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INSTITUTE FOR COLLIDER PARTICLE PHYSICS
UNIVERSITY OF THE WITWATERSRAND

Connecting multi-lepton anomalies at the LHC and Astrophysical observations

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Outline

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- The 2HDM+S model and Dark matter
- Astrophysical predictions
- Conclusions

Motivation

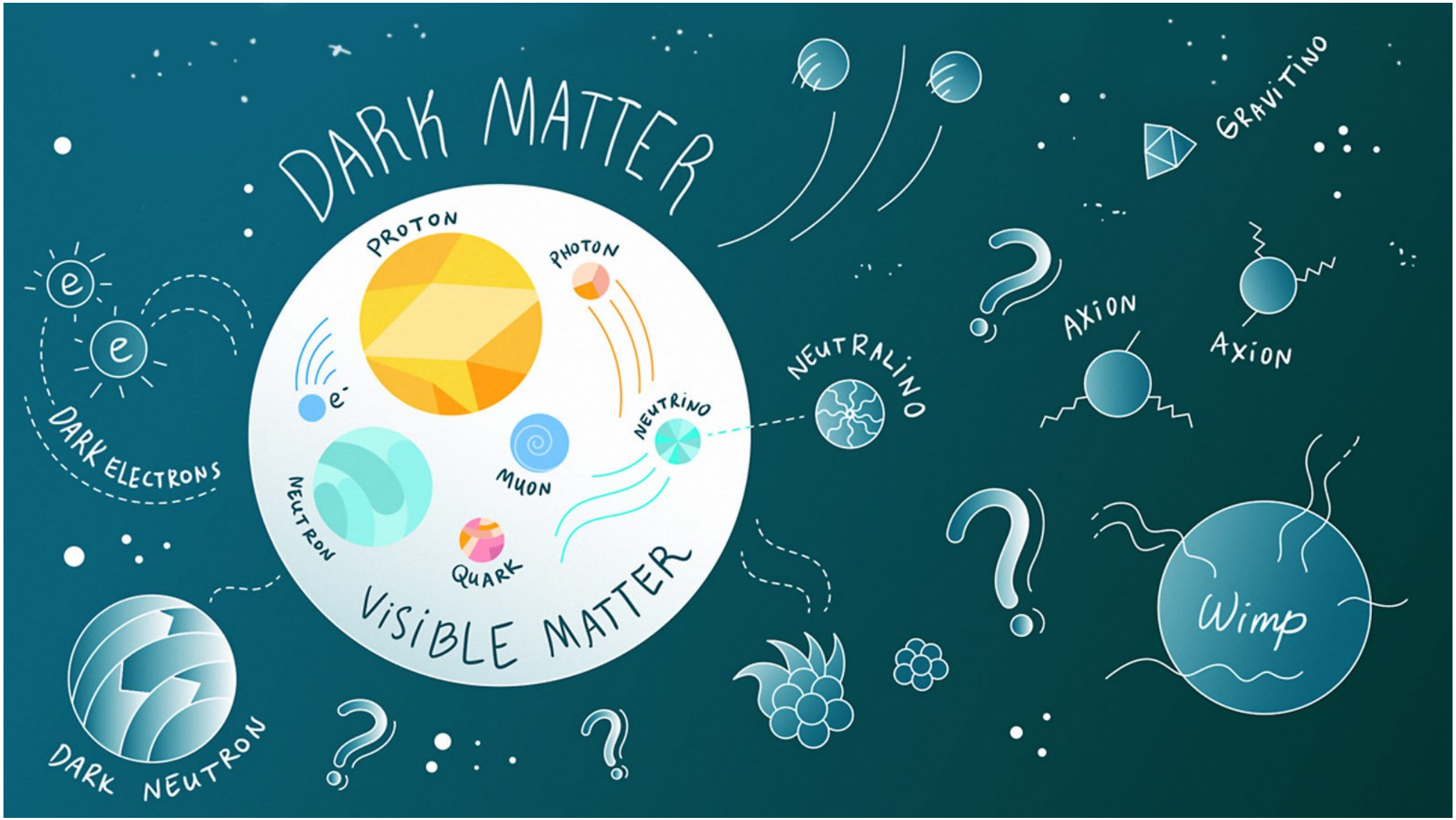
Motivation

- Multi-lepton anomalies at the Large Hadron Collider are reasonably well described by a two Higgs doublet model with an additional singlet scalar S (2HDM+S).
- In this work, we demonstrate that using this model we are also able to describe the excesses in gamma-ray flux from the galactic centre and the cosmic-ray spectra from AMS-02.
- More specifically, this is achieved through Dark Matter (DM) annihilation via the singlet scalar S. Of great interest is the flux of synchrotron emissions which results from annihilation of DM in Milky-Way satellites.

  Additionally, we make predictions for MeerKAT observations of the nearby dwarf galaxy Reticulum II and we demonstrate the power of this instrument as a new frontier in indirect dark matter searches.
- We aim to use astrophysics as an indirect probe of the 2HDM+S model motivated by LHC anomalies. This is done via a DM particle coupling to S as a mediator to the SM, where the parameters of the collider model are fixed to describe the LHC data

The 2HDM+S model and Dark matter

The 2HDM+S model & Dark matter



The 2HDM+S model & Dark matter

- The 2HDM+S consists of the CP-conserving 2HDM with a softly broken Z2 symmetry extended by a real singlet field φS .
- The general CP-conserving 2HDM+S potential consists of the two-Higgs doublet model (2HDM) potential in addition to the Singlet terms:

$$
\begin{aligned}
V(\Phi) = {} & m_{11}^2 |\Phi_1|^2 + m_{22}^2 |\Phi_2|^2 - m_{12}^2 (\Phi_1^\dagger \Phi_2 + \text{h.c.}) + \frac{\lambda_1}{2} \left(\Phi_1^\dagger \Phi_1\right)^2 + \frac{\lambda_2}{2} \left(\Phi_2^\dagger \Phi_2\right)^2 \\
& + \lambda_3 \left(\Phi_1^\dagger \Phi_1\right) \left(\Phi_2^\dagger \Phi_2\right) + \lambda_4 \left(\Phi_1^\dagger \Phi_2\right) \left(\Phi_2^\dagger \Phi_1\right) + \frac{\lambda_5}{2} \left[\left(\Phi_1^\dagger \Phi_2\right)^2 + \text{h.c.} \right] \\
& + \frac{1}{2} m_S^2 \Phi_S^2 + \frac{\lambda_6}{8} \Phi_S^4 + \frac{\lambda_7}{2} \left(\Phi_1^\dagger \Phi_1\right) \Phi_S^2 + \frac{\lambda_8}{2} \left(\Phi_2^\dagger \Phi_2\right) \Phi_S^2 .
\end{aligned}
$$

- We consider a model without explicit CP violation where the λ are taken to be real. This potential is obtained by imposing the Z2 symmetry (explicitly broken):

$\Phi_1 \to \Phi_1, \quad \Phi_2 \to -\Phi_2, \quad \Phi_S \to \Phi_S$ and $\Phi_1 \to \Phi_1, \quad \Phi_2 \to \Phi_2, \quad \Phi_S \to -\Phi_S$

- Models with two Higgs doublets generally have tree-level flavor changing neutral currents (FCNCs). Couple all quarks of a given charge to a single Higgs doubled by imposing a Z2 symmetry to the Yukawa sector.
- In our study, we consider the mass heriarchy which corresponds to the physical scalars: h < S < H. This mass heriarchy is introduced to explain several anomalous features in the LHC Run 1 and Run 2 data. The CP-even neutral scalars have the following masses: 125 < 150 < [250-300] GeV

The 2HDM+S model & Dark matter

Dark matter annihilation

- In this work we consider interactions of S with three types of DM candidates χr,χd and χv with spins 0, ½ and 1, respectively where gχi and Mχi are the coupling strengths of DMs with the singlet real scalar S. Having these interactions, we consider DM annihilation through S following $2 \to 2$ and $2 \to 3$ scattering expressed by the following langarangians:

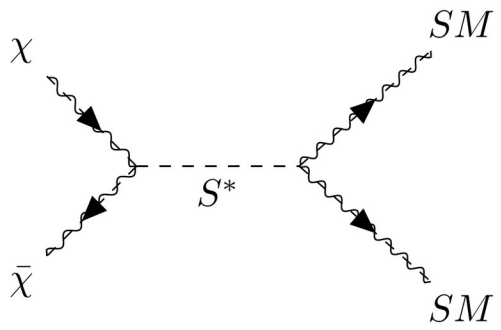
$$\mathcal{L}_0 = \frac{1}{2} m_{\chi_r} g^S_{\chi_r} \chi_r \chi_r S,$$

$$\mathcal{L}_{\frac{1}{2}} = \bar{\chi_d}(g^S_{\chi_d} + i g^P_{\chi_d} \gamma_5)\chi_d S,$$

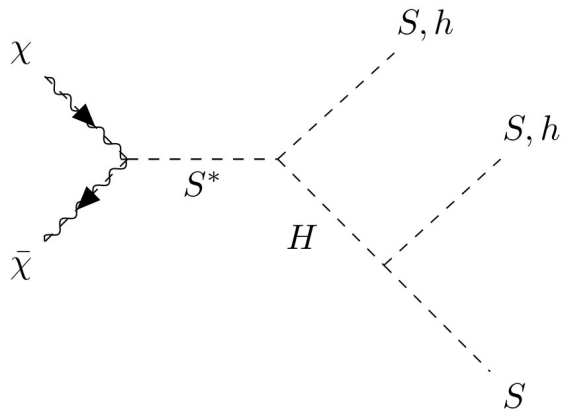
$$\mathcal{L}_1 = g^S_{\chi_v} \chi^\mu_v \chi_{v\mu} S,$$

- Our simulation are done through the MG5_aMC-interfaced with pythia8 for our scattering processes:

- $2 \to 2$



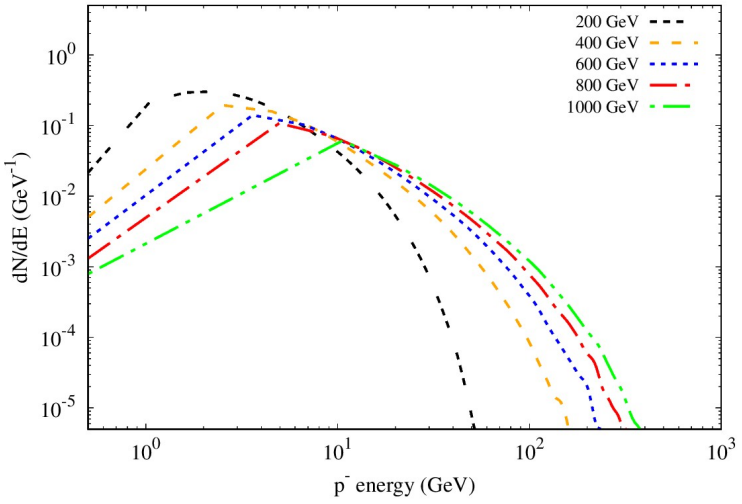
$2 \to 3$

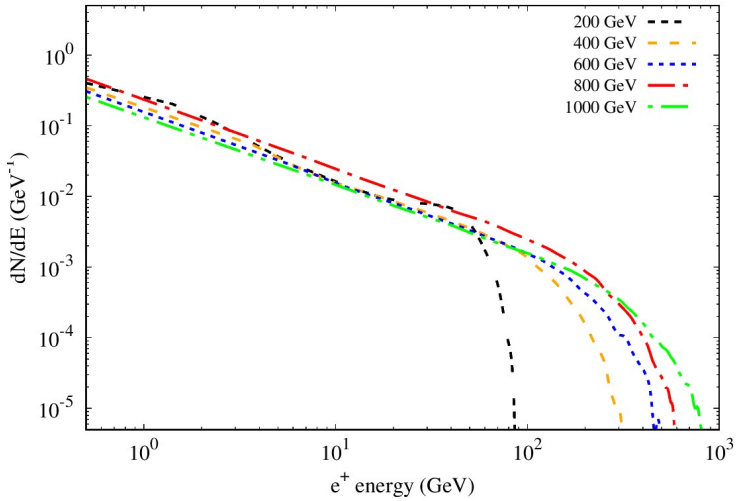


The 2HDM+S model & Dark matter

Dark matter annihilation

- For the 2 to 3 scattering, we have dN/dE (number of particles per bin energy) with our threshold mass of 200 GeV > ½ mass of S.
- The anti protons and positron spectrum expressed into a log scale are as follows:

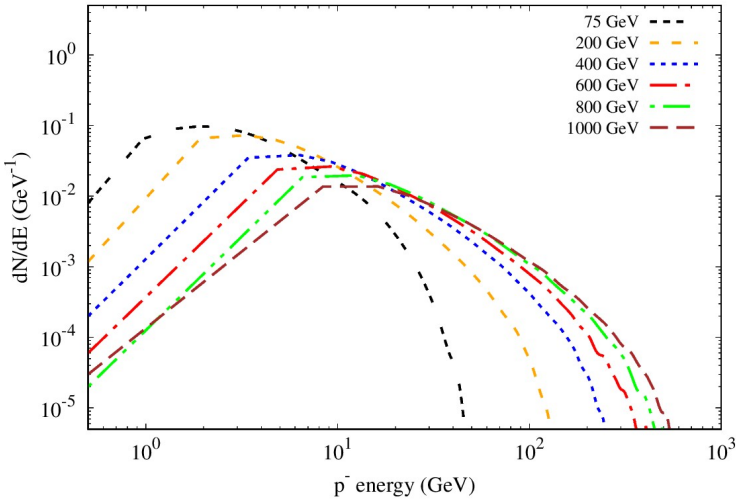


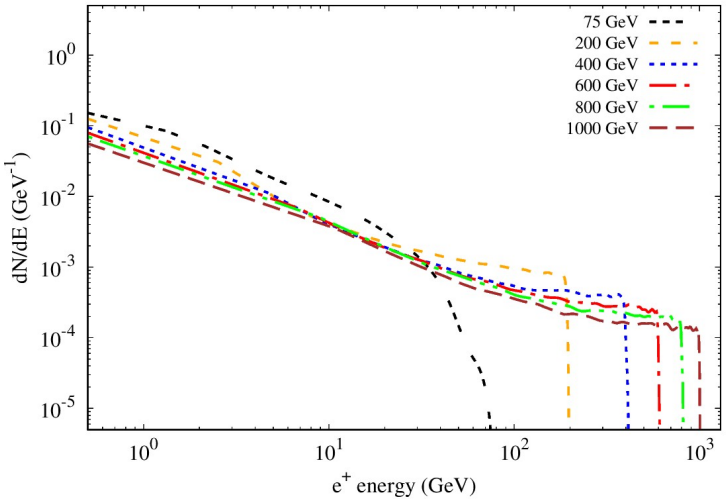


The 2HMD+S model & Dark matter

Dark matter annihilation

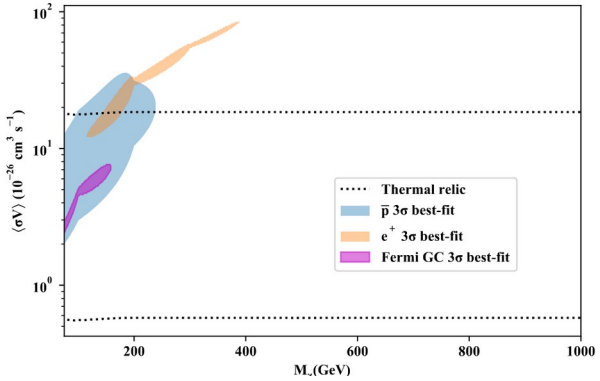
- For the 2 to 2 scattering, we have dN/dE (number of particles per bin energy) with our threshold mass of 75 GeV = ½ mass of S.
- The anti protons and positron spectrum expressed into a log scale are as follows:

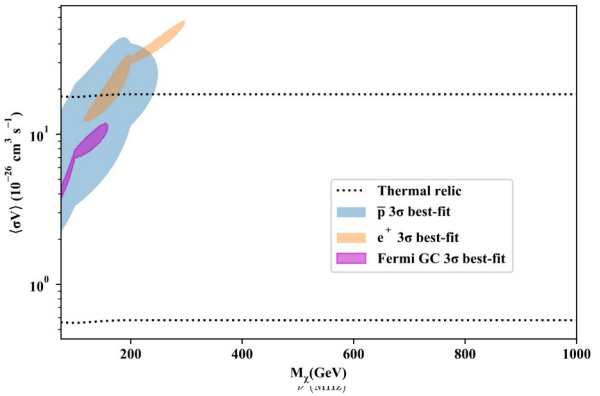


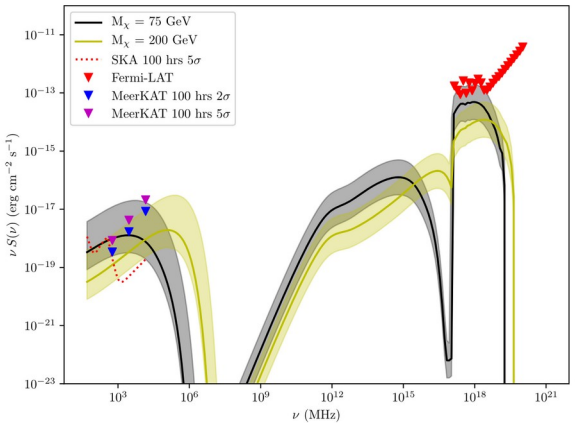


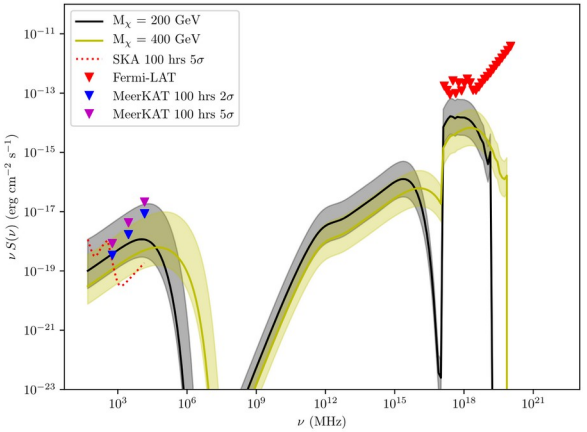
Astrophysical predictions

Astrophysical analysis









Conclusions

Conclusions

- In order to further explore results with more data and new final states, the parameters of the model were fixed in 2017 . This include setting the scalar masses as mH = 270 GeV, mS = 150 GeV, treating S as a SM Higgs-like scalar and assuming the dominance of the decays H → Sh,SS
- The parameters of the model are fixed to the LHC data, except for the mass of the DM and the size of the coupling to the mediator S. The mass of the DM is scanned, where the coupling of the DM to the mediator S is varied, and various diffusion scenarios are considered.
- Satisfactory description of the gamma-ray flux from the galactic centre and the cosmic-ray spectra from AMS-02 is obtained with the MED diffusion scenario. The best description of the excesses is obtained for DM masses below 200 GeV.
- For the 2σ confidence interval the relic cross-section can be excluded for the mass below 75 GeV, and the upper edge of the 200 GeV mass uncertainty region is explored. A 5σ confidence level detection is almost possible at lower end of the mass range.

Conclusions

- The MeerKAT sensitivity estimates have highly competitive constraining power, even somewhat exceeding that of Fermi-LAT data. In addition to this, the full SKA will likely be capable of achieving a 5σ probe of the thermal relic cross-section for 2HDM+S models, with WIMP masses below 100 GeV, with less than 100 hours of integration time.
- Being a SM singlet, S is predominantly produced via the decay of the heavy scalar. Through the decay $H \rightarrow SS$ the production of DM from the decay of S can recoil against SM particles that S can also decay into. Of particular interest would be the resonant search for $S \rightarrow ZZ, Z\gamma, \gamma\gamma$ in association with moderate missing transverse energy carried by the DM.
- This is a new study which has no been performed yet at the LHC or nor being documented.

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Multi anomalies & DM at the LHC

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Thank you for your time.....