Indirect searches:
Scanning the Sky for Dark Matter Particles

Kerstin Perez

July 30, 2019

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Scanning the Sky for Dark Matter Particles

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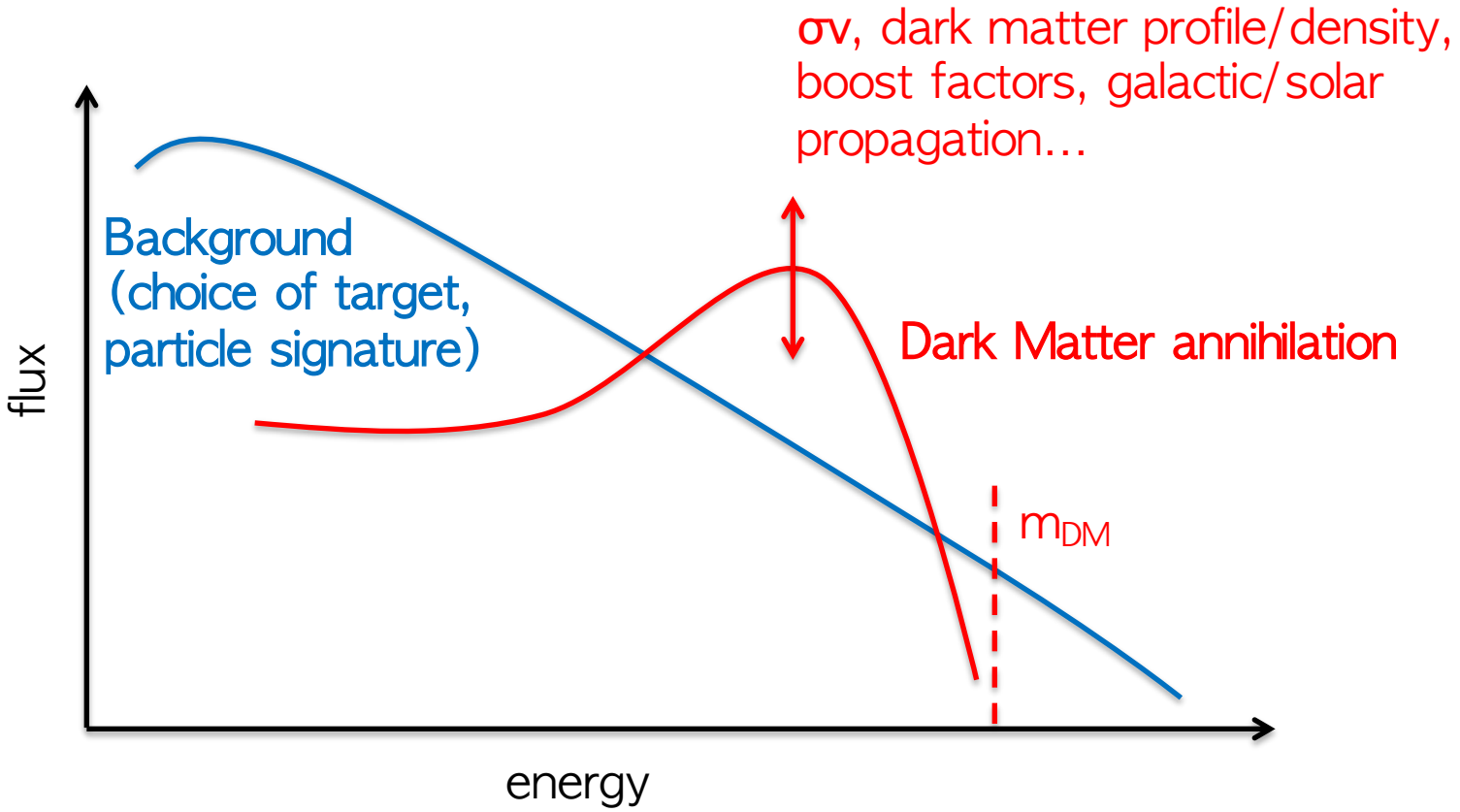
*** Photo from 33 km up in the air!**
Prototype GAPS balloon flight from Taiki, Japan in June 2012

The challenge of astroparticle searches…

Common challenge = minimize/constrain astrophysical background, maximize predicted dark matter signal



The challenge of astroparticle searches…

γ -rays, X-rays…

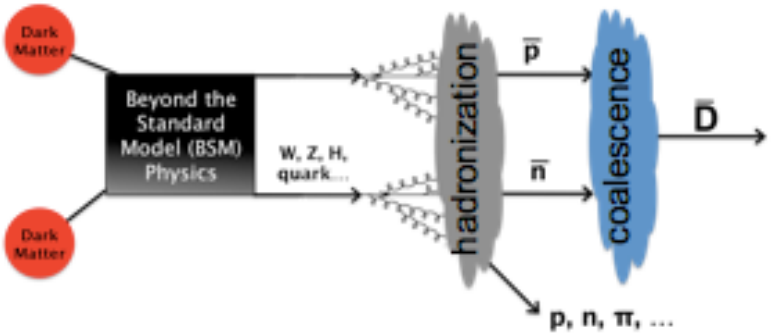
flux: $\Phi_i \propto \frac{dN_i}{dE}\langle\sigma_{X\bar{X}}v\rangle \frac{1}{m_X} J(\Delta\Omega)\Delta\Omega$

annihilation: $J(\Delta\Omega) \propto \langle \int_{l.o.s.} dl\ \rho_X^2 \rangle_\Omega$

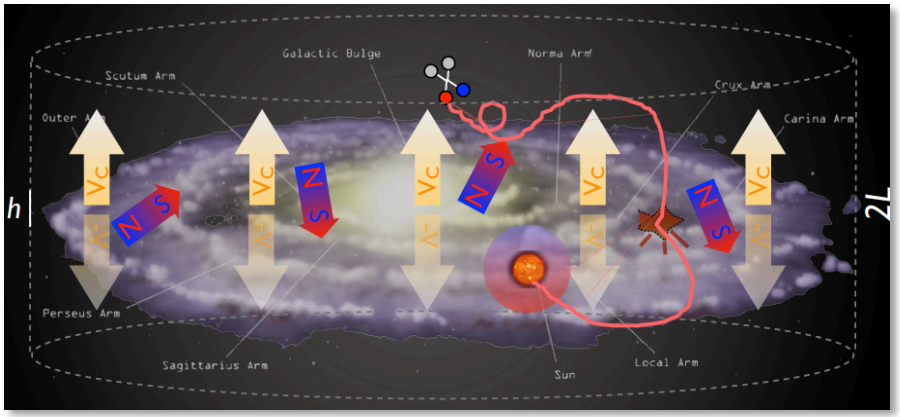
Choose high **J-factor** (Galactic center, dwarf galaxies), low or well-constrained *predicted* astrophysical background

Charged (anti)particles

Choose low or well-constrained *predicted* background signature, need precise modelling of **cosmic-ray propagation**.

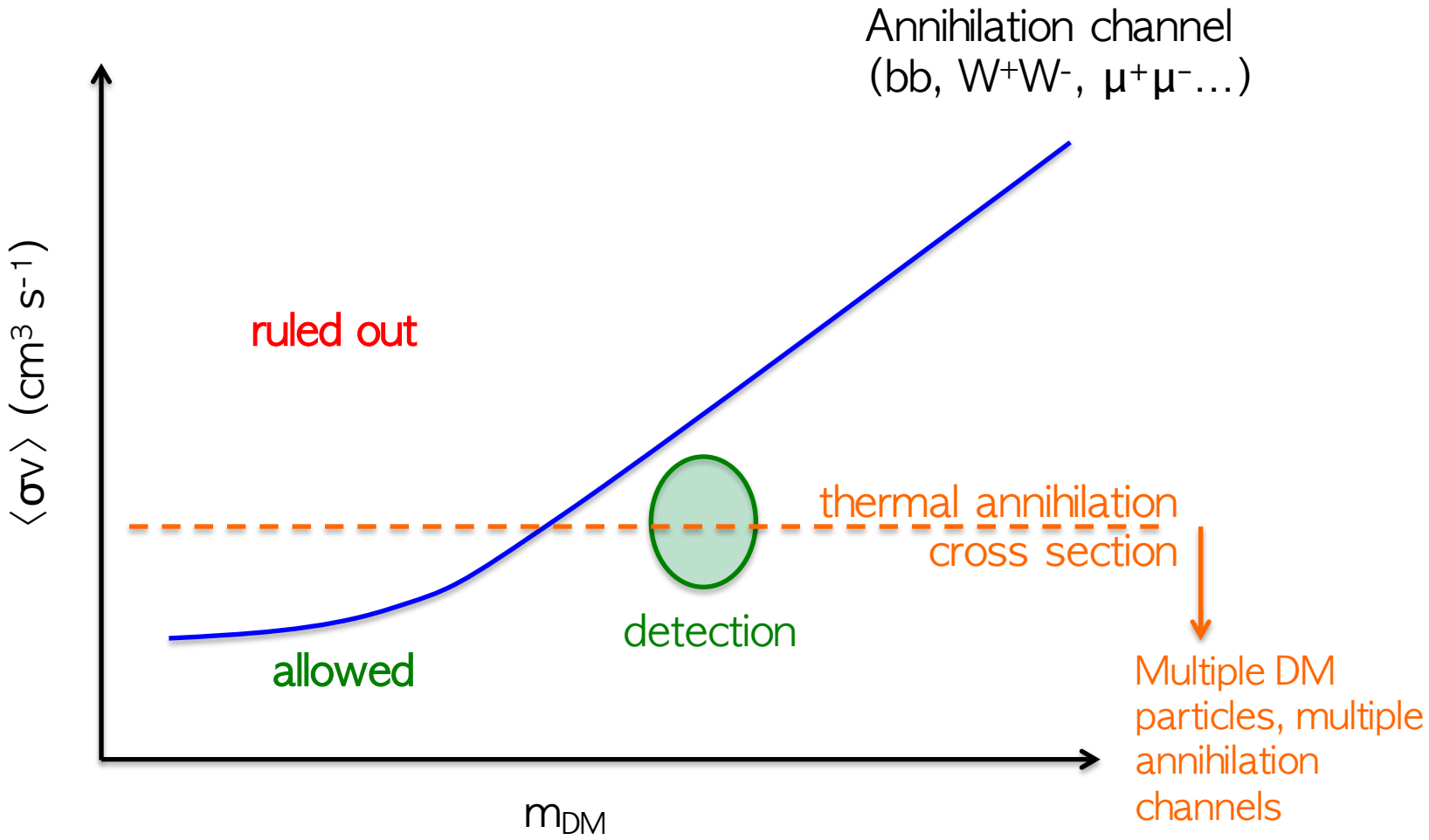


Credit: M. Cirelli (TAUP 2015)



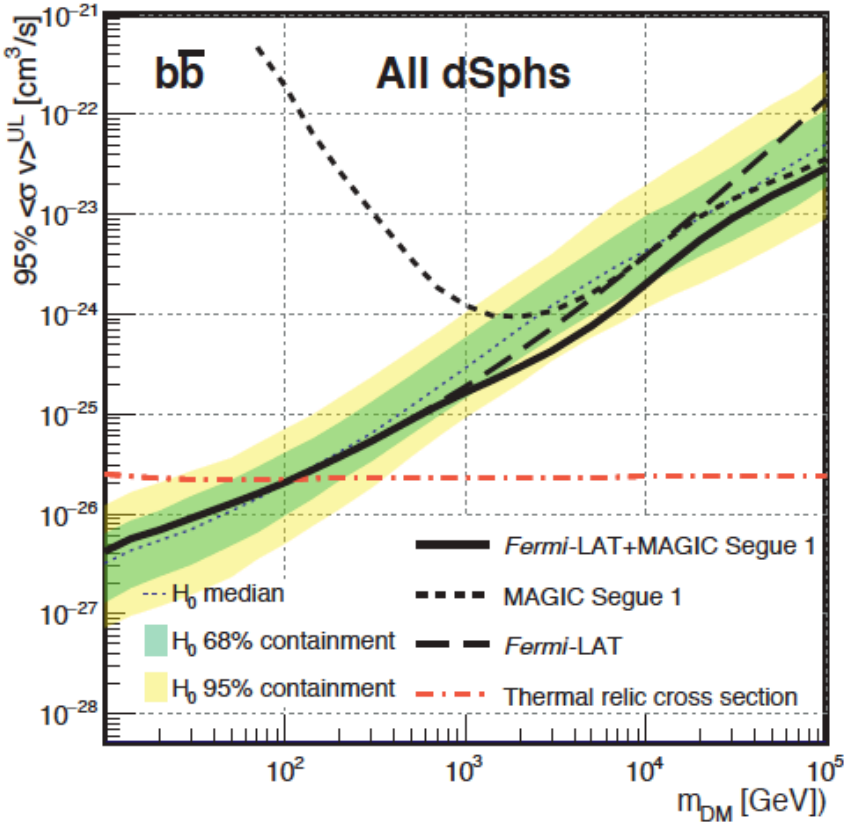
For p̄, D̄, H̄e… additional uncertainties from **hadronization, nuclear coalescence.**

No signal? Set a limit.

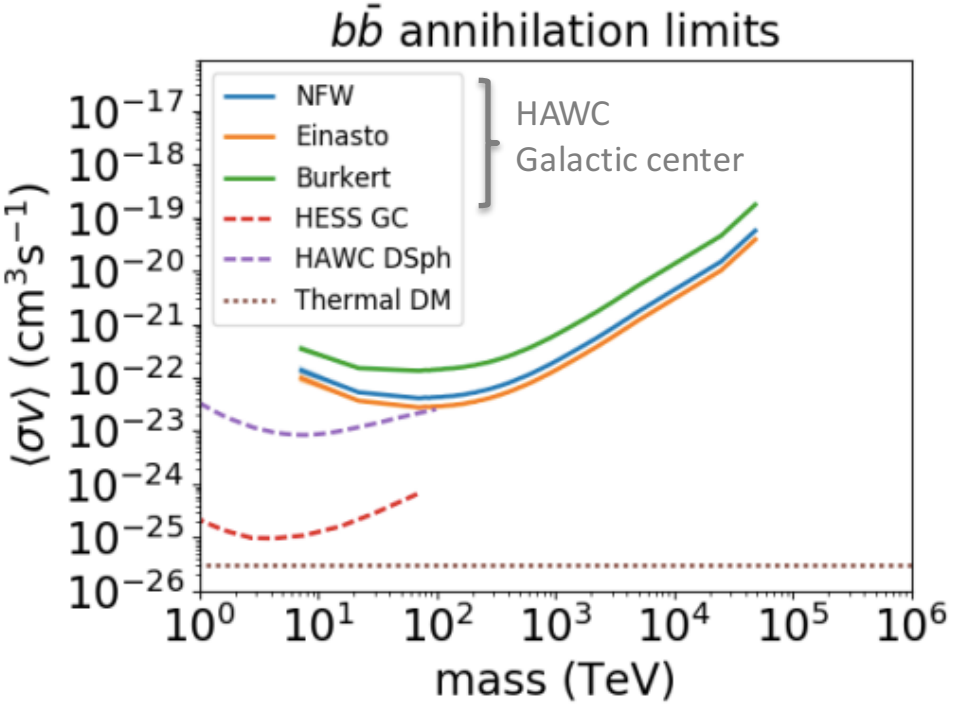


Gamma-rays: non-detection limits

M. L. Ahnen+ (2016)



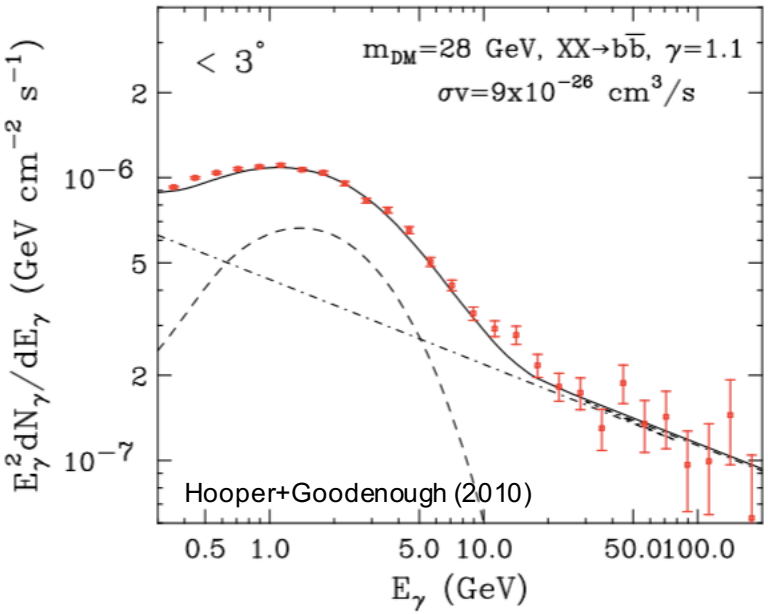
A.Abeseykara+ (2017) 1710.10288

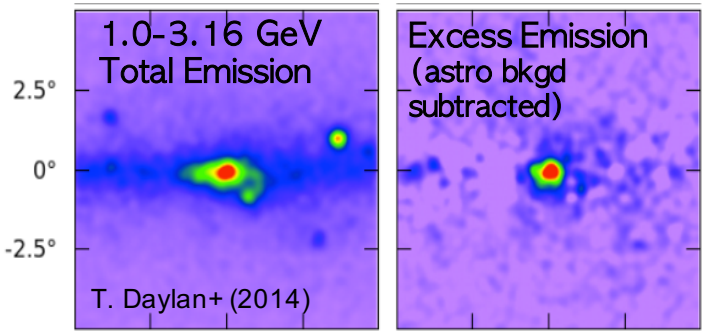


Fermi and MAGIC observations of **dwarf spheroidal galaxies** give leading constraints from ~1-100s of GeV

HAWC and HESS observations of our **Galactic center** give leading constraints from TeV gamma-rays

Current status: The gamma-ray "GeV excess"





- An excess of gamma-rays at the Galactic Center, with **spectrum, morphology, intensity consistent with annihilating dark matter**

  e.g. Hooper, Linden (2011), Abazajian, Kaplinghat (2012), Gordon, Macias (2013), Daylan, et al. (2014), Calore, Cholis, Weniger (2014), Murgia, et al. (2015), Ackermann et al. (2017)

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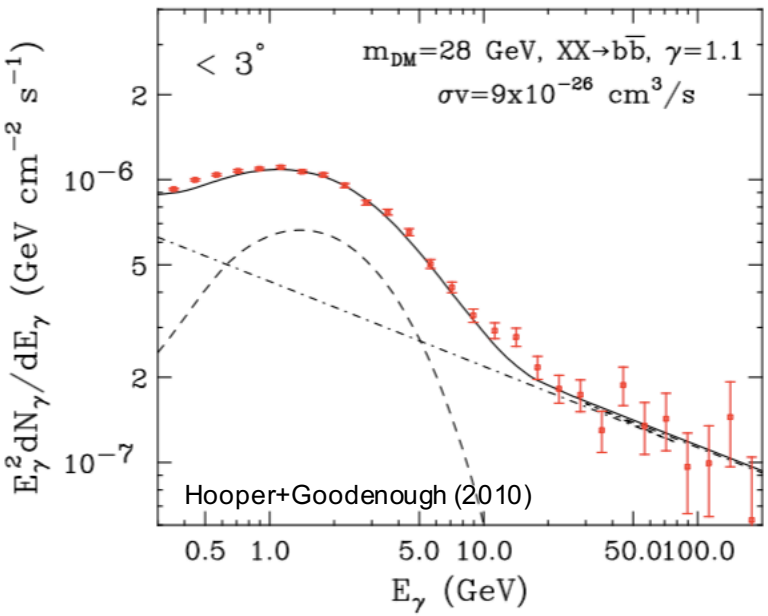

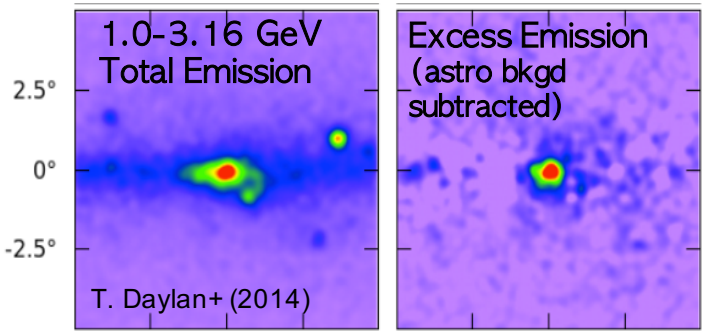

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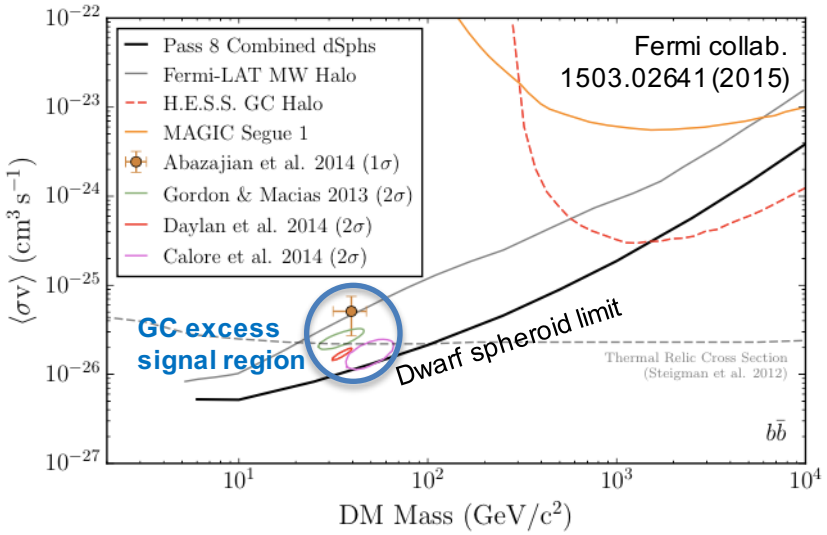
- Non-detection limits from dwarf galaxies weakened by Galactic and dwarf halo profiles, astrophysical background models – compatible with dark matter interpretation of Galactic Center excess

  e.g. Agrawal+ 1411.2592, Karwin+ 1612.05687, Hayashi+ 1603.08046, Klop+ 1609.03509, Abazajian+ 1510.06424, Benito+ 1612.02010



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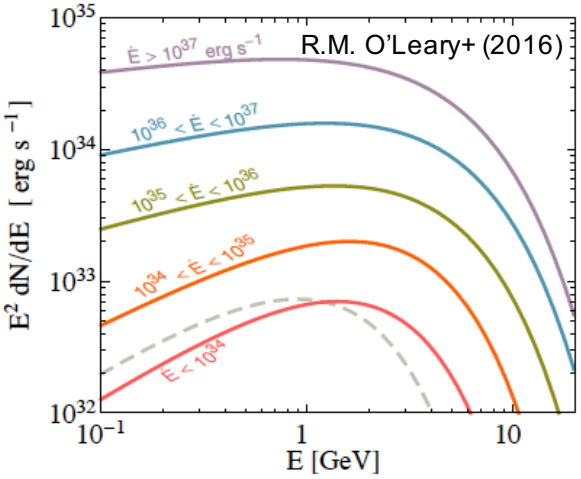
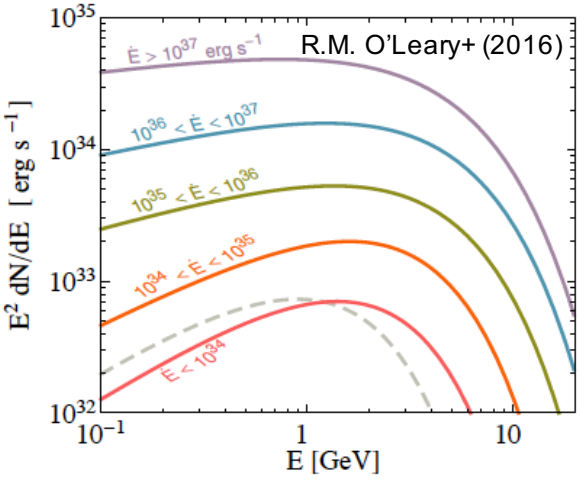


- Spectrum also consistent with **millisecond pulsars (MSPs)**
- Could indicates a population of pulsars with a luminosity function and binary progenitor population quite different from those in the Milky Way disk or globular clusters

Interpretation depends on poorly-understood Galactic pulsar population

Current status: The gamma-ray "GeV excess"



- Spectrum also consistent with **millisecond pulsars (MSPs)**
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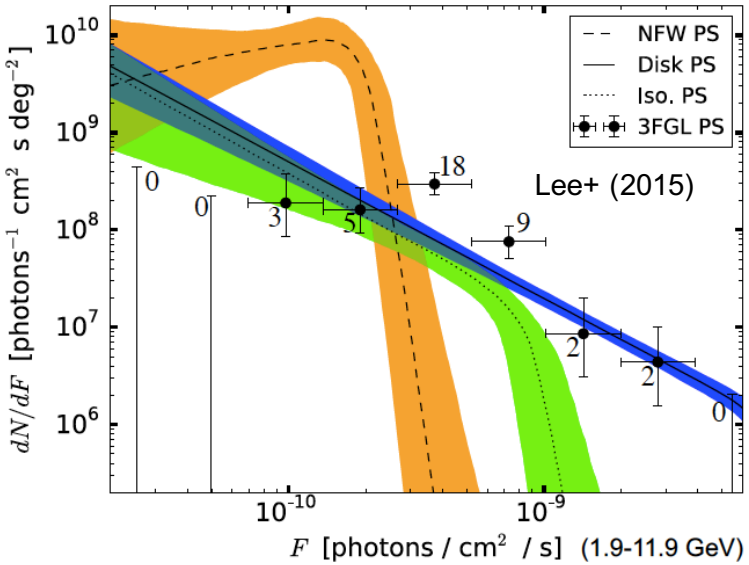
- **A population of faint sources predicts more hot and cold pixels than a flat dark matter signal**



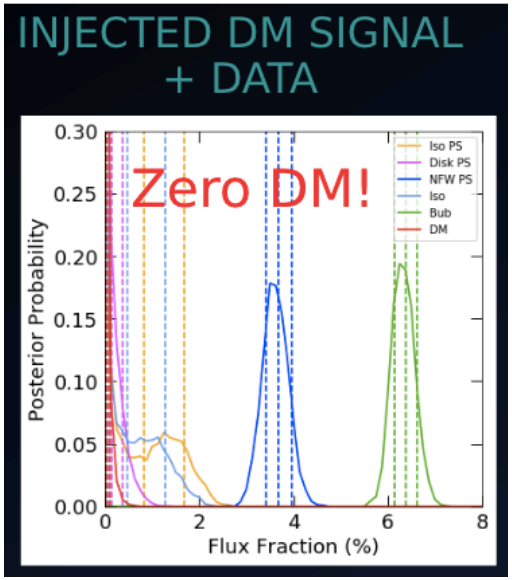
← Full excess can be due unresolved point sources

Lee+ (2015) 1506.05124

Bartels+ (2015) 1506.05104

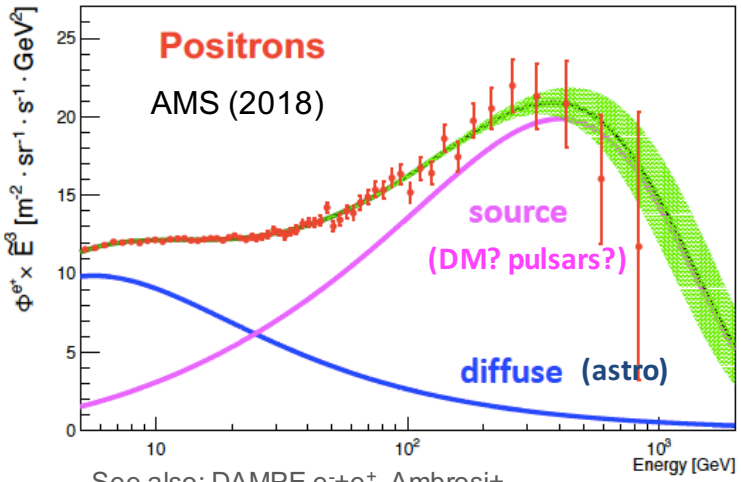
Unmodeled sources make DM be mis-attributed to point sources →

Leane, Slatyer+ (2019) 1904.08430



Interpretation depends on poorly-understood Galactic pulsar population

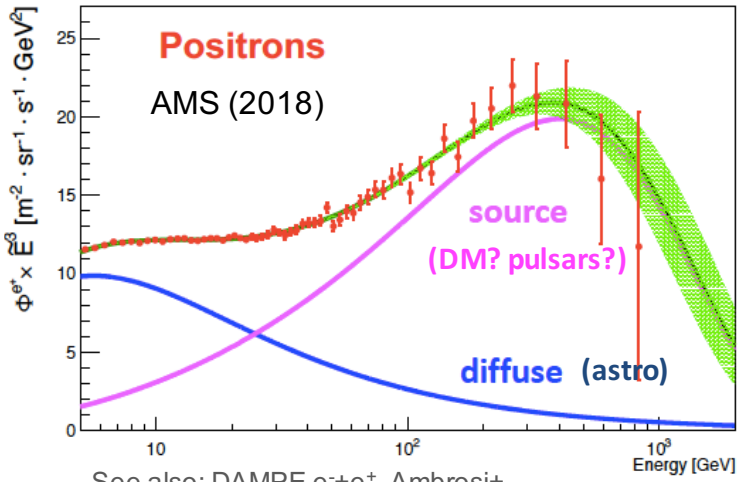
Current status: The "positron excess"



See also: DAMPE e^-+e^+, Ambrosi+ 1711.10981 Nature (2017)

- Rising positron fraction observed since PAMELA 2008, confirmed to higher energies by AMS-02
- Implies heavy TeV-scale dark matter. Need enhanced annihilation cross section and leptophilic annihilation (to avoid antiproton bounds).
- Or local pulsars...

Current status: The "positron excess"



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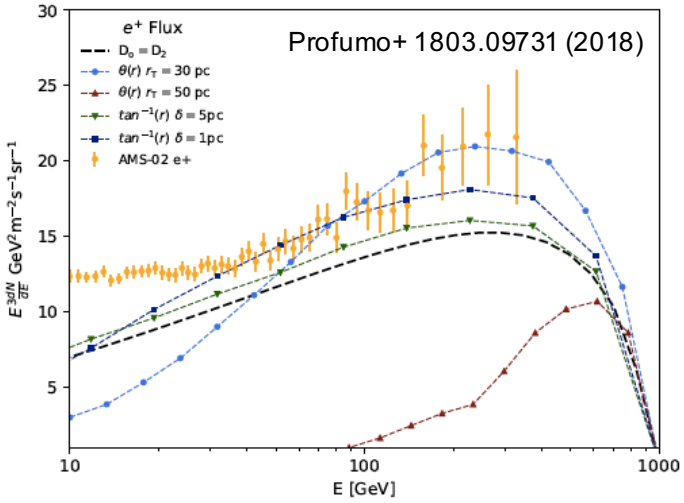
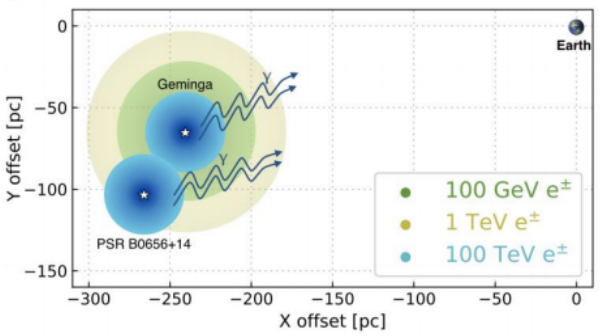
↓ HAWC – if Galactic diffusion similar to diffusion in regions of nearby pulsars, excess cannot be due to Geminga and PSR B0656+14



← Likely implies that diffusion not uniform throughout local interstellar medium

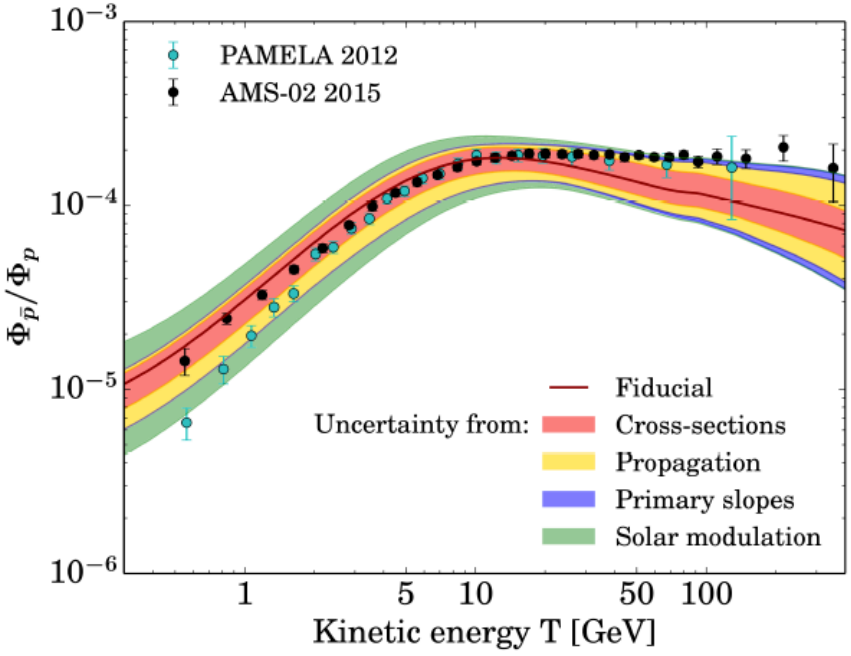
See also: Hooper+Linden 1711.07482 (2017)

Abeysekara+ 1711.06223 Science (2017)

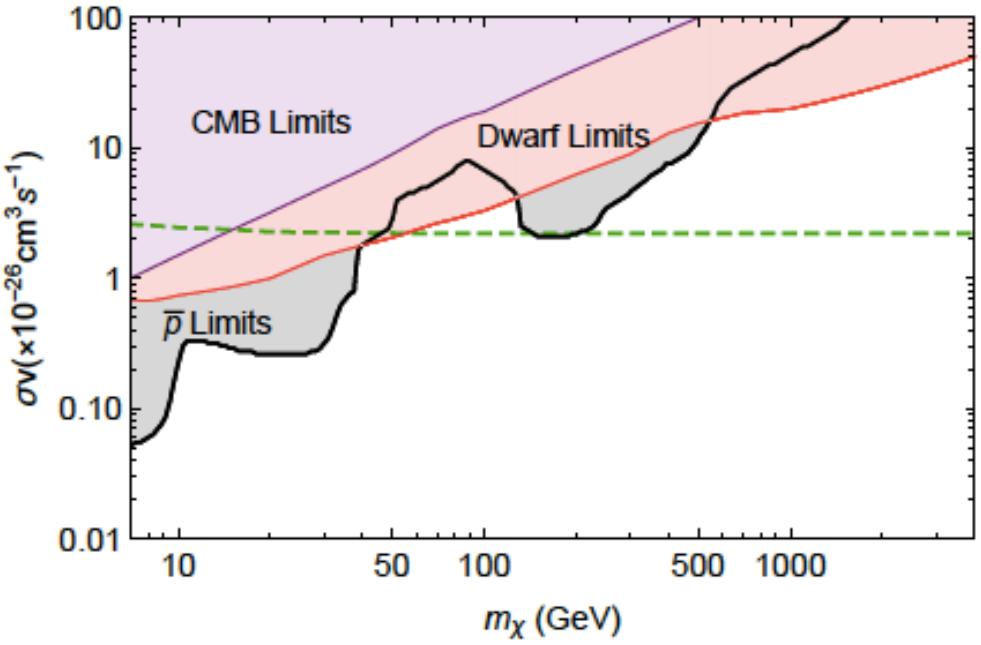


Interpretation depends on poorly-understood Galactic propagation (diffusion)

Antiprotons: dark matter limits



G. Giesen+(2015)



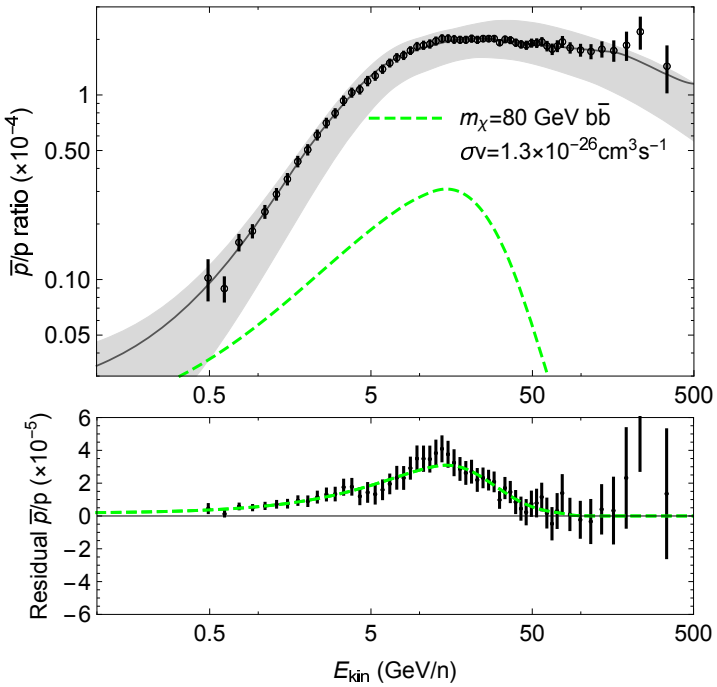
I. Cholis+(2019)

- High-precision AMS measurement prompts improved modeling of production cross-sections and propagation
- Strongest constraints on dark matter annihilation (to bb) below 40 GeV

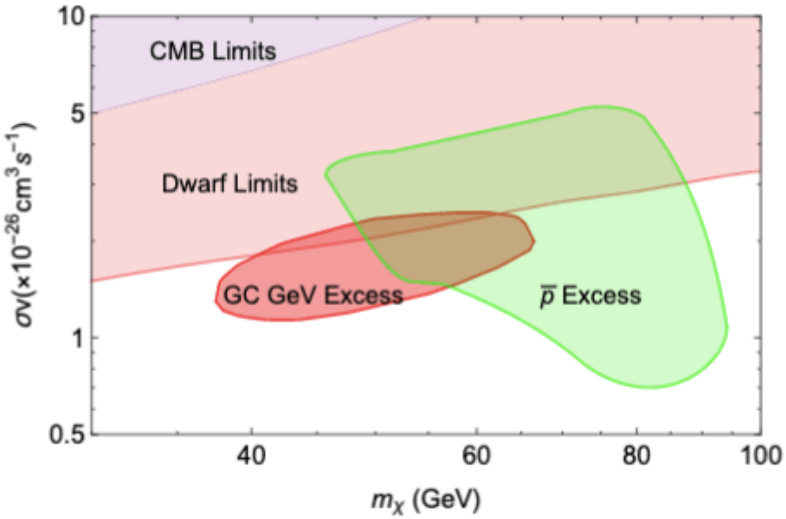
Current status: an antiproton excess?

↓ Possible excess in ~5-20 GeV antiprotons, at level of few % of total flux

Cuoco+(2016), Cui+(2016), Cui+ (2018), A. Cuoco+ (2019), Cholis+ (2019)



← Signal from ~50-100 GeV dark matter?

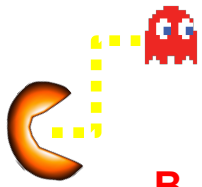


↑ Antiproton signal consistent with Galactic center GeV excess!?

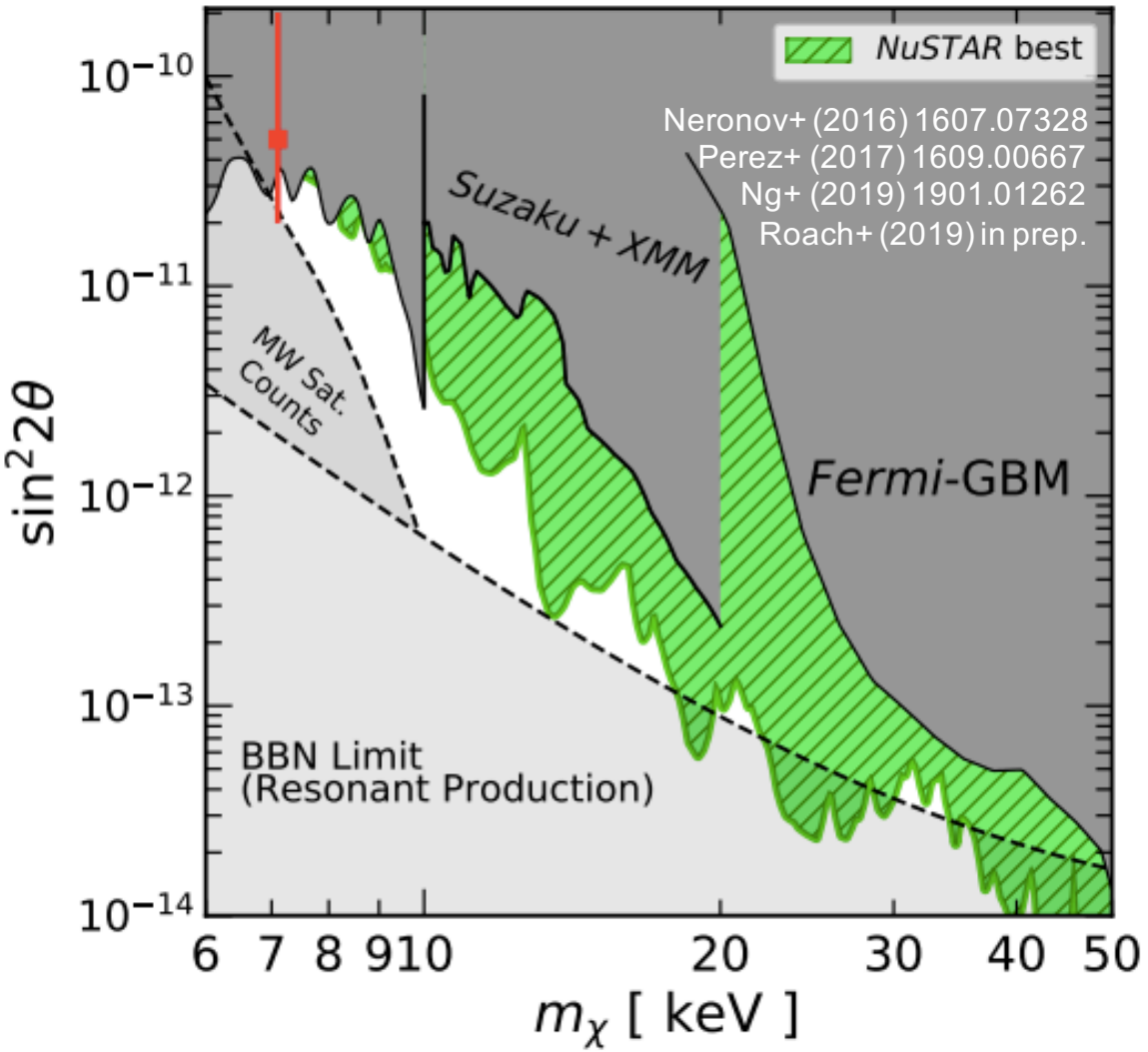
Interpretation depends on Galactic and Solar propagation, antiproton production uncertainties, ***possible correlated systematic uncertainties from AMS***

X-ray searches: narrowing window for sterile neutrinos

- Sterile neutrinos are a candidate for keV-mass dark matter, motivated by neutrino mass and mixing
- Can decay to a neutrino and a photon with $E_{photon} = m_{DM} / 2$ → X-ray line search!
- Finite parameter space for sterile neutrinos to be all of dark matter in the simplest models!
- Novel ***NuSTAR*** method helping close this window

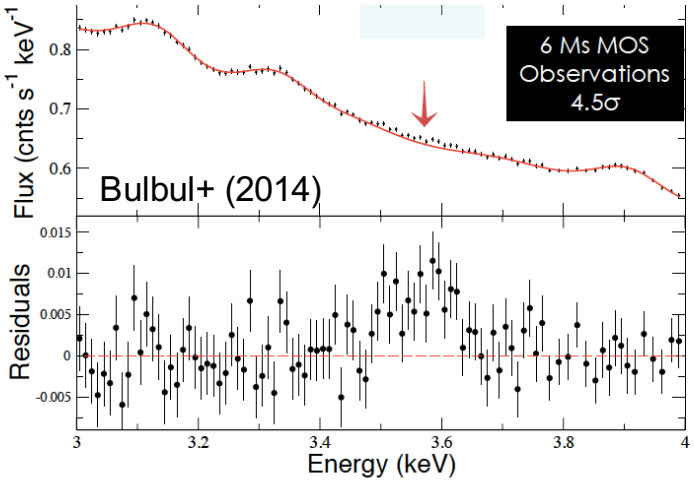


More here at DPF:
B. Roach, DM session
Tues 2-4pm

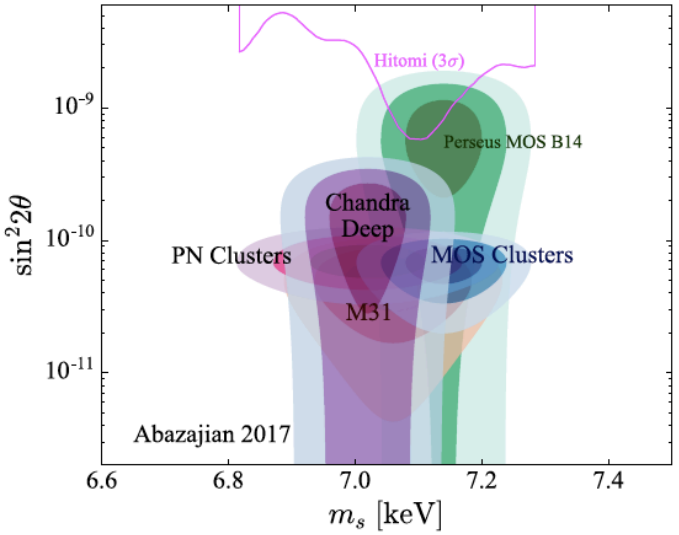


Current status: the "3.5 keV line"?

1. A faint line detected in XMM-Newton spectra of stacked galaxy clusters



2. Line consistent with observations using many instruments and astrophysical regions



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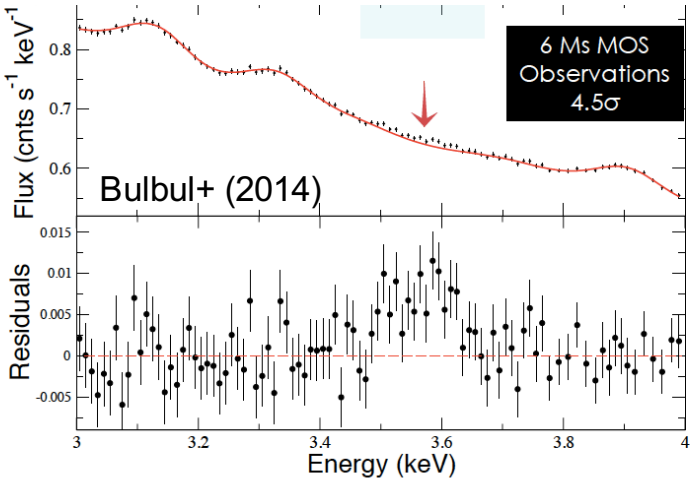

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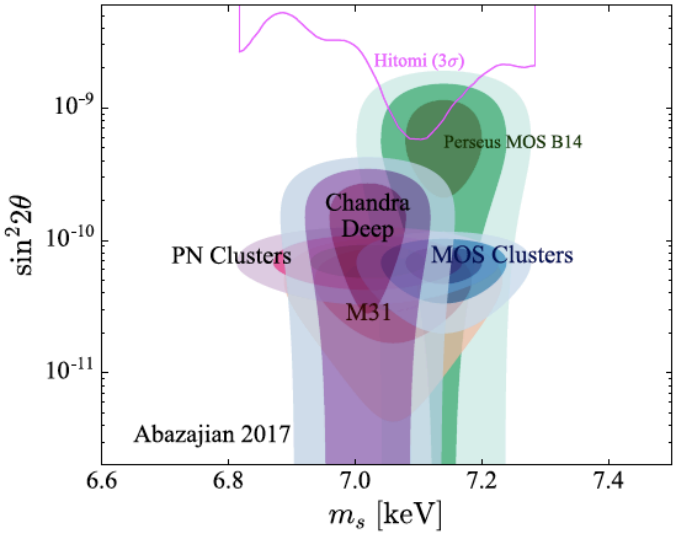
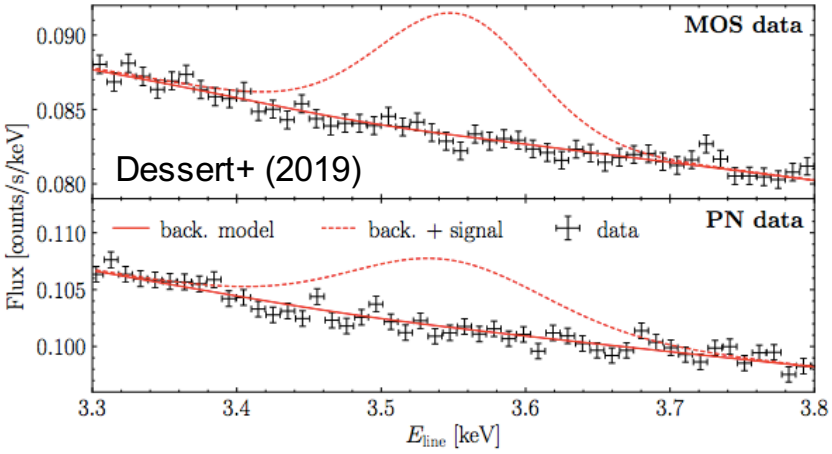
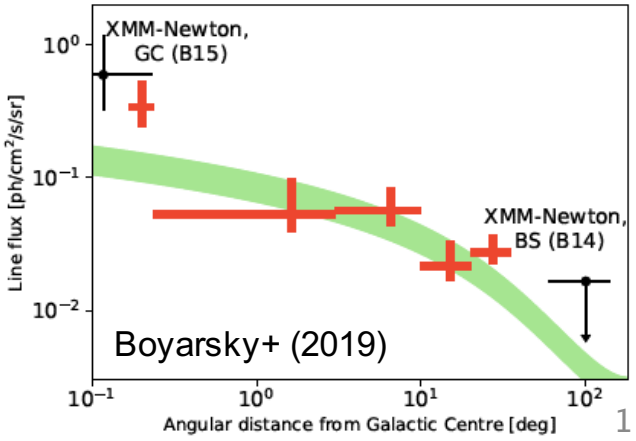


3. Ruled out by statistically combining limits from 30 Ms (!) of XMM-Newton blank-sky data

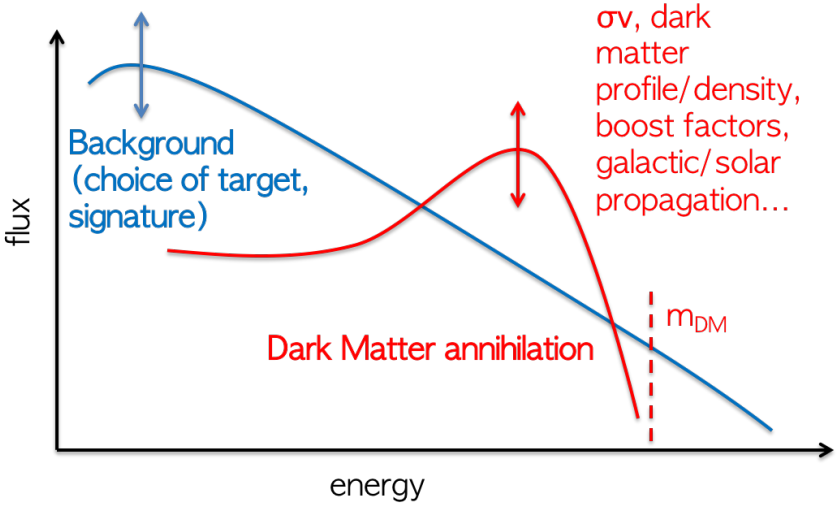
More here at DPF:
C. Dessert, DM session Tues 2-4pm



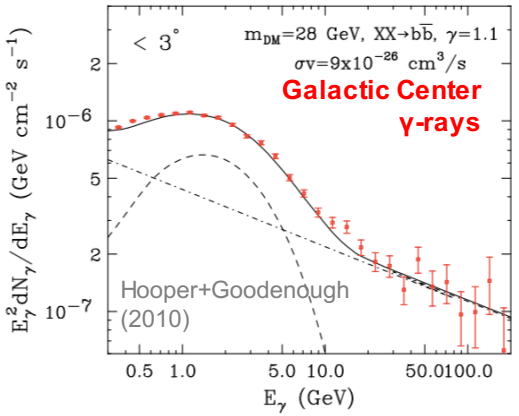
4. Though still some debate.



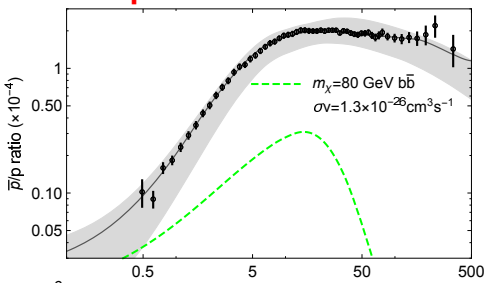
The challenge of astroparticle searches…



Cuoco+(2016), Cui+(2016), Cui+ (2018), A. Cuoco+ (2019), Cholis+ (2019)

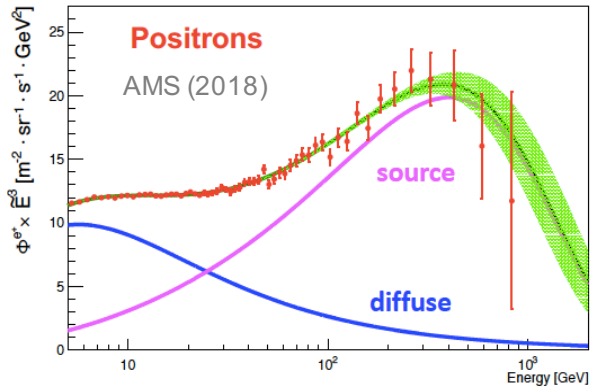


Antiprotons



Positrons

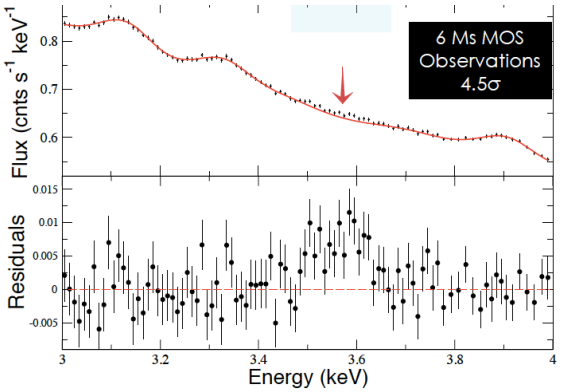
AMS (2018)



1. Cosmic rays are full of surprises!
2. Surprises are difficult to interpret due to large/uncertain astrophysical backgrounds
3. Need cross-correlation with different signatures

X-rays: 3.5 keV

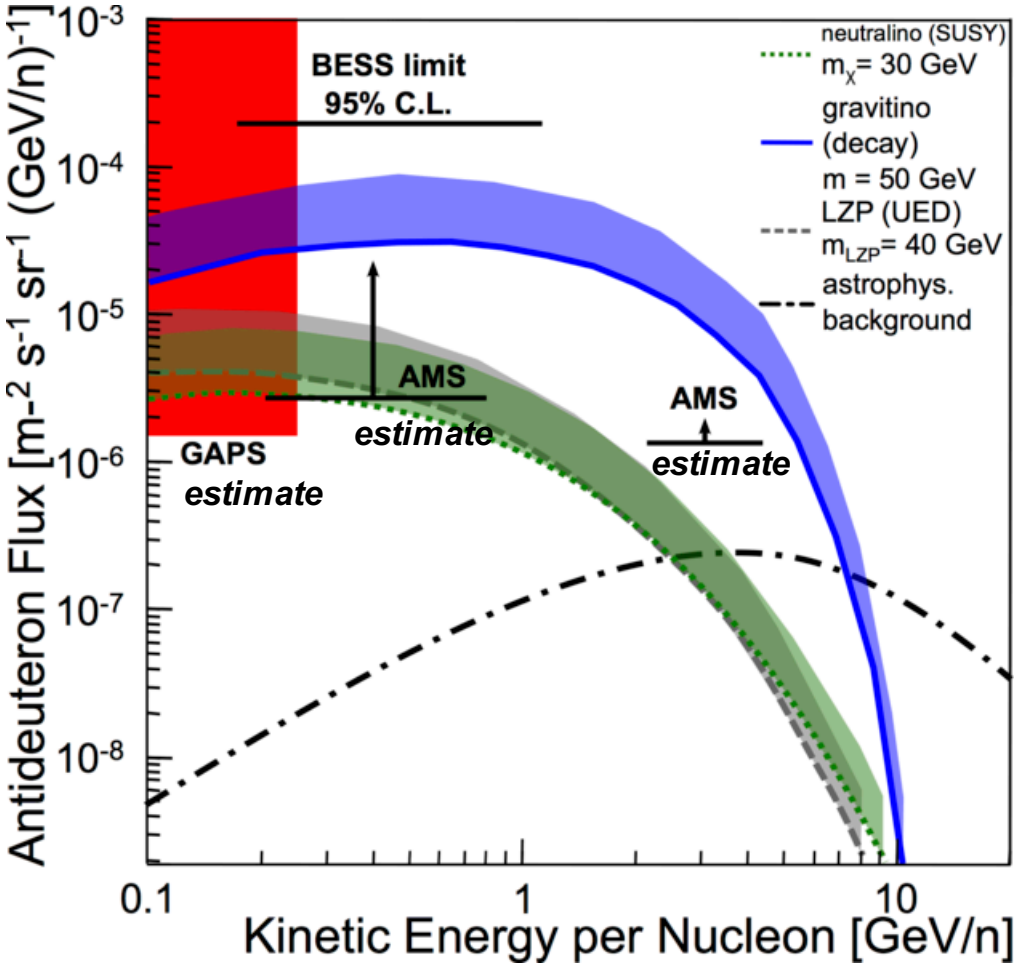
Bulbul+ (2014)



New physics in cosmic-ray **antideuterons**

A generic *new physics* signature with ***essentially zero*** **conventional astrophysical background**

Astro 2020 White Paper: K. Perez+ (2019) 1904.05938



- GAPS first experiment optimized specifically for low-energy antinuclei signatures
- **First GAPS Antarctic flight: late 2021**

More here at DPF:
M. Xiao, DM session Tues 2-4pm
F. Rogers Dets. Session Thurs 2-4pm

Review of experiment and theory:
Phys. Rept. 618 (2016) 1-37

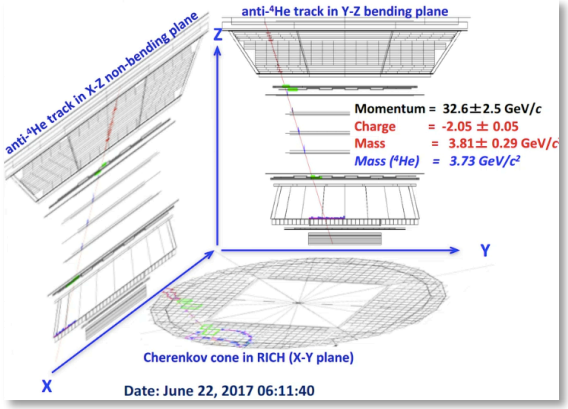
Lots of updates!
Google: "**antideuteron workshop 2019**"

New physics in cosmic-ray **antihelium?**

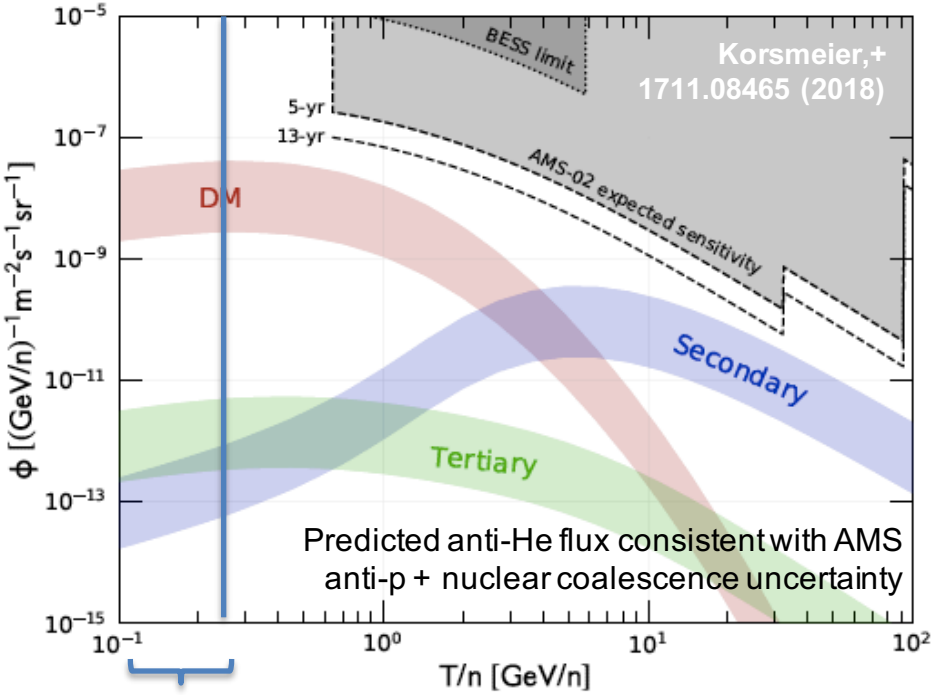
- **pre-2016:** "New work on anit-He signatures is promising, but outside the scope of current experiments" – me, repeatedly

- **2018:** "To date, we have observed eight events…with Z = -2. All eight events are in the helium mass region." – S. Ting (La Palma, AMS overview)

AMS Candidate Anti-He4 event (p = 32.6 GeV/c)



Very difficult* to account for AMS-02 rate via dark matter*…independent measurement essential!



See also: Googan+Profumo 1705.09664, Blum+ 1704.05431

Exciting time for indirect searches for dark matter!

The **advantages** of astroparticle searches:

- New measurements are teaching us about both dark matter and astrophysics of the universe
- Many tantalizing possible dark matter signals, but need cross-correlation with new targets and new signatures
- **To make progress on understanding dark matter, we should remain open to as many different astroparticle messengers as possible…stay tuned!**