper) Limits



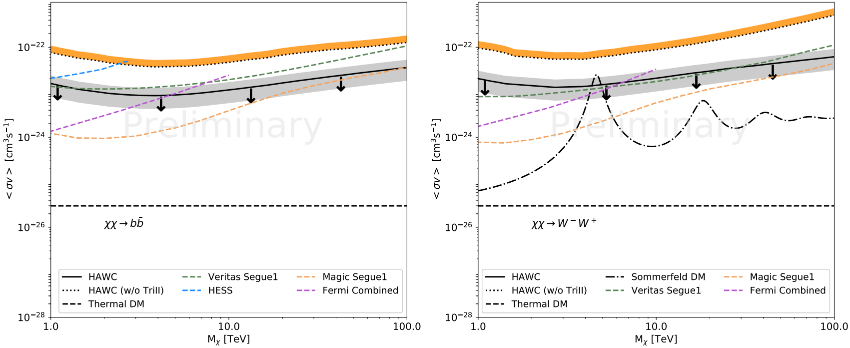
Ran the analysis for 507 days of HAWC data for five annihilation channels ($b\bar{b}, t\bar{t}, WW, \tau\tau, \mu\mu$)

Combined results were computed for 14 dSph and 14 dSph+TriangulumII

Limits are driven by TriangulumII, Segue1 and Coma B

$\tau\tau$ is the strongest limit for HAWC [see arXiv:1706.01277]

Dark Matter Annihilation (Upper) Limits

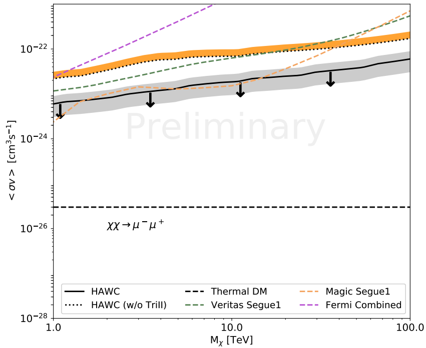


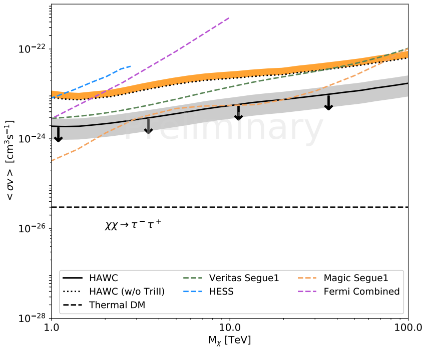
Gray band: HAWC systematics, Orange band: Astrophysical systematics

HAWC dSph limits are better than VERITAS and HESS, than Fermi after ~3 TeV.

Magic Segue1 limits → negative fluctuation

Dark Matter Annihilation (Upper) Limits





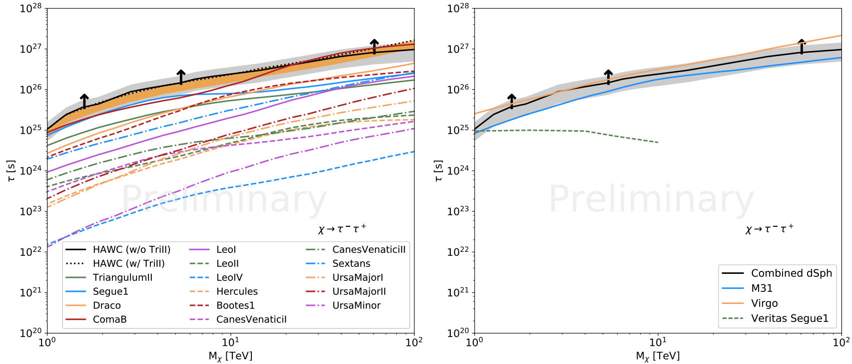
Because of their gamma-ray spectrum, leptonic channel are expected to yield better limits

HAWC dSph limits are better after a few TeV

M31 limits are comparable and Virgo limits are not good (as expected)

M31 is a good source for searching DM annihilation

Dark Matter Decay (Lower) Limits

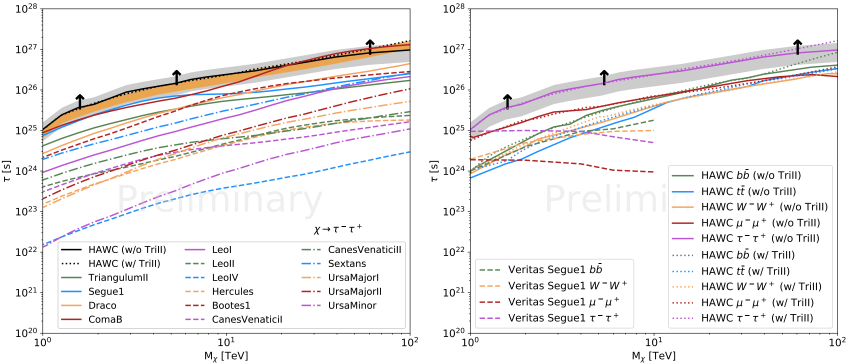


Gray band: HAWC systematics, Orange band: Astrophysical systematics

Limits are driven by TriangulumII, Segue1 and Coma B

(TriangulumII is not so strong, smaller D factor)

Dark Matter Decay (Lower) Limits



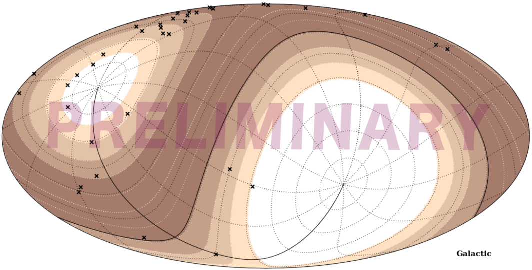
HAWC $\tau\tau$ limit is the strongest limit [see arXiv:1706.01277]

Virgo is a good source for searching DM decay

With the extended source analysis, this will only get better

Some other sources

There is also another class of objects: dIrr galaxies
- 31 dIrr galaxies in HAWC FOV (5 of them can be considered extended)
- Low gamma-ray background
- Low baryon-dark matter ratio



Summary

- Results for 15 dSph were shown (analysis as point sources)
- Annihilation:
  Better limits in $\tau\tau$ and $\mu\mu$ channels for $M_\chi >$ ~3 TeV than other experiments
- Decay:
  Better limits in all channels compared to other experiments
- Limits will improve with:
  - including more dSph galaxies
  - more observation time
  - improvements on the analysis techniques and detector