Interplay of Indirect and Collider Searches for Dark Matter

Rebecca Leane
MIT Center For Theoretical Physics

DM@LHC, UW Seattle
Aug 14th 2019

Massachusetts Institute of Technology

Why indirect detection is exciting

- Universe has been running experiments <u>for us</u> over very long time scales
- Can uniquely access specific scales: long decay lengths, smaller couplings, high energies
- Well defined target rates: dark matter in its natural habitat

… and what about it is not exciting:

… and what about it is not exciting:

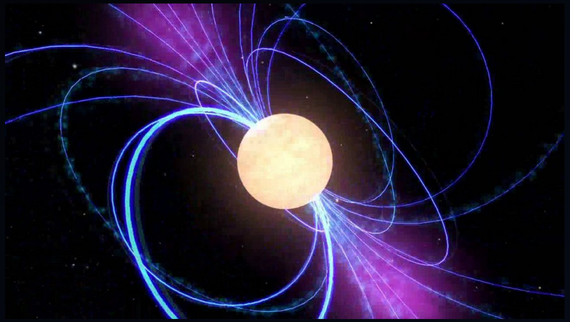


Image: NASA

Backgrounds.

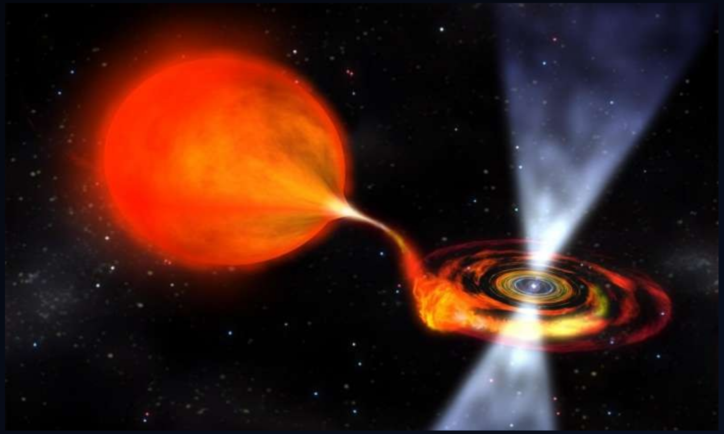


Image: University of Southampton

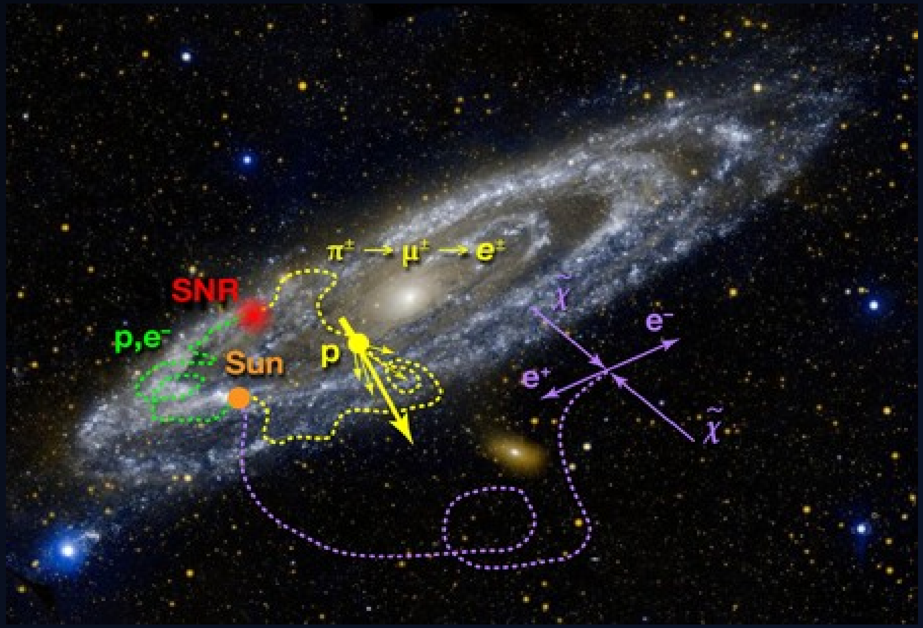


Image: GALEX, JPL-Caltech, NASA; Drawing: APS/Alan Stonebraker

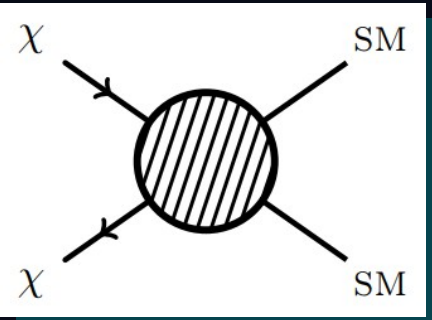
INDIRECT DETECTION vs COLLIDERS

Well defined target rate	Rate unclear
High energies	Restricted < TeV
Potential long exposure, also long time scales!	Only experiment running time
Backgrounds :(	Controlled environment

What do we see in indirect detection, and what can the LHC tell us about it?

Rebecca Leane

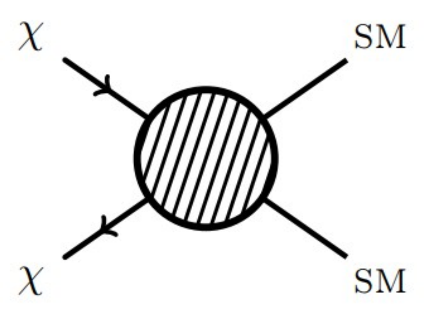
Indirect Detection Ingredients



(Neutral particles)

$$\Phi(E,\psi) = \overbrace{\frac{\sigma_{\mathrm{A}} v}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}}^{\text{Particle Physics}} \overbrace{\int d\ell\,\rho\left[r(\ell,\psi)\right]^2}^{\text{Astrophysics}}$$

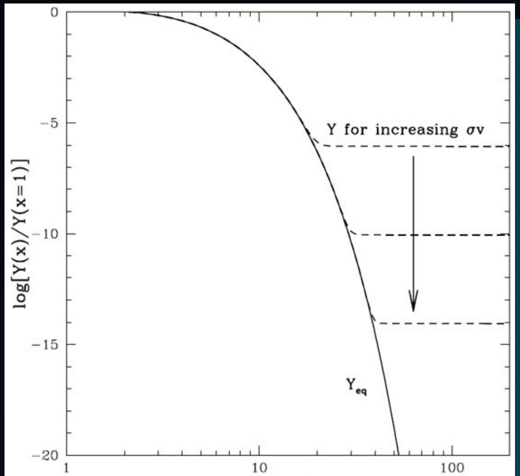
Indirect Detection Ingredients



(Neutral particles)

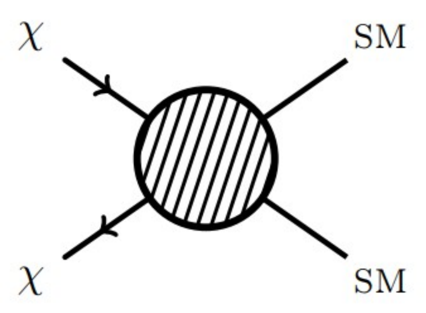
$$\Phi(E,\psi) = \overbrace{\frac{\sigma_A v}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}}^{\text{Particle Physics}} \overbrace{\int d\ell\,\rho\left[r(\ell,\psi)\right]^2}^{\text{Astrophysics}}$$

Annihilation cross section



Kolb+Turner

Indirect Detection Ingredients



Particle Physics

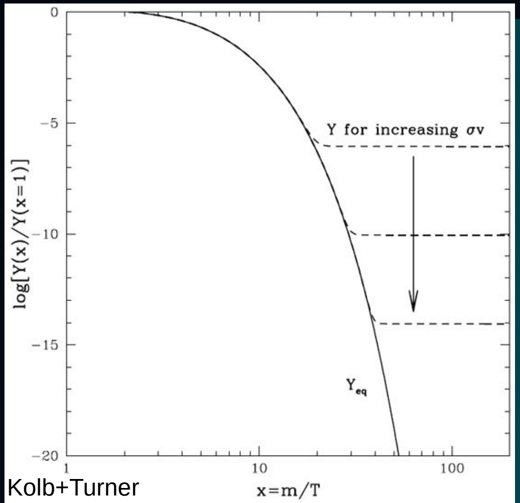
Astrophysics

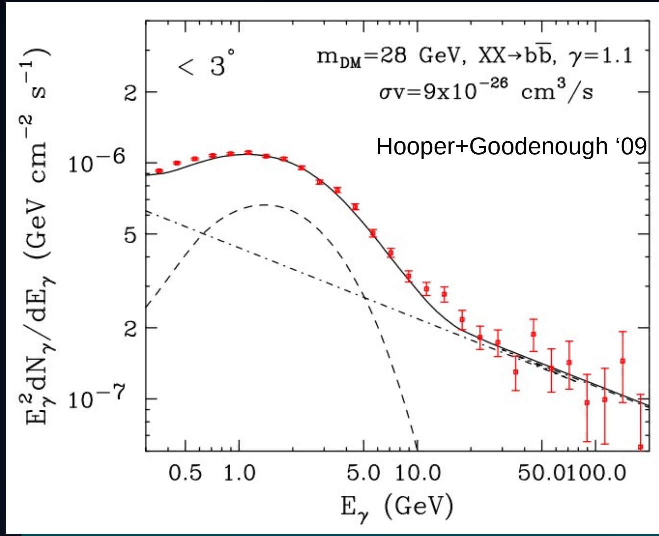
(Neutral particles)

$$\Phi(E,\psi) = \underbrace{\frac{\sigma_A v}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}}_{\text{Particle Physics}} \underbrace{\int d\ell\, \rho\left[r(\ell,\psi)\right]^2}_{\text{Astrophysics}}$$

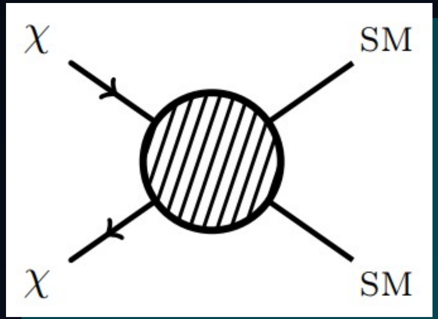
Annihilation cross section

Energy spectrum





Indirect Detection Ingredients



(Neutral particles)

Particle Physics

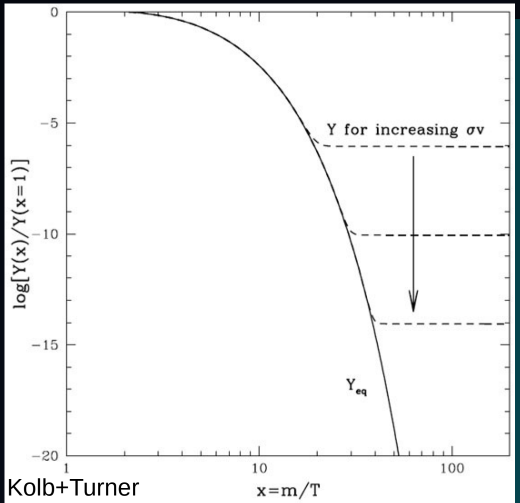
Astrophysics

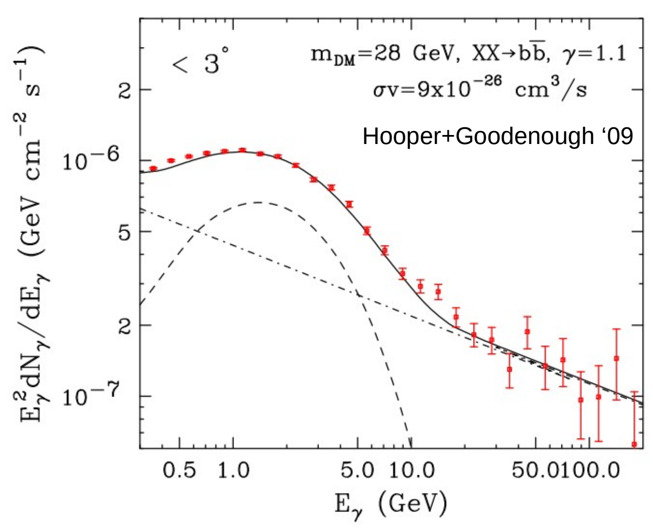
$$\Phi(E,\psi) = \frac{\sigma_A v}{8\pi m_\chi^2}\,\frac{dN_\gamma}{dE}\int d\ell\,\rho\left[r(\ell,\psi)\right]^2$$

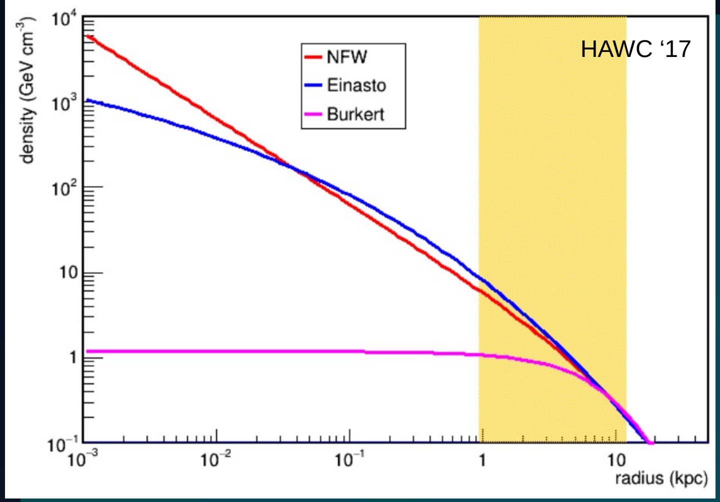
Annihilation cross section

Energy spectrum

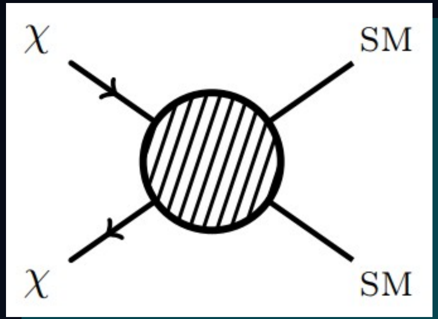
“J factor”, DM density







Indirect Detection Ingredients



Particle Physics

Astrophysics

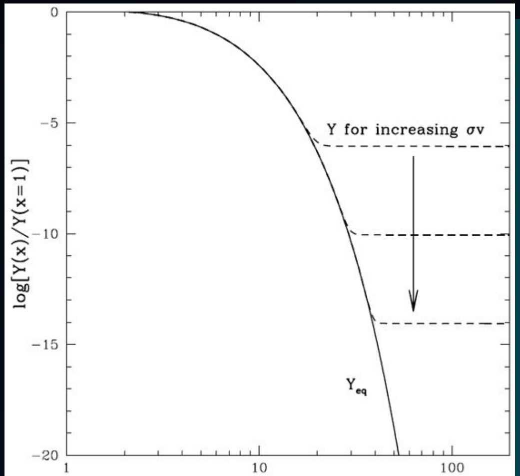
(Neutral particles)

$$\Phi(E,\psi) = \frac{\sigma_A v}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}\int d\ell\,\rho\left[r(\ell,\psi)\right]^2$$

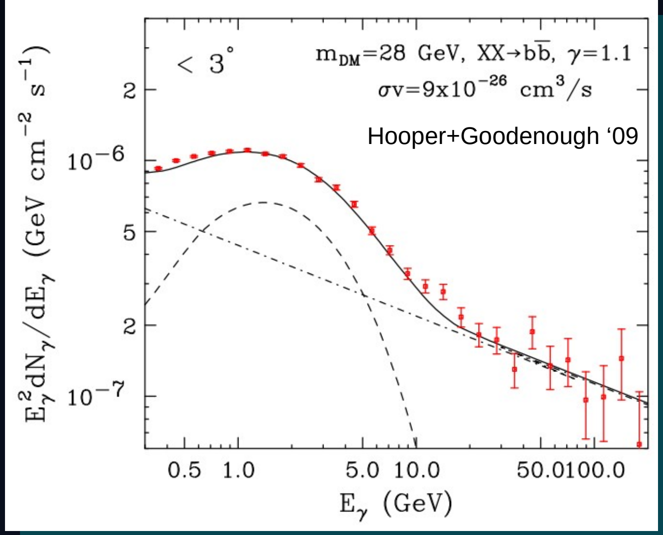
Annihilation cross section

Energy spectrum

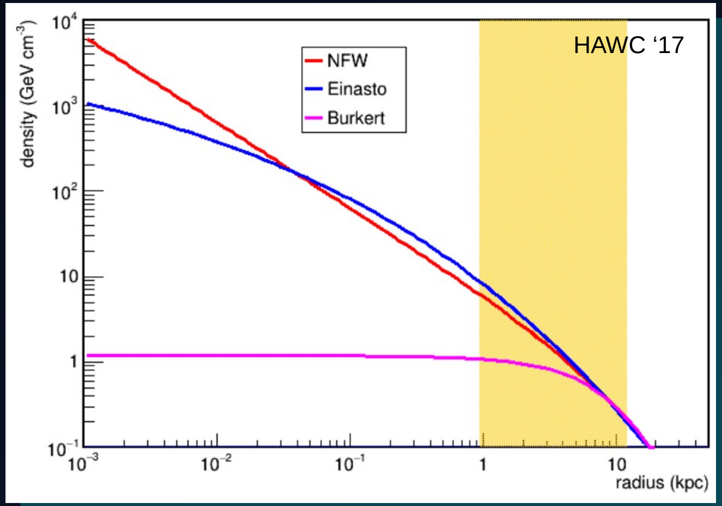
“J factor”, DM density



Kolb+Turner



Hooper+Goodenough ‘09



HAWC ‘17

Look where this is large!

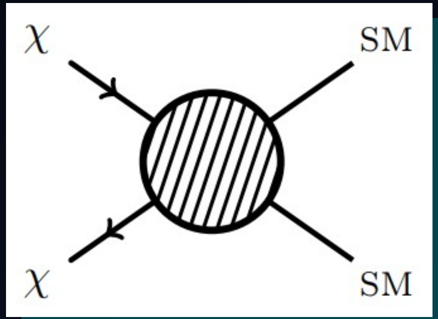
Indirect Detection Ingredients

Particle Physics

Astrophysics

(Neutral particles)

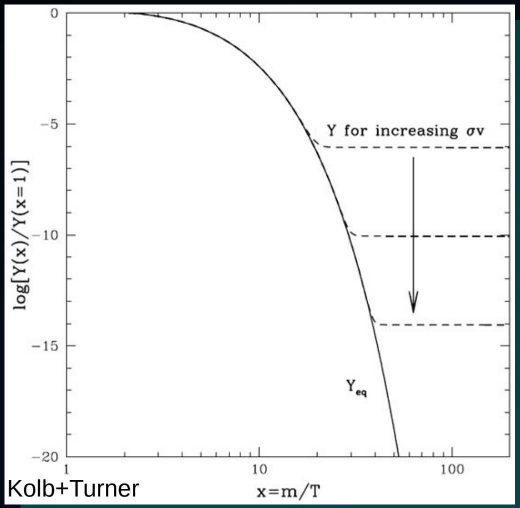
$$\Phi(E,\psi) = \frac{\sigma_A v}{8\pi m_\chi^2} \frac{dN_\gamma}{dE} \int d\ell\, \rho\left[r(\ell,\psi)\right]^2$$

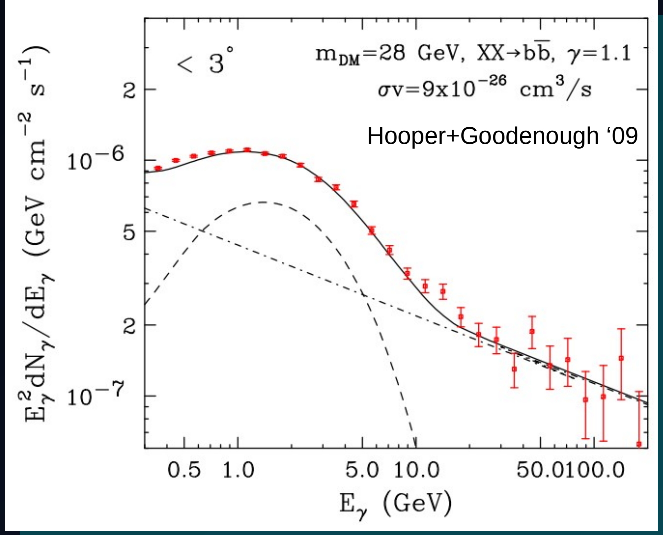


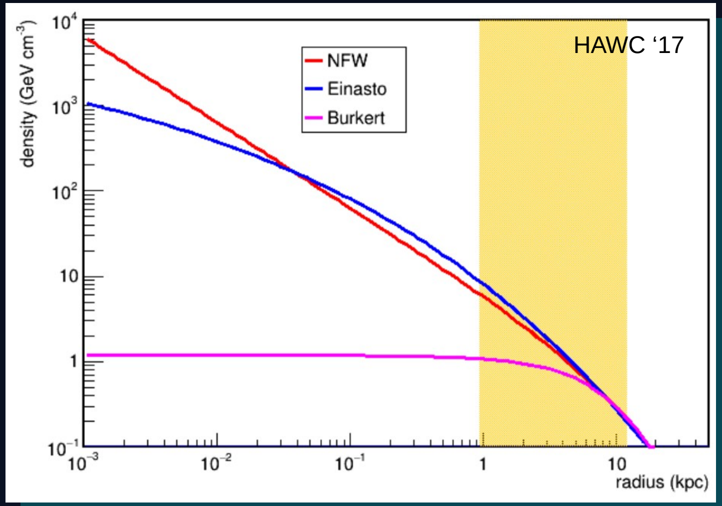
Annihilation cross section

Energy spectrum

“J factor”, DM density







Look where this is large!

...or places with low background!

GALACTIC CENTER EXCESS

Rebecca Leane

GALACTIC CENTER EXCESS

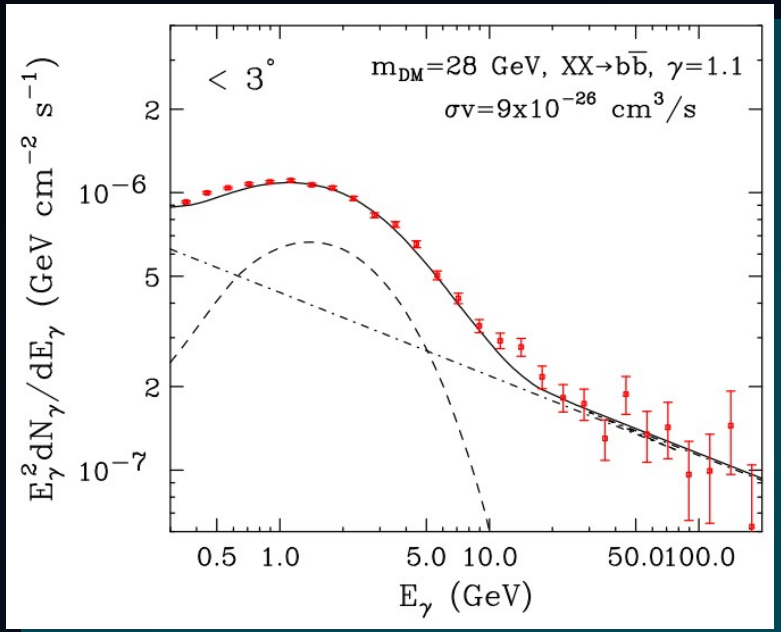
- Highly statistically significant excess in GeV gamma rays

- Consistent with a DM signal:

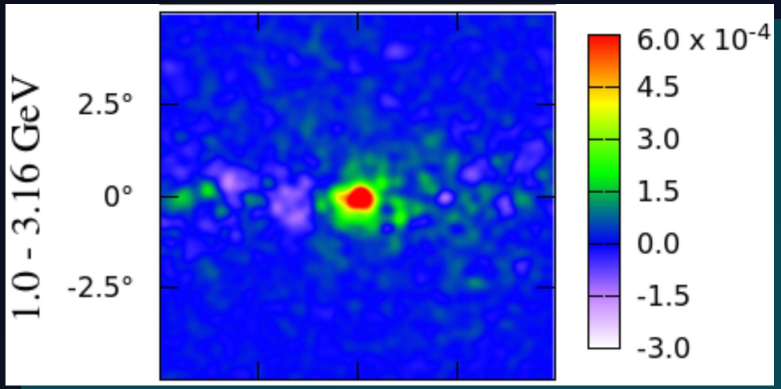
  Intensity (relic cross section) ✓

  Spectrum ✓

  Morphology ✓



Hooper+Goodenough '09



Daylan et al '14

GALACTIC CENTER EXCESS

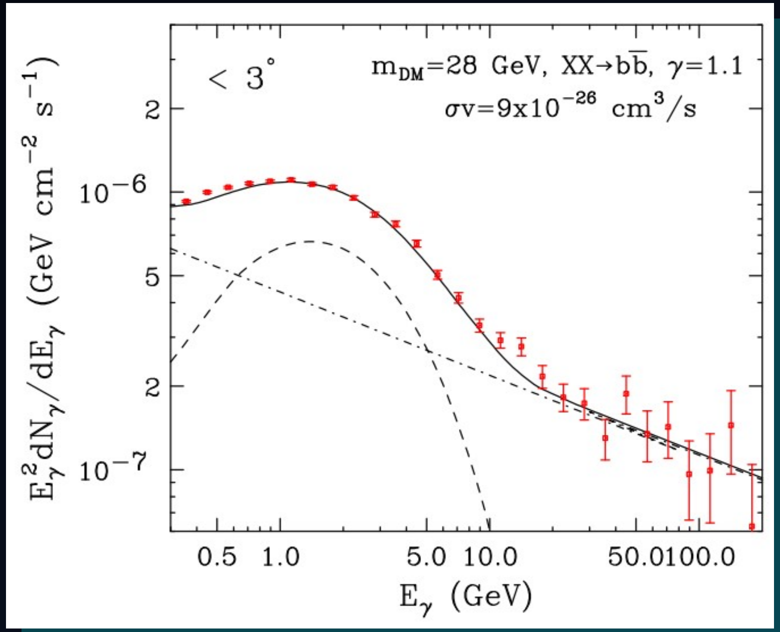
- Highly statistically significant excess in GeV gamma rays
- Consistent with a DM signal:

Intensity (relic cross section) ✓

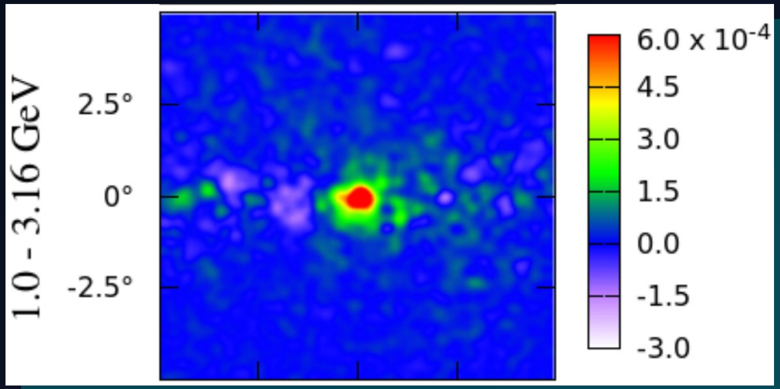
Spectrum ✓

Morphology ✓

Exciting ✓



Hooper+Goodenough '09



Daylan et al '14

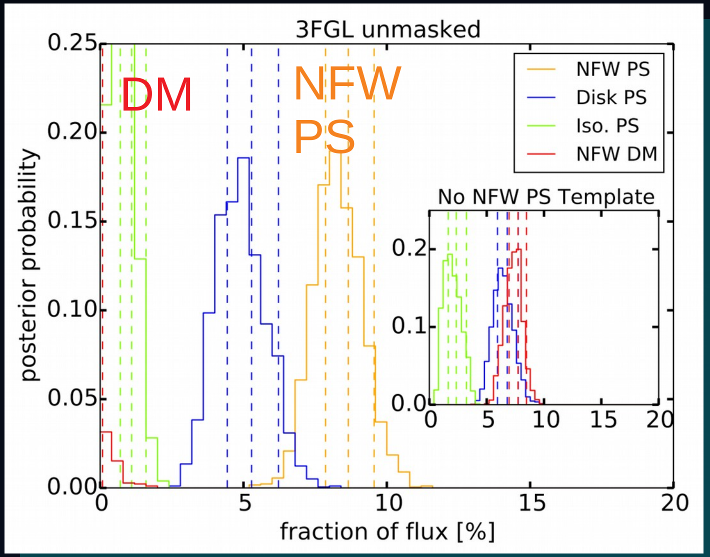
GALACTIC CENTER EXCESS

- Millisecond pulsars match energy spectrum, other questions remain

- As of ~2015, consensus of point source explanation, evidence for "clumpy" rather than "smooth" signal

Lee et al '15
Bartels et al '15

Lee et al, 2015



GALACTIC CENTER EXCESS

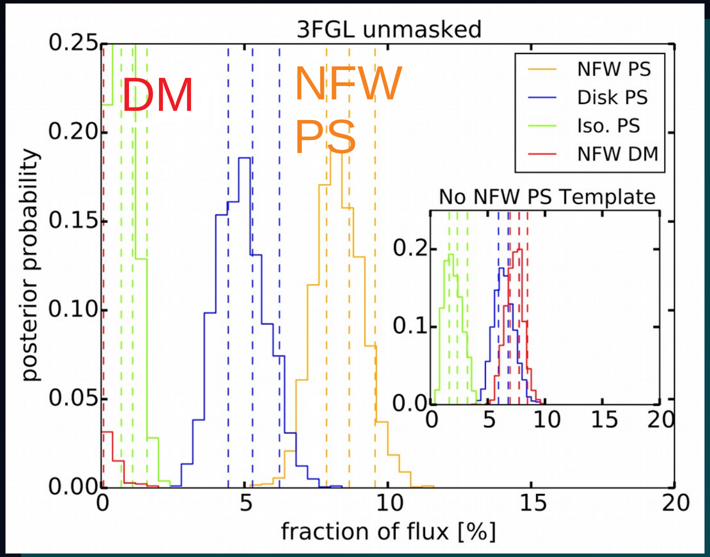
- Millisecond pulsars match energy spectrum, other questions remain
- As of ~2015, consensus of point source explanation, evidence for "clumpy" rather than "smooth" signal

Lee et al '15
Bartels et al '15

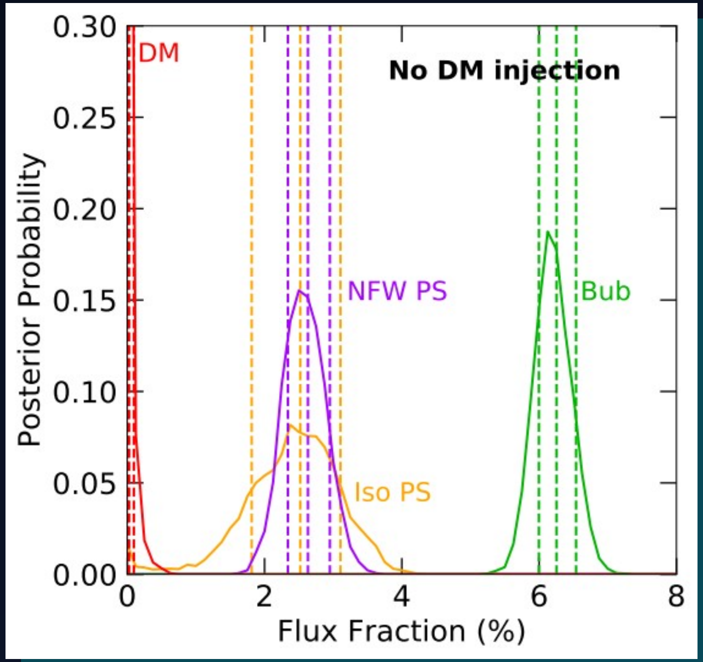
Recent developments:

Mismodelling can hide a dark matter signal !

Lee et al, 2015



RL+Slatyer, 2019



GALACTIC CENTER EXCESS

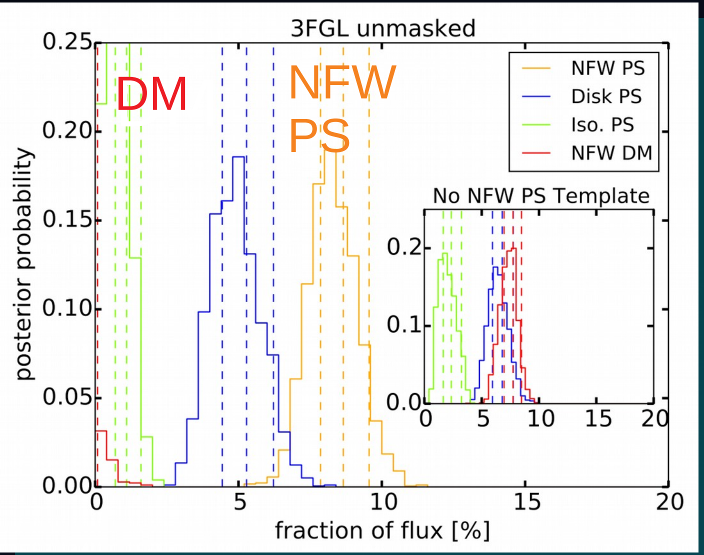
- Millisecond pulsars match energy spectrum, other questions remain
- As of ~2015, consensus of point source explanation, evidence for “clumpy” rather than “smooth” signal

Lee et al ‘15
Bartels et al ‘15

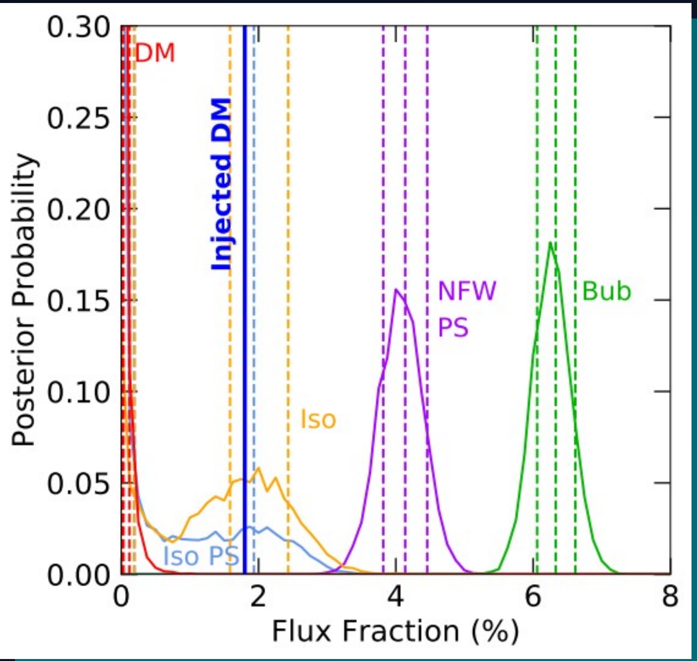
Recent developments:

Mismodelling can hide a dark matter signal !

Lee et al, 2015



RL+Slatyer, 2019



GALACTIC CENTER EXCESS

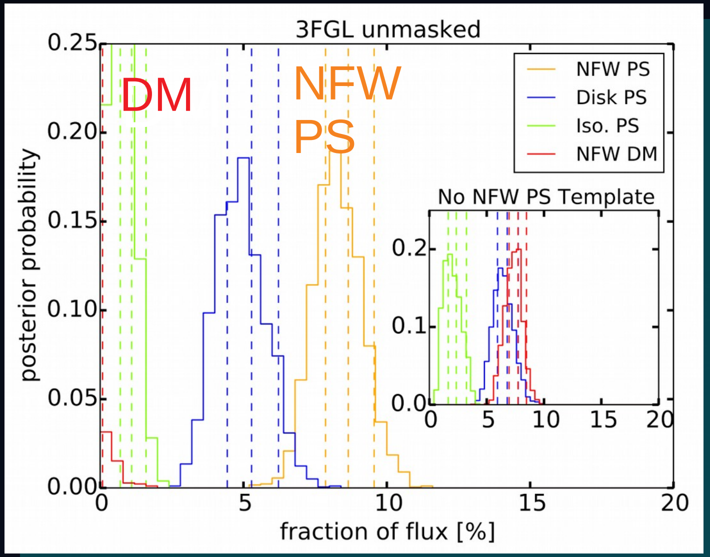
- Millisecond pulsars match energy spectrum, other questions remain
- As of ~2015, consensus of point source explanation, evidence for "clumpy" rather than "smooth" signal

Lee et al '15
Bartels et al '15

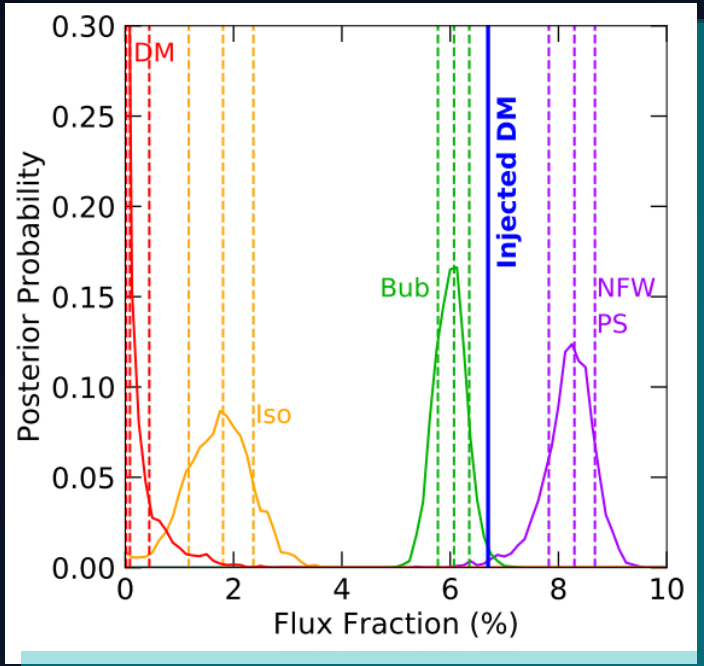
Recent developments:

Mismodelling can hide a dark matter signal !

Lee et al, 2015



RL+Slatyer, 2019

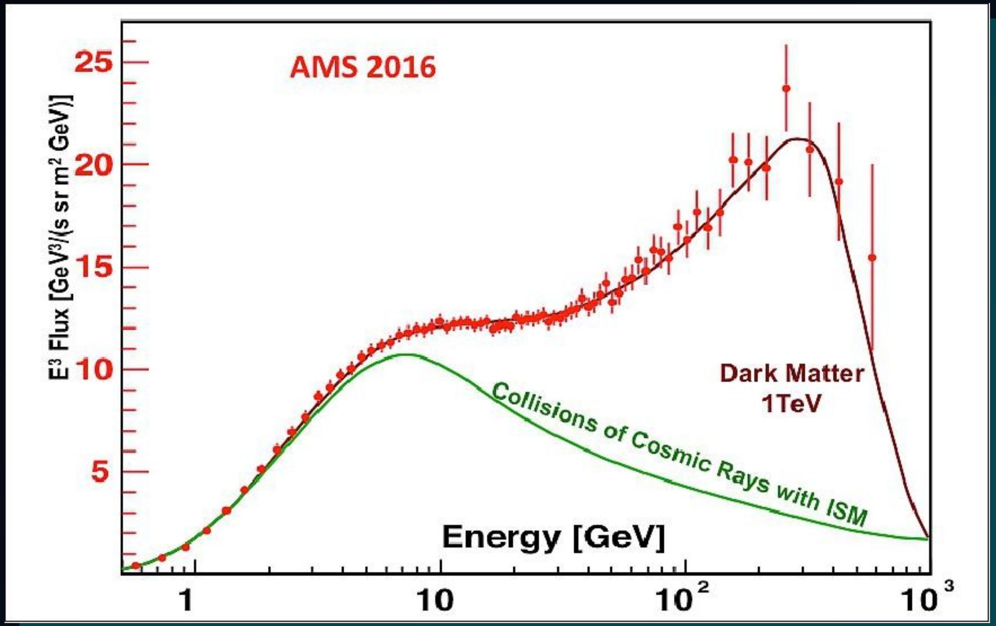


POSITRON EXCESS

Rebecca Leane

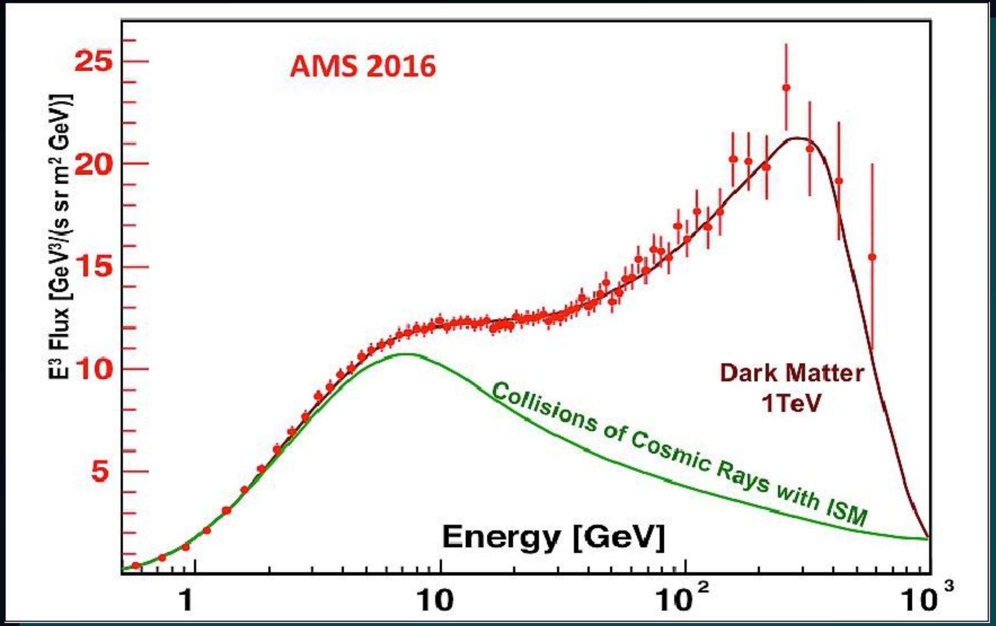
POSITRON EXCESS

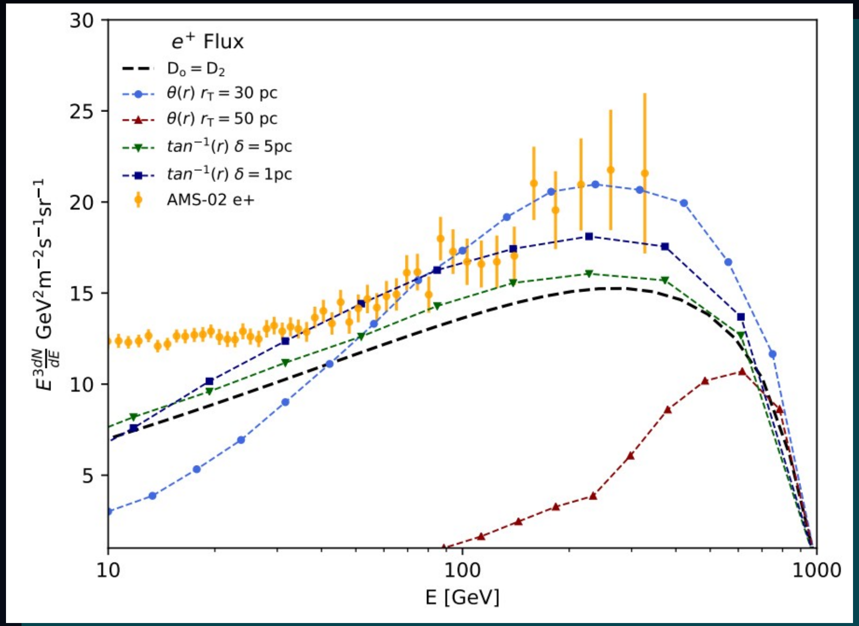
- Observed by PAMELA, AMS-02, recently DAMPE
- If DM, needs to be ~TeV
- But, could be pulsars...



POSITRON EXCESS

- Observed by PAMELA, AMS-02, recently DAMPE
- If DM, needs to be ~TeV
- But, could be pulsars…





Excess cannot be due to main pulsar candidates if Galactic diffusion similar to diffusion in regions of nearby pulsars

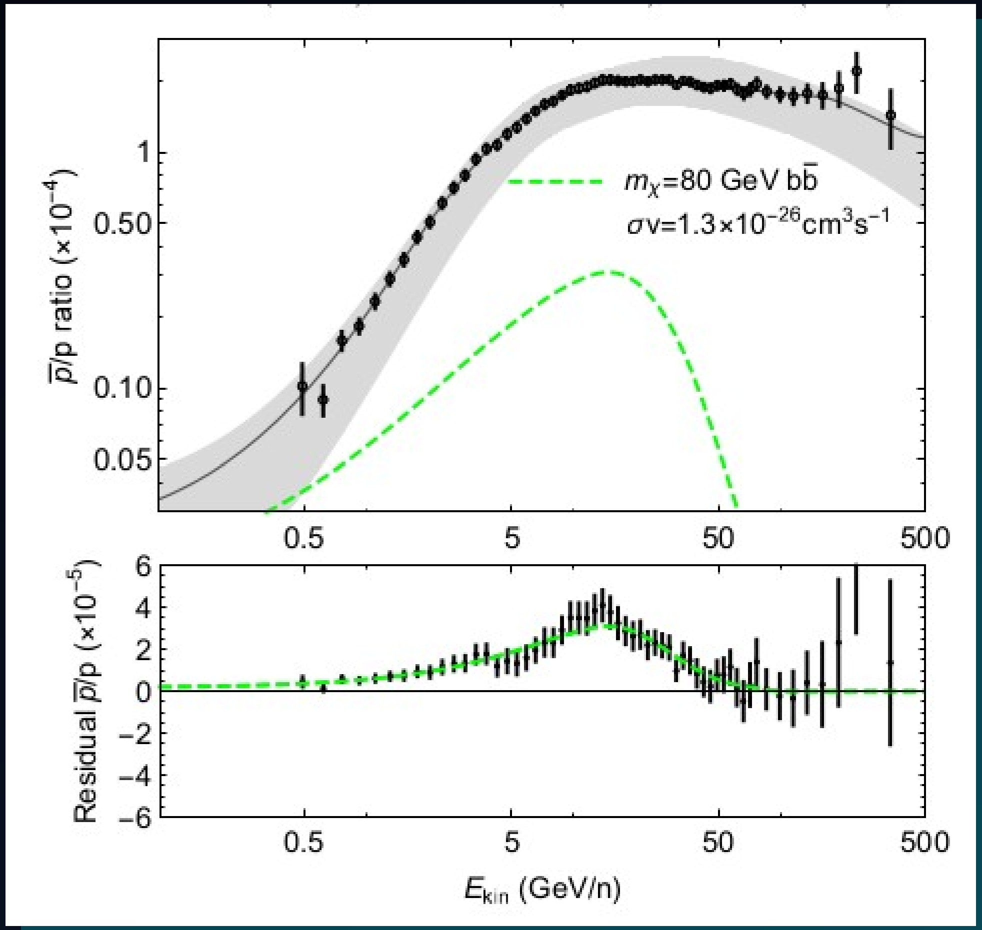
HAWC Collab, '17

Implies diffusion coefficient is not uniform

Profumo et al '18
Hooper+Linden '17

ANTIPROTON EXCESS

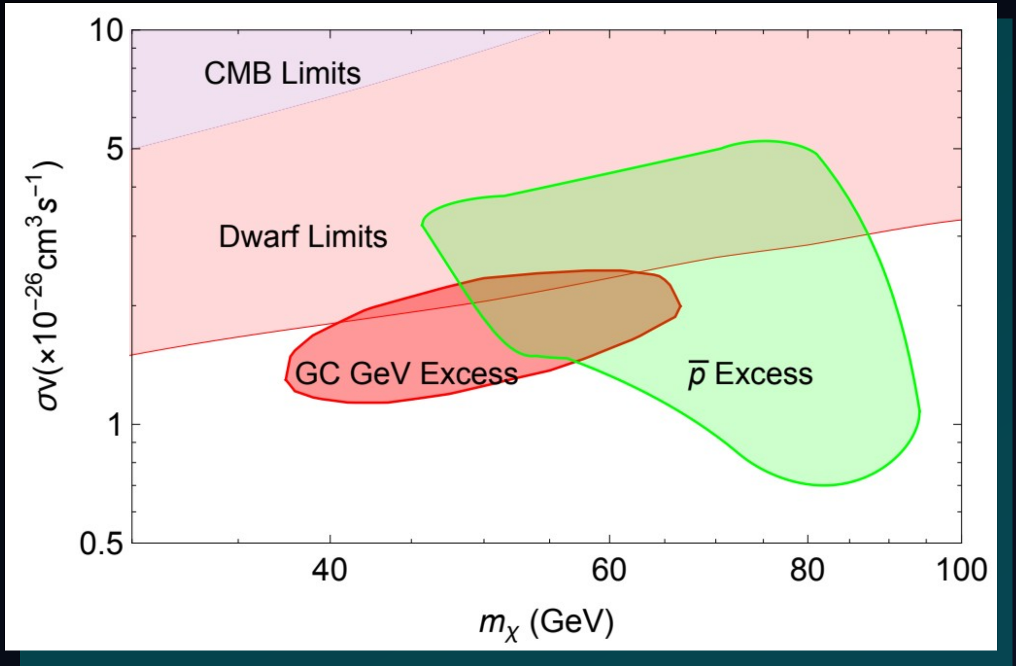
- Excess in antiprotons
- AMS correlated uncertainties?



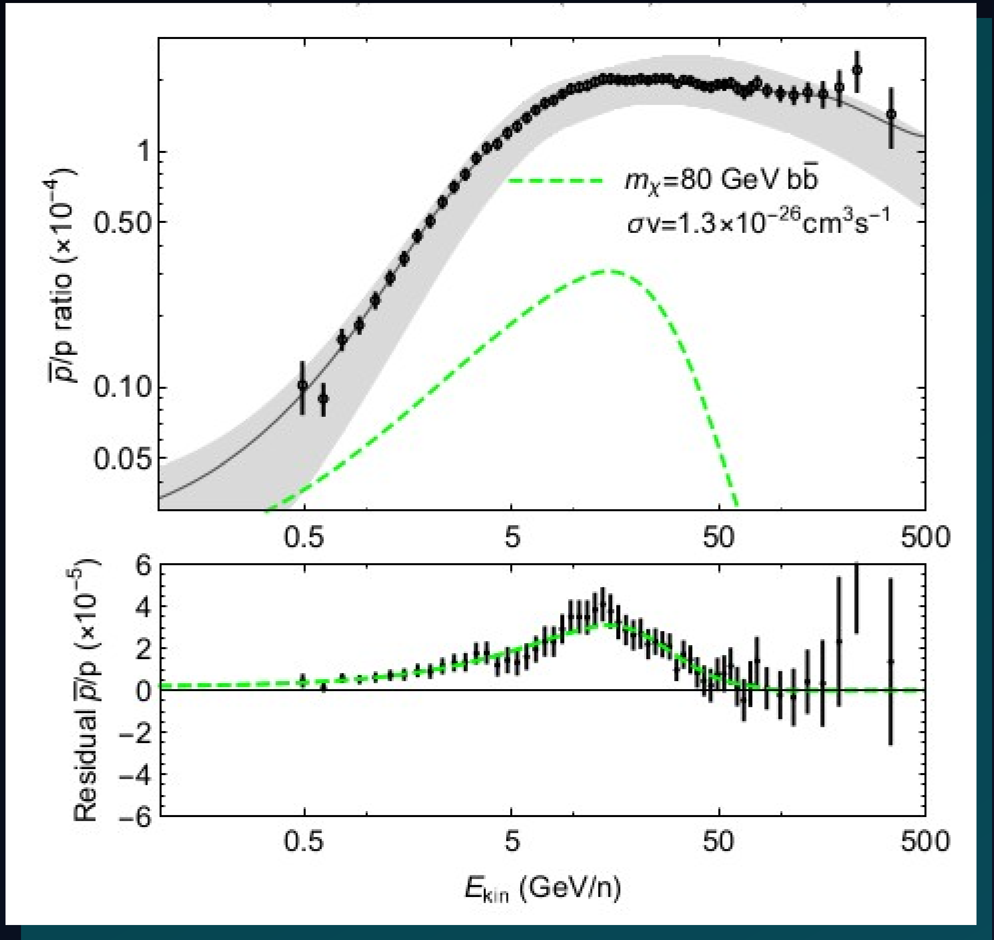
Cuoco et al ‘16 and ‘19, Cui et al ‘16 and ‘19, Cholis et al ‘19

ANTIPROTON EXCESS

- Excess in antiprotons
- AMS correlated uncertainties?
- Link to GCE? :O



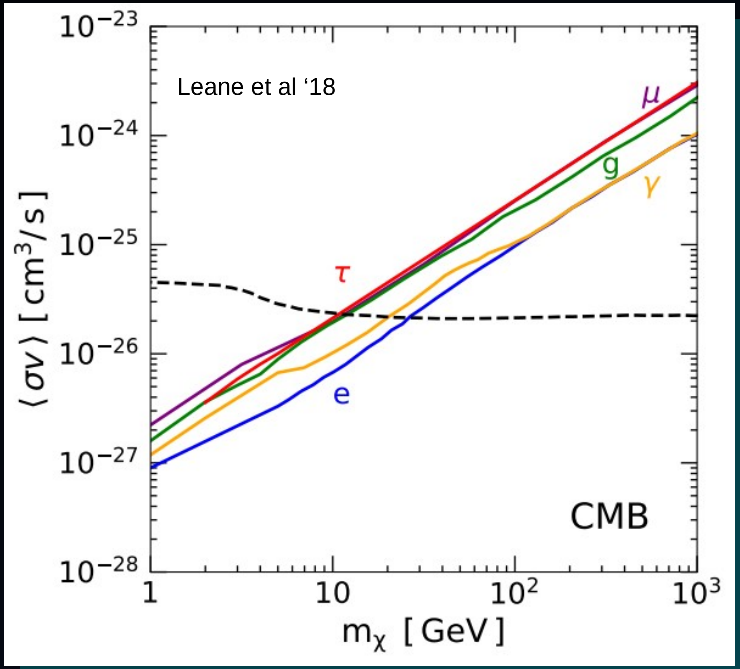
Cholis et al ‘19



Cuoco et al ‘16 and ‘19, Cui et al ‘16 and ‘19, Cholis et al ‘19

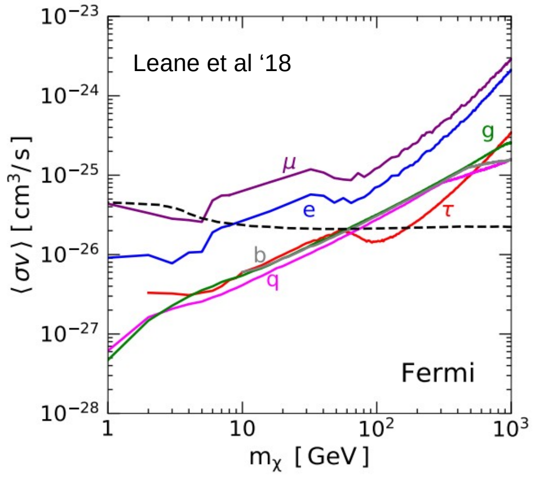
BOUNDS

Strongest low mass

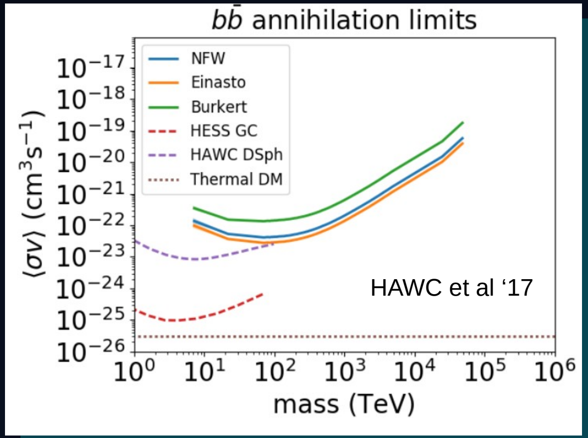


Also see Slatyer '15

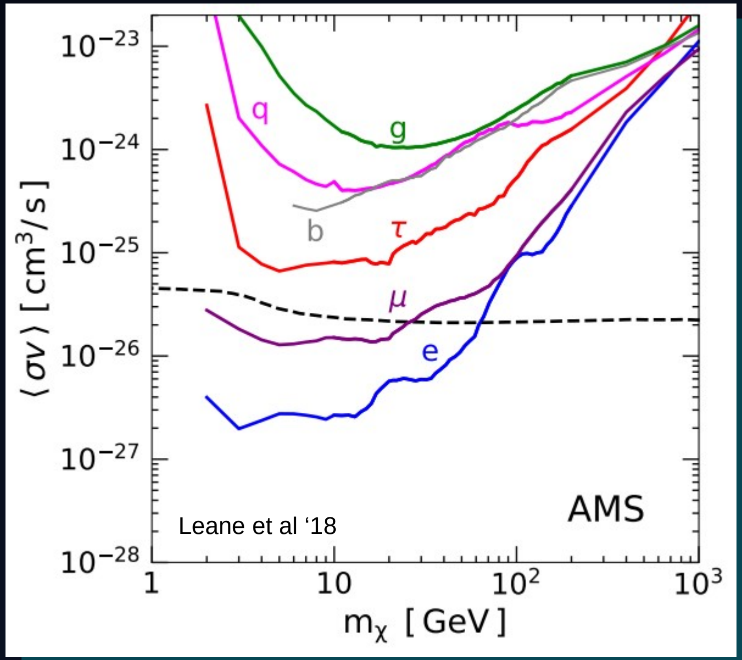
Strongest for hadrons



Also see Fermi Collab '16



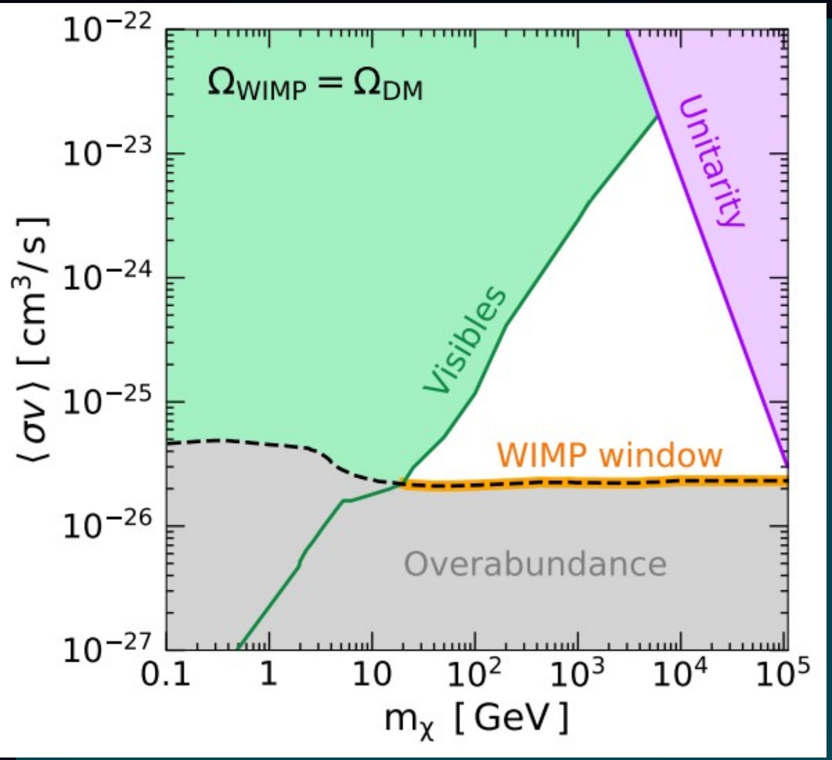
Strongest for leptons



Also see AMS collab '14

(strongest *and most robust* bounds)

COMBINING ALL CONSTRAINTS



WIMP is not dead!

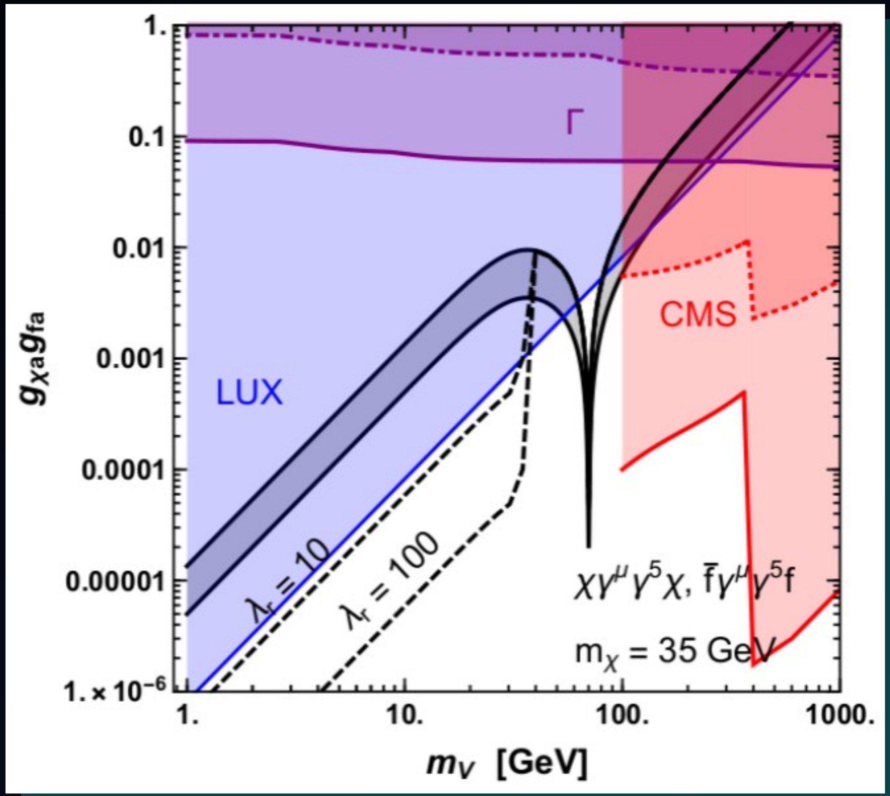
RL, Slatyer, Beacom, Ng '18

S-wave 2→2 thermal DM to visible states must have mass greater than 20 GeV

LHC CONSTRAINS RELEVANT MODELS

- To fit energy spectrum shape, want sizable coupling to hadrons, especially b-quarks
- Consider simplified models to compare minimal setup

SPIN-1 MEDIATOR SIMPLIFIED MODEL

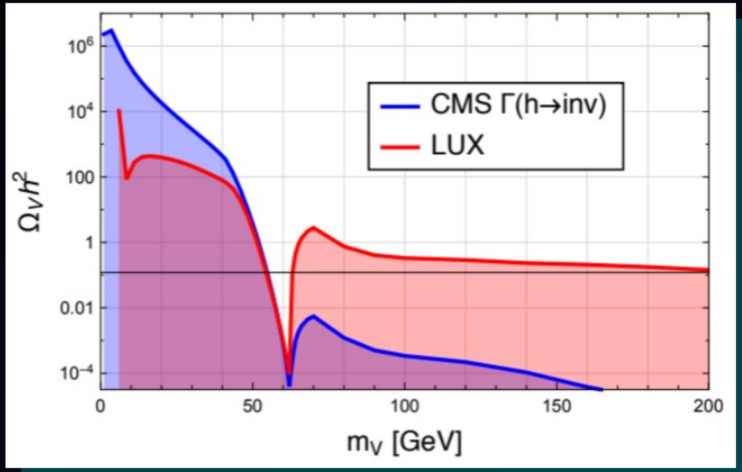


Escudero et al '16

- Vector mediator: don't even go there
- Axial vector mediator: DD suppressed, better, but have to be right on resonance (note new DD bounds…)

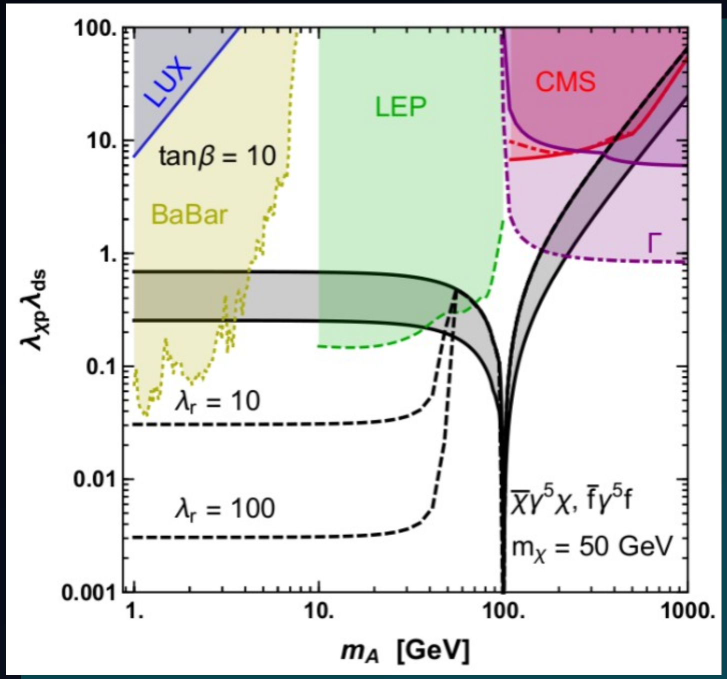
SPIN-0 MEDIATOR SIMPLIFIED MODELS

Higgs portal, spin-1 DM



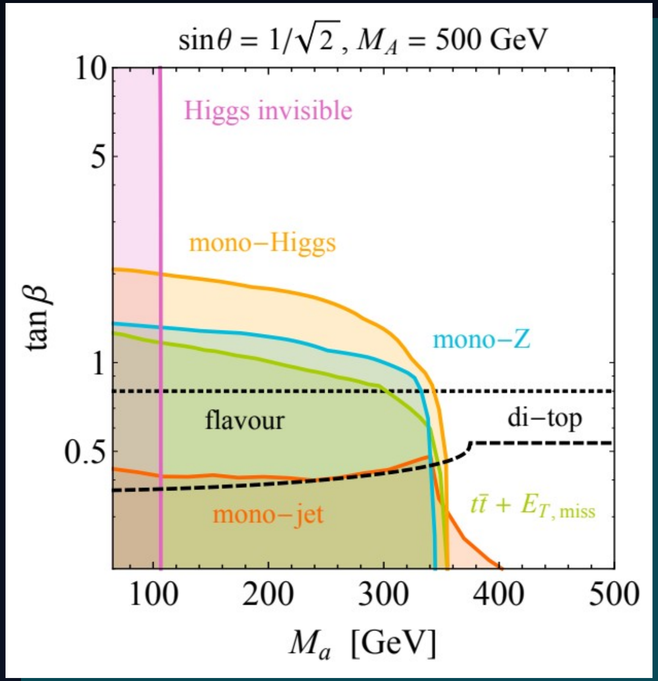
DiFranzo et al '15
(also see Djouadi et al '11)

2HDM



Escudero et al '16

2HDM+pseudoscalar

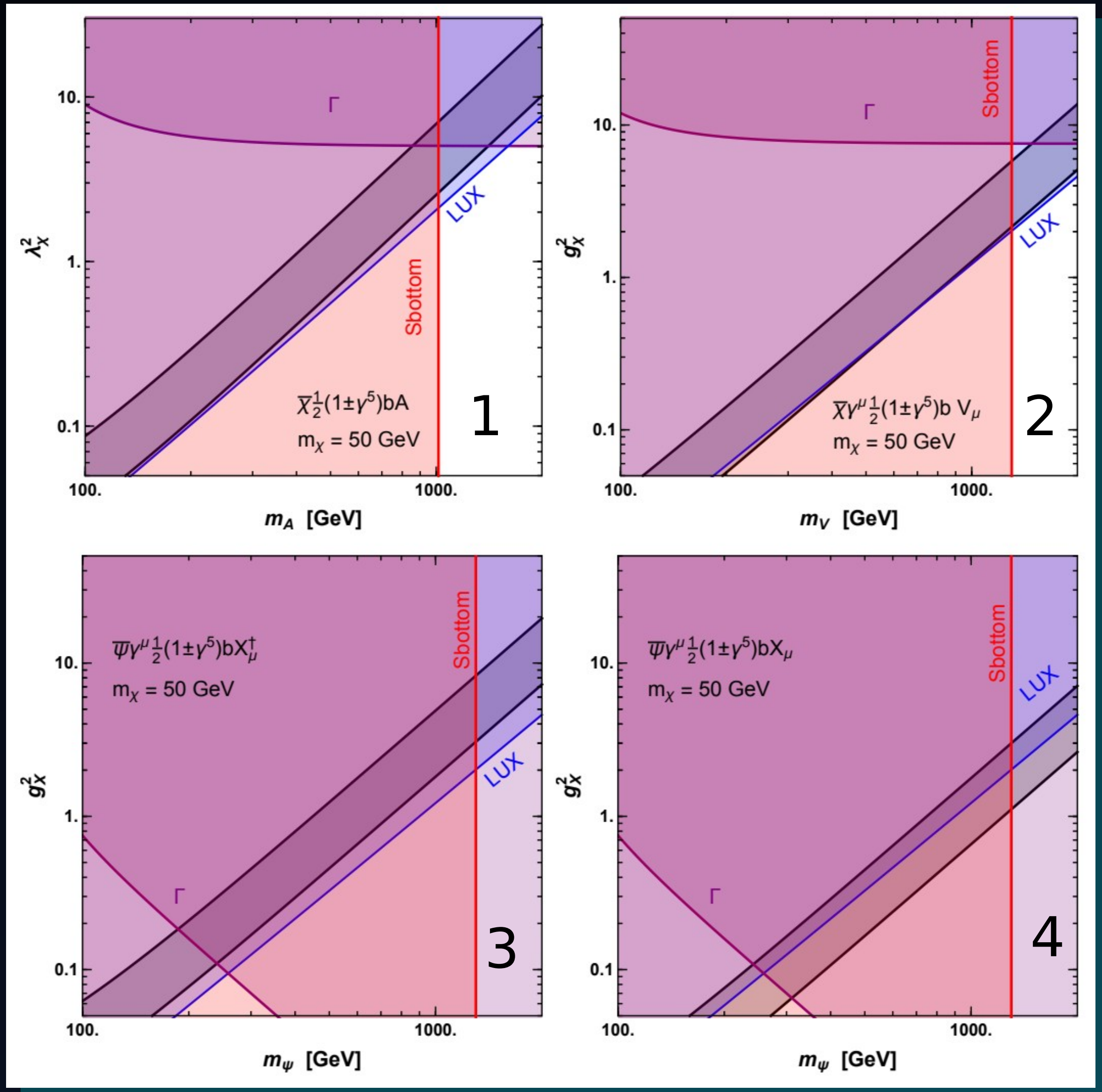


Bauer et al '17
(also see Ipek et al '14)

T-CHANNEL PROCESS

1. Dirac DM + scalar med
2. Dirac DM + vector med
3. Complex vec DM + fermonic med
4. Real vec DM + fermonic med

T-channel is out.
All excluded from CMS sbottom search and direct detection !

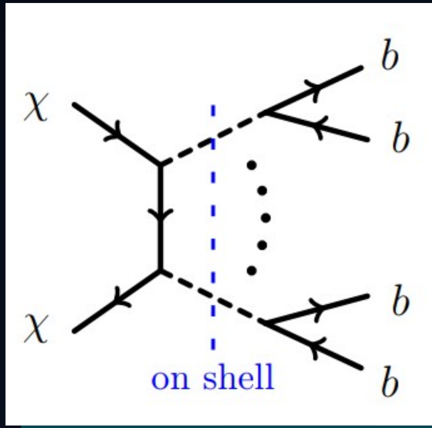


Escudero et al ‘16

HIDDEN SECTOR MODELS

- Colliders (coupled with direct detection) exclude viable models for indirect detection excesses

- Consider instead a hidden sector model (small couplings to the SM, abundance set only by dark coupling), can get both excesses very nicely



Abdullah et al '14

Abdullah et al '14
Boehm et al '14
Berlin et al '14

Also see
Escudero et al '17

SUMMARY

- Indirect detection very exciting right now, especially interesting given potential overlaps in GCE and antiproton signals
- Indirect detection best probe for higher masses/energies, longer lifetimes
- LHC sets powerful constraints on DM models, key to moving forward
- Hidden sectors work well for indirect detection, collider and direct detection bounds greatly weakened
- Interplay interesting moving forward: increased DM parameter space probed, colliders important to distinguish model types more generally

EXTRA SLIDES

Massachusetts Institute of Technology