Search for TeV-Range Dark Matter with Electron and Positron Cosmic Rays

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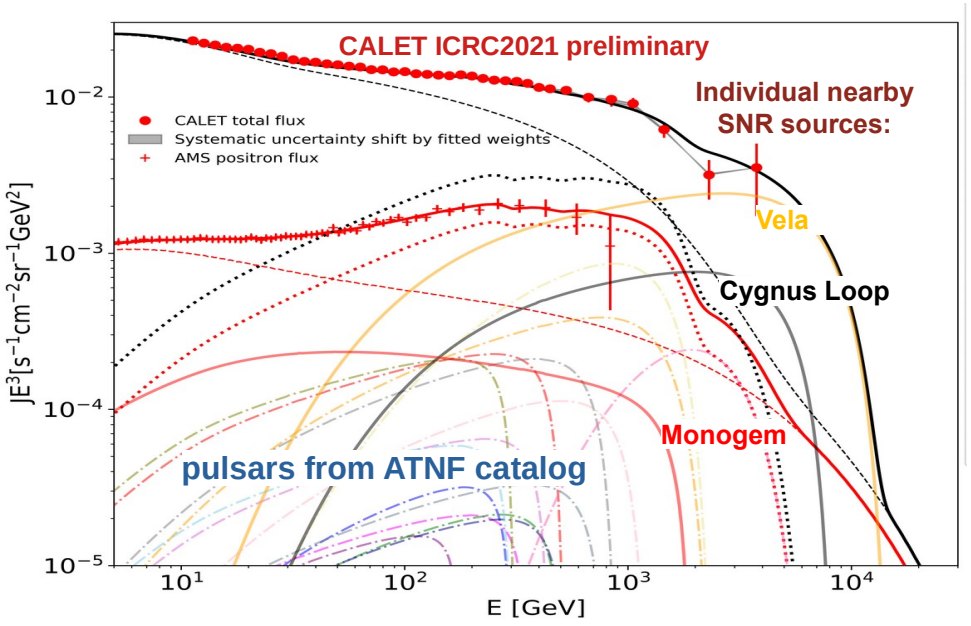
- **Product:** Limits on DM annihilation and decay from a combined analysis of the latest all-electron spectrum measured by CALET [currently: S. Torii, Y. Akaike et al. POS ICRC 2021 (105)] and the positron-only spectrum from AMS-02 [M. Aguilar et al. Phys. Rev. Lett. 122, 041102]
- **Basic Concept:** Astrophysical base model which fits the data well → add flux from DM calculated with DRAGON and increase scale factor → limit on annihilation rate or lifetime when χ^2 exceeds a given threshold
- **Goals:**
  - Extend limits to heavy, TeV-mass range DM based on CALET's TeV-region electron spectrum measurement
  - Improve reliability by introducing a realistic background model considering individual astrophysical sources
  - Obtain stricter limits by using a relative χ^2 increase threshold, which could be considered reliable only if studying the variability of the limits with background model parameters and/or randomized samples and taking the worst limit from the sampled cases.

Intermediate step background model: Nearby pulsars/SNR treated as individual sources

Primary electron spectrum with low-energy spectral break and exponential cut-off, and nearby SNR sources, secondary electrons, secondary positrons, extra pulsar source for positron excess

$$\Phi_{ele} = C_e E^{-(\gamma_e - \Delta\gamma_e)} \left(1 + \left(\frac{E}{E_B}\right)^{\frac{\Delta\gamma_e}{s}}\right)^s e^{-\left(\frac{E}{E_{cut_e}}\right)} + \Phi_{near\,SNR} + C_s \Phi_{s(e^-)} + \Phi_{ex}$$

$$\Phi_{pos} = C_s \Phi_{s(e^-)} + \Phi_{ex} \quad ; \quad \Phi_{tot} = \Phi_{ele} + \Phi_{pos}$$

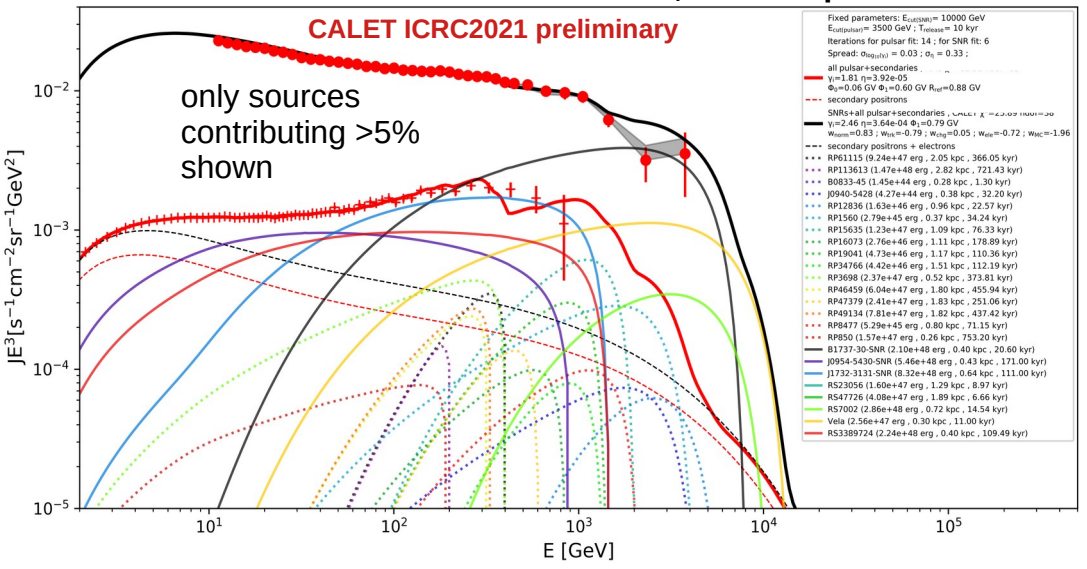


Final background model: All astrophysical sources treated as individually sources

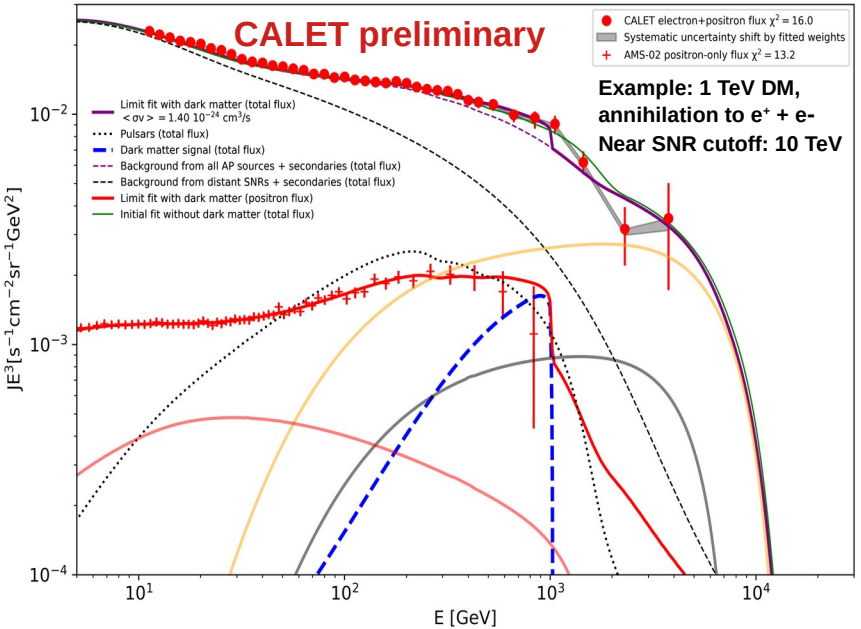
- Known sources (ATNF-catalog pulsars with their SNRs) combined with randomly generated sources (time, position, energy) throughout the galaxy up to 200 Myr age → ~7.5 million sources
- Random source spectrum index spread with Gaussian distribution (average index is a free parameter in the fitting)
- ~1/3 of samples gives good fit to CALET&AMS after 1000 trials of source spectrum index randomization

→ **suitable background model without ad-hoc parametrization**

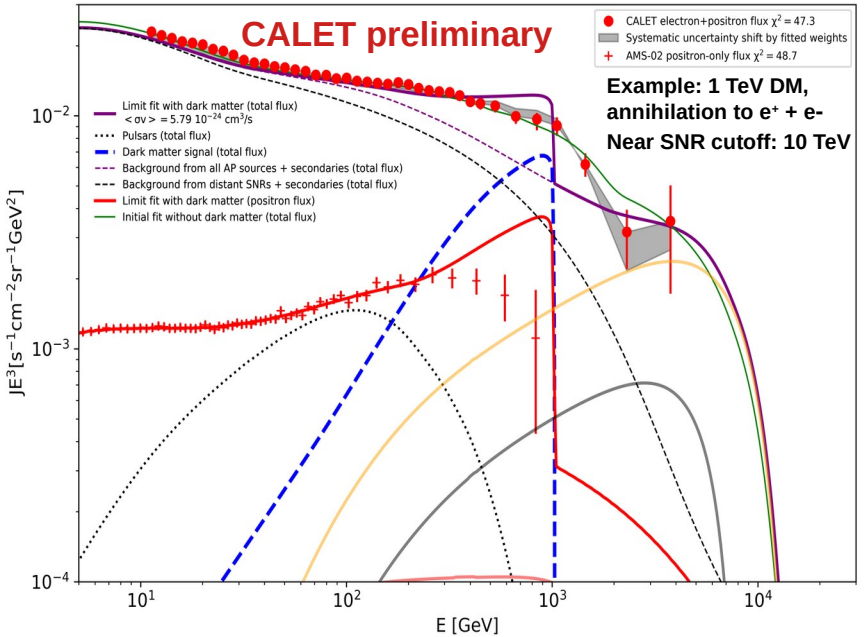
Fit of one sample to CALET and AMS data:
color line: ind. sources – solid: SNRs , dashed: pulsars



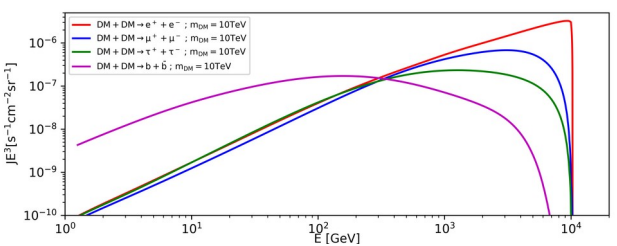
Limit and DM Signal Calculation



Relative Limit: χ^2 increases by 3.841 compared to χ^2 of the base model, thus the addition of DM is disfavored at 95% CL (better but not conservative since base model is over-fitted - assumes the base model is true. which is not certain)



Absolute Limit: χ^2 exceeds the 95% CL threshold for the fit's number of degrees of freedom, thus the whole model including the DM flux is excluded



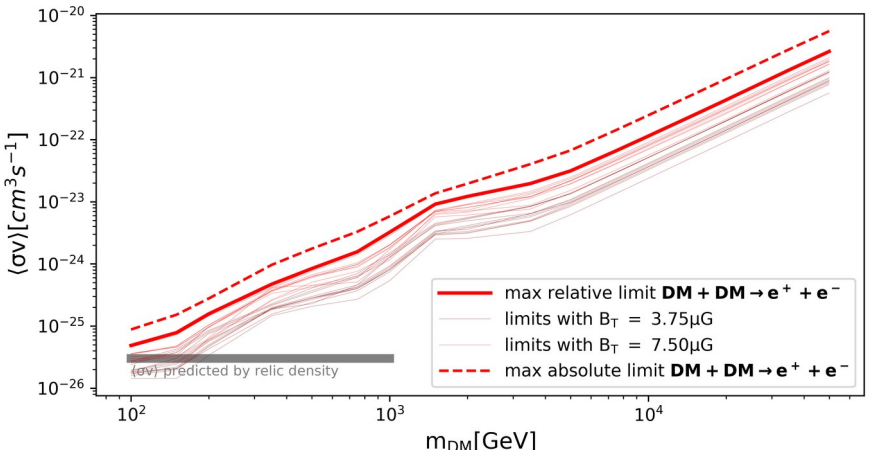
- Flux of electrons and positrons per annihilation or decay from decay of primary annihilation products calculated with PYTHIA
- Flux at Earth calculated with DRAGON (using propagation parameters tuned to measured nuclei spectra up to Oxygen), assuming 0.3 GeV/cm^3 local DM density and NFW halo.
  - ← **Flux for annihilation channels, $\langle\sigma v\rangle = 3\times10^{-26}$ cm^3/s**

Considering Background Variation

Intermediate step background model

Variation of non-fitable background parameters → 24 cases:

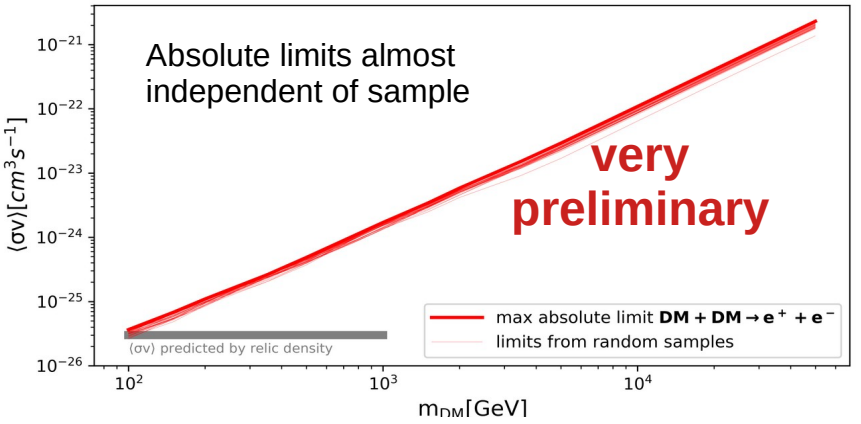
Parameter	Values
Distant SNR cut-off energy E_{cutd}	0.5, 1.0, 2.0 TeV
Near SNR cut-off energy E_{cutSNR}	10, 20, 50, 100 TeV
Local turb. B-field strength B_T	3.75, 7.50 μG

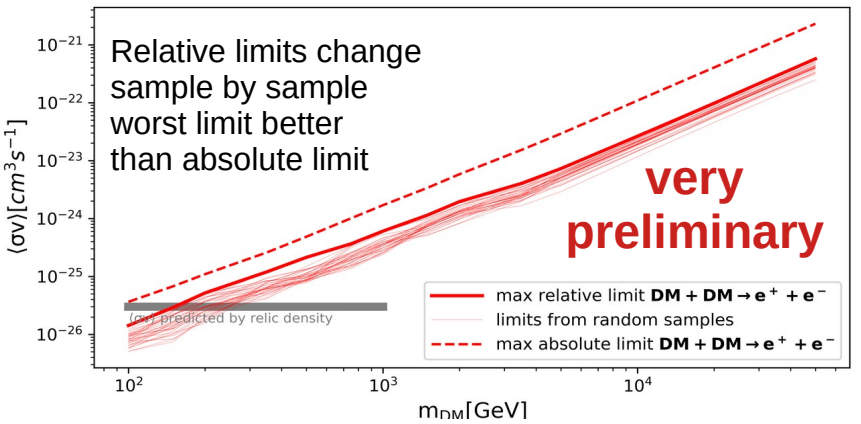


Absolute limits: Almost no change under different bkg conditions, except magnetic field variation but 7.5 μG conservative value
Relative limits: significant dependence on the conditions, worst limit from studied cases better than absolute limit

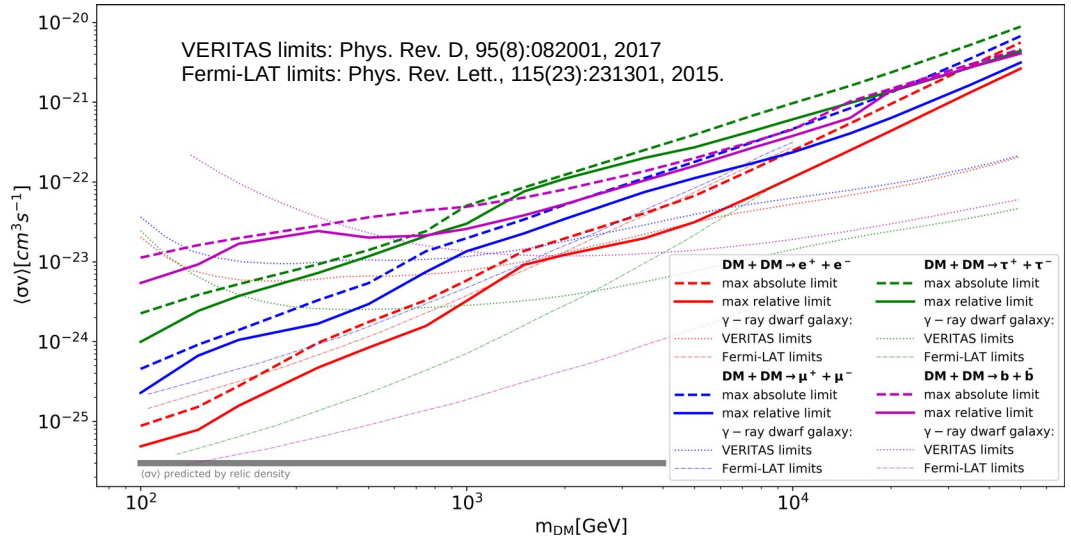
Final background model

34 samples with random source distributions:





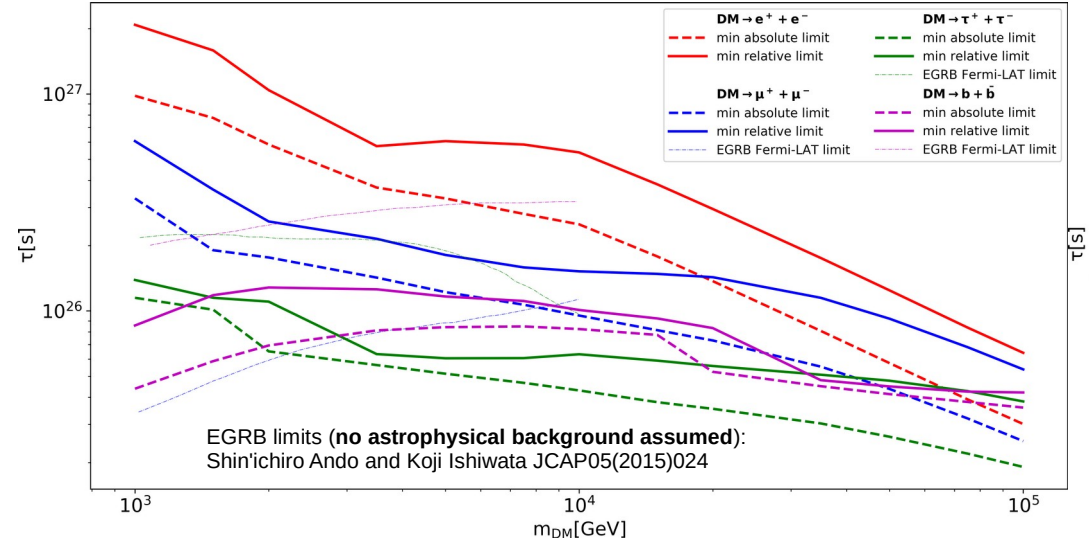
Limit Results with Intermediate Bkg. Model

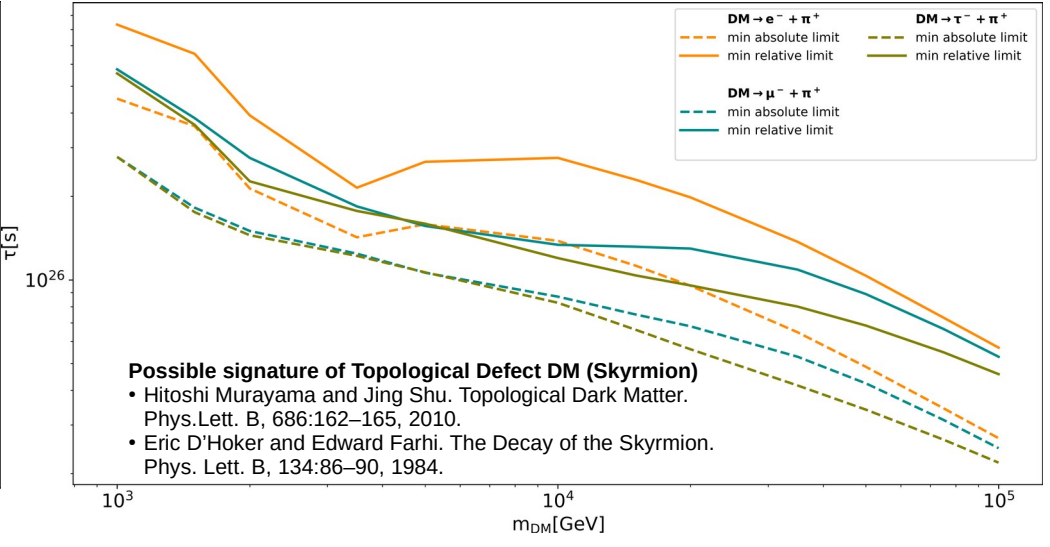


Annihilation	Decay	Decay (Skyrmion)
DM+DM → e^++e^-	DM → e^++e^-	DM → π^+ + e^-
DM+DM → μ^++μ^-	DM → μ^++μ^-	DM → π^+ + μ^-
DM+DM → τ^++τ^-	DM → e^++e^-	DM → π^+ + τ^-
DM+DM → b+$\bar{b}$	DM → b+$\bar{b}$	

Annihilation: Cross-section limits up to 50 TeV DM mass
Decay: Lifetime limits up to 100 TeV DM mass

Presented at IDM2022 conference, proceedings:
https://scipost.org/preprints/scipost_202210_00006v1/





Conclusions & Outlook

- With the current electron+positron spectrum data from CALET up to 4.8 TeV, together with positron-only AMS-02 data, limits on decaying DM lifetime up to 100 TeV DM mass (annihilation: 50 TeV) have been obtained.
- Limits based on bkg. model with individual treatment of nearby sources published in conference proceedings (IDM2022).
- Relative limit definition gives stronger limits, but not conservative unless full variability of the background taken into account.
- Final version of the background model with all SNR and pulsar contribution from randomized individual source samples has been developed and very preliminary limits from a small number of samples have been calculated.
- What remains to be done: Double check and refine method, process many more background samples, calculate limits for different channels, publish...

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