Search for Dark Matter gamma-ray emission from dwarf spheroidal galaxies with LHAASO-KM2A

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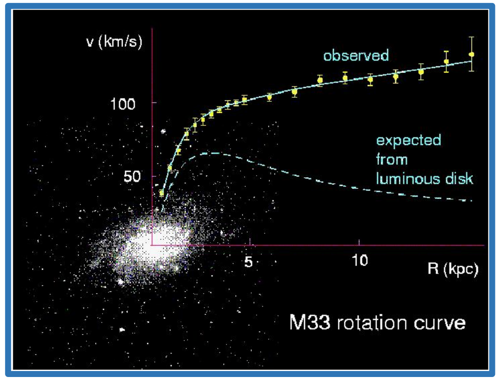
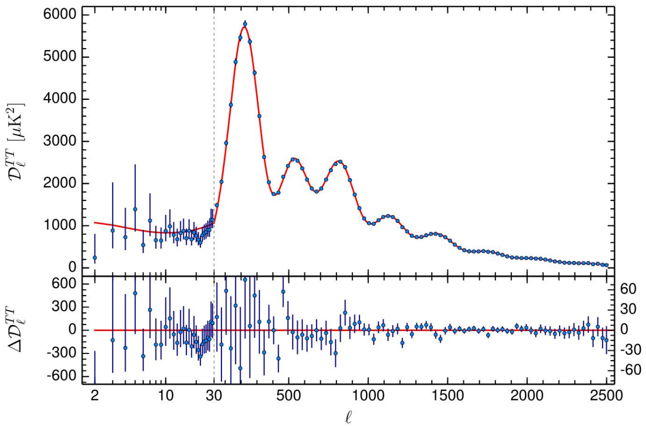
CONTENTS

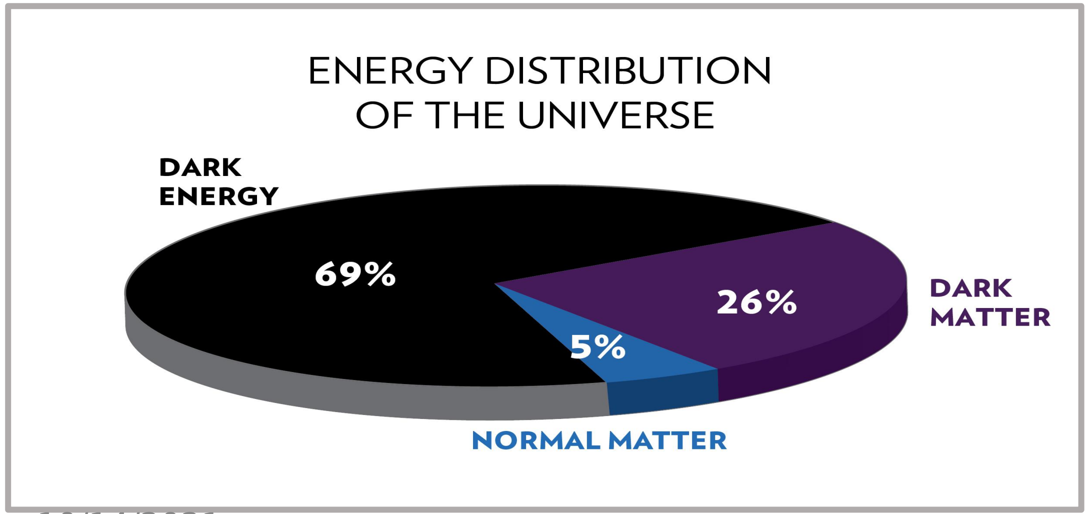
- **Introduction of Dark Matter and Dwarf spheroidal galaxies (dSphs)**
- **As an example, we show constraints from Segue 1 for both annihilation and decay processes**
- **Constraints from all Dwarf spheroidal galaxies are given**

Evidence of DM

Galaxy rotation curve , Bullet Cluster , Dwarf Galaxy , CMB







Based on Planck data:

Baryonic: 5%;

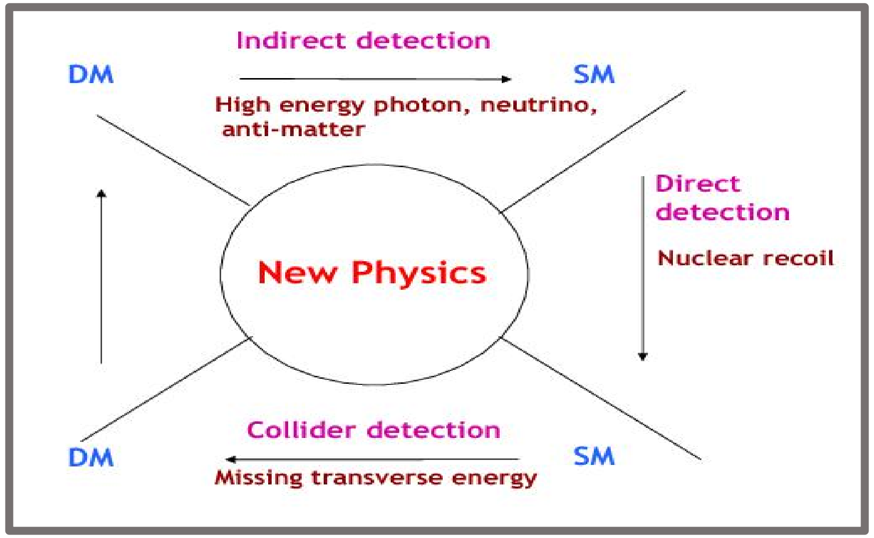
Dark matter: 26%;

Dark Energy: 69%;

arxiv: 1502.01589v3

dwarf spheroidal (dSph) galaxy

Dark Matter (WIMPs) detection: Collider, Direct Detection and Indirect Detection



The Milky Way dwarf spheroidal (dSph) galaxy is considered to be one of the most promising targets for indirect detection of DM

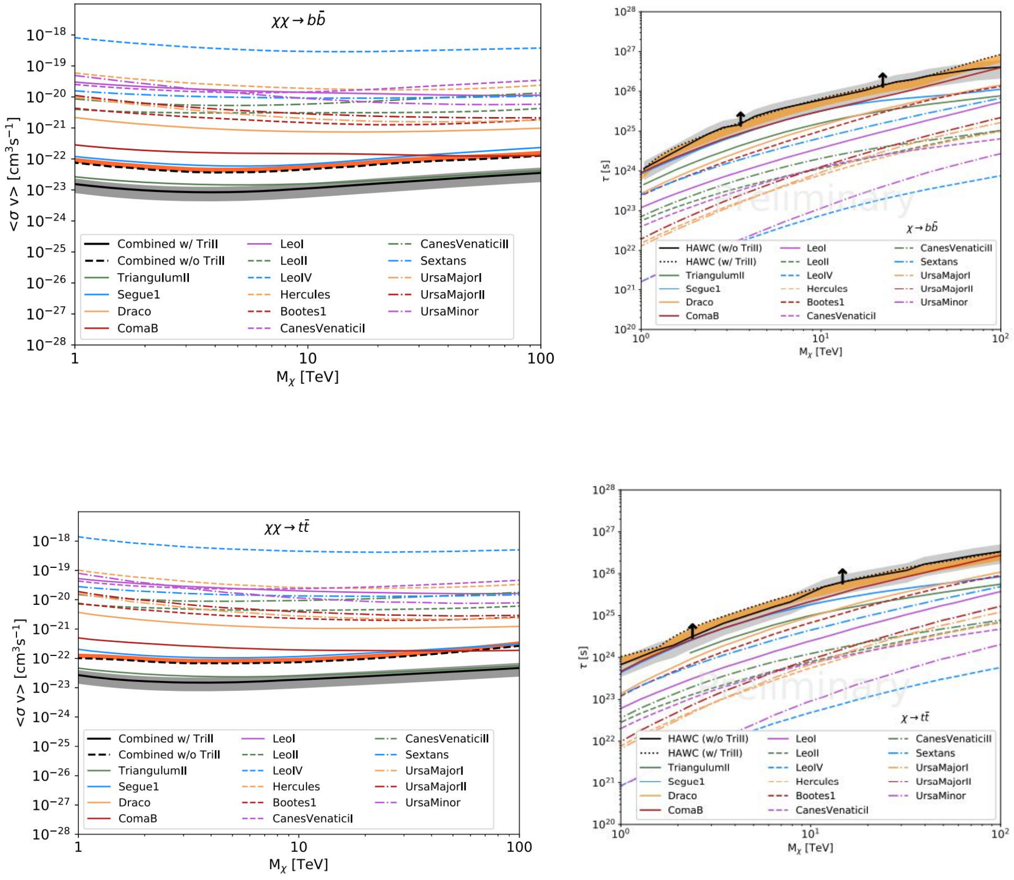
1. Proximity : satellites of the Milky-Way halo
(< 100 kpc for many of them)

2. Low γ-ray background:
Lack of astrophysical γ-ray production mechanisms
Dense DM

3. **Low γ-ray background from galactic**
higher galactic latitude for many of them

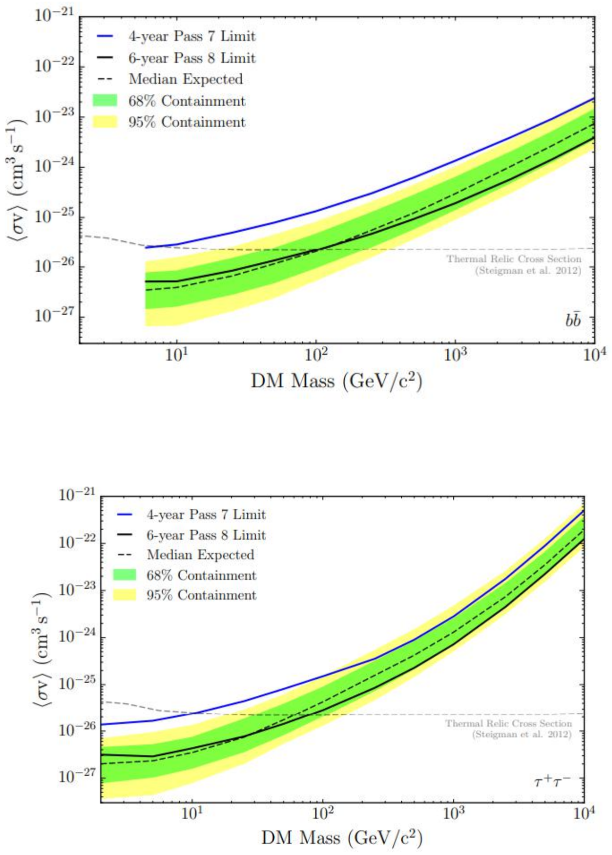
Results of other experiments

HAWC



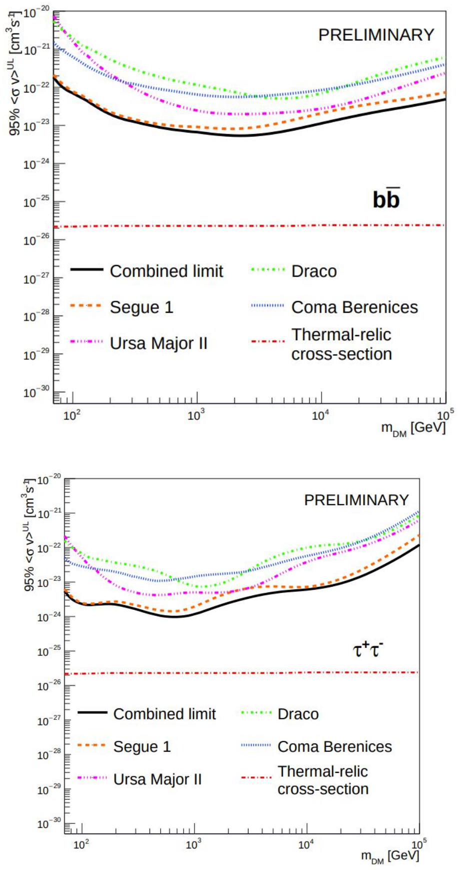
arXiv:1706.01277v1

Fermi-LAT



arxiv: 1503.02641

MAGIC



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19 dwarf galaxies are chosen within LHAASO view

Source	RA. (deg)	DEC. (deg)	$r_{\rm eff}$	$\theta_{\max}$ (deg)	$\log_{10} J_{\rm obs}$ ($\mathrm{GeV^2cm^{-5}}$)	$\log_{10} D_{\rm obs}$ ($\log_{10}[\mathrm{GeVcm^{-2}}]$)
Boötes I	210.02	14.50	0.352	0.47	18.2 ± 0.4	17.9 ± 0.2
Canes Venatici I	202.02	33.56	0.398	0.53	17.4 ± 0.3	17.6 ± 0.5
Canes Venatici II	194.29	34.32	0.399	0.13	17.6 ± 0.4	17.0 ± 0.2
Coma Berenices	186.74	23.90	0.377	0.31	19.0 ± 0.4	18.0 ± 0.2
Draco	260.05	57.92	0.442	1.30	18.8 ± 0.1	18.5 ± 0.1
Draco II*	238.20	64.56	0.451	–	18.1 ± 2.8	18.0 ± 0.9
Hercules	247.76	12.79	0.348	0.28	16.9 ± 0.7	16.7 ± 0.4
Leo I	152.12	12.30	0.346	0.45	17.8 ± 0.2	17.9 ± 0.2
Leo II	168.37	22.15	0.372	0.23	18.0 ± 0.2	17.2 ± 0.4
Leo IV	173.23	−0.54	0.303	0.16	16.3 ± 1.4	16.1 ± 0.9
Leo V	172.79	2.22	0.314	0.07	16.4 ± 0.9	15.9 ± 0.5
Pisces II*	344.63	5.95	0.327	–	16.9 ± 1.6	17.0 ± 0.6
Segue 1	151.77	16.08	0.357	0.35	19.4 ± 0.3	18.0 ± 0.3
Sextans	153.26	−1.61	0.299	1.70	17.5 ± 0.2	17.9 ± 0.2
Triangulum II*	33.32	36.18	0.403	–	20.9 ± 1.3	18.4 ± 0.8
Ursa Major I	158.71	51.92	0.432	0.43	17.9 ± 0.5	17.6 ± 0.3
Ursa Major II	132.87	63.13	0.449	0.53	19.4 ± 0.4	18.4 ± 0.3
Ursa Minor	227.28	67.23	0.455	1.37	18.9 ± 0.2	18.0 ± 0.1
Willman 1*	162.34	51.05	0.430	–	19.5 ± 0.9	18.5 ± 0.6

arxiv: 1910.05017
1903.11910

Data:

KM2A Half Array
Data: 2019.12.27-2020.11.30 V1
Live time: 312.6 days

Method:

Almost same as Crab (1).

Energy bin width: logE = 0.2
Estimate the background with the "direct integration method"

(1) Chinese Physics C Vol. 45, No. 2 (2021) 025002

Annihilation process of DM

Flux prediction, <σv> is the only parameter

$$\frac{dF}{dE}_{annihilation} = \frac{\langle \sigma_A v \rangle}{8\pi M_\chi^2} \frac{dN_\gamma}{dE} J$$

1. DM distribution: Navarro-Frenk-White (NFW) model

arXiv:1408.0002
1606.04898

$$J = \int_{\text{source}} d\Omega \int dx \rho^2(r(\theta, x))$$

$$\rho_{\text{NFW}}(r) = \frac{\rho_s}{(r/r_s)^\gamma (1 + (r/r_s)^\alpha)^{(\beta-\alpha)/\gamma}}$$

2. Differential flux per annihilation: $\frac{dN_\gamma}{dE}$, HDMSpectra package

arxiv: 2007.15001

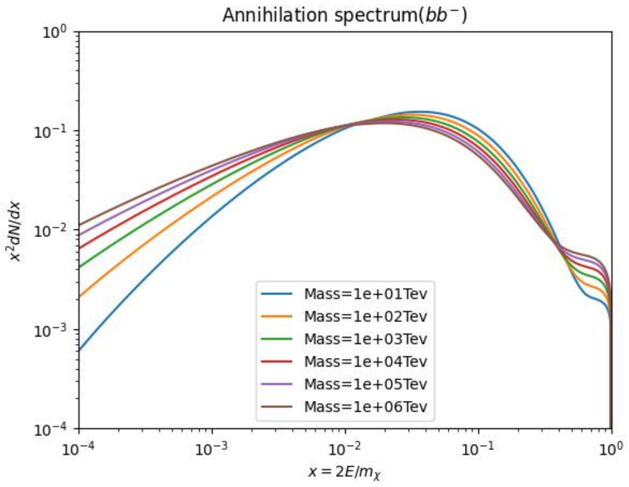
3. Final states

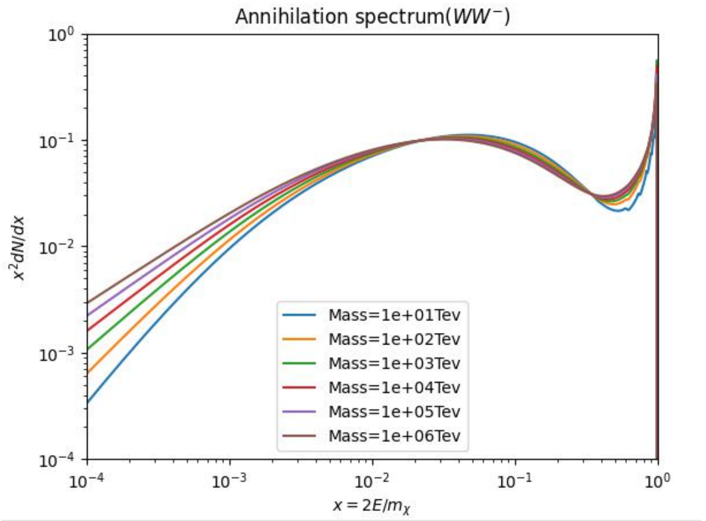
$$b\bar{b},\ t\bar{t},\ \mu^+\mu^-,\ \tau^+\tau^-, \text{ and } W^+W^-$$

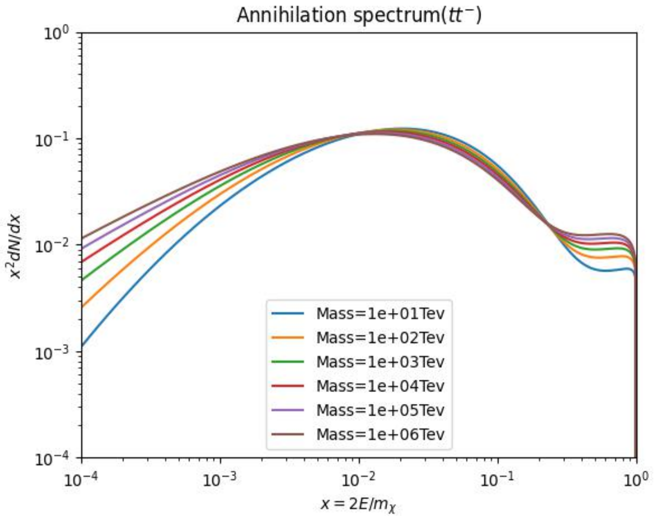
This particles could generate stable particles, such as gamma, eletron, protons, neutrinos .....

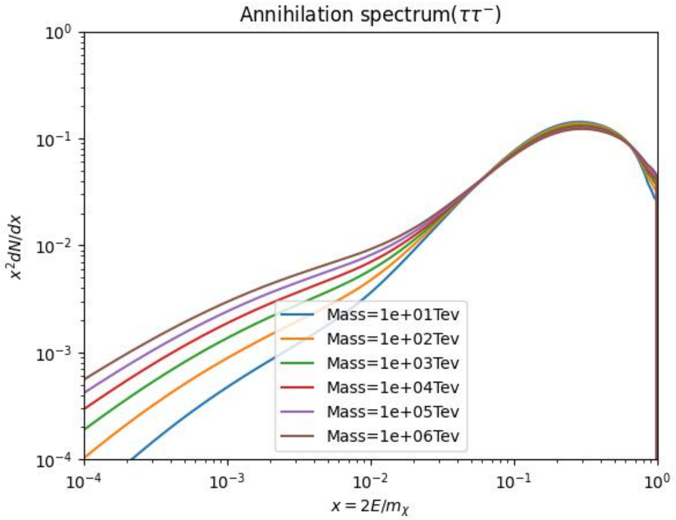
Give constraints for each final states below

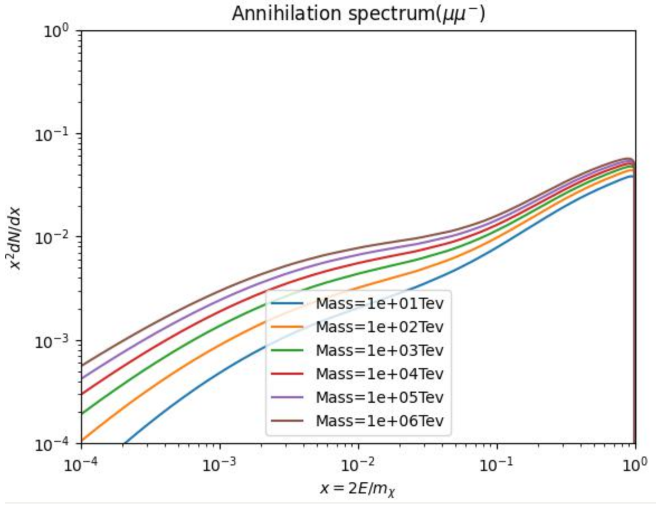
Annihilation spectrum for dark matter $\frac{dN_\gamma}{dE}$











arxiv: 2007.15001

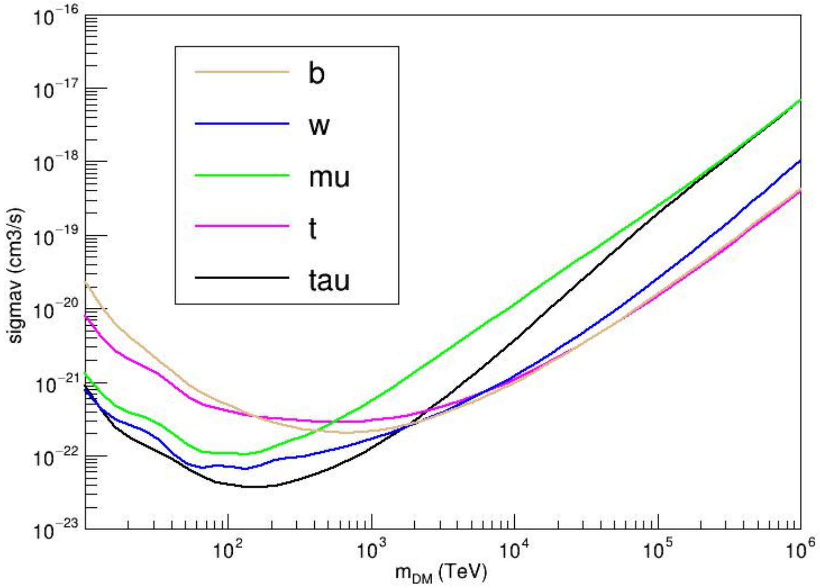
As an example: Segue 1

$$L = \prod_i P(Non_i, Noff_i + Nsig_i(<\sigma v>)) * \mathcal{J}_{Jfac}$$

$$TS = 2Log\left(\frac{L_1(<\sigma v>)}{L_0(<\sigma v>=0)}\right)$$

TS ~ chi2(1)

$$TS_{max} - 2.71 = TS_{95\%}$$



Absorption of gamma-rays:

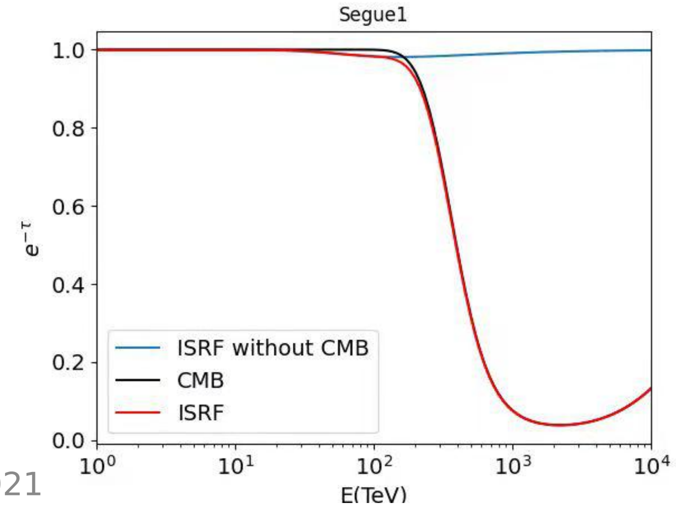
ISRF (including starlight, IR and CMB)

$$\tau_{\gamma\gamma}^{\rm CMB}(E_\gamma, L) = \frac{-4T_{\rm CMB}L}{\pi^2 E_\gamma^2}\int_{m_e}^{\infty}\varepsilon_c^3\,\sigma_{\gamma\gamma}(\varepsilon_c)\ln\left[1-e^{-\frac{\varepsilon_c^2}{E_\gamma T_{\rm CMB}}}\right]{\rm d}\varepsilon_c$$

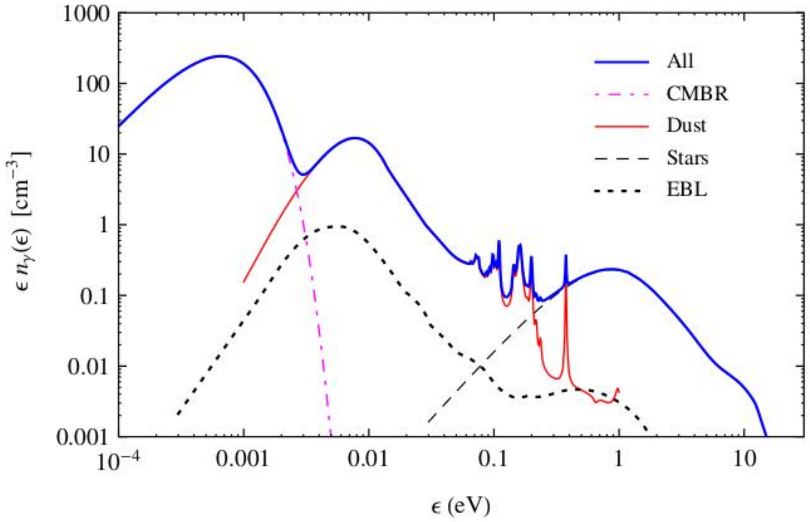
$$\tau_{\gamma\gamma}^{\rm SL+IR}(E_\gamma, L, b, l) = \int_0^L {\rm d}s \iint \sigma_{\gamma\gamma}(E_\gamma,\varepsilon)\, n_{\rm SL+IR}\left[\varepsilon, \mathbf{x}(s,b,l)\right]\frac{1-\cos\theta}{2}\sin\theta{\rm d}\theta\,{\rm d}\varepsilon$$

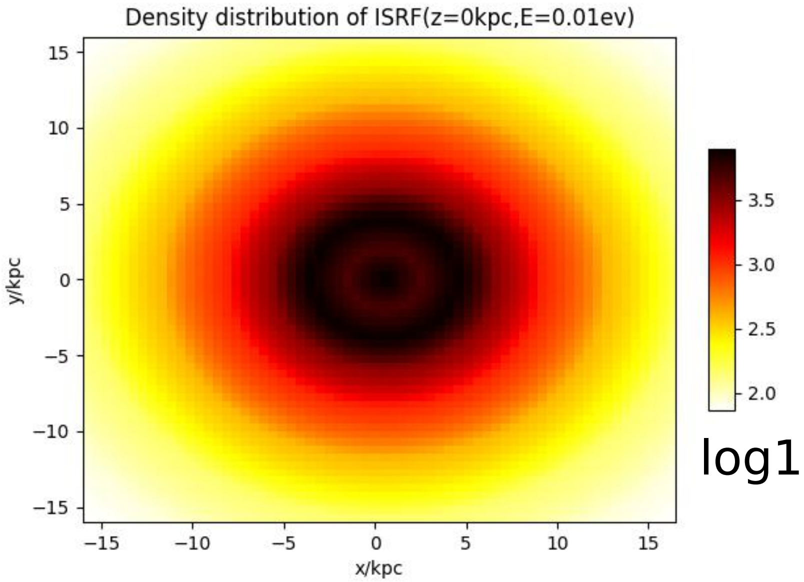
$$\sigma_{\gamma\gamma} = \frac{\pi}{2}\frac{\alpha^2}{m_e^2}(1-\beta^2)\left[(3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)-2\beta(2-\beta^2)\right]$$

$$\beta = \sqrt{1-1/s}\quad , \text{ and }\quad s = \frac{\varepsilon E_\gamma}{2m_e^2}(1-\cos\theta)\,,$$



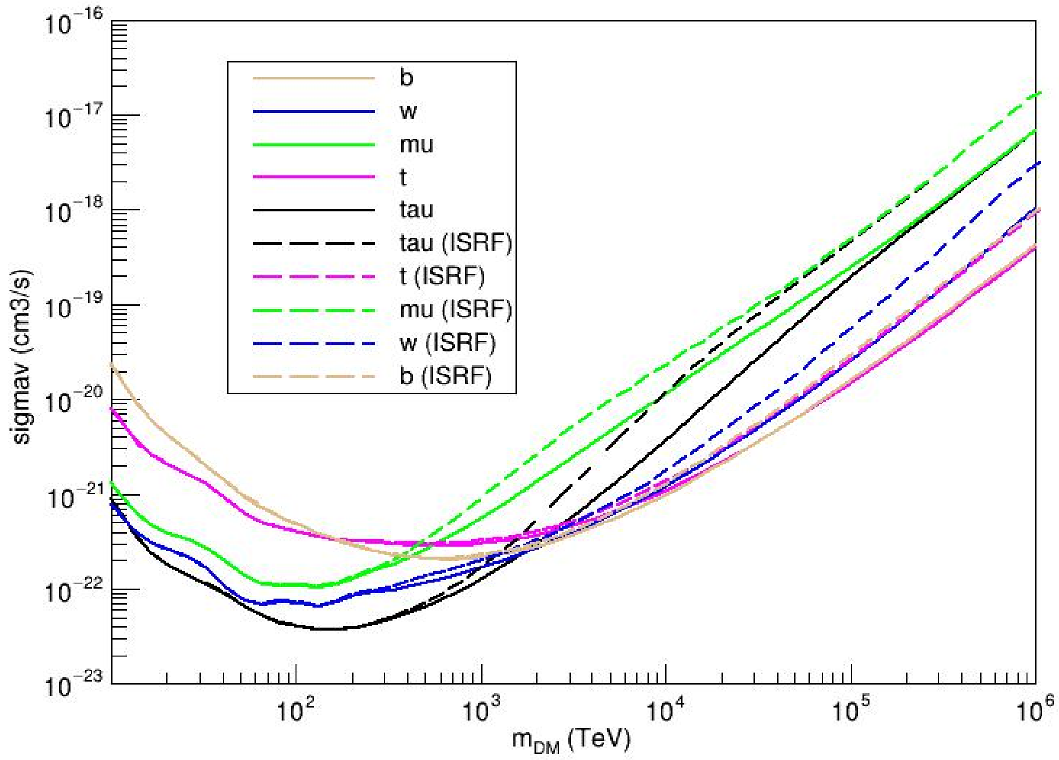
$n_{\rm SL+IR}$: from GALPROP





log10

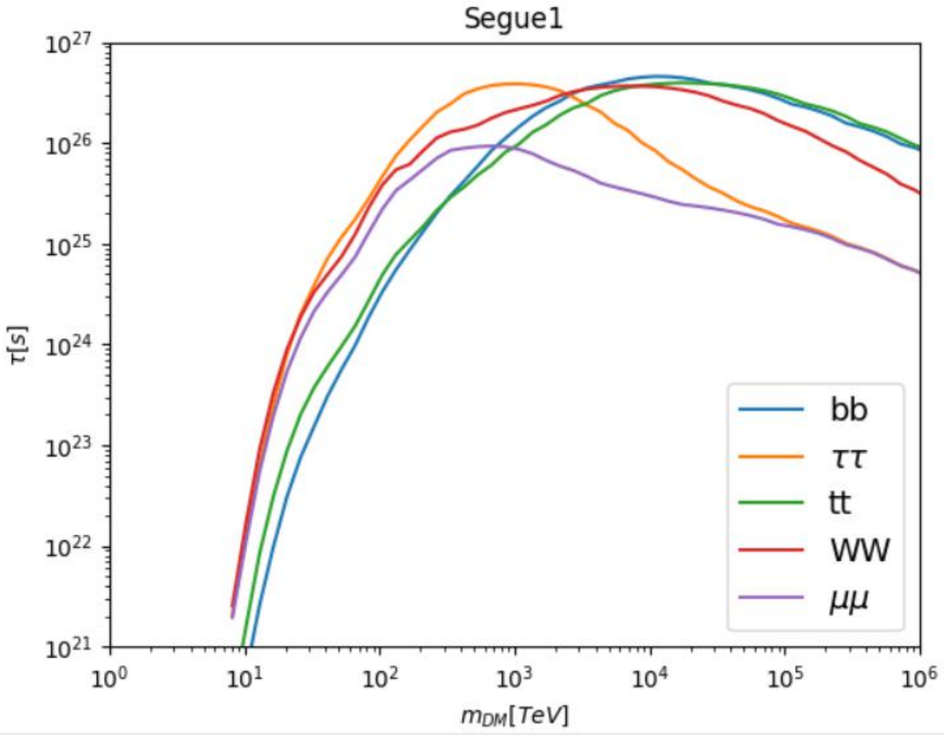
Constraints from Segue 1



Decay process of DM

$$\Phi = \frac{1}{4\pi}\frac{1}{m_\chi \tau}\int_{E_{\min}}^{E_{\max}} \frac{dN_\gamma}{dE_\gamma} dE_\gamma \times D$$

$$D = \int_{\text{source}} d\Omega \int_{\text{l.o.s}} dx \rho(r(\theta, x))$$



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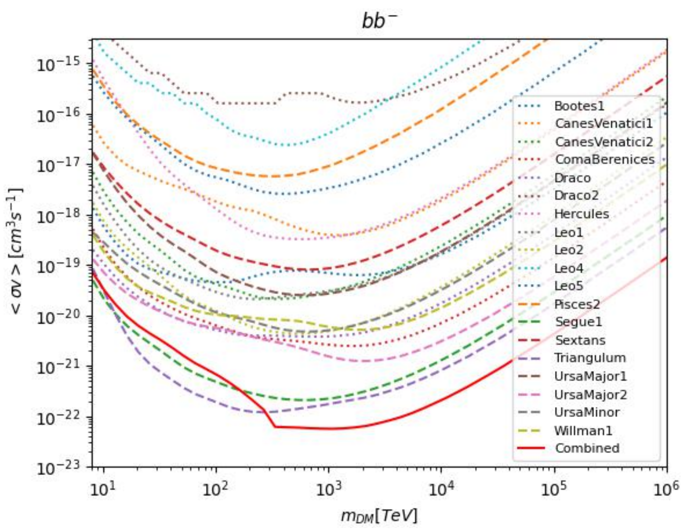
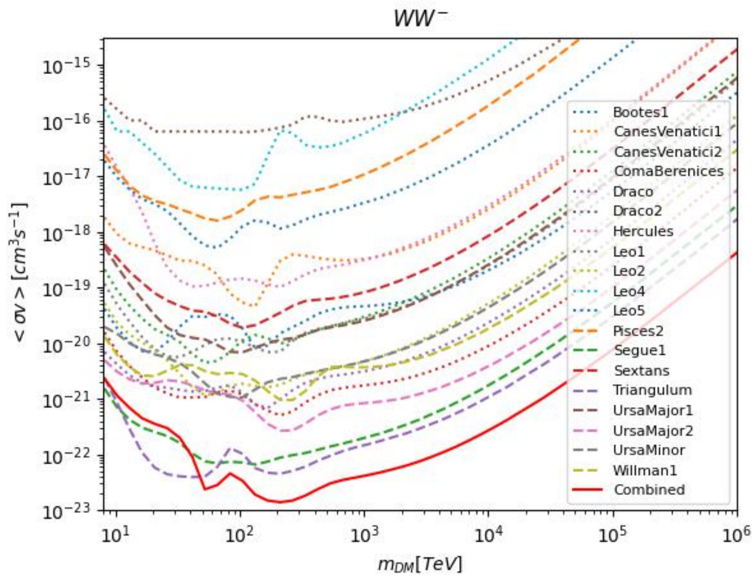
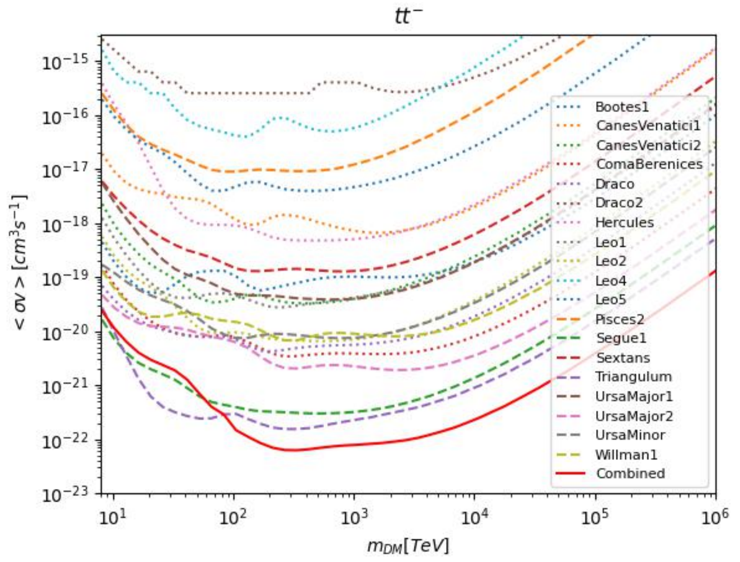
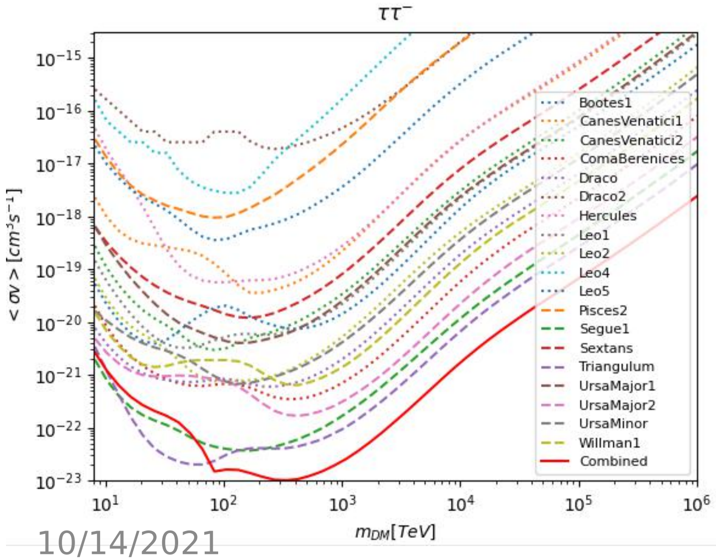
arXiv:1408.0002
1802.06811
1603.08046

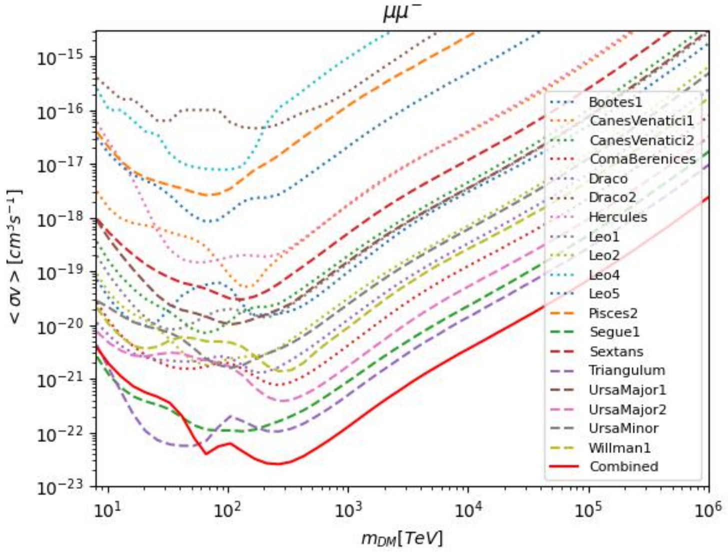
Annihilation process

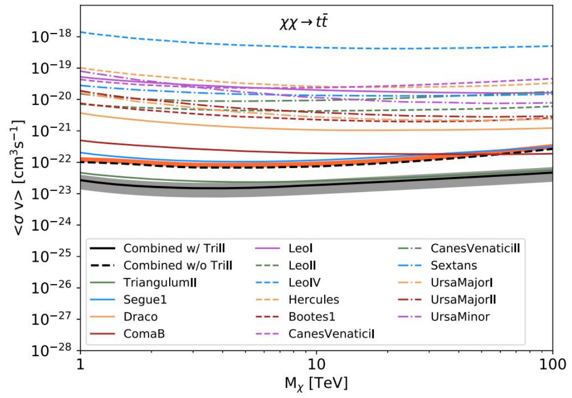






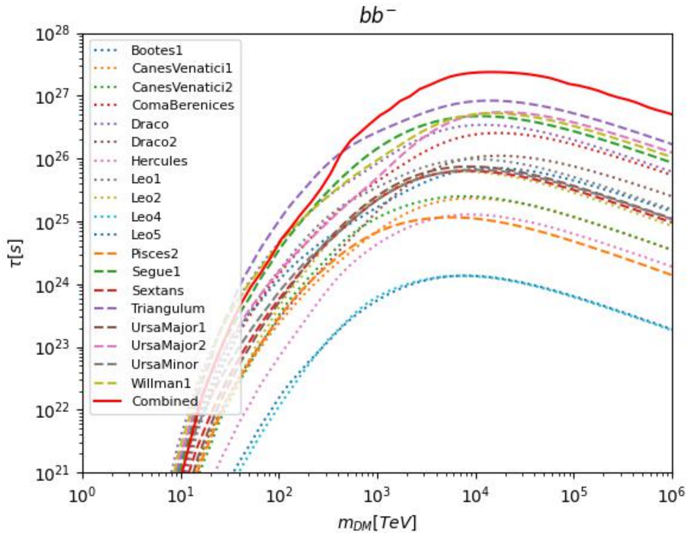


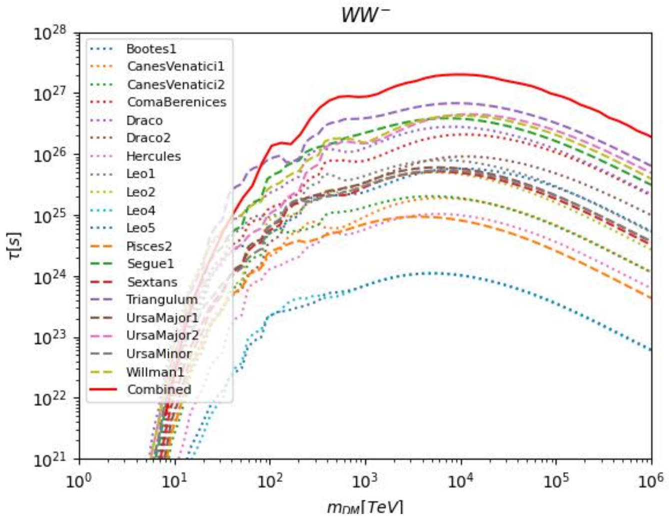


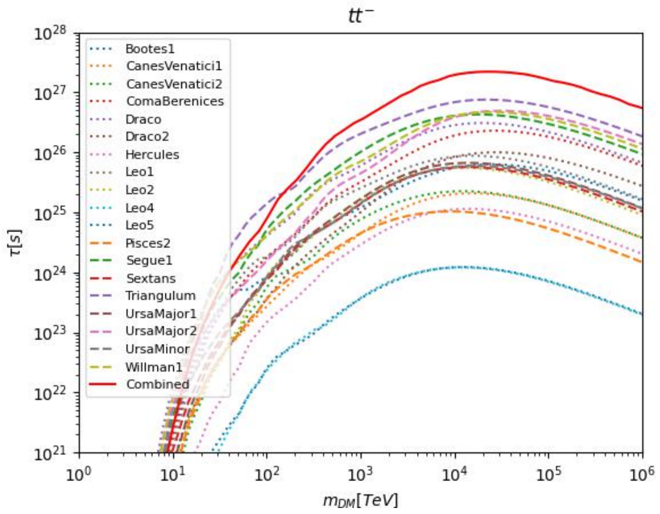


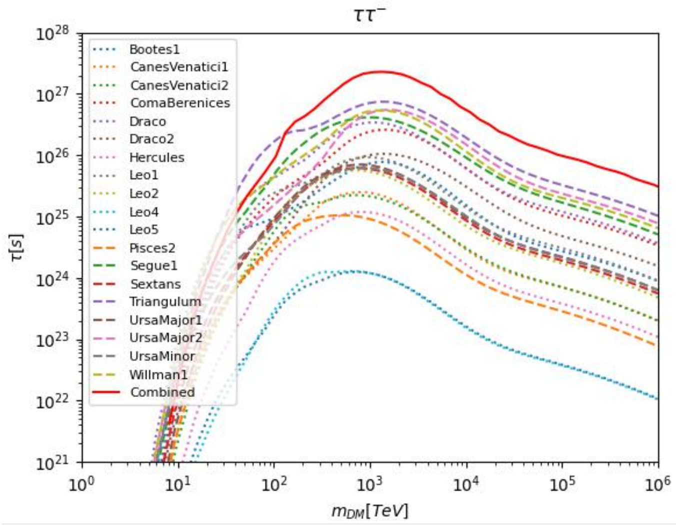
HAWC results

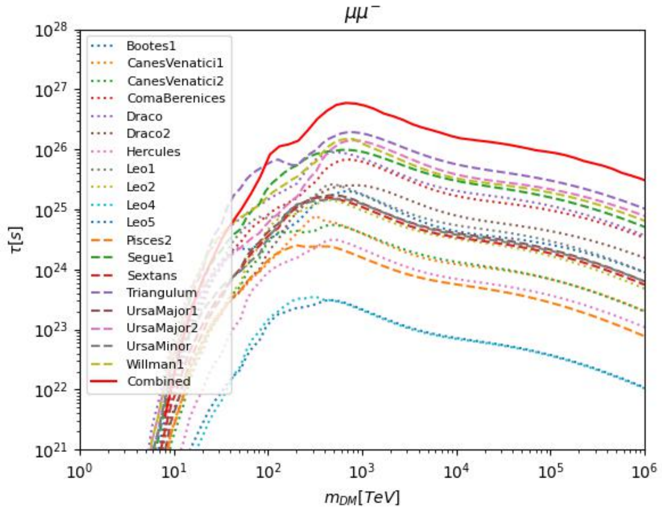
Decay process

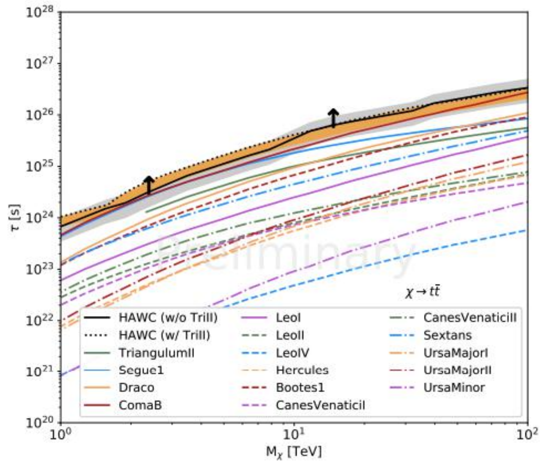












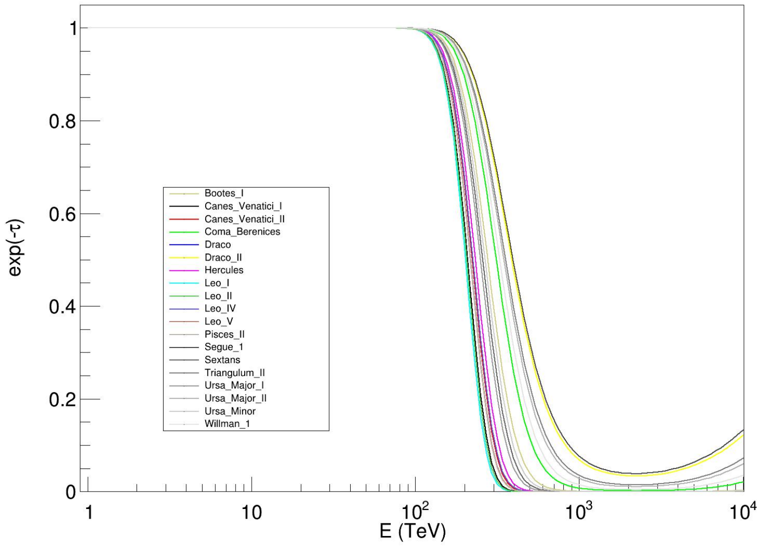
HAWC results

- We focus on 19 Dwarf spheroidal galaxies
- Five processes: $b\bar{b}$, $t\bar{t}$, $\mu^+\mu^-$, $\tau^+\tau^-$, and W^+W^-
- Constraints from annihilation and decay processes of Dark Matter are given for 19 dSphs
- For m_{DM}>100 TeV, LHAASO could give most strigent constraints; For m_{DM}<100TeV, constraints are weaker than HAWC results, WCDA is needed

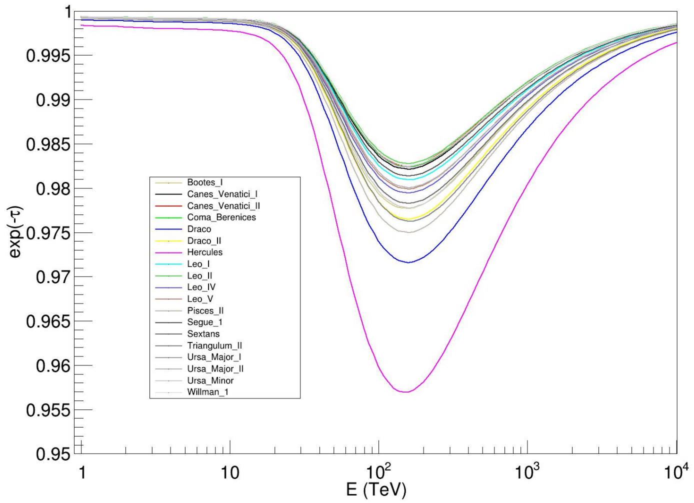
Thank You !!!

Absorption of gamma-rays for all dSphs:

CMB



ISRF (without CMB)



ISRF