

# Search for Gamma-Ray Signatures of Dark Matter Annihilation in the Galactic Center with KM2A

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1. IHEP

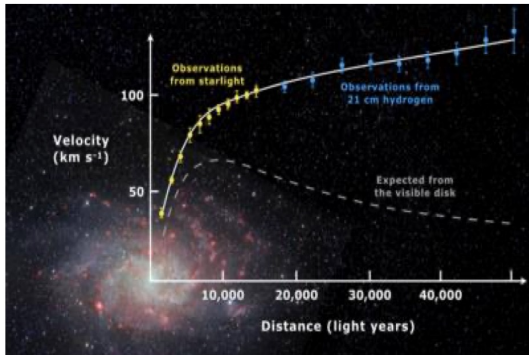
2. Zhengzhou University

3. Guangxi University

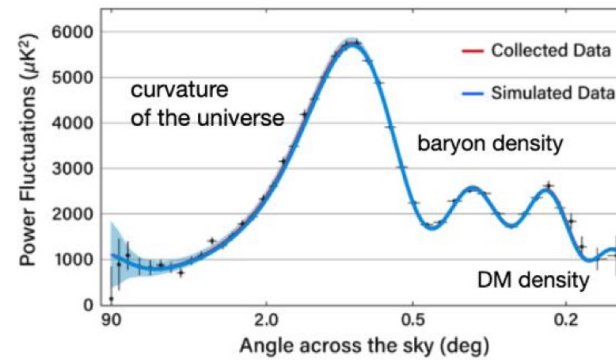
# Dark matter

- Dark matter is one of the most mysterious components in modern physics and cosmology

Rotation Curve



Cosmic Microwave Background

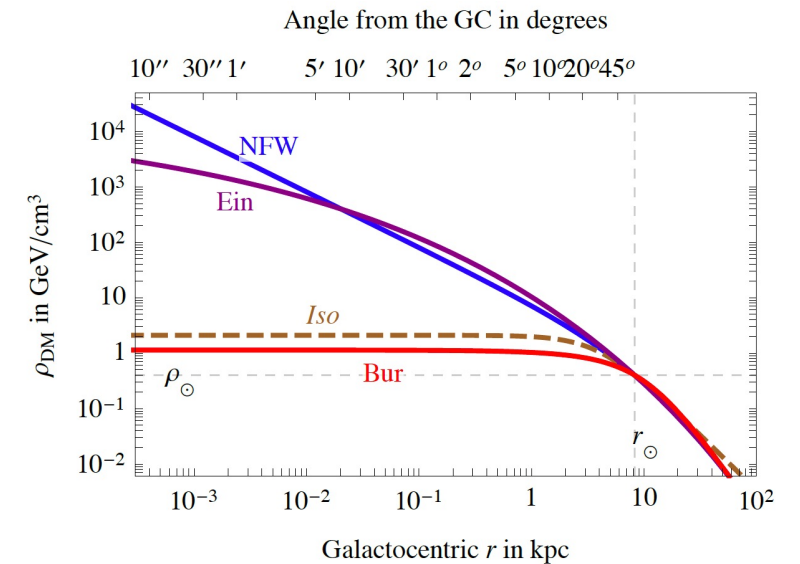
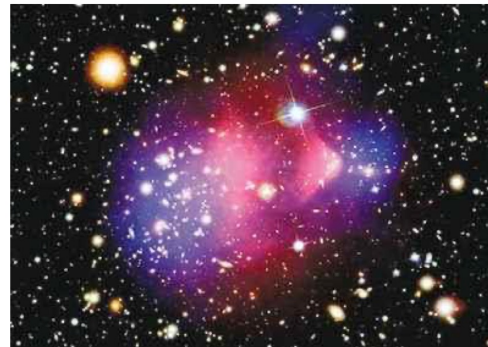


- The region around the Galactic Center (GC) is one of the richest and most promising targets for the indirect detection of dark matter

Gravitational Lensing

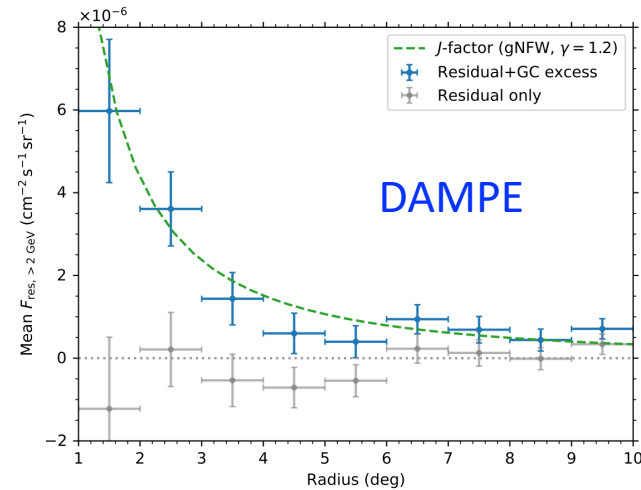
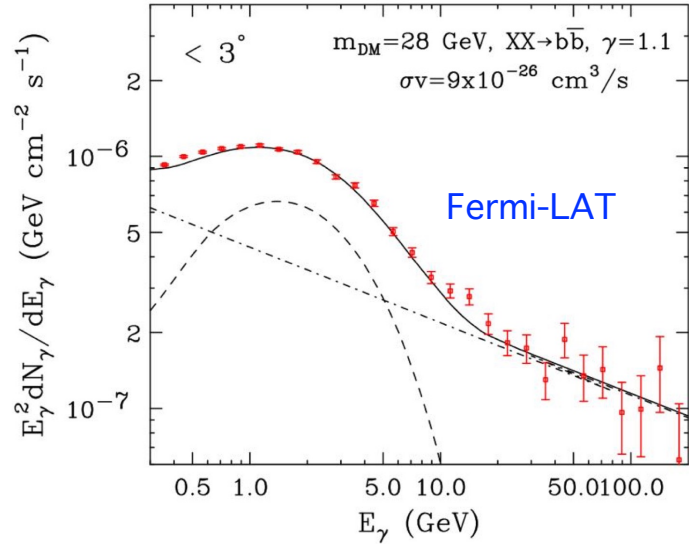


The Bullet Cluster

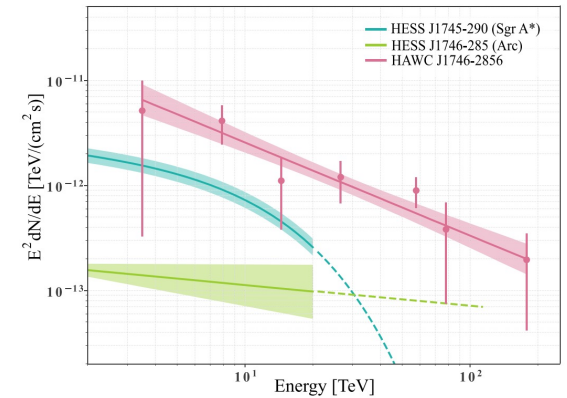
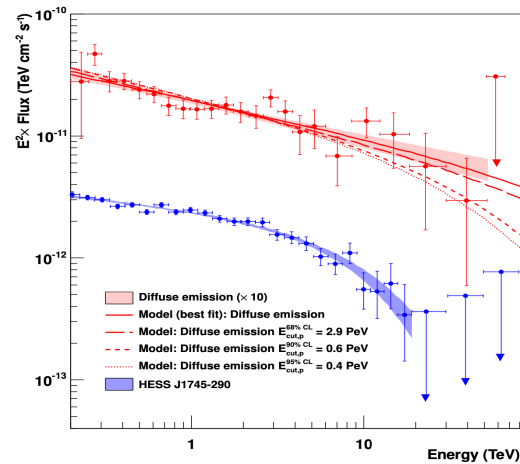
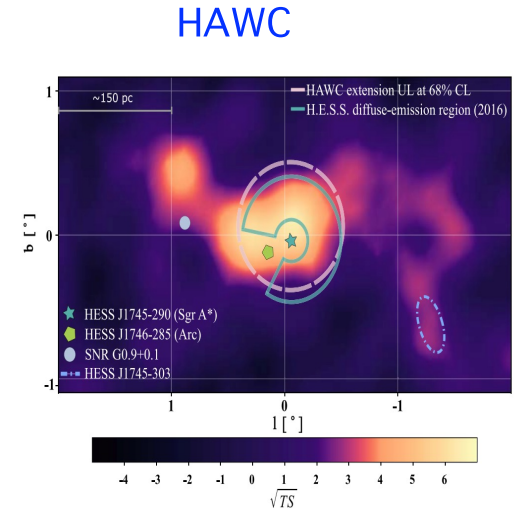
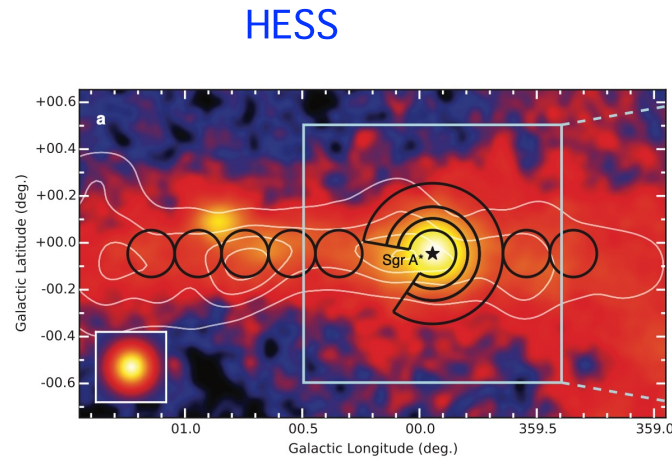


# The Galactic Center in the Gamma-Ray Sky

- GC GeV excess

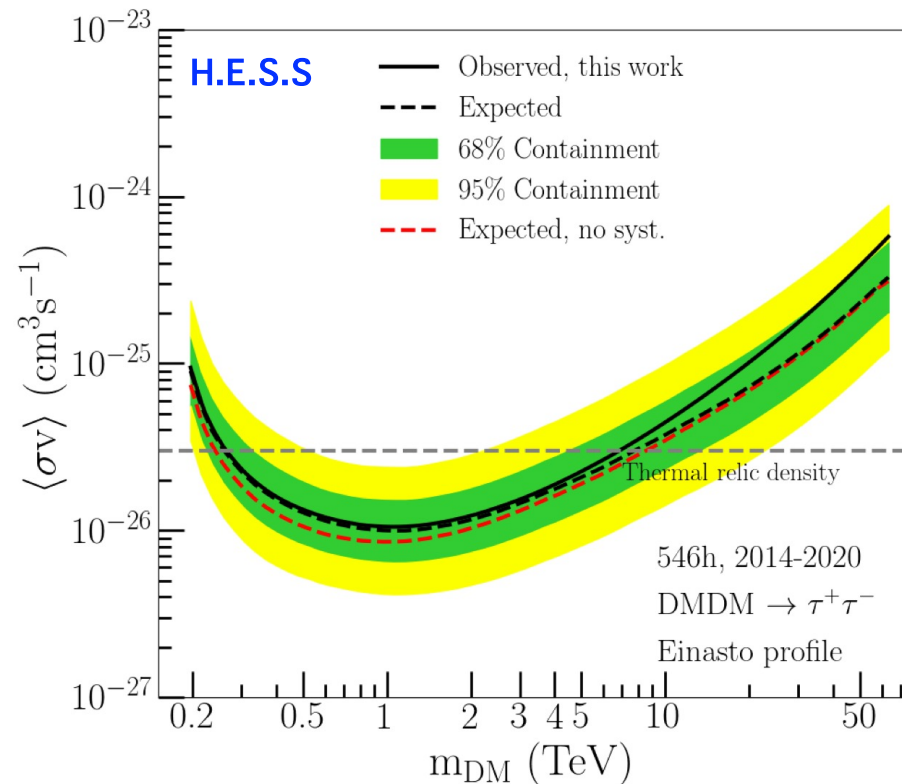


- VHE gamma-rays around GC

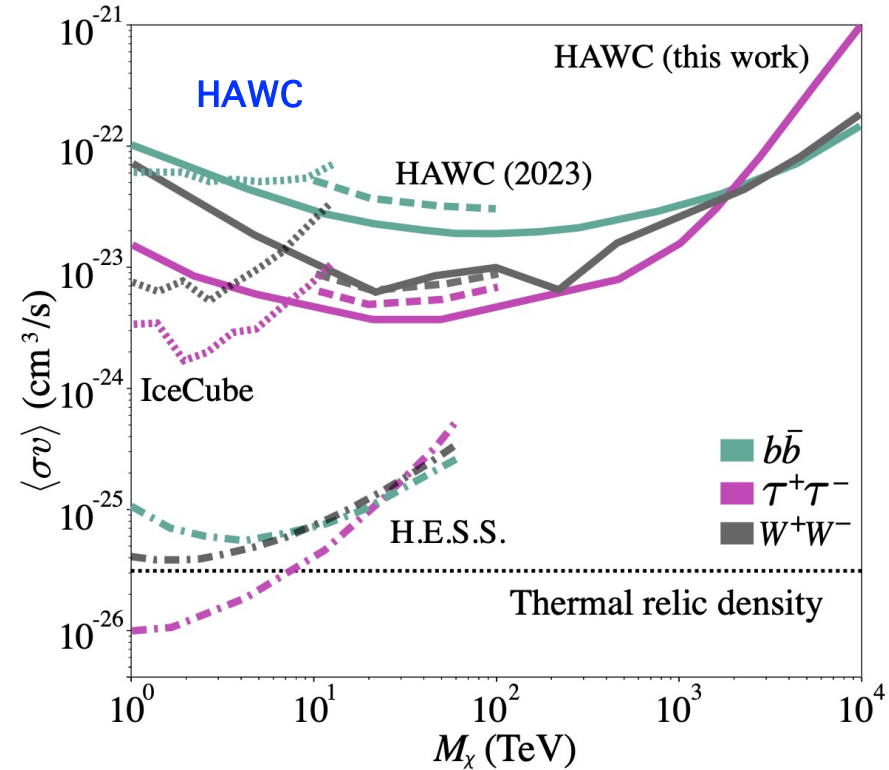


# Indirect dark matter search around the GC

- The Galactic Center region provides stringent constraints on the dark matter annihilation cross section



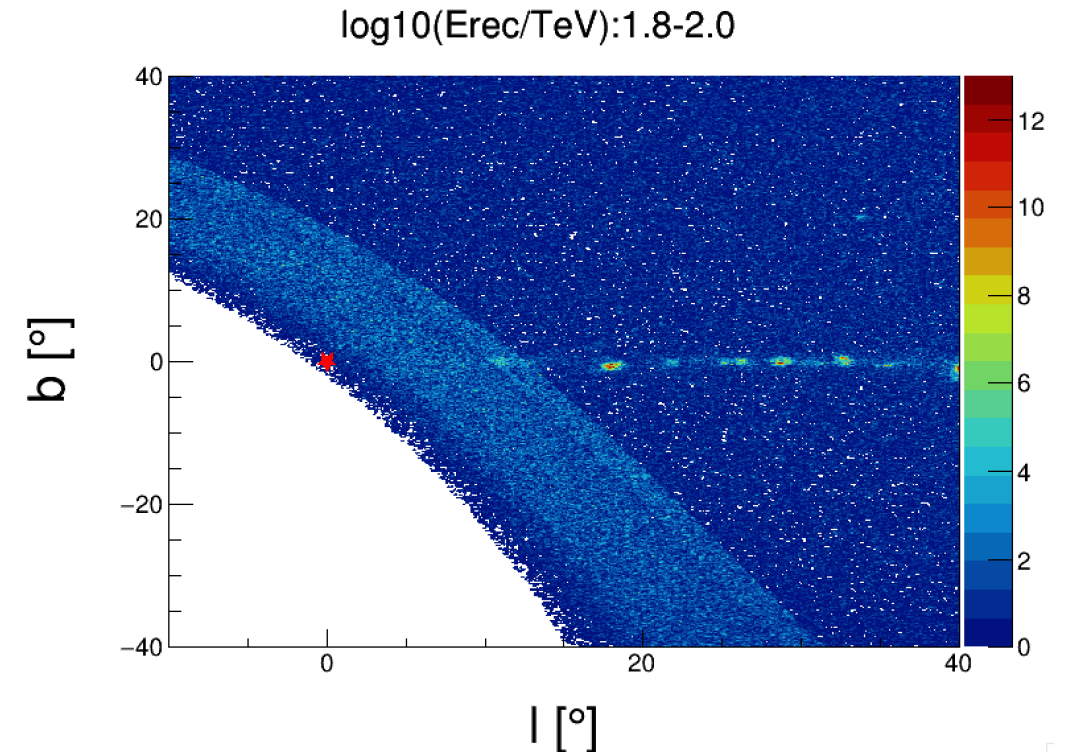
Phys.Rev.Lett. 129 (2022), 111101



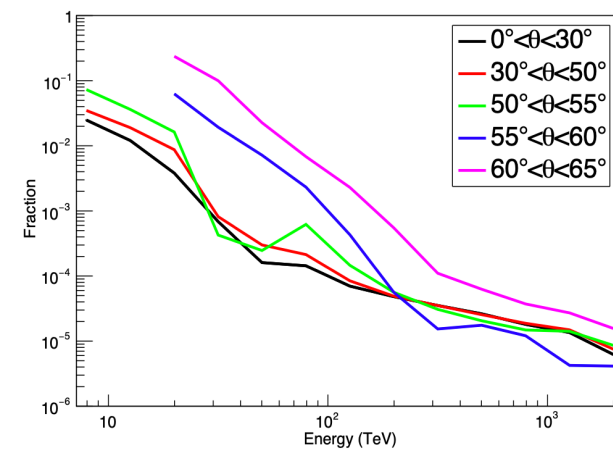
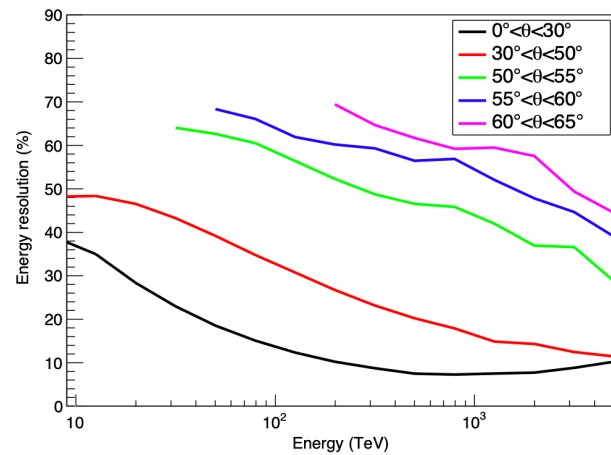
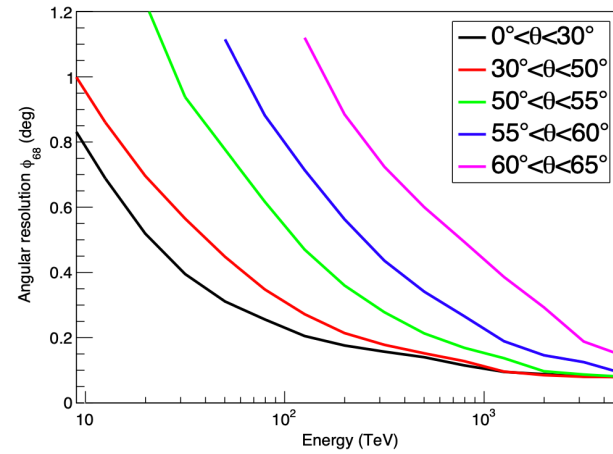
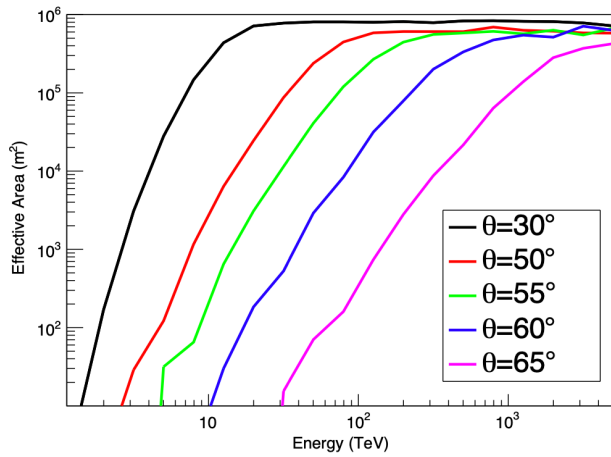
2509.06210

# GC and KM2A data set

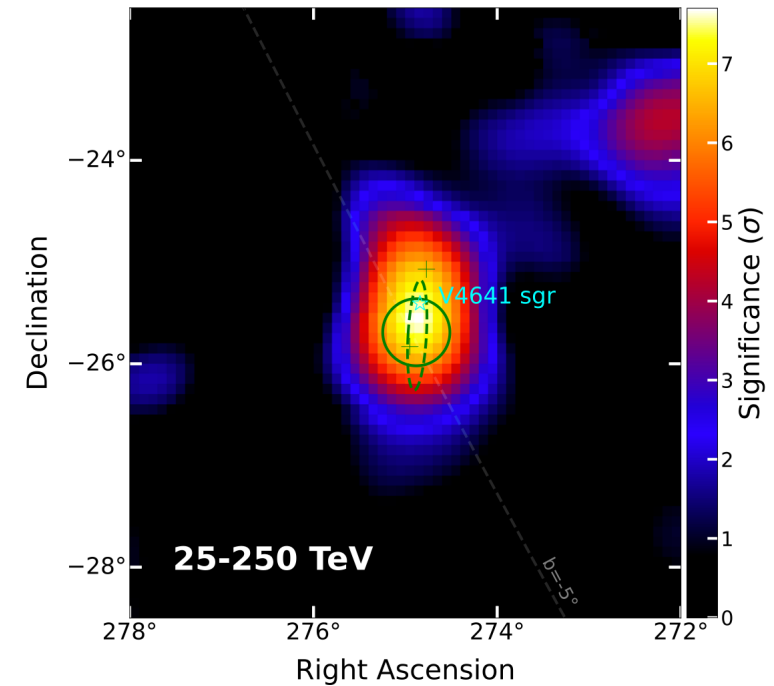
- The GC (RA =  $266.4^\circ$  Dec =  $-28.9^\circ$ ), culminating at a zenith angle of  $58^\circ$
- Large-zenith-angle (z50z60) data ( $50^\circ < \theta < 60^\circ / \theta < 50^\circ$ )
- The life time of the KM2A data is 1944.3 days
- Energy range( $\log_{10}(\text{Erec}/\text{TeV})$ ): [1.4 ,3.0]
- The event selection and background estimation method follow the official procedure



# The performances of KM2A for large-zenith-angle



V4641 Sgr, cluminating at a zenith angle of  $55^\circ$



[Natl. Sci. Rev. 12, nwaf496](#)

# Significance map around GC from KM2A

- Method: Likelihood analysis

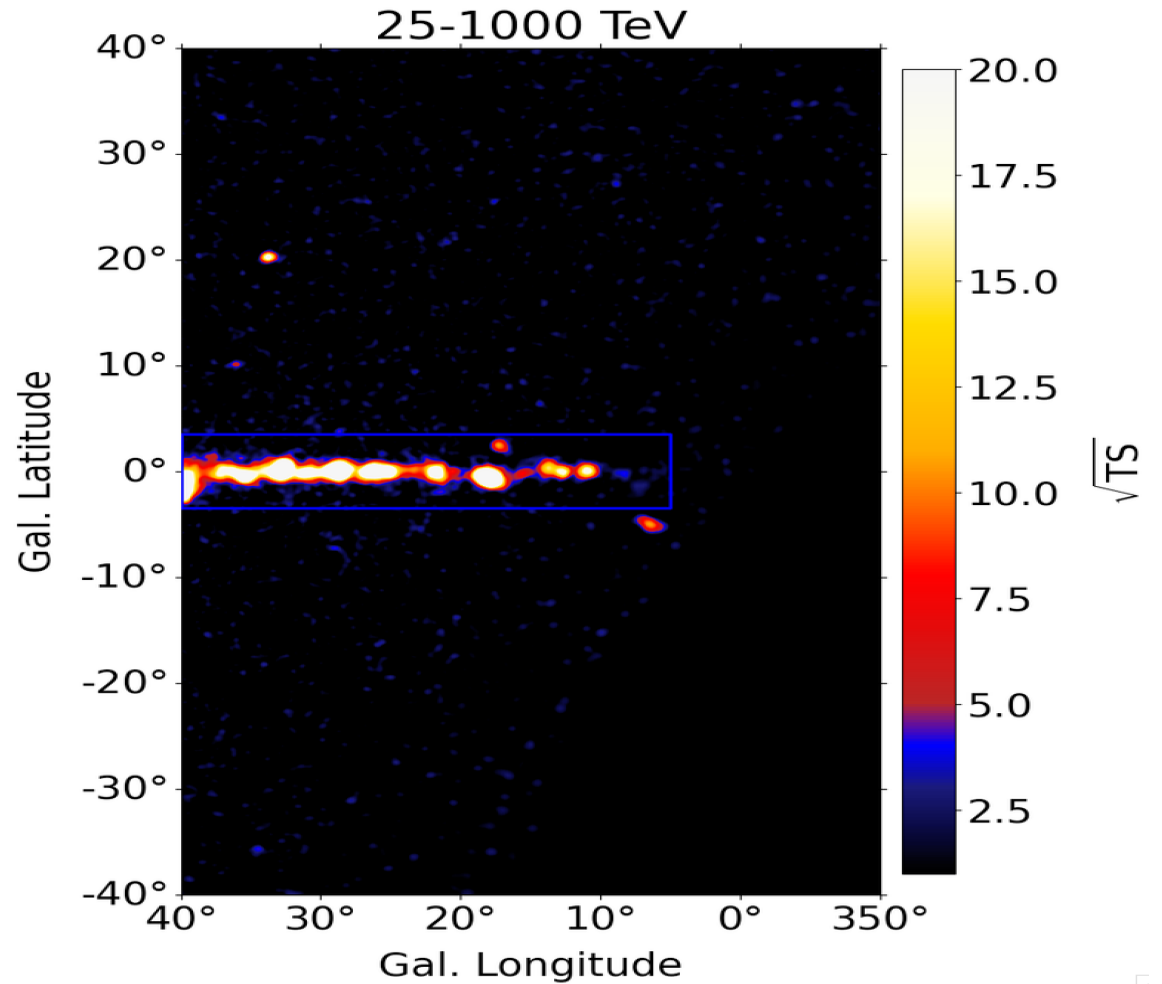
$$\ln \mathcal{L}(\vec{\theta} | \vec{n}) = \sum_i^{E_{\text{bins}}} \sum_i^{\text{ROI}} (N_{ij} \ln \lambda_{ij} - \lambda_{ij})$$

$$TS = -2(\ln \mathcal{L}_0 - \ln \mathcal{L}_1)$$

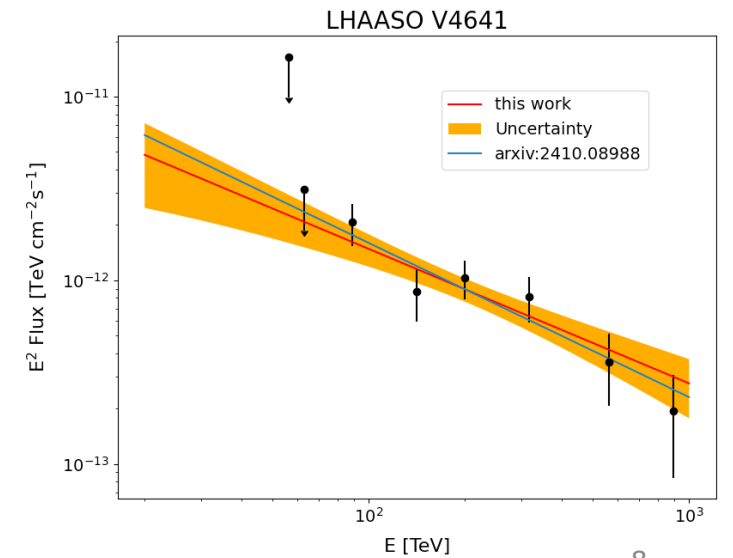
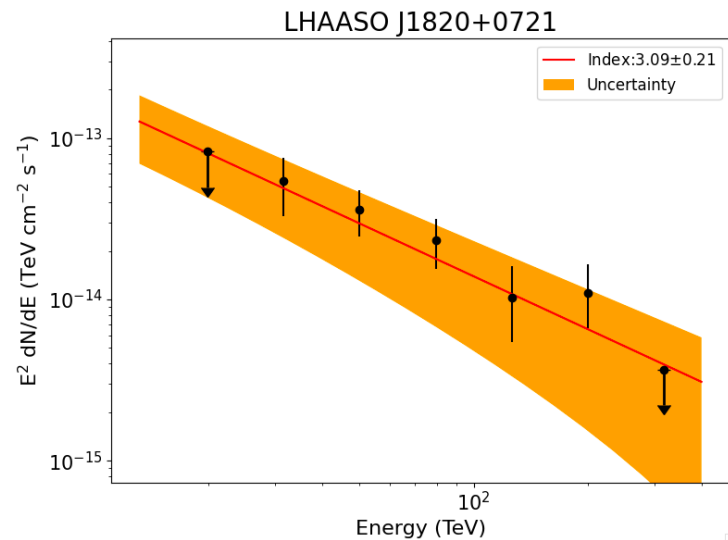
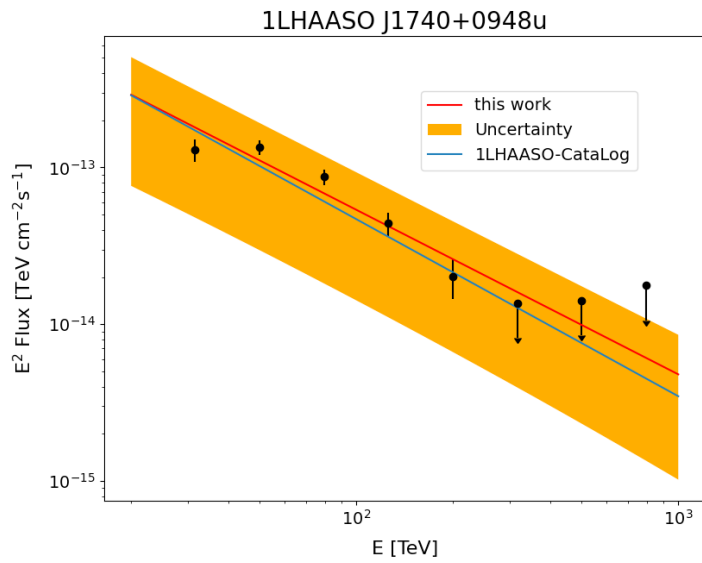
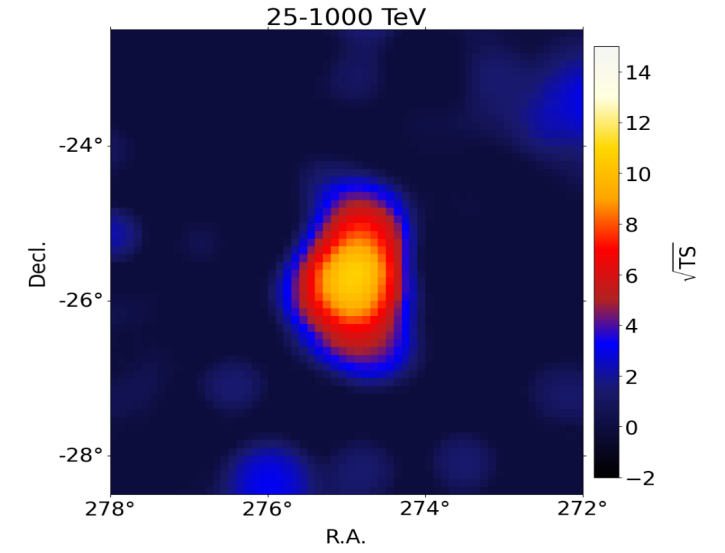
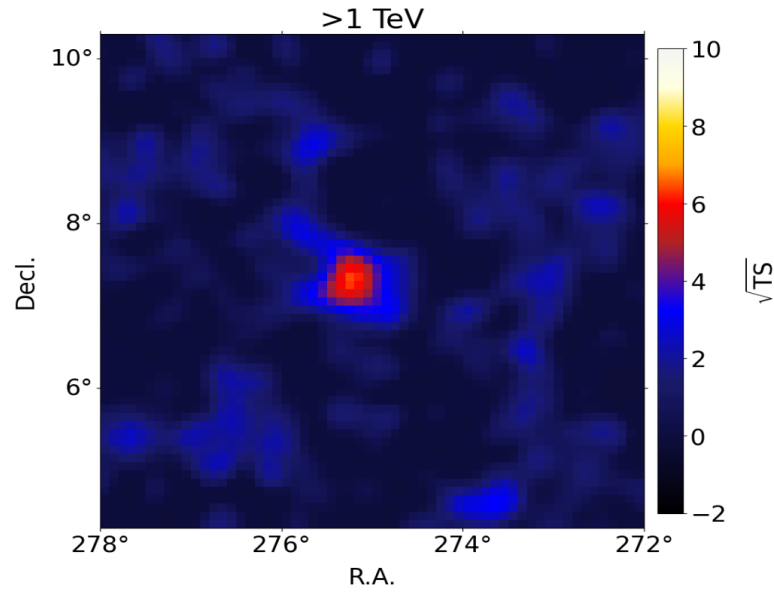
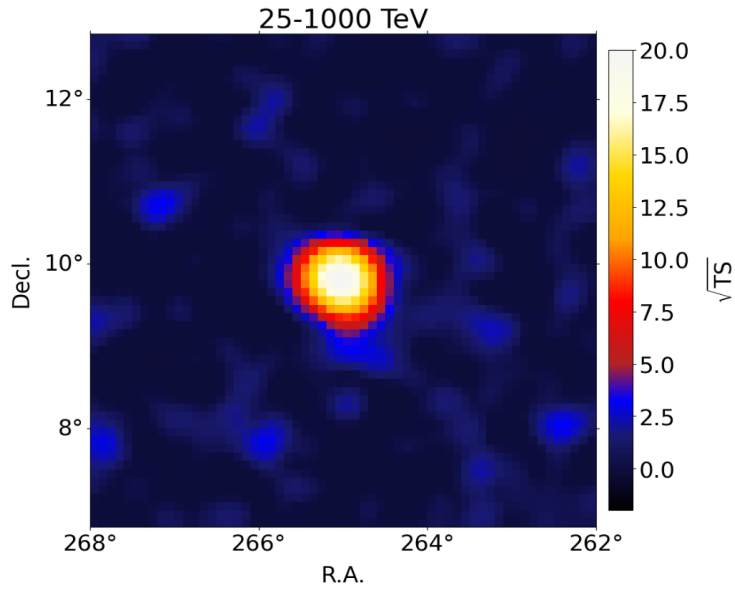
- Mask region for dark matter search:

$$|b| < 3.5^\circ \ \&\& \ 5^\circ < l$$

- Three additional gamma-ray sources with a significance of  $5\sigma$  are used to validate the analysis



# Three residual gamma sources



# DM annihilation modelling: Prompt gamma-ray intensity

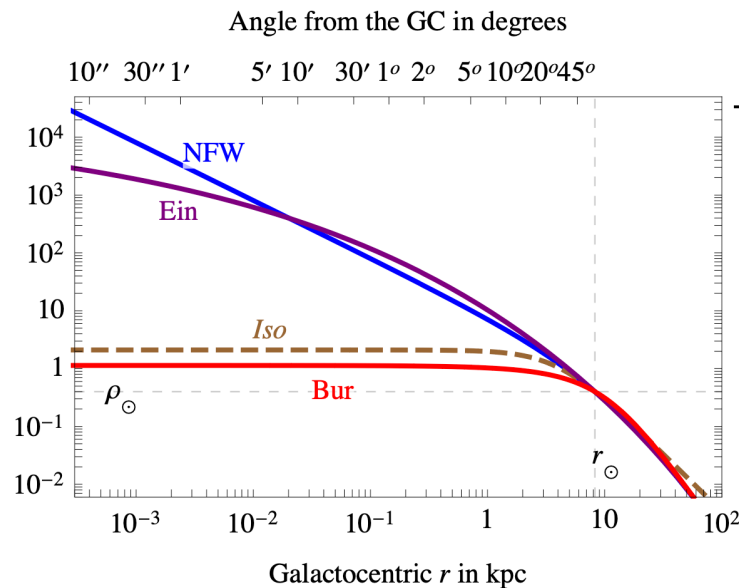
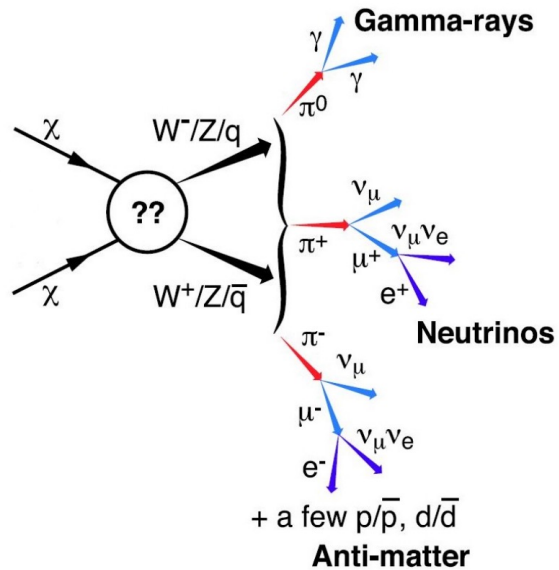
$$\frac{d\Phi_{\gamma,\text{anni}}}{dE_{\gamma}}(E_{\gamma}, b, l) = \frac{\langle\sigma_{AV}\rangle}{8\pi M_{\text{DM}}^2} \frac{dN_{\gamma}}{dE_{\gamma}}(E_{\gamma}) \int_0^{\infty} \rho_h^2[r(s, b, l)] e^{-\tau_{\gamma\gamma}(E_{\gamma}, s, b, l)} ds,$$

cross-section

Spectrum

J factor

[JCAP10\(2015\)014](#)



The **NFW profile** is adopted as the nominal model

$$\rho_h(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2},$$

$$r_s = 20 \text{ kpc}$$

$$s = \sqrt{s^2 + R_{\odot}^2 - 2sR_{\odot}\cos b\cos\ell},$$

$$\rho_s = 0.39 \text{ GeV/cm}^3$$

# gamma-ray absorption

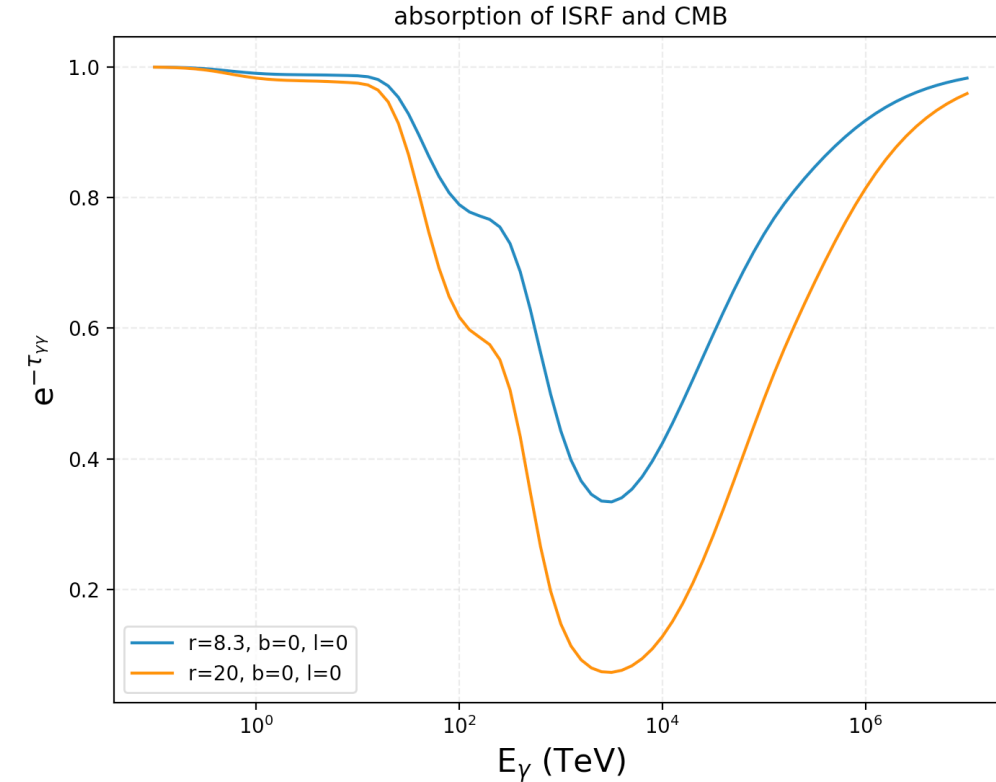
## Interstellar Radiation Field

$$\tau(E, L) = \int d \cos(\theta) \int dE_{\text{ISRF}} \int_{l.o.s.} dL \frac{dn(r, E_{\text{ISRF}})}{dE_{\text{ISRF}}} \sigma_{\gamma\gamma \rightarrow e^+e^-}(s) ,$$

[Astron.Astrophys. 449 \(2006\) 641](#) From GALPROB

## CMB

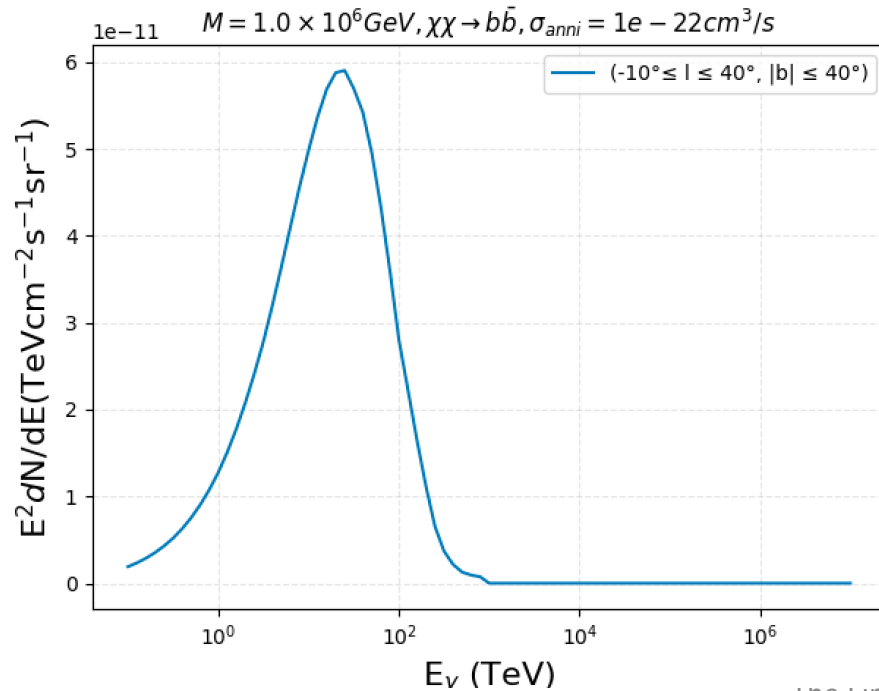
$$\tau_{\gamma\gamma}^{\text{CMB}}(E_\gamma, L) = \frac{-4T_{\text{CMB}}L}{\pi^2 E_\gamma^2} \int_{m_e}^{\infty} \varepsilon_c^3 \sigma_{\gamma\gamma}(\varepsilon_c) \ln \left[ 1 - e^{-\frac{\varepsilon_c^2}{E_\gamma T_{\text{CMB}}}} \right] d\varepsilon_c .$$



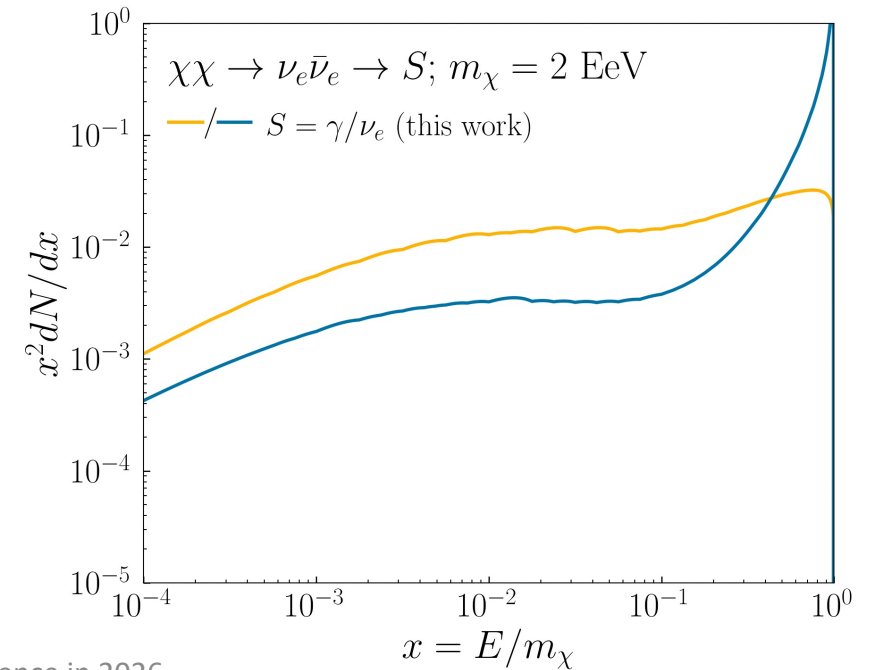
# Energy spectrum of DM annihilation

$$\frac{d\Phi_{\gamma,\text{anni}}}{dE_{\gamma}}(E_{\gamma}, b, l) = \frac{\langle\sigma_{Av}\rangle}{8\pi M_{\text{DM}}^2} \frac{dN_{\gamma}}{dE_{\gamma}}(E_{\gamma}) \int_0^{\infty} \rho_{\text{h}}^2[r(s, b, l)] e^{-\tau_{\gamma\gamma}(E_{\gamma}, s, b, l)} ds,$$

HDM Spectra

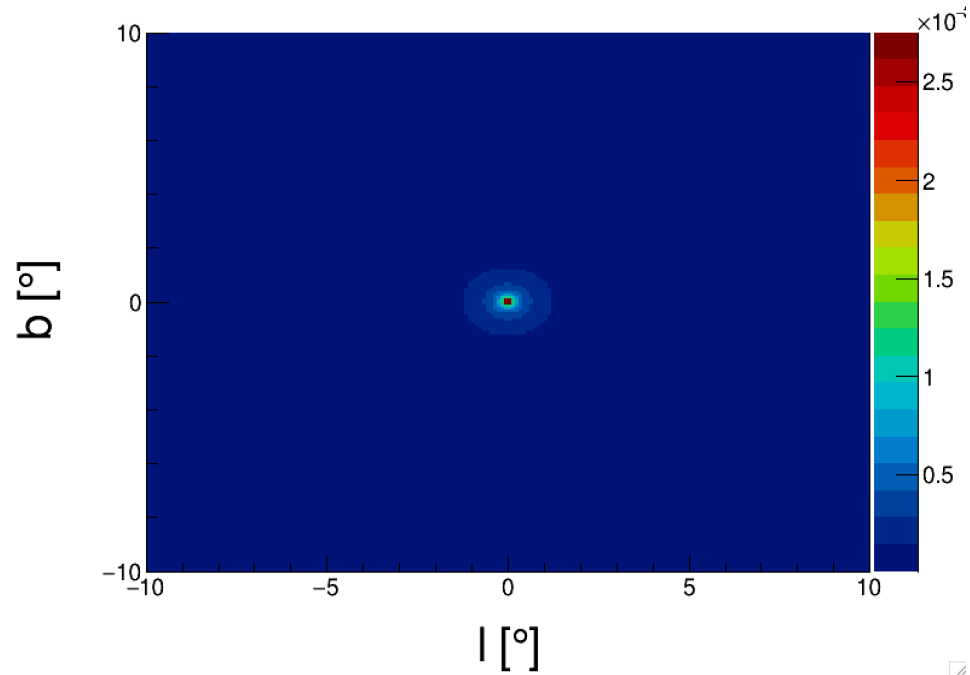


[JHEP06\(2021\)121](#)

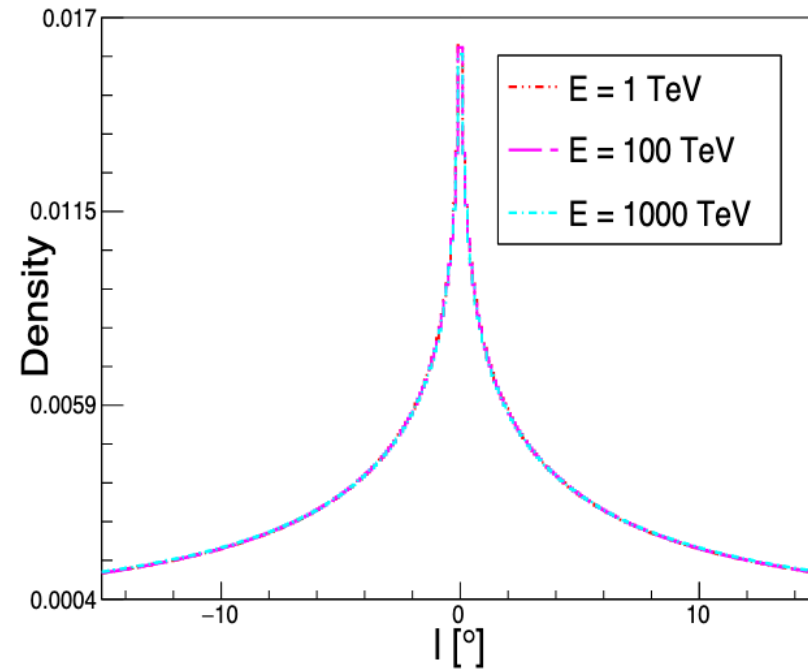


# Spatial distribution

NFW



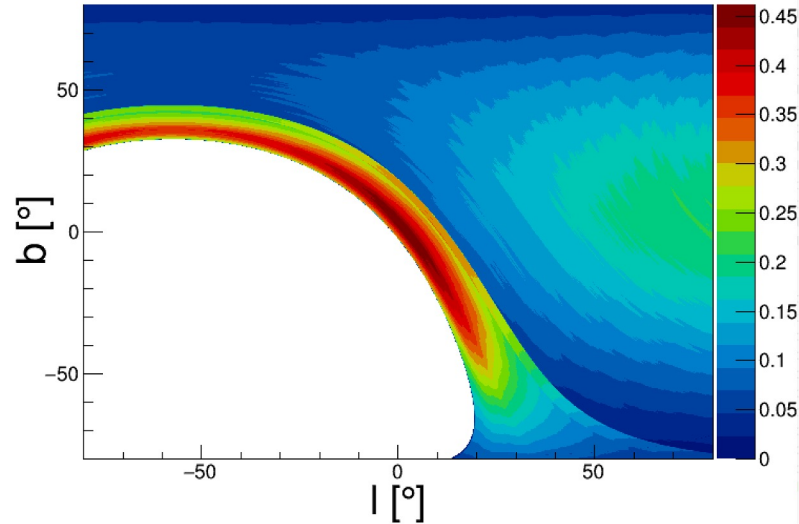
Energy-independent !!!



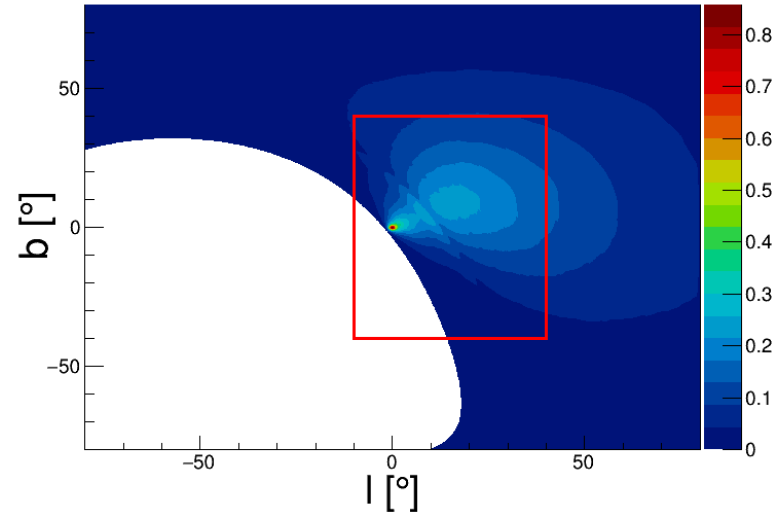
$$\frac{d\Phi_{\gamma,\text{anni}}}{dE_{\gamma}}(E_{\gamma}, b, l) = \frac{\langle \sigma_{A\nu} \rangle}{8\pi M_{\text{DM}}^2} \frac{dN_{\gamma}}{dE_{\gamma}}(E_{\gamma}) \int_0^{\infty} \rho_{\text{h}}^2[r(s, b, l)] e^{-\tau_{\gamma\gamma}(E_{\gamma}, s, b, l)} ds,$$

# Optimization of ROI

Cosmic-ray BKG  
log10(Erec/TeV):2.0-2.2



Expected DM signal map with  $M_\chi = 10^6$  GeV  
log10(Erec/TeV):2.0-2.2

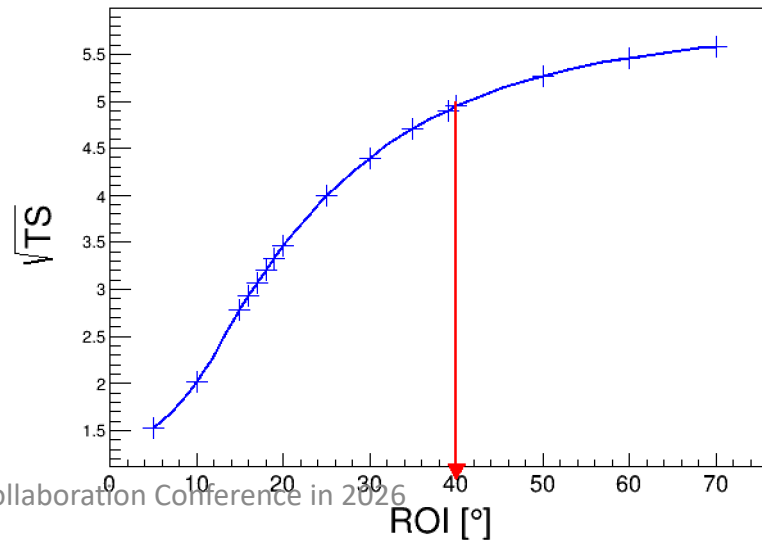


Calculation the  $\mathcal{L}$  in each ROI:

$$\ln \mathcal{L}(\vec{\theta} | \vec{n}) = \sum_i^{E_{\text{bins}}} \sum_j^{\text{ROI}} (N_{ij} \ln \lambda_{ij} - \lambda_{ij}) \quad ,$$

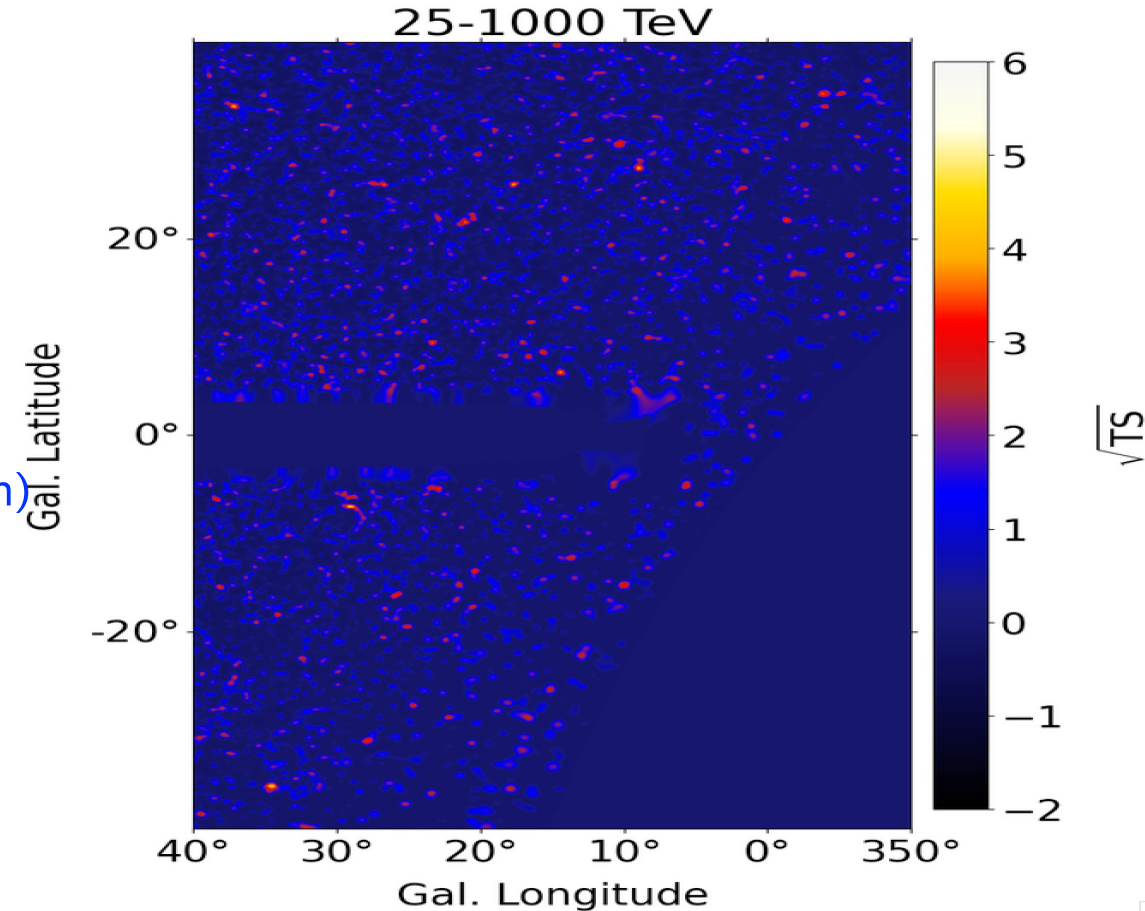
$$N = n_{\text{sig}}^{\text{exp}} + n_{\text{bkg}}^{\text{exp}}$$

ROI:  $|b| < 40^\circ$  &&  $-10^\circ < l < 40^\circ$



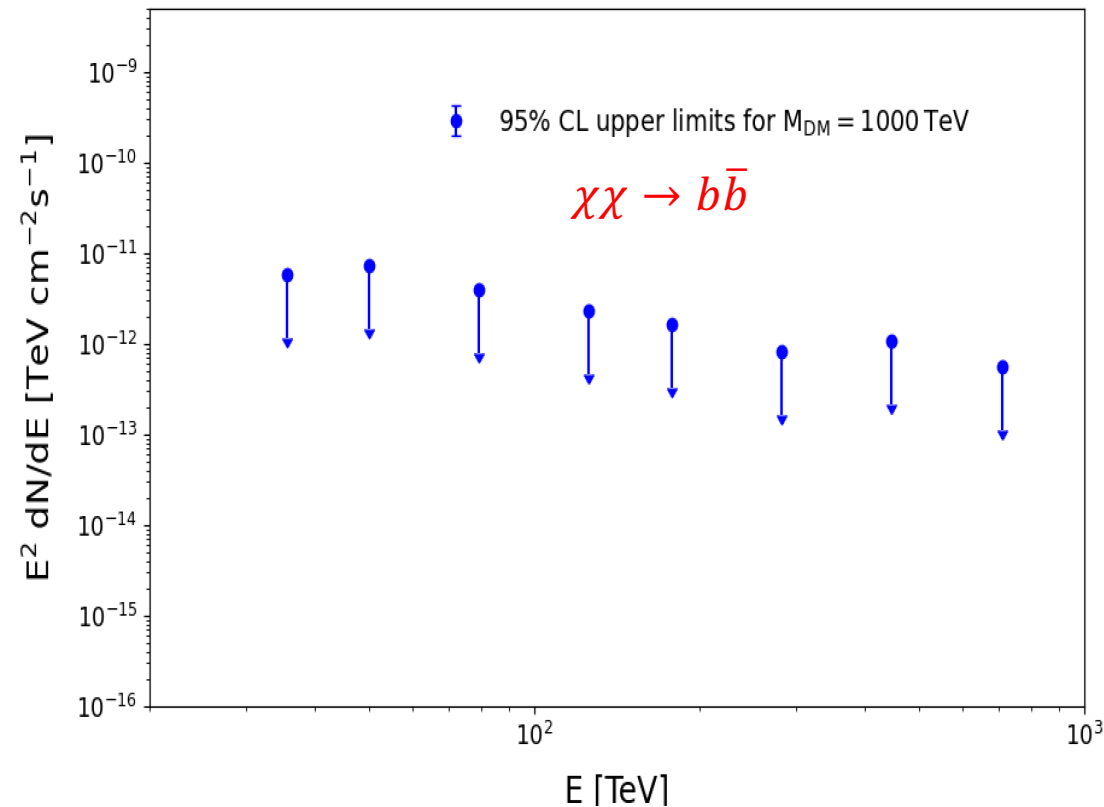
# Search for DM signal with KM2A data

- The significance map after masking  $|b| < 3.5^\circ$  &&  $5^\circ < l < 40^\circ$  and subtracting the gamma sources
- Fit components:
  1. DM with calculated spatial and spectra (float normalization)
  2. DGE: Planck Dust model / PL (float)
  3. three residual gamma sources with float normalization
- No evidence of DM signal with significance less than  $1\sigma$



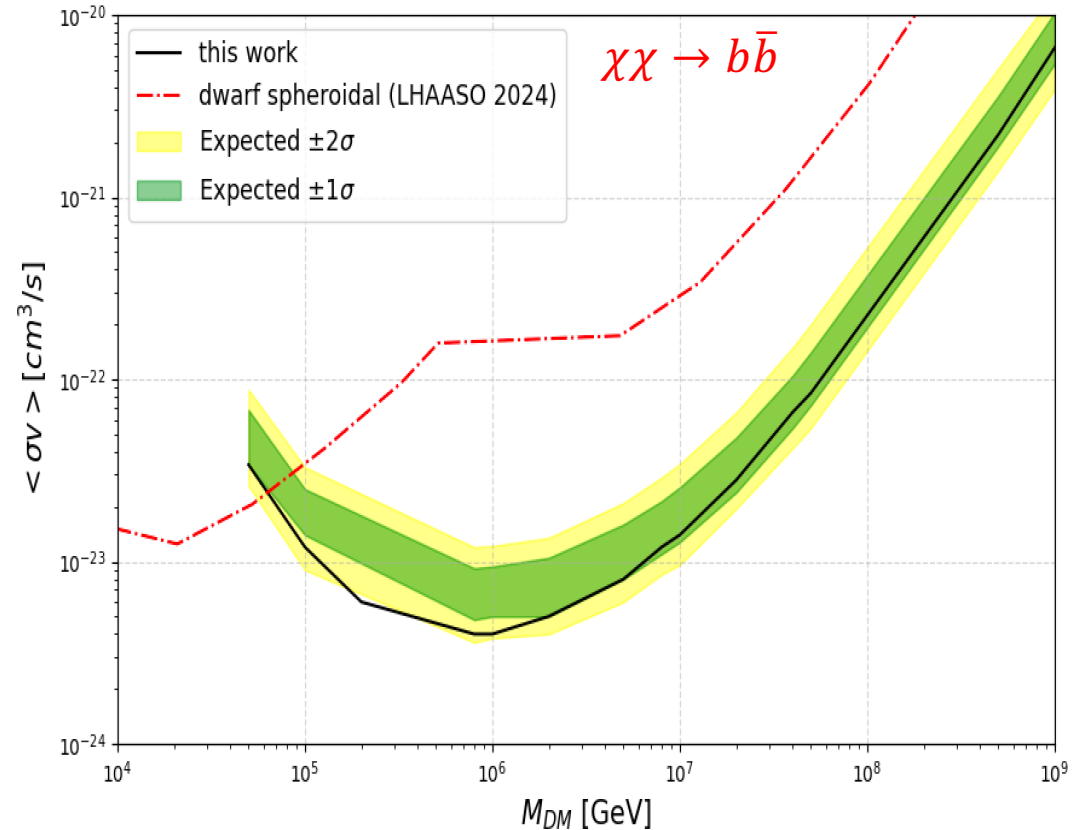
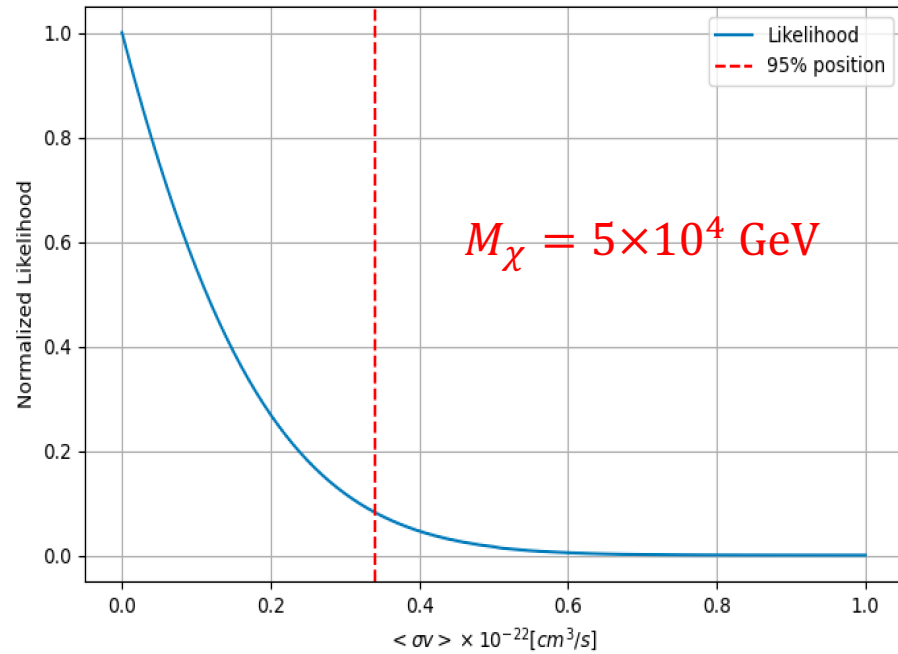
# Search for DM signal with KM2A data

- Search for the DM annihilation signal in the mass range 10 TeV – 1 EeV
- No evidence signal is found ( $1\sigma$ )



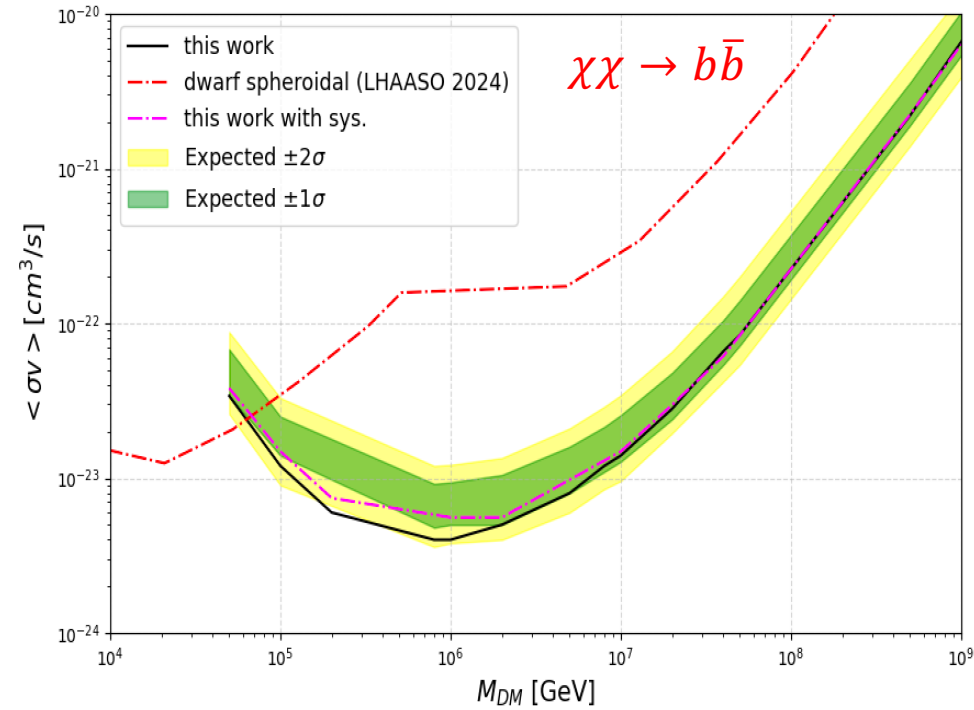
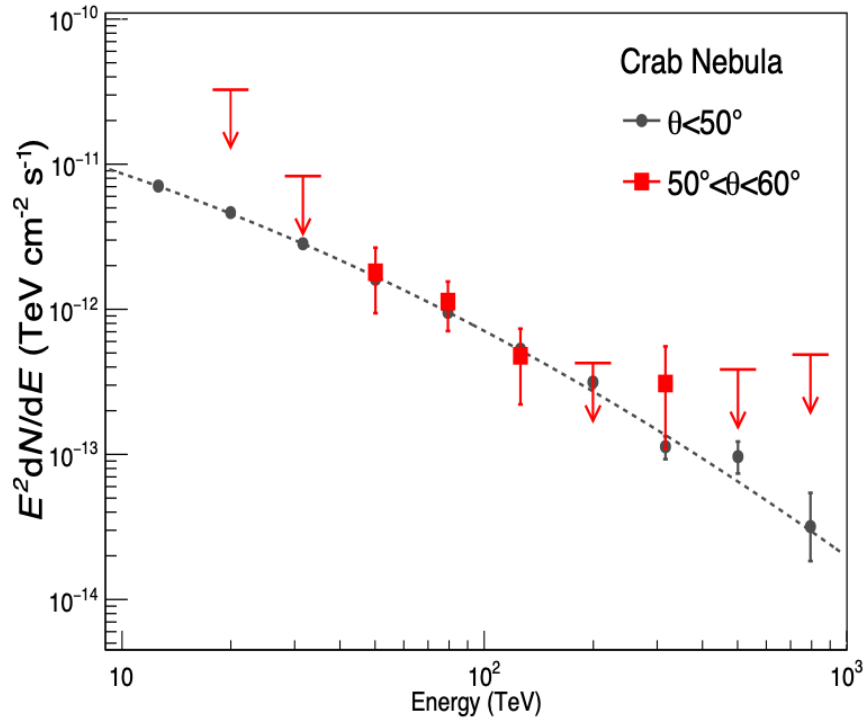
# Upper limits on the DM annihilation cross-section

- Profile likelihood to determine the 95% CL upper limits under different DM mass assumption
- The expected bands are determined with 1000 mock data under the background-only hypothesis



# Systematic Uncertainty

- The [atmospheric model](#) used in the Monte Carlo simulations due to seasonal and daily changes: 7%
- The DGE: artificially adjust the normalization of DGE by  $N_0 - 2\sigma$ ;



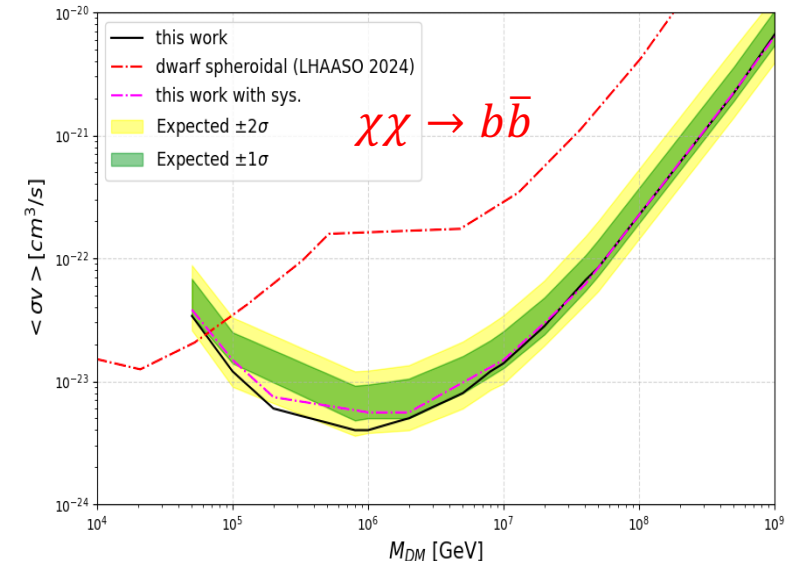
# Summary

- The [large-zenith-angle KM2A data](#) cover the GC and can therefore be used to search for dark matter annihilation signals
- We perform an indirect dark matter search over the mass range [10 TeV–1 EeV](#). The most stringent constraints are obtained around the PeV scale, [improving](#) upon previous LHAASO dSph work by [one order of magnitude](#).

Next:

Discuss different DM density profile models

Further systematic uncertainties



# Back Up

# Crab observation of large-zenith-Angle data

