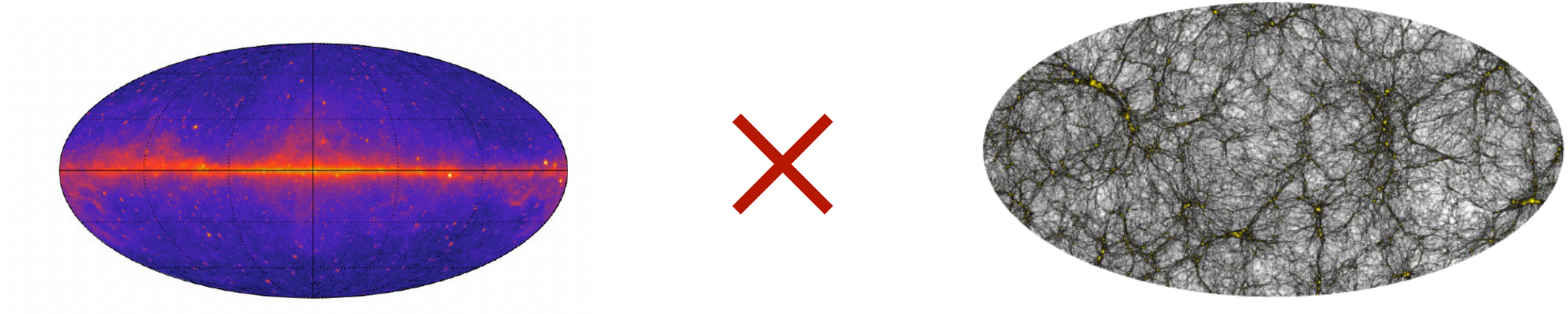
Shear x Gamma

Cross-correlating the Unresolved Gamma-Ray Background with Weak Lensing.

arXiv:2501.10506

Bhashin Thakore, 20/06/2025 (in collaboration with M. Negro, M. Regis, D. Gruen, S. Camera, N.Fornengo, A. Roodman, A. Cuoco, A. Porredon, and T. Schutt)

Tomographic Approaches for WIMP Search



- The fluctuations in the gamma-ray field need to be statistically correlated to the DM distribution in the universe (i.e. the DM fluctuations on top of a smooth Universe).

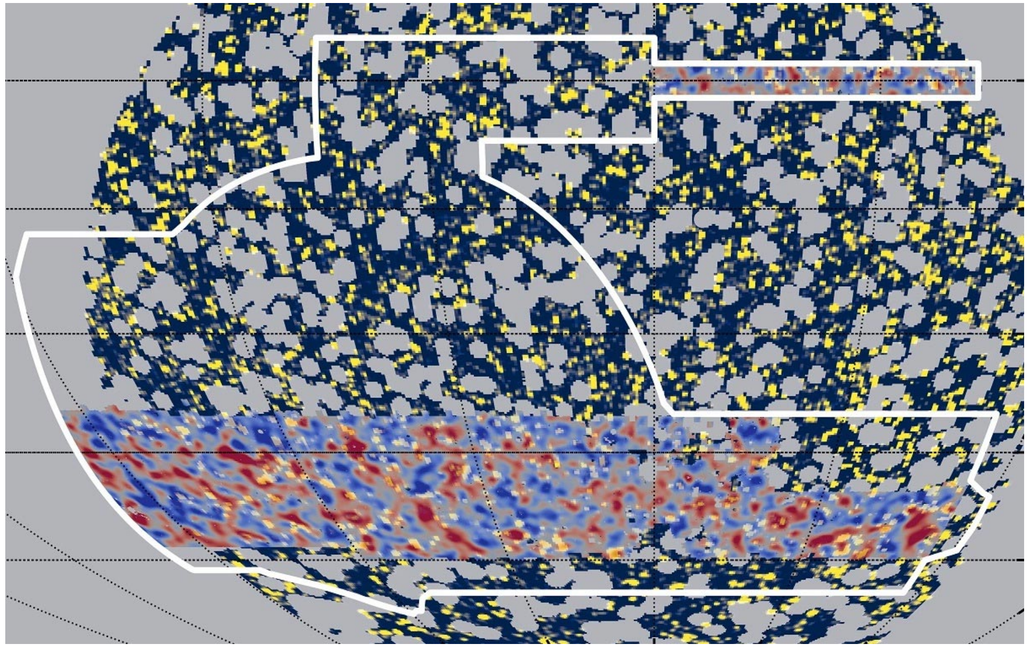
- Since dark matter is responsible for the weak lensing effect observed in distant source galaxies, any potential annihilation or decay from DM particles would be correlated with the lensing effect.

- The energy, redshift, and scale dependence of the cross-correlations have the potential to distinguish astrophysical signals from self-annihilating dark matter signals.

DES Y1 x Fermi 9-yr (2020) v/s DES Y3 x Fermi 12-yr (2024)

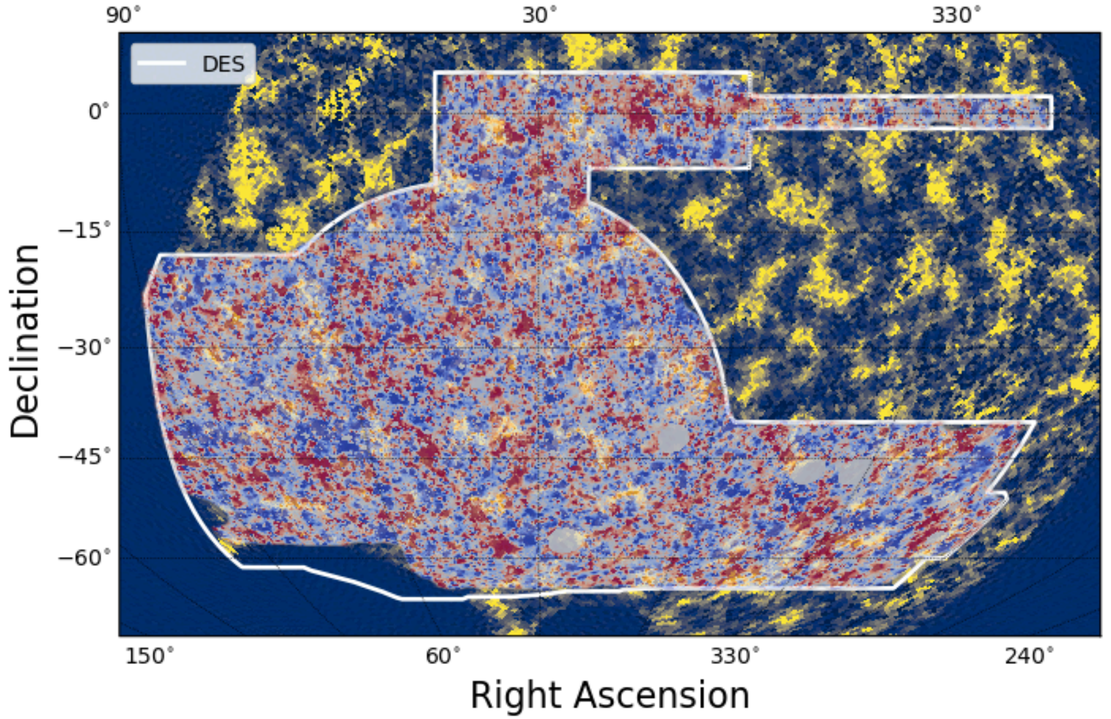
Y1 x 9yr

Amazzalorso et. al. (2020)



D. Gruen/SLAC/Stanford; C. Chang/University of Chicago; A. Drlica-Wagner/Fermilab

Y3 x 12yr



2-pt Correlation Estimator

Tangential ellipticity of source galaxy i, in redshift bin r, relative to pixel j

Photon intensity flux in energy bin a, relative to pixel j

$$\Xi^{ar}(\theta) = \Xi^{\text{signal}}_{\Delta\theta_h,\Delta E_a,\Delta z_r} - \Xi^{\text{random}}_{\Delta\theta_h,\Delta E_a,\Delta z_r} = \frac{\sum_{i,j} e^r_{ij,\text{t}}\, I^a_j}{R\sum_{i,j} I^a_j} - \frac{\sum_{i,j} e^r_{ij,\text{t}}\, I^a_{j,\text{random}}}{R\sum_{i,j} I^a_{j,\text{random}}}$$

Angular bin

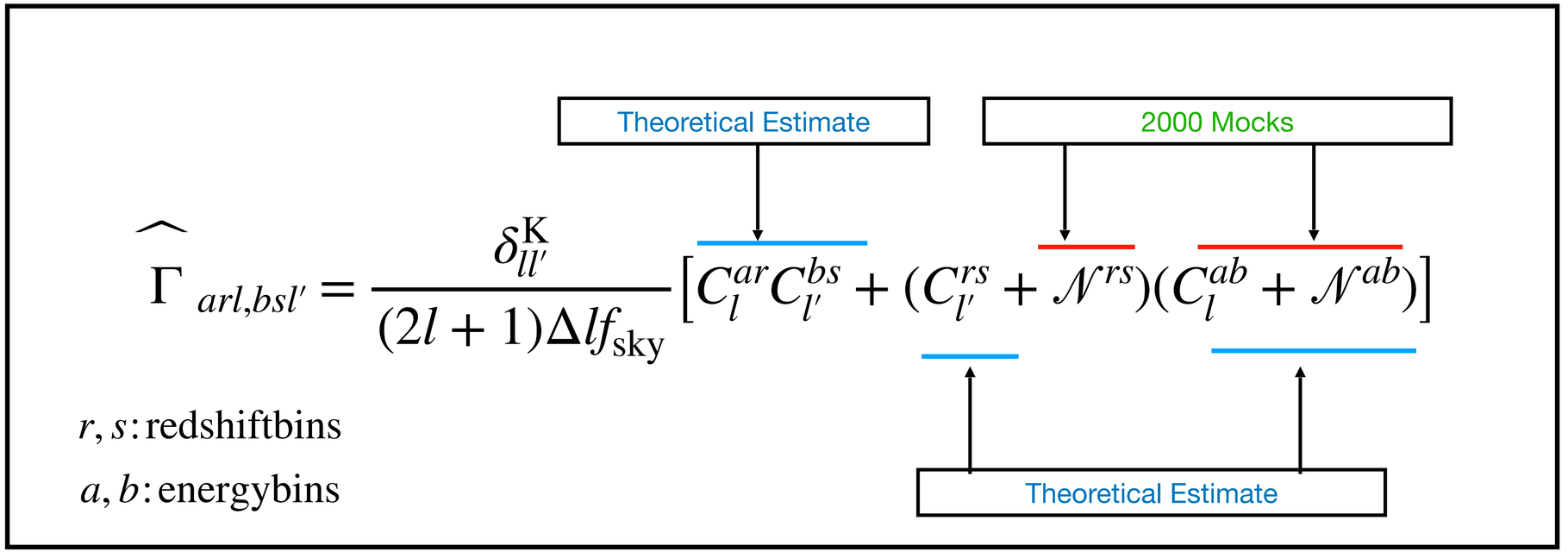
Energy bin

Redshift bin

Summation over the DES source galaxies and unmasked gamma-ray pixels

Random term, subtracted from the signal to reduce additive shear systematic effects, random very-large-scale structures or chance shear alignments relative to the mask (affecting the variance).

Covariance



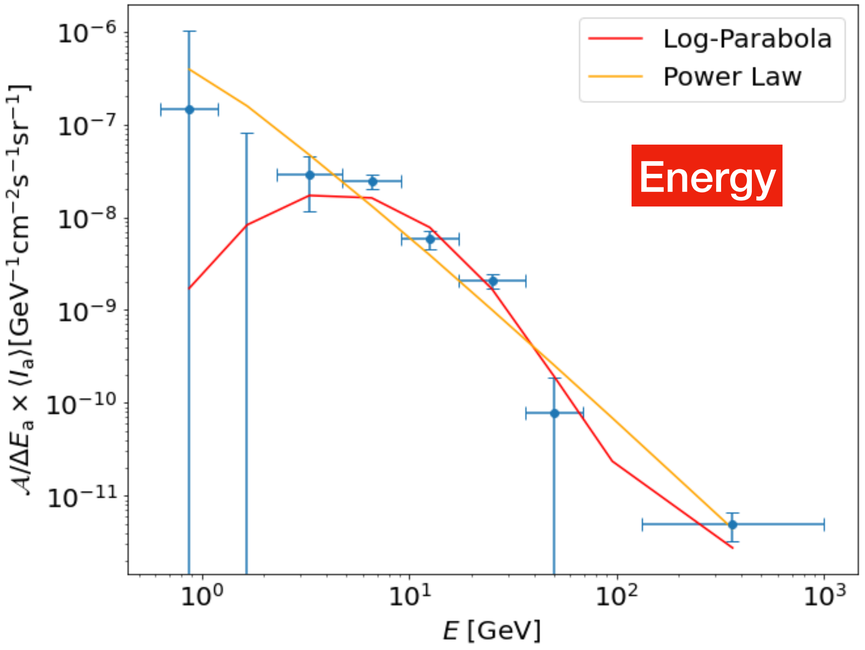
Hartlap factor = $(N_s - N_b - 2)/(N_s - 1)$ ~ 0.78

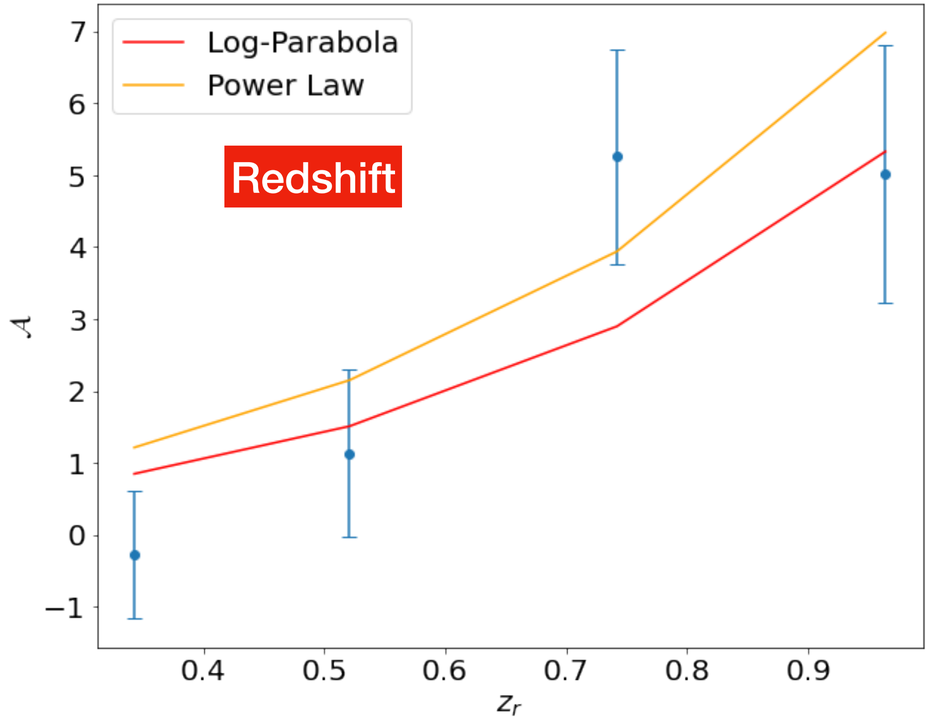
The Phenomenological Models

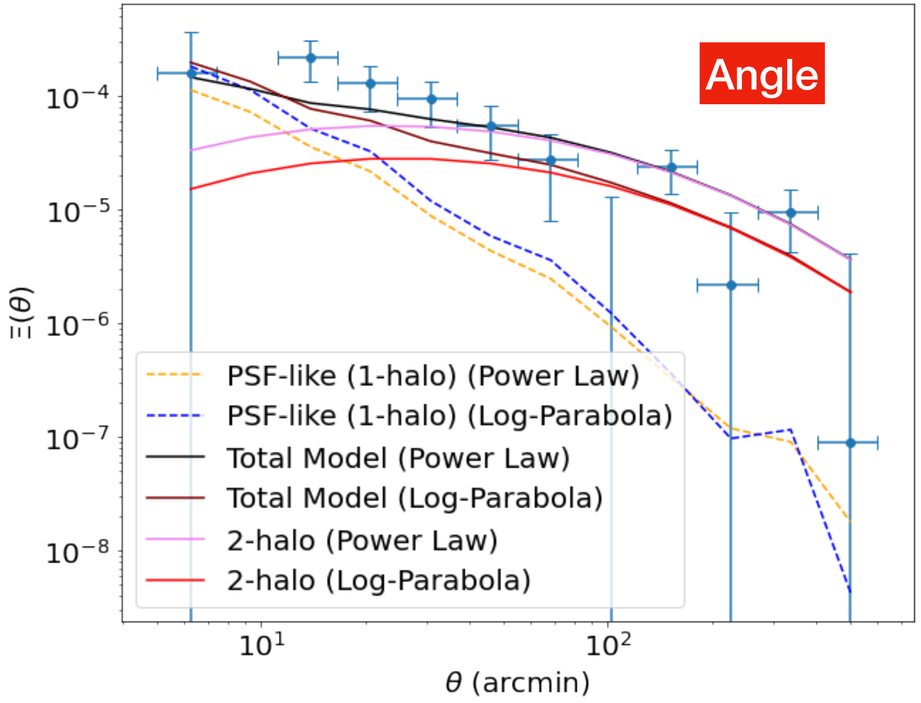
- The considerations of a potential cross-correlation signal were based on two phenomenological models - the power law and the log-parabolic models.

$$\Xi(\theta)_{\mathrm{PL}} = A_1 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_1} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_1} \times \hat{\Xi}^{a}_{1-\mathrm{halo}}(\theta) + A_2 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_2} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_2} \times \hat{\Xi}^{ar}_{2-\mathrm{halo}}(\theta)$$

$$\Xi(\theta)_{\mathrm{LP}} = A_1 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_1-\gamma_1 \log_{10}\frac{E_a}{E_p}} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_1} \times \hat{\Xi}^{a}_{1-\mathrm{halo}}(\theta) + A_2 \times \left(\frac{\mathrm{E_a}}{\mathrm{E_p}}\right)^{-\alpha_2-\gamma_2 \log_{10}\frac{E_a}{E_p}} \times \left(\frac{1+z_r}{1+z_p}\right)^{\beta_2} \times \hat{\Xi}^{ar}_{2-\mathrm{halo}}(\theta)$$







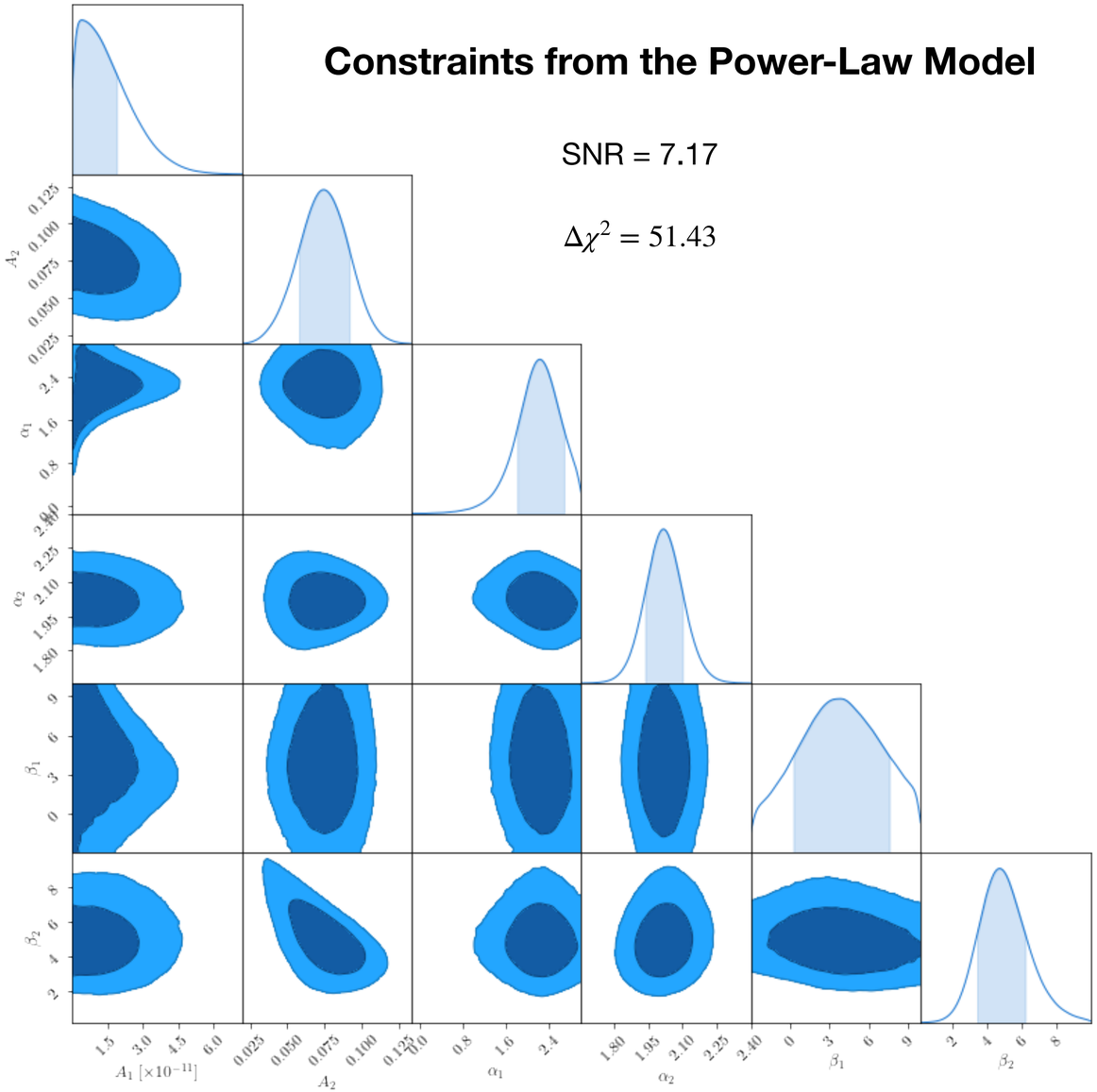
	Data set						
	Full	Low-z	High-z	Low-E	High-E	Small-θ	Large-θ
$\Delta\chi^2_{\mathrm{lp}}$	78.9	3.40	75.3	23.3	55.4	5.82	73.7
$\mathrm{SNR}_{\mathrm{lp}}$	8.88	2.45	8.70	4.89	7.49	2.42	8.58
$\Delta\chi^2_{\mathrm{pl}}$	51.4	0.92	53.7	15.8	38.7	8.72	47.3
$\mathrm{SNR}_{\mathrm{pl}}$	7.17	1.66	7.34	4.03	6.24	2.96	6.88

The Phenomenological Models (Contd.)

Constraints from the Power-Law Model

SNR = 7.17

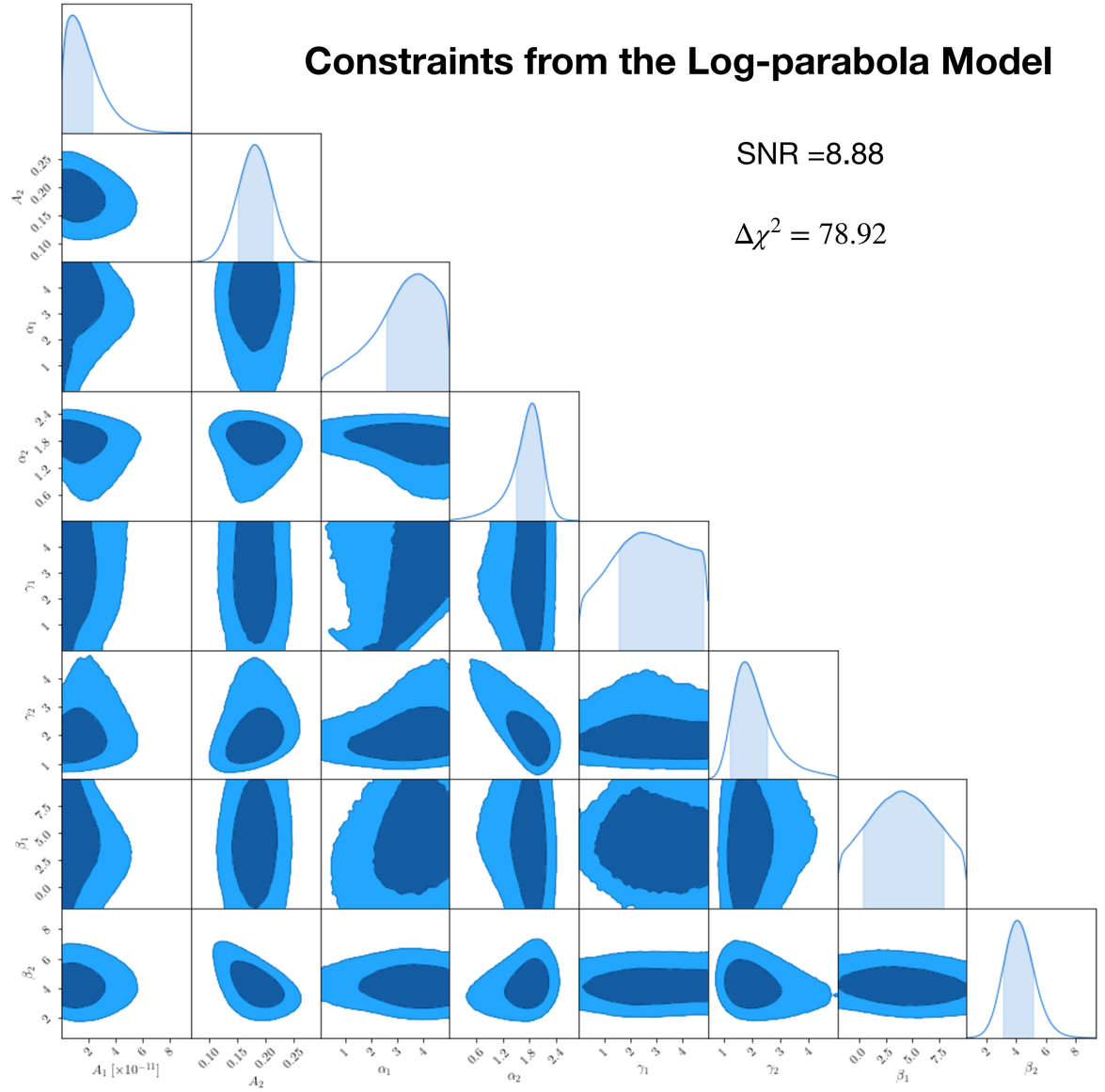
$\Delta\chi^2 = 51.43$



Constraints from the Log-parabola Model

SNR =8.88

$\Delta\chi^2 = 78.92$



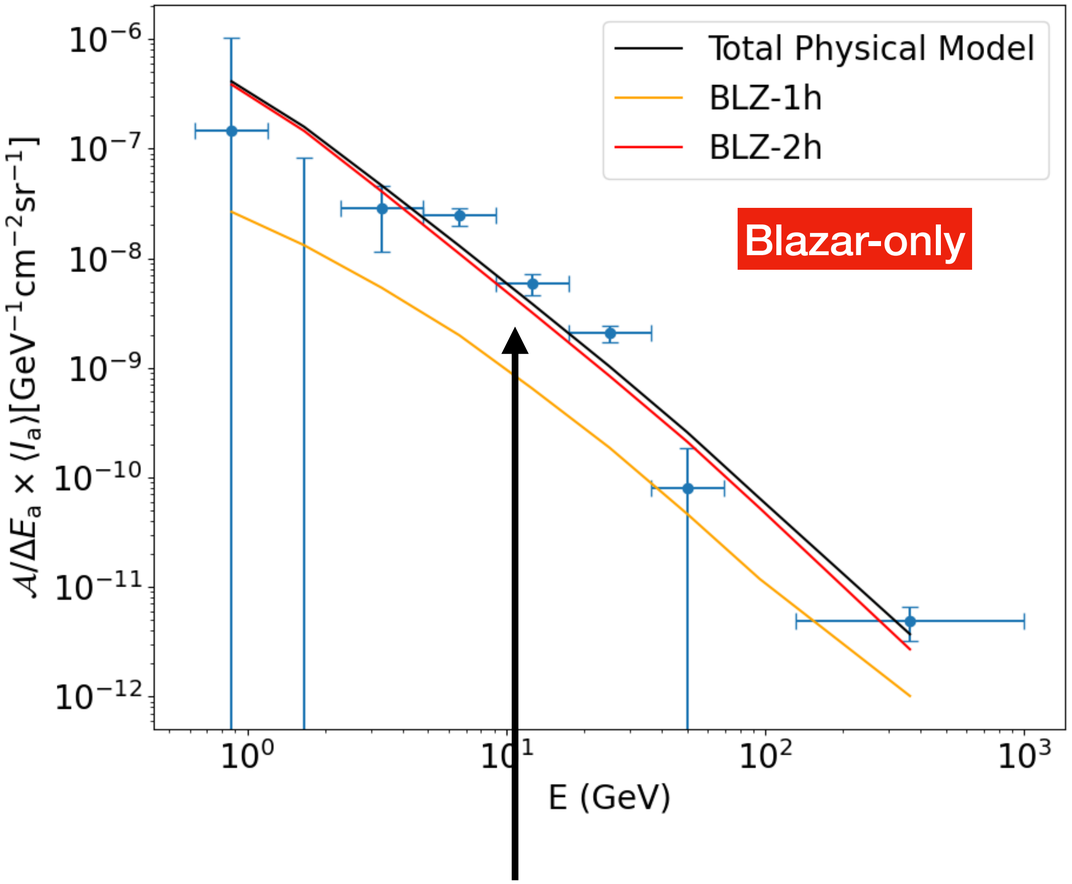
The Physical Model

- The physical model considerations were divided into two primary categories:
  1. Astrophysics-only contributions, consisting of Blazar components.
  2. A dark matter component, consisting of a certain dark-matter model.

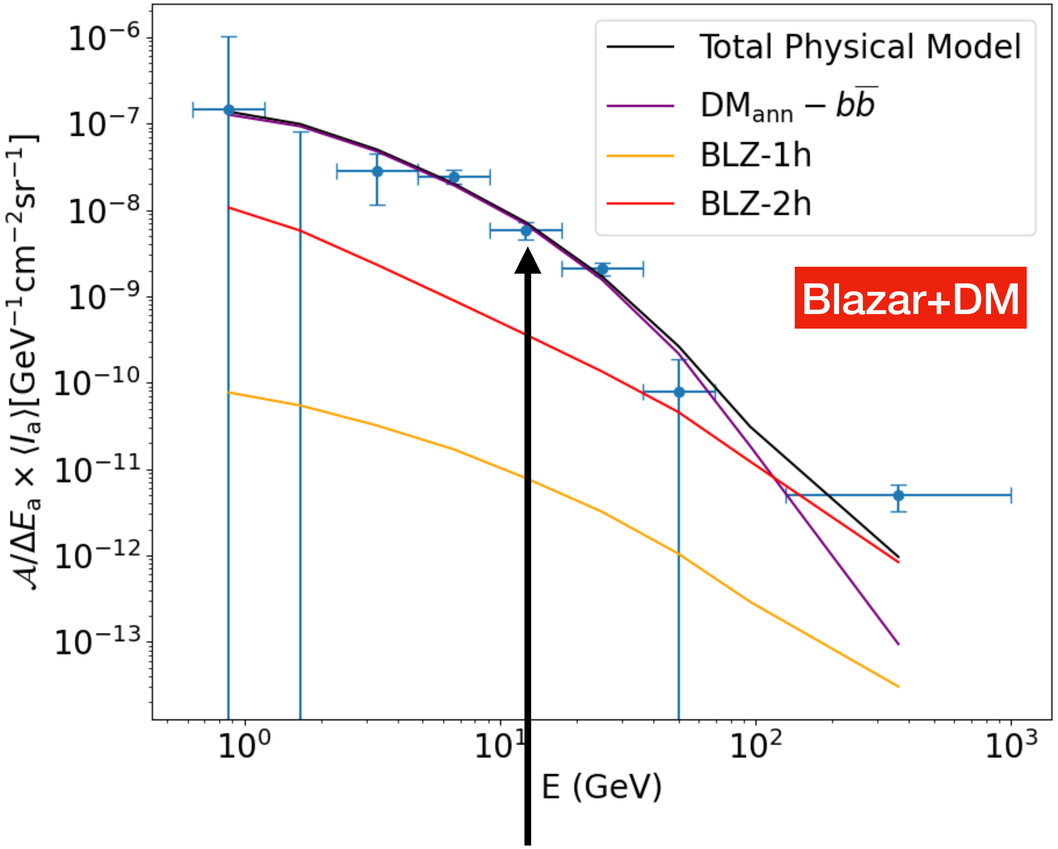
$$\Xi(\theta) = \overbrace{\underbrace{A_{\mathrm{BLZ-1halo}} \times \hat{\Xi}^{ar}_{\mathrm{BLZ-1halo}}(\theta, \mu, p_1) + A_{\mathrm{BLZ-2halo}} \times \hat{\Xi}^{ar}_{\mathrm{BLZ-2halo}}(\theta, \mu, p_1)}_{\text{Astrophysical components}} + A_{\mathrm{DM}} \times \hat{\Xi}^{ar}_{\mathrm{DM}}(\theta)}^{\text{Added DM component}}$$

$$\langle \sigma_{\rm ann} \nu \rangle = 32^{+10}_{-8} \langle \sigma_{\rm ann} \nu \rangle_{\rm th}$$

$$m_{\rm DM} = 363.07^{+138.10}_{-39.48} {\rm GeV}$$



- Dominant 2-halo Blazar component.
- E-dependence not well-reproduced.



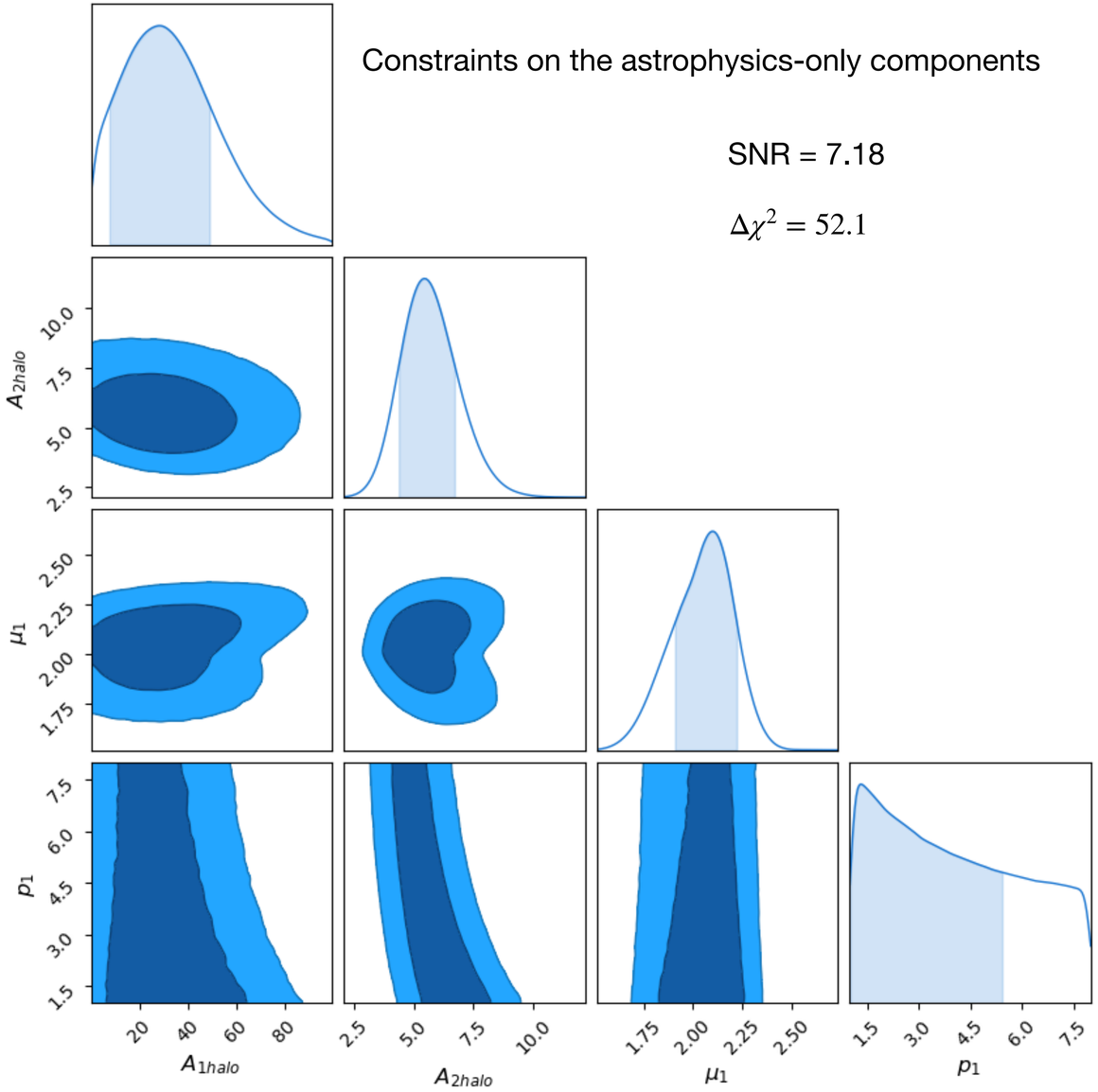
- Dominant DM component.
- E-dependence well-reproduced.
- >5-sigma preference for BLZ+DM

The Physical Model (Contd.)

Constraints on the astrophysics-only components

SNR = 7.18

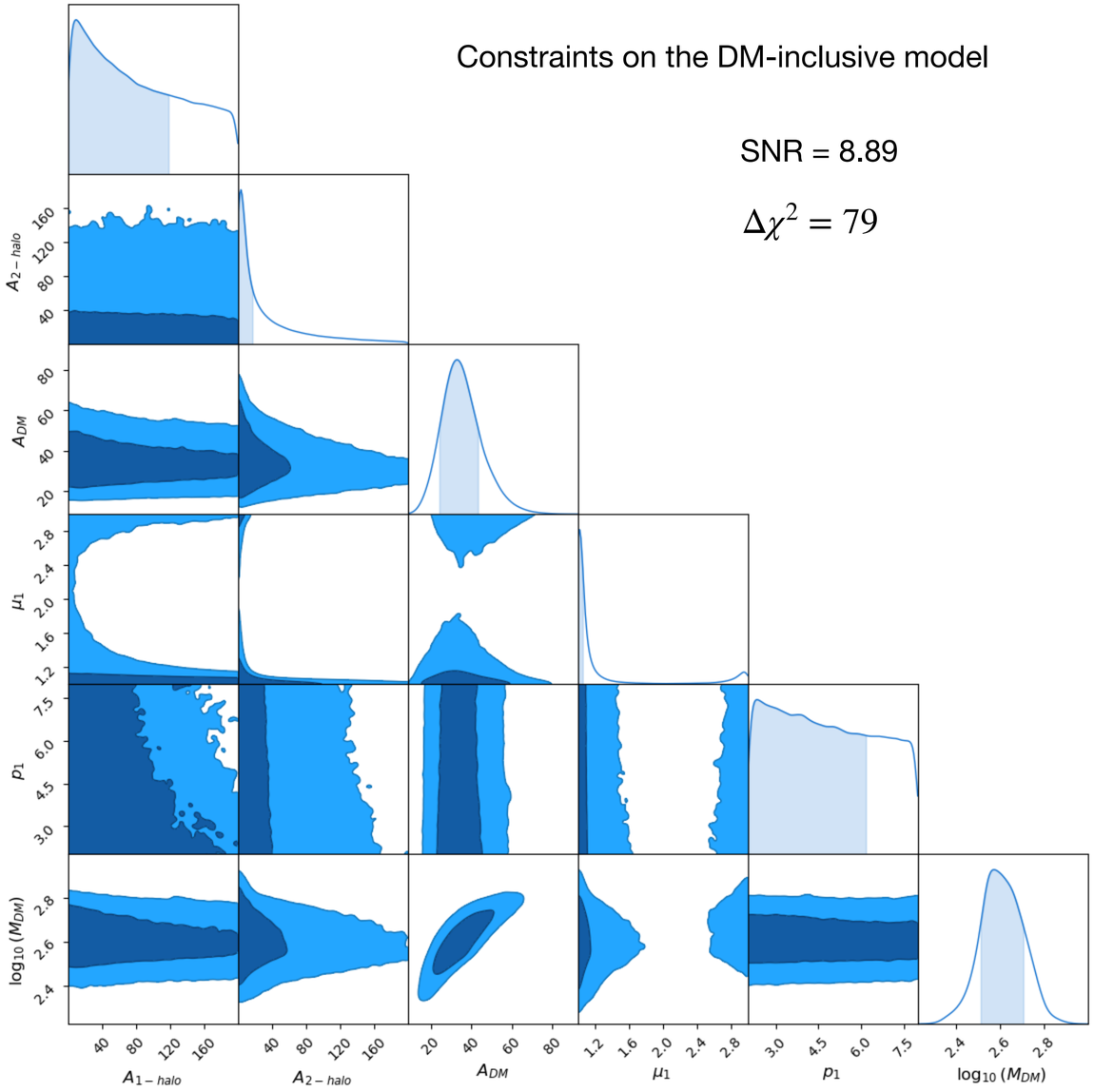
$\Delta\chi^2 = 52.1$



Constraints on the DM-inclusive model

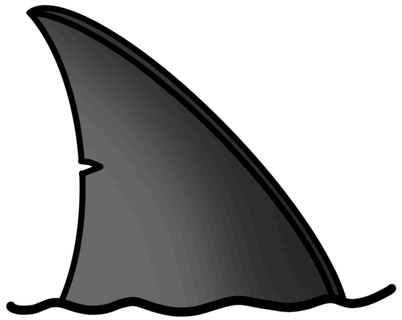
SNR = 8.89

$\Delta\chi^2 = 79$



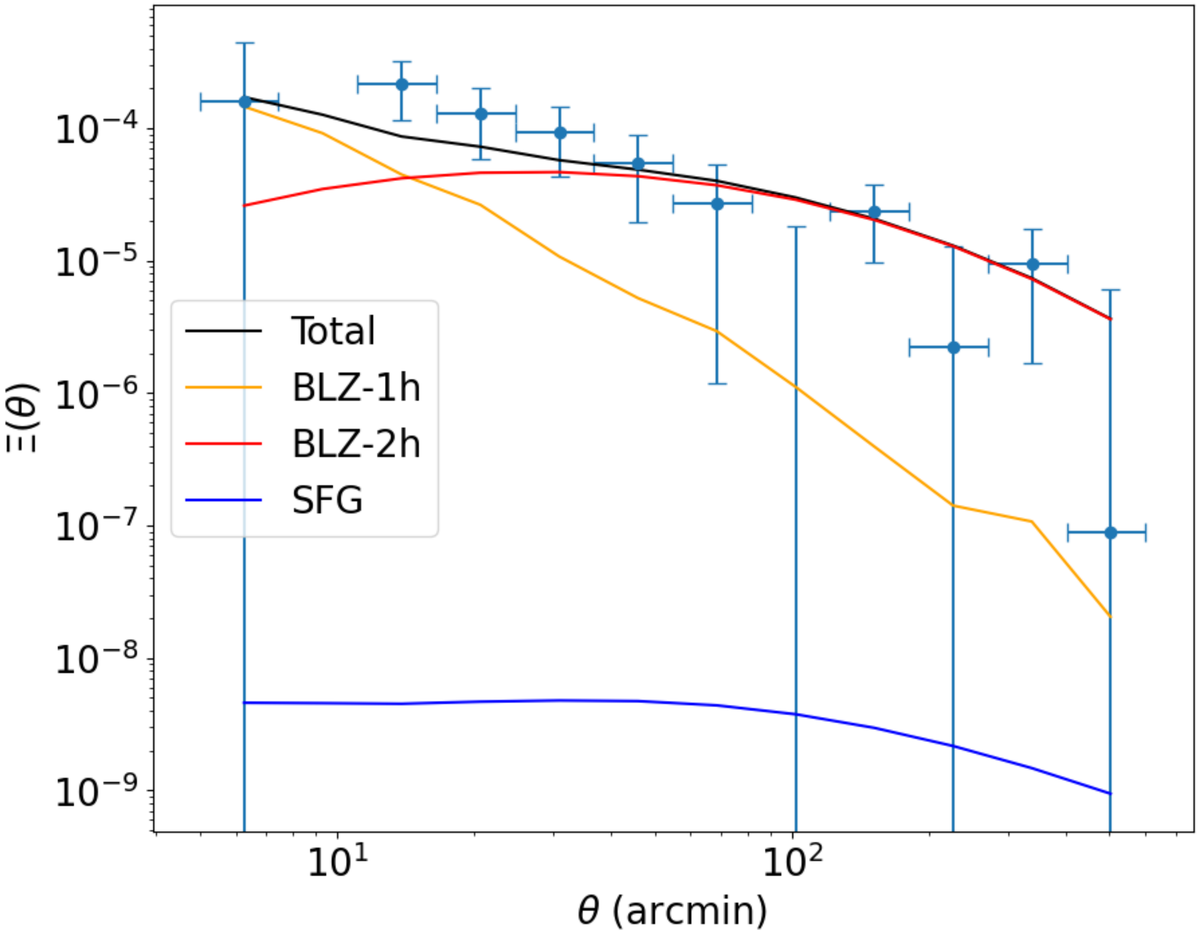
Summary

- Cross-correlations between tracers of gravitational structure and the UGRB have the potential to separate WIMP DM signals that annihilate or decay in gamma-ray energies.
- Phenomenologically, a cross-correlation between weak lensing and the UGRB provides a significant detection of a signal, at an SNR of 8.9.
- Physically, while Blazars appear to dominate the UGRB, with the current models, they cannot explain the stronger signals obtained using the log-parabolic phenomenological model.
- A change in the way the astrophysical components are modelled as well as combining the current observations with those obtained from galaxy clustering cross-correlations could provide better constraints on both astrophysical as well as DM signals.

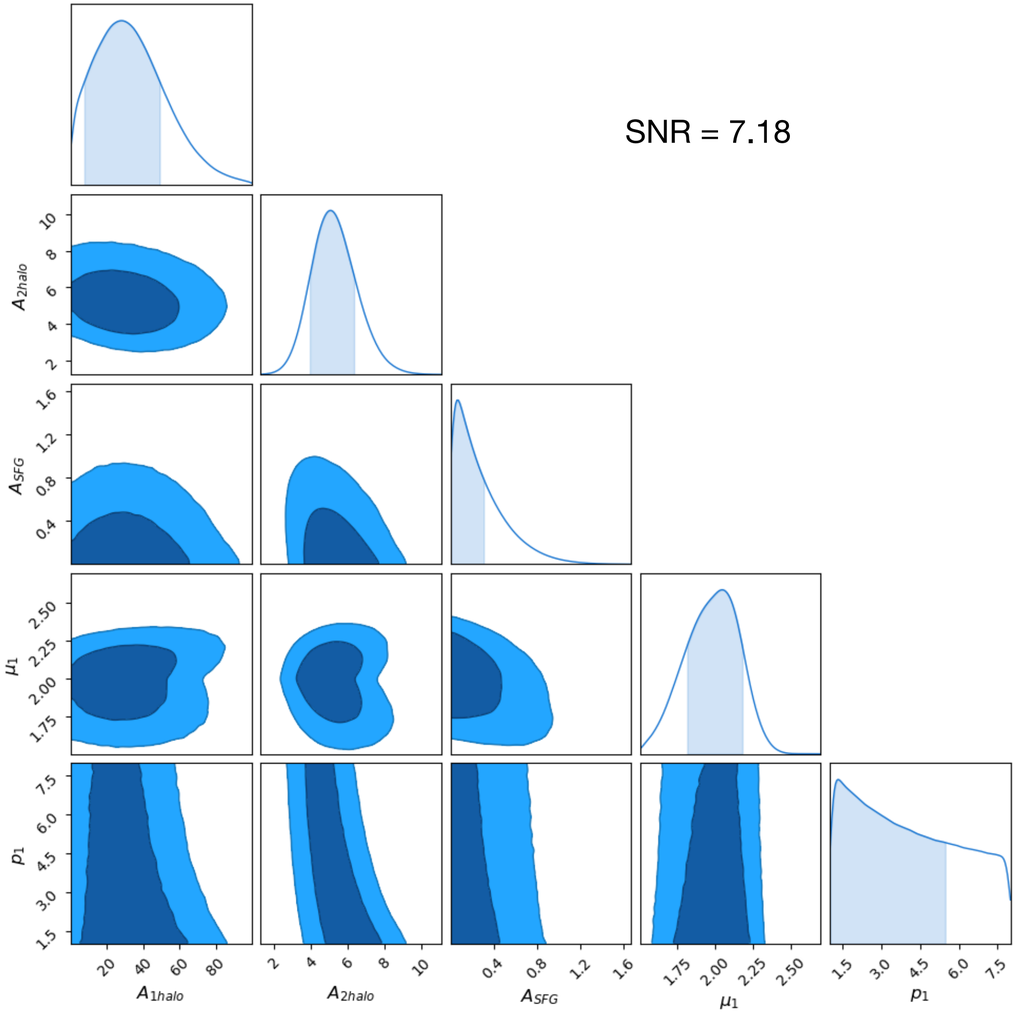


Fin.

Blazars+SFGs



SNR = 7.18



Blazars+mAGNs