Linking the LHC and astrophysics with anomalies

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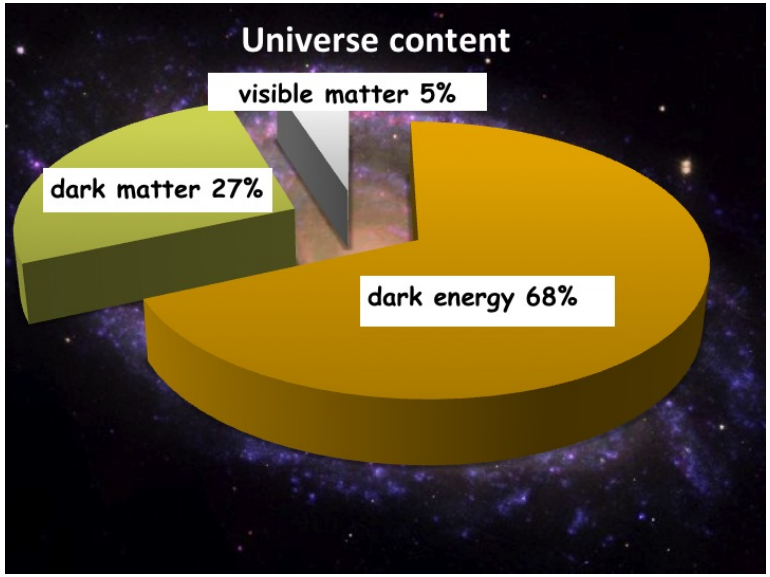
THE MATTER WITH DARK MATTER

- Missing Mass $\rightarrow$ Massive Particle
- Weakly interacting with "normal" matter
- Annihilate or decay to produce indirect signatures?
- Collisions with "normal" matter?
- Appear in collider experiments?



LET'S GO ANOMALY HUNTING!

- Dark matter is an anomaly
- Look for other anomalies?
- They might have something in common

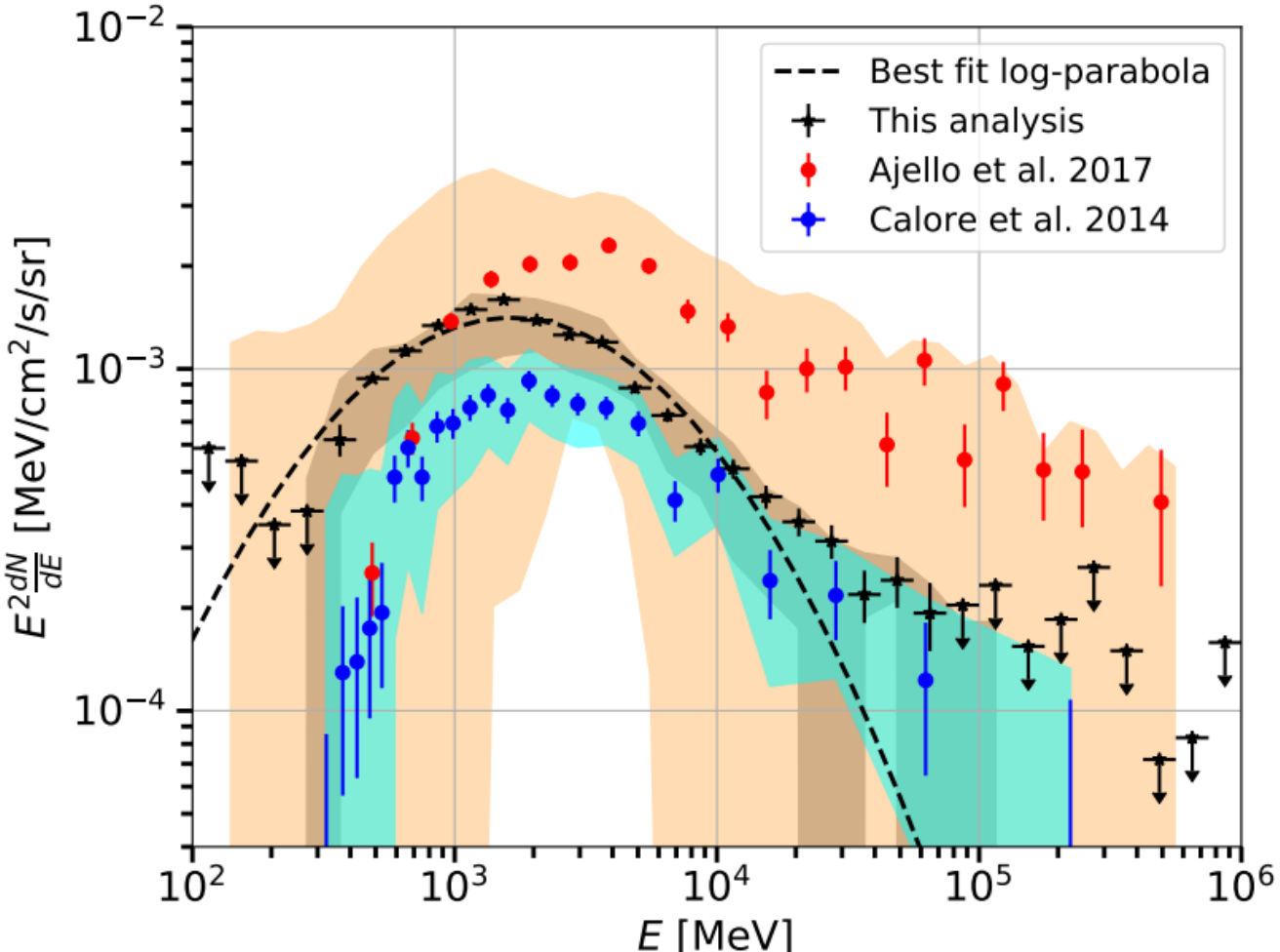
Not so fast!

- Hunting anomalies is tricky
- Most of them are just a flash in the pan!
  - BICEP 2
  - 600 GeV at the LHC
  - Superluminal neutrinos

Focus on those that have endured over time

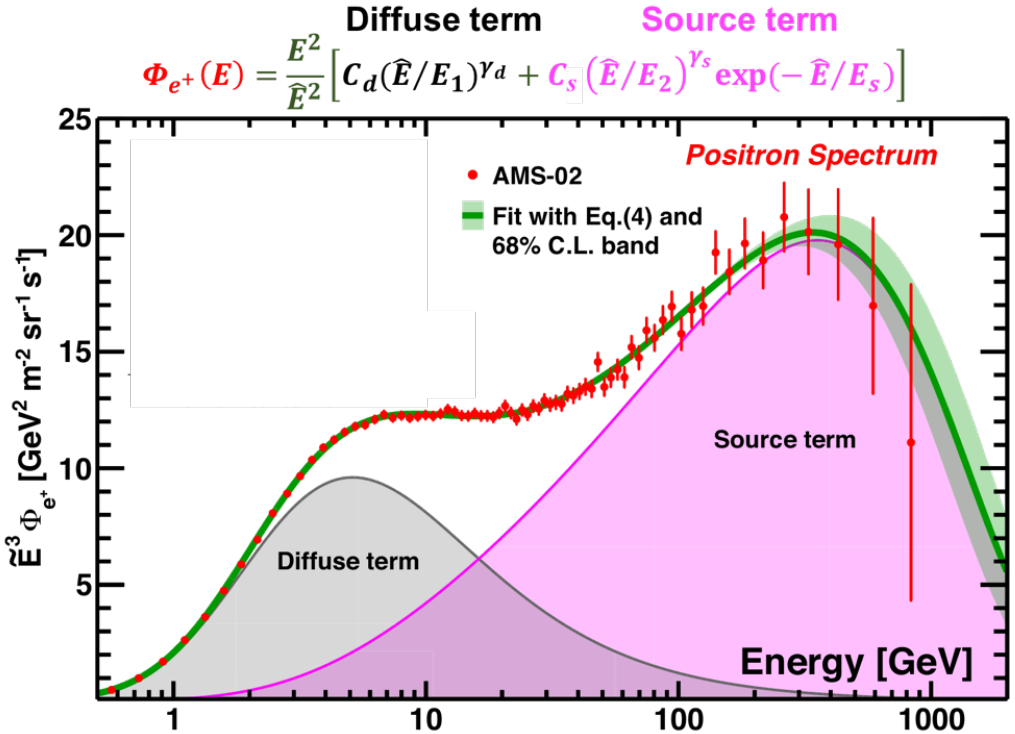
ASTROPHYSICS ANOMALY: EXCESS PHOTONS

- The saga continues!
- Fermi-LAT sees excess gamma-rays and prefers a dark matter explanation too (2101.04694)



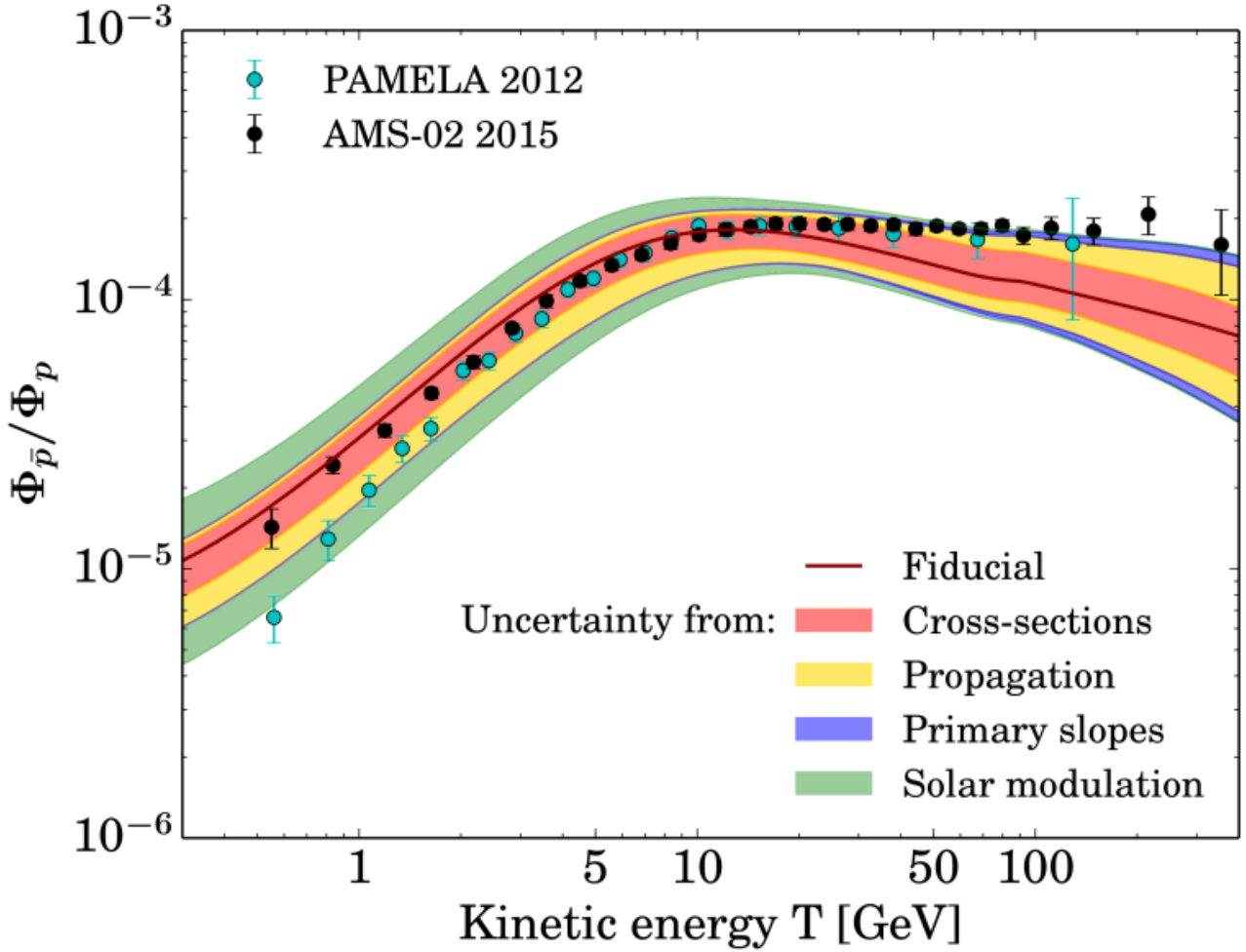
ASTROPHYSICS ANOMALY: EXCESS POSITRONS

- AMS-02 and PAMELA show excess positrons
- Source term is unexplained! (Phys. Rev. Lett. 122, 041102)



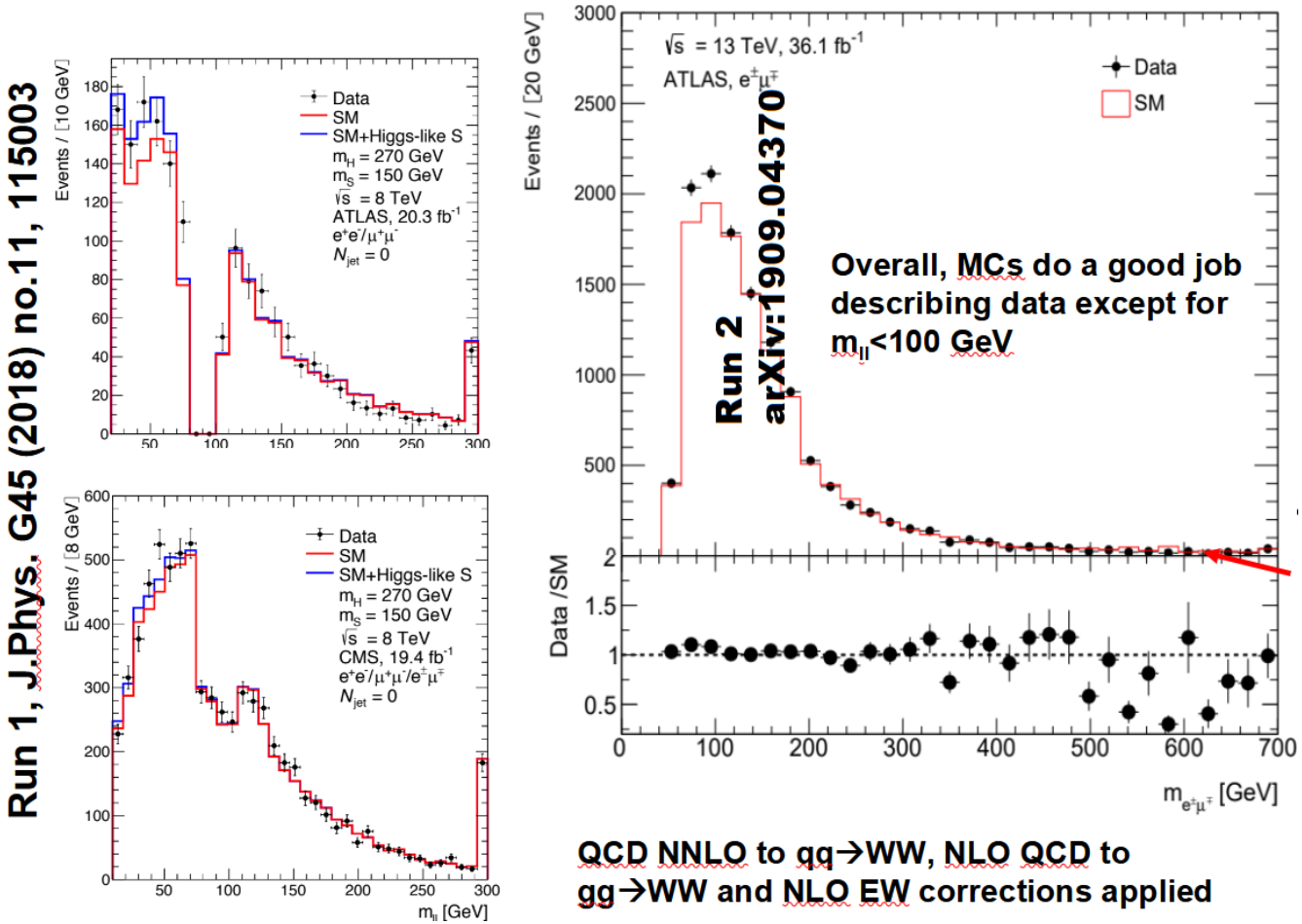
ASTROPHYSICS ANOMALY: EXCESS ANTI-PROTONS

- AMS-02 sees excess anti-protons too (1504.04276)
  - May just be correlated errors (2005.04237)



LHC ANOMALY: LEPTONS

Multi-lepton (lepton being μ,e) final states show mounting excesses (example slide from B. Mellado)



LHC LEPTONS: SUMMARY

- Anomalies at the LHC
  - Leptonic excesses enhanced in run 2
  - (slide from B. Mellado)

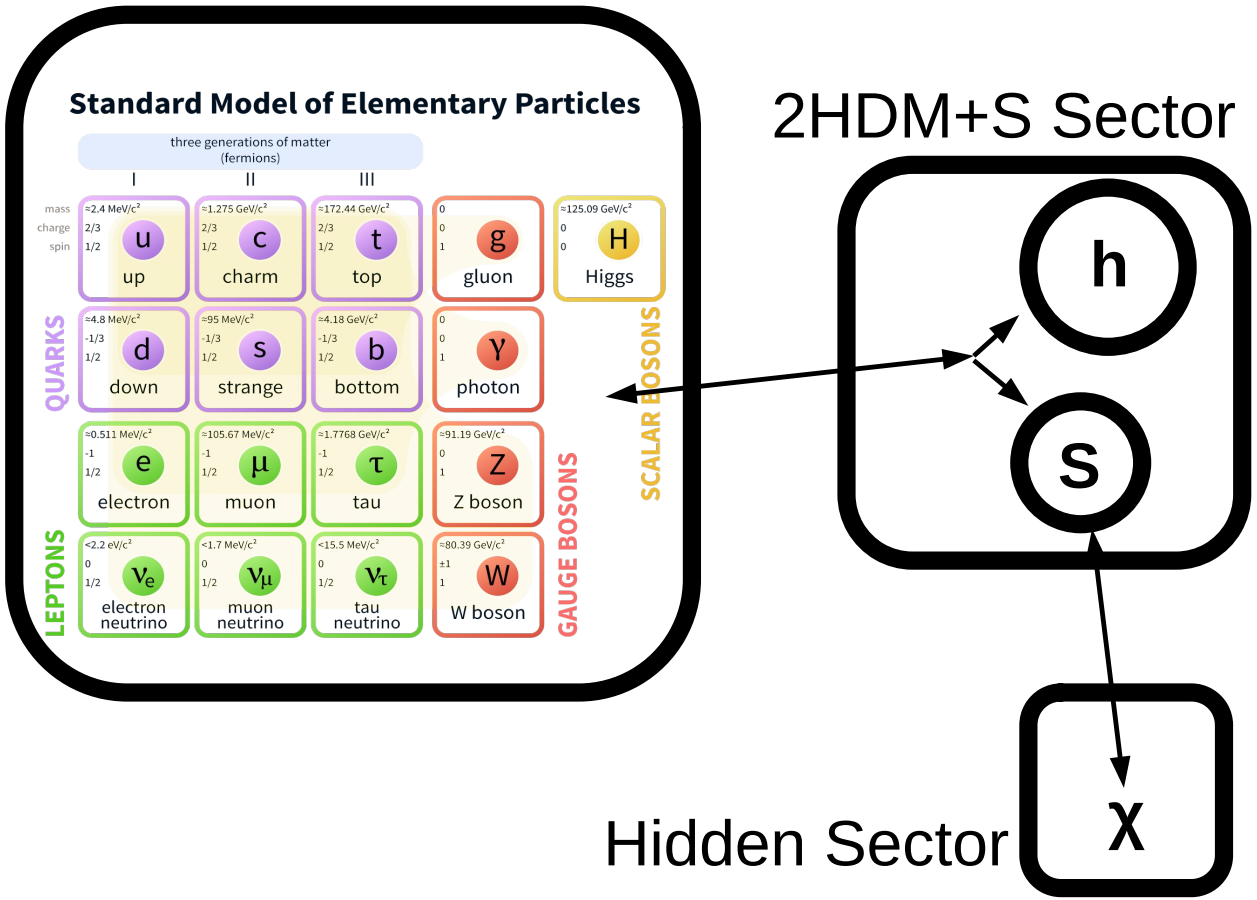
Anatomy of the multi-lepton anomalies

Final state	Characteristic	Dominant SM process	Significance
l^+l^- + jets, b-jets	m_{ll}<100 GeV, dominated by 0b-jet and 1b-jet	tt+Wt	>5σ
l^+l^- + full-jet veto	m_{ll}<100 GeV	WW	~3σ
$l^\pm l^\pm$ & $l^\pm l^\pm l$ + b-jets	Moderate H_T	ttW, 4t	>3σ
$l^\pm l^\pm$ & $l^\pm l^\pm l$ et al., no b-jets	In association with h	Wh, WWW	~4.5σ
Z(→l^+l^-)+l	p_{TZ}<100 GeV	ZW	>3σ

Anomalies cannot be explained by mismodelling of a particular process, e.g. ttbar production alone.

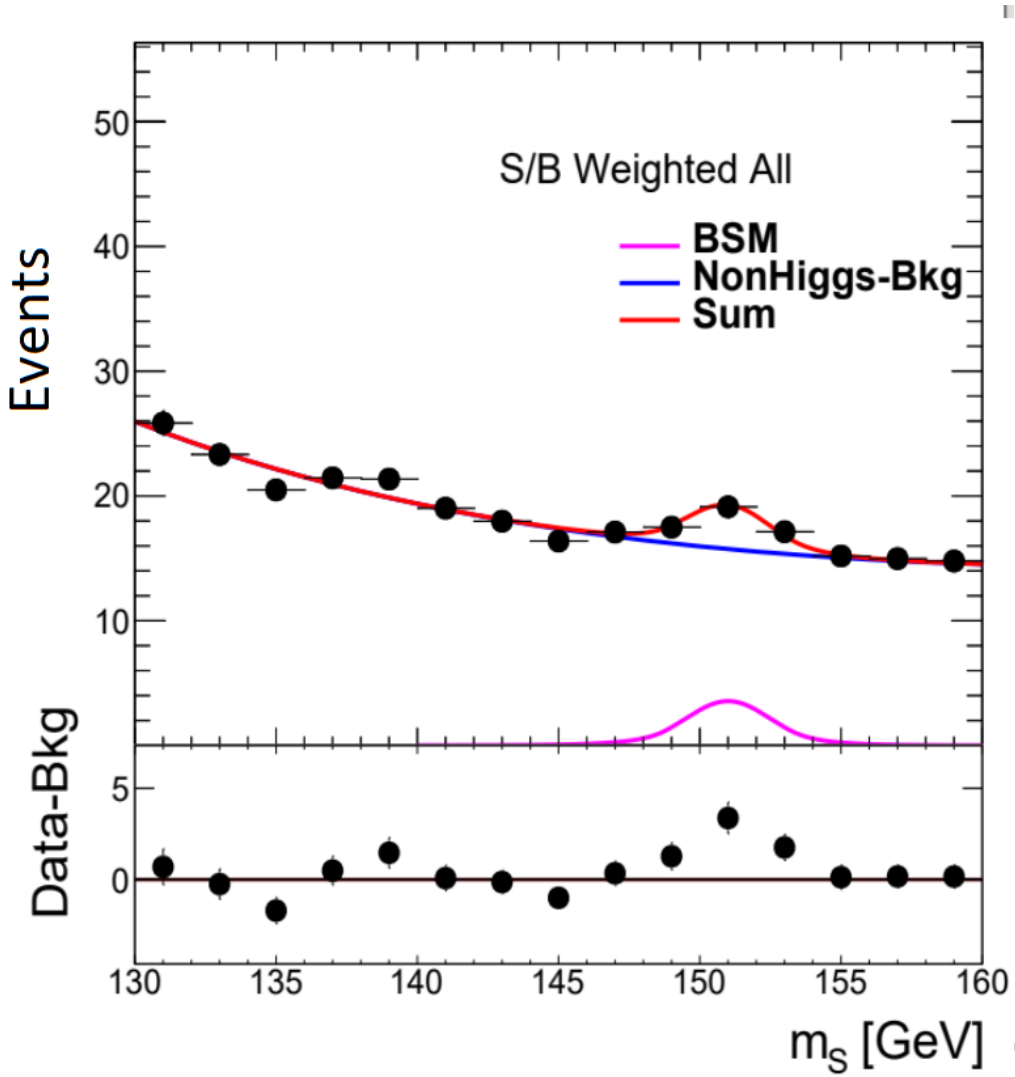
ENTER 2HDM+*S*

- Covers all the anomalies (1606.01674 and 1809.06344)



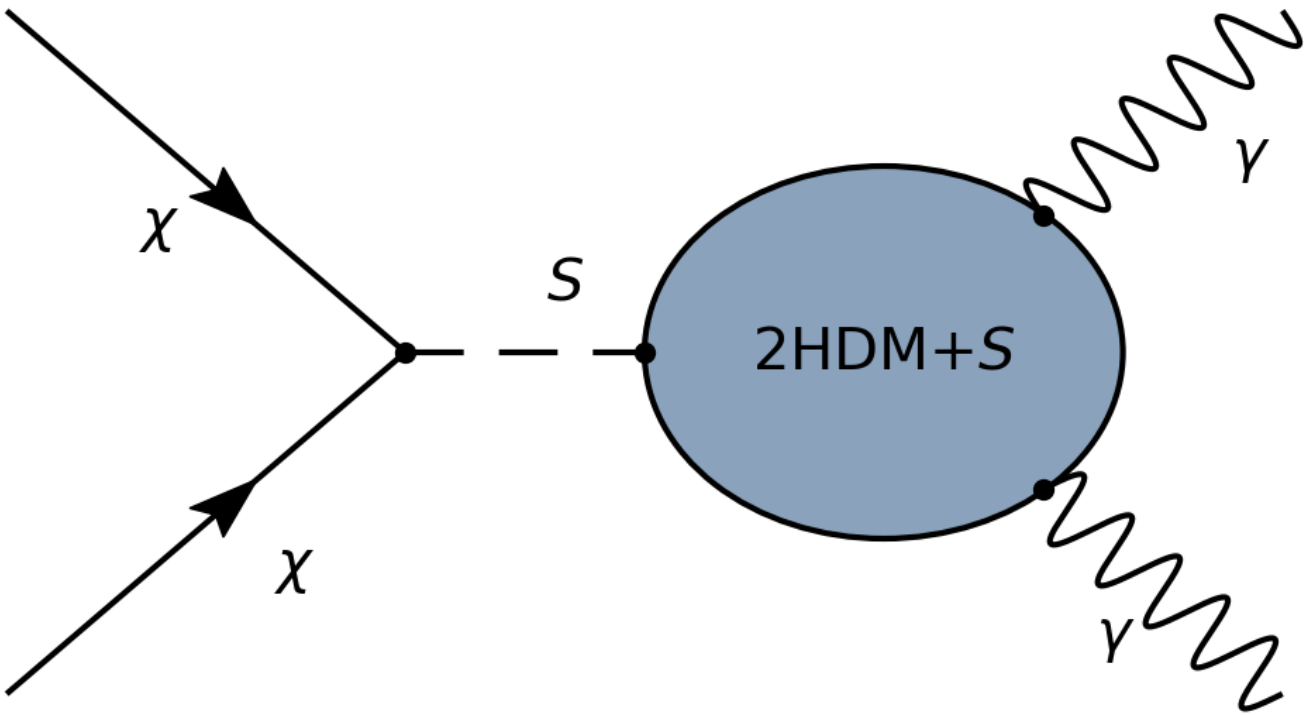
EVIDENCE FOR S?

- S boson now has 5σ evidence! (2109.03800)
- (Plot from B. Mellado using di-photon and $Z\gamma$ data)



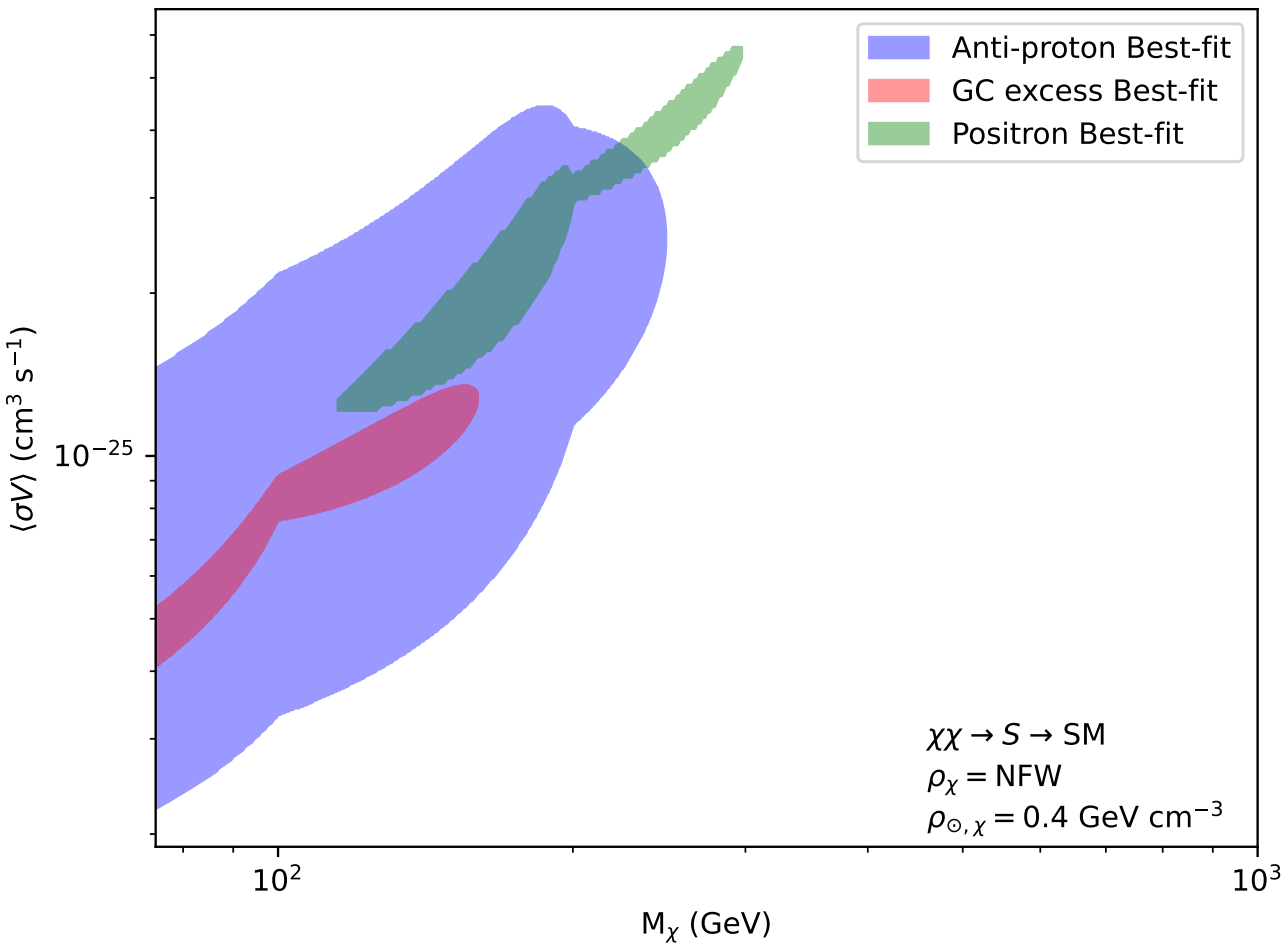
HOW WOULD WE SEE ASTROPHYSICAL CONSEQUENCES?

- Look at places with lots of dark matter
- Count the gamma-rays
- Compare to dark matter predictions
- Finally, put limits on annihilation rate



CAN WE EXPLAIN OTHER ANOMALIES TOO?

- Particle injection from $\chi\chi \to S \to \text{SM}$
- Fitted to AMS-02 and Fermi galactic centre data (arXiv:2102.10596)

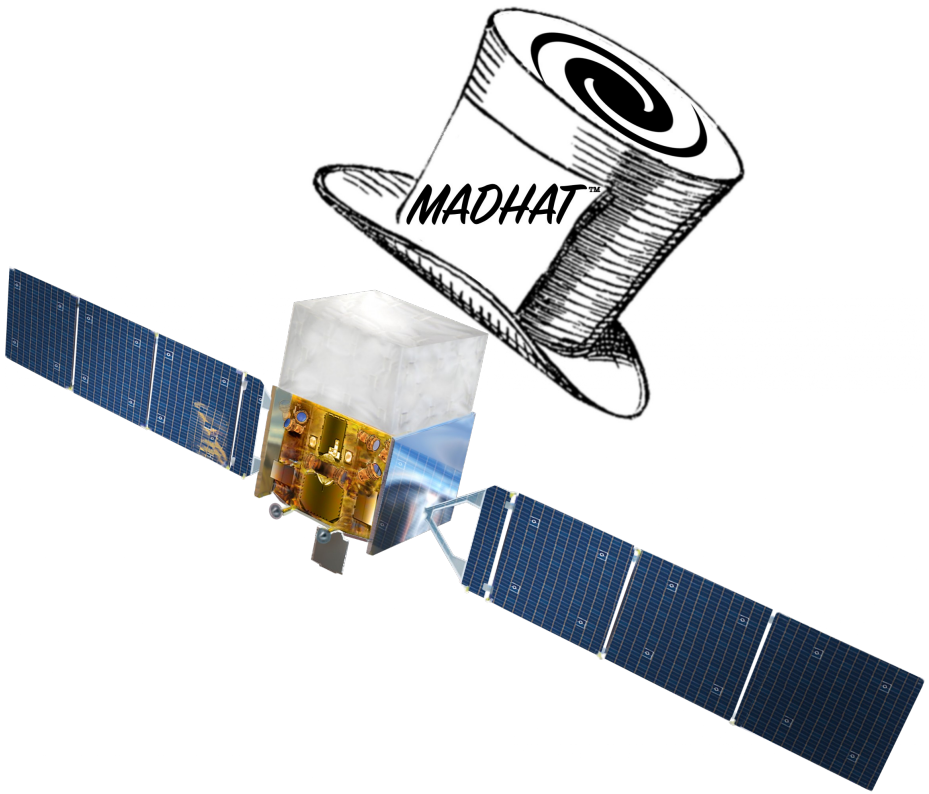


FERMI-LAT WITH A MADHAT

- While mad, this is the wrong hat

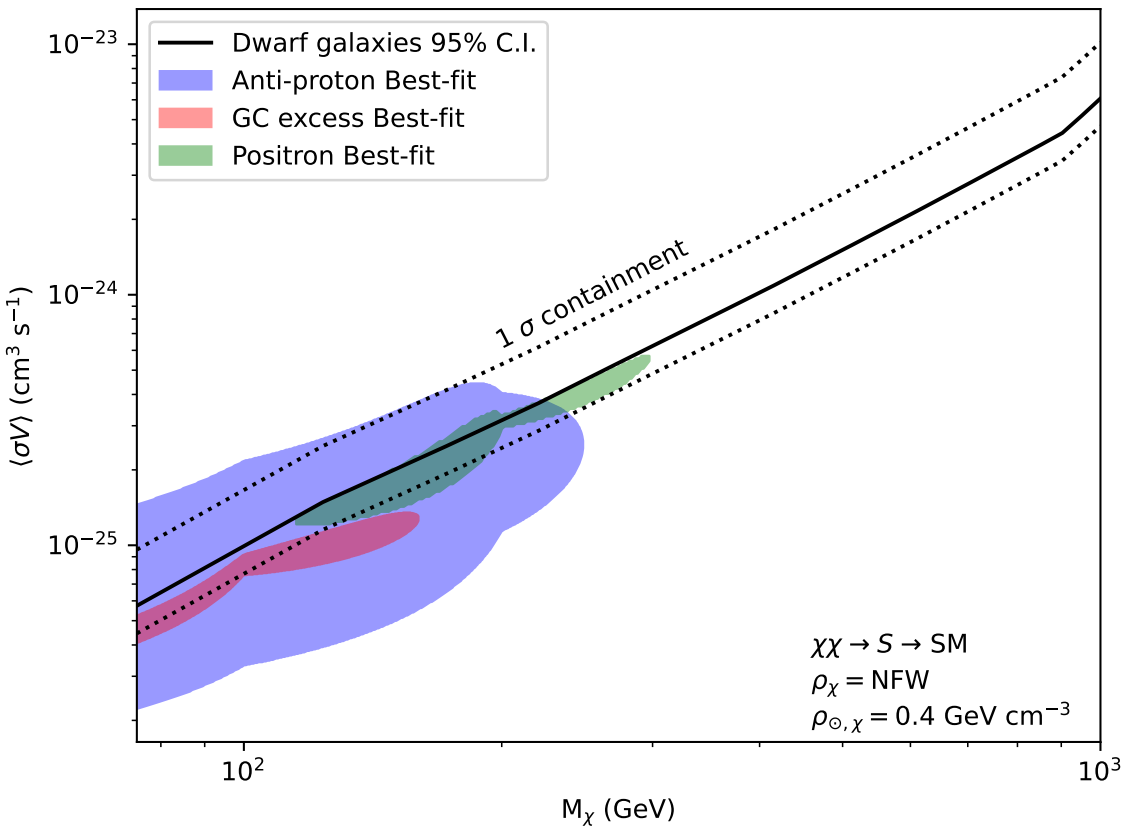
FERMI-LAT WITH A MADHAT

- MADHAT (1802.0386 and 1901.02890)
- Dark matter limits from integrated fluxes
- Stacked analysis with dwarf galaxies
- Fermi Pass 8 data



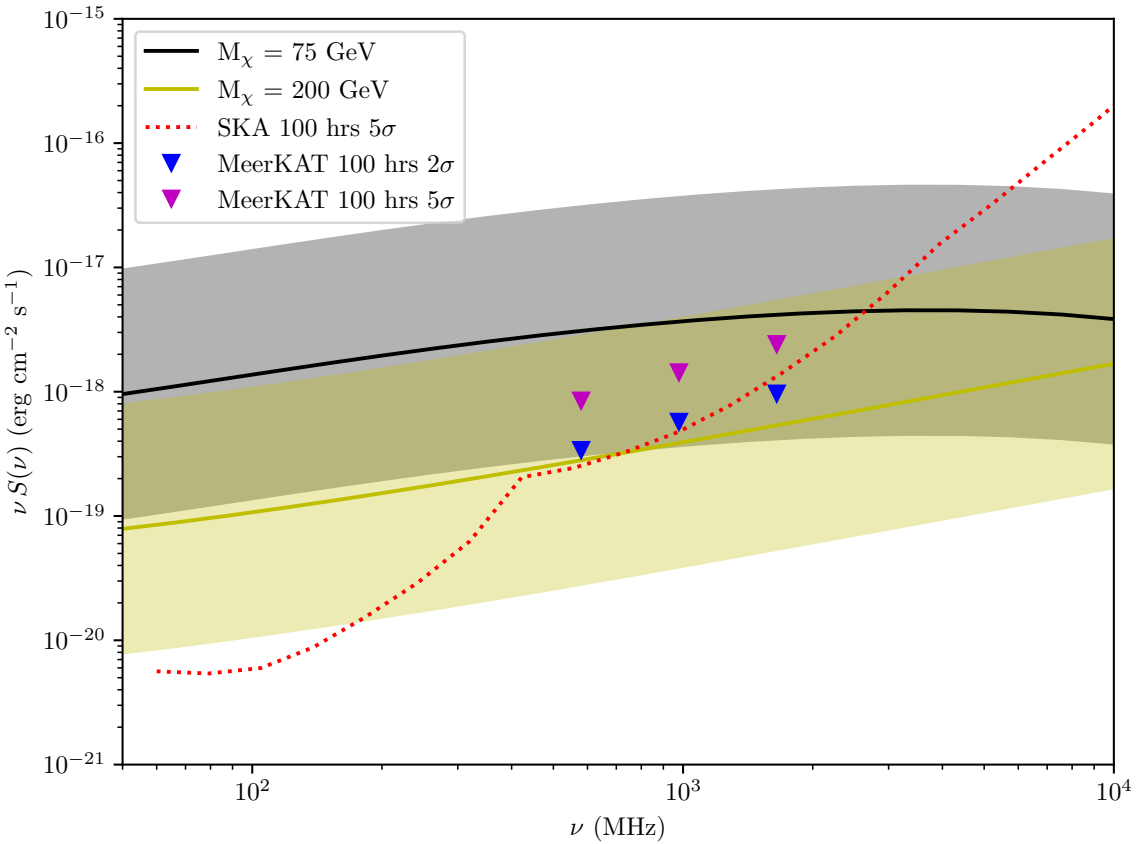
OUR ANALYSIS

- DM spectra from 2HDM+S
- 29 dwarf galaxies from (1802.06811)
- Use MADHAT to find the cross-section limits



MEERKAT TO THE RESCUE?

- MeerKAT could make detections in dwarf galaxies (arXiv:2102.10596)
- 5σ for lower masses with < 100 hours
- SKA can explore the whole parameter space!



SUMMARY

- 2HDM+S offers an explanation for LHC anomalies
  - New strong evidence of S in particular
- Also works for astrophysics too
  - Surprising agreement
  - Caveat: data systematics
  - Caveat: might only explain part of excesses
- DM mass around 100 GeV favoured
  - Motivate collider searches?
- 2HDM+S can be strongly probed via astrophysics
  - Parameter space not fully explored by Fermi
  - MeerKAT and SKA look hopeful
  - What about HESS and CTA?
- Showed complimentary probes with small and large scales