A search for dark matter annihilation in the newly discovered dwarf galaxy Reticulum 2

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In collaboration with
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arXiv:1503.02320,1410.2242

Fermilab March 31, 2015

Dark matter

Large scales — gravity

Microscopic physics — what *is* it?

Look for its *particle interactions*

Gamma-rays — Fermi satellite

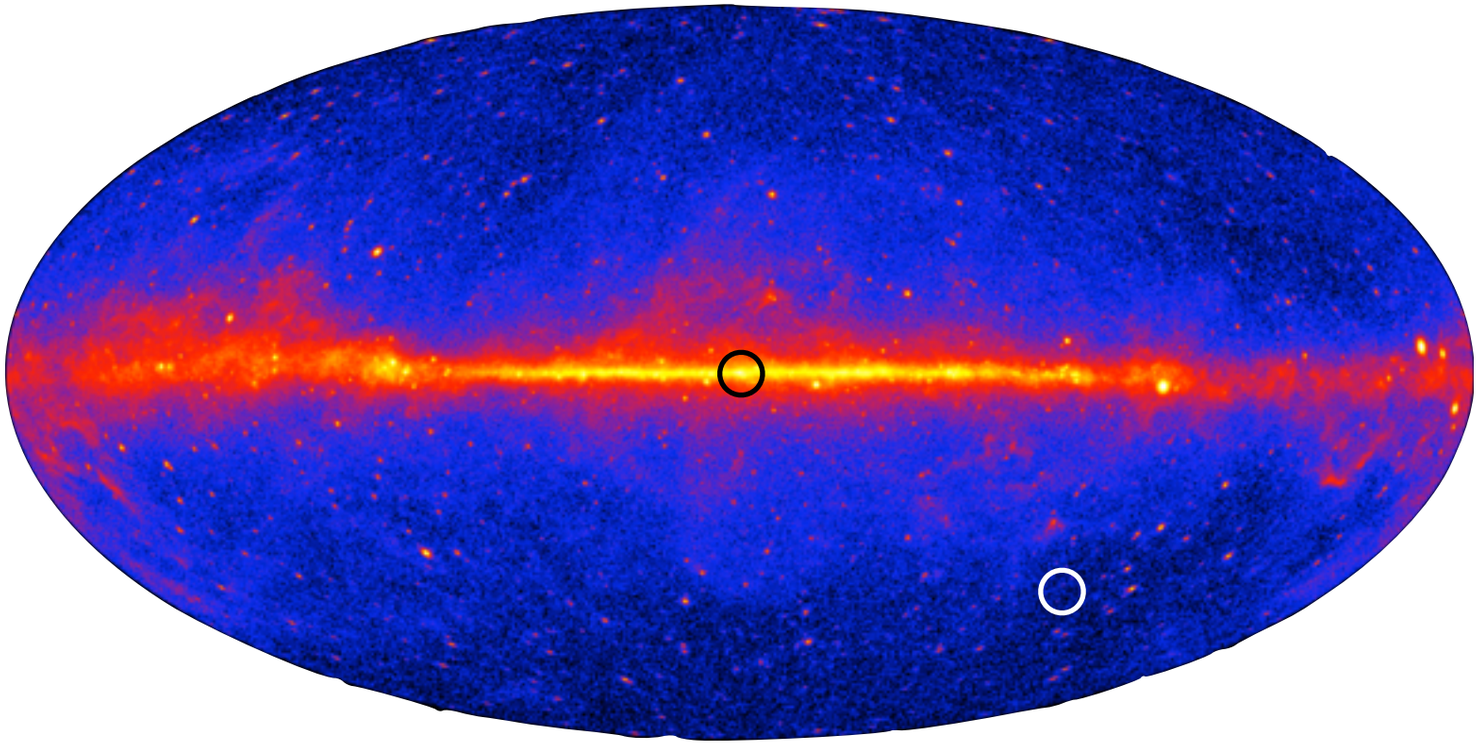
Milky Way dwarf galaxies

Nearby

Lots of dark matter

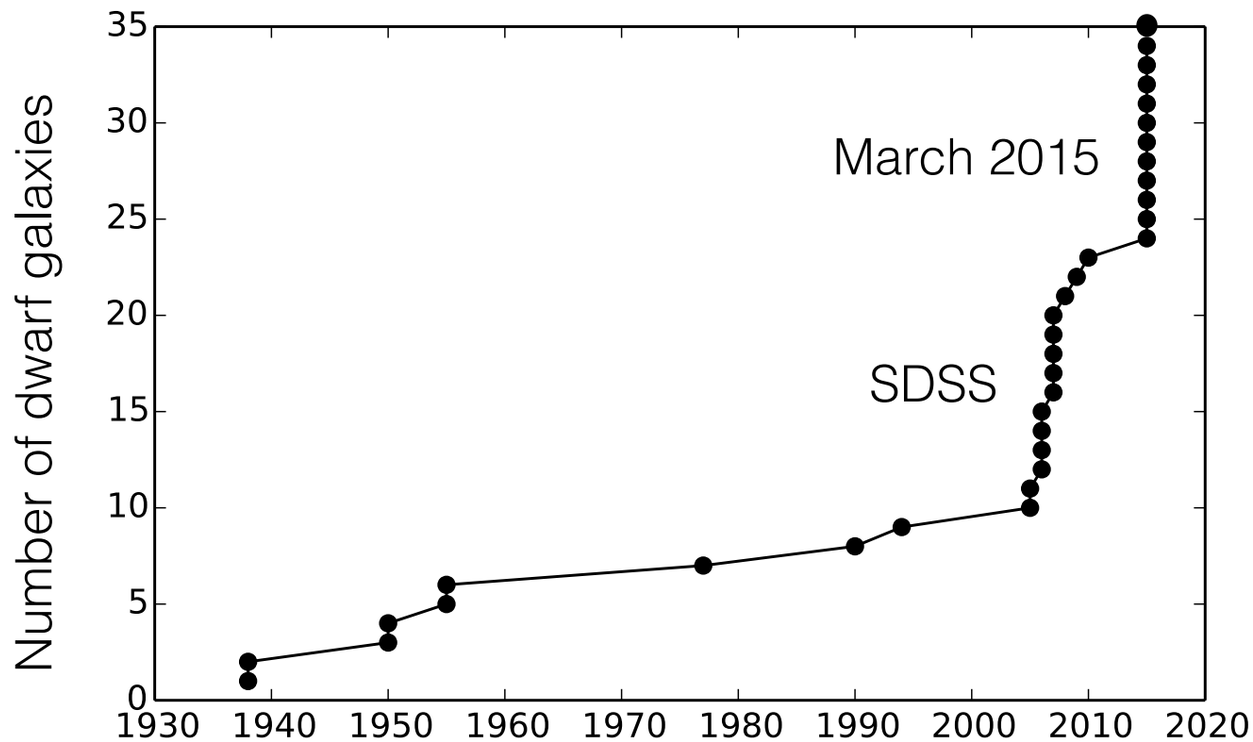
Not much else —> no astrophysical background

This is important! e.g. Galactic center



Powerful search methods

Milky Way dwarf galaxies



March 10

BEASTS OF THE SOUTHERN WILD. DISCOVERY OF A LARGE NUMBER OF ULTRA FAINT SATELLITES IN THE VICINITY OF THE MAGELLANIC CLOUDS.

Sergey E. Koposov, Vasily Belokurov, Gabriel Torrealba, and N. Wyn Evans

March 10

Eight New Milky Way Companions Discovered in First-Year Dark Energy Survey Data

K. Bechtol[1,†], A. Drlica-Wagner[2,†], E. Balbinot[3,4], A. Pieres[5,4], J. D. Simon[6], B. Yanny[2], B. Santiago[5,4], R. H. Wechsler[7,8,11], J. Frieman[2,1], A. Walker[9], P. Williams[1], E. Rozo[10,11], E. S. Rykoff[11], A. Queiroz[5,4], E. Luque[5,4], A. Benoit-Lévy[12], R. A. Bernstein[6], D. Tucker[2]

March 18

A NEW FAINT MILKY WAY SATELLITE DISCOVERED IN THE PAN-STARRS1 3π SURVEY

Benjamin P. M. Laevens[1,2], Nicolas F. Martin[1,2], Rodrigo A. Ibata[1], Hans-Walter Rix[2], Edouard J. Bernard[3], Eric F. Bell[4], Branimir Sesar[2], Annette M. N. Ferguson[3], Edward F. Schlafly[2], Colin T. Slater[4], William S. Burgett[5], Kenneth C. Chambers[6], Heather Flewelling[6], Klaus A. Hodapp[6], Nicholas Kaiser[6], Rolf-Peter

March 20

HYDRA II: A FAINT AND COMPACT MILKY WAY DWARF GALAXY FOUND IN THE SURVEY OF THE MAGELLANIC STELLAR HISTORY

Nicolas F. Martin[1,2], David L. Nidever[3], Gurtina Besla[4], Knut Olsen[5], Alistair R. Walker[6], A. Katherina

March 31

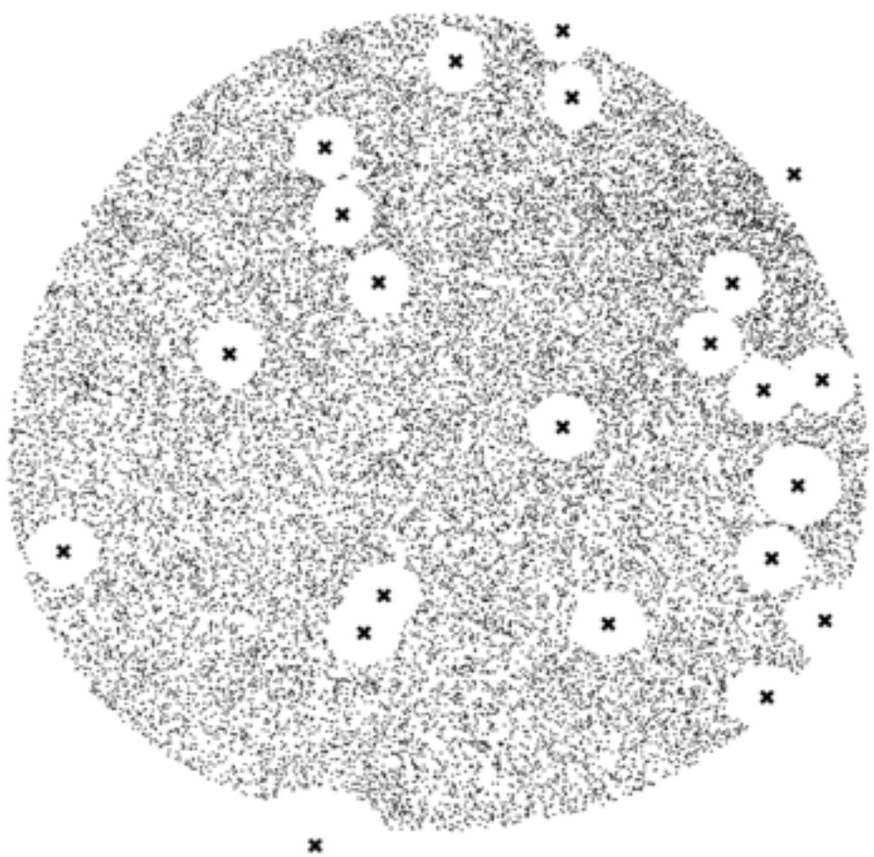
A HERO'S DARK HORSE: DISCOVERY OF AN ULTRA-FAINT MILKY WAY SATELLITE IN PEGASUS

Dongwon Kim, Helmut Jerjen, Dougal Mackey, Gary S. Da Costa, and Antonino P. Milone

Reticulum 2

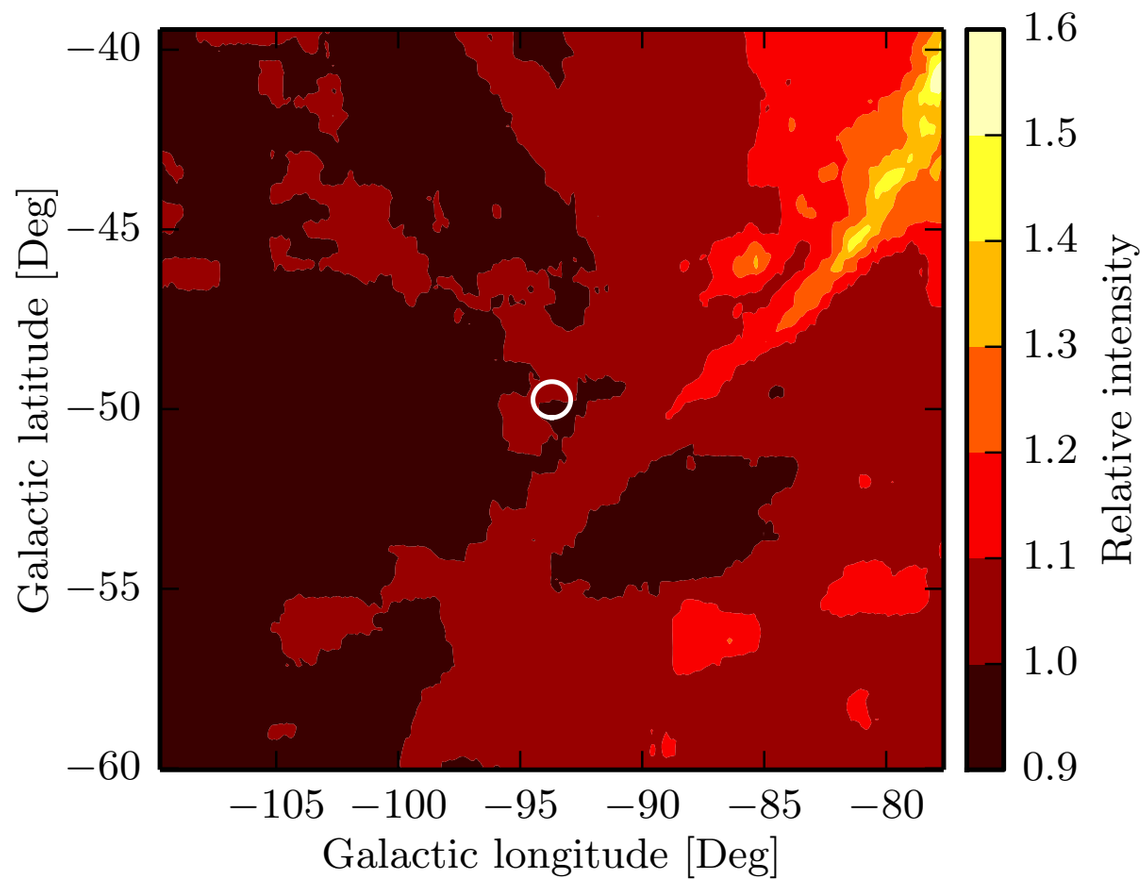
nearest of the new DES dwarfs (30 kpc)

Gamma-rays 1-300 GeV



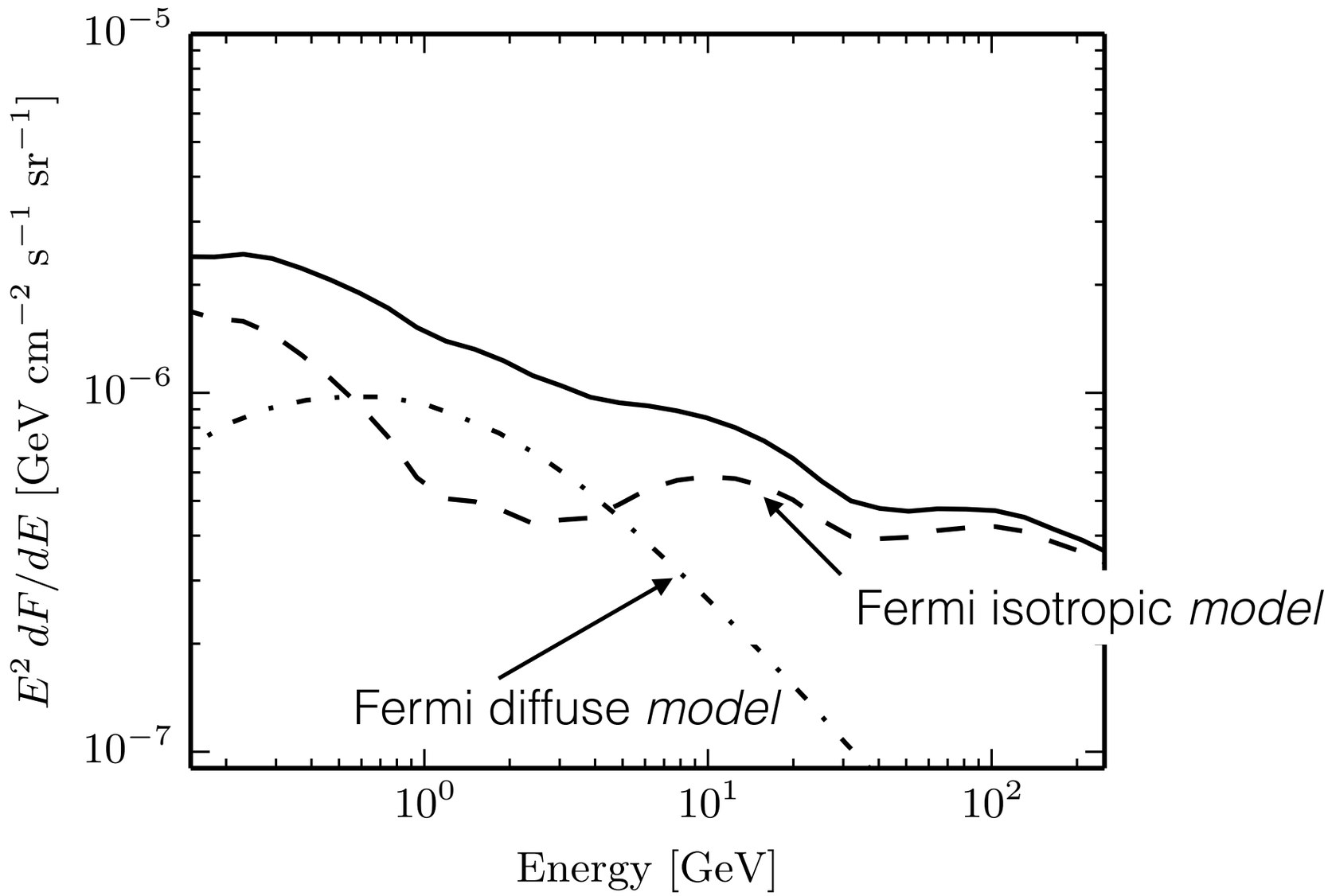
Far away from known sources

Gamma-ray background model at 8 GeV



Uniform background

A first look at the gamma-ray signal



AGS et. al. arXiv:1503.02320

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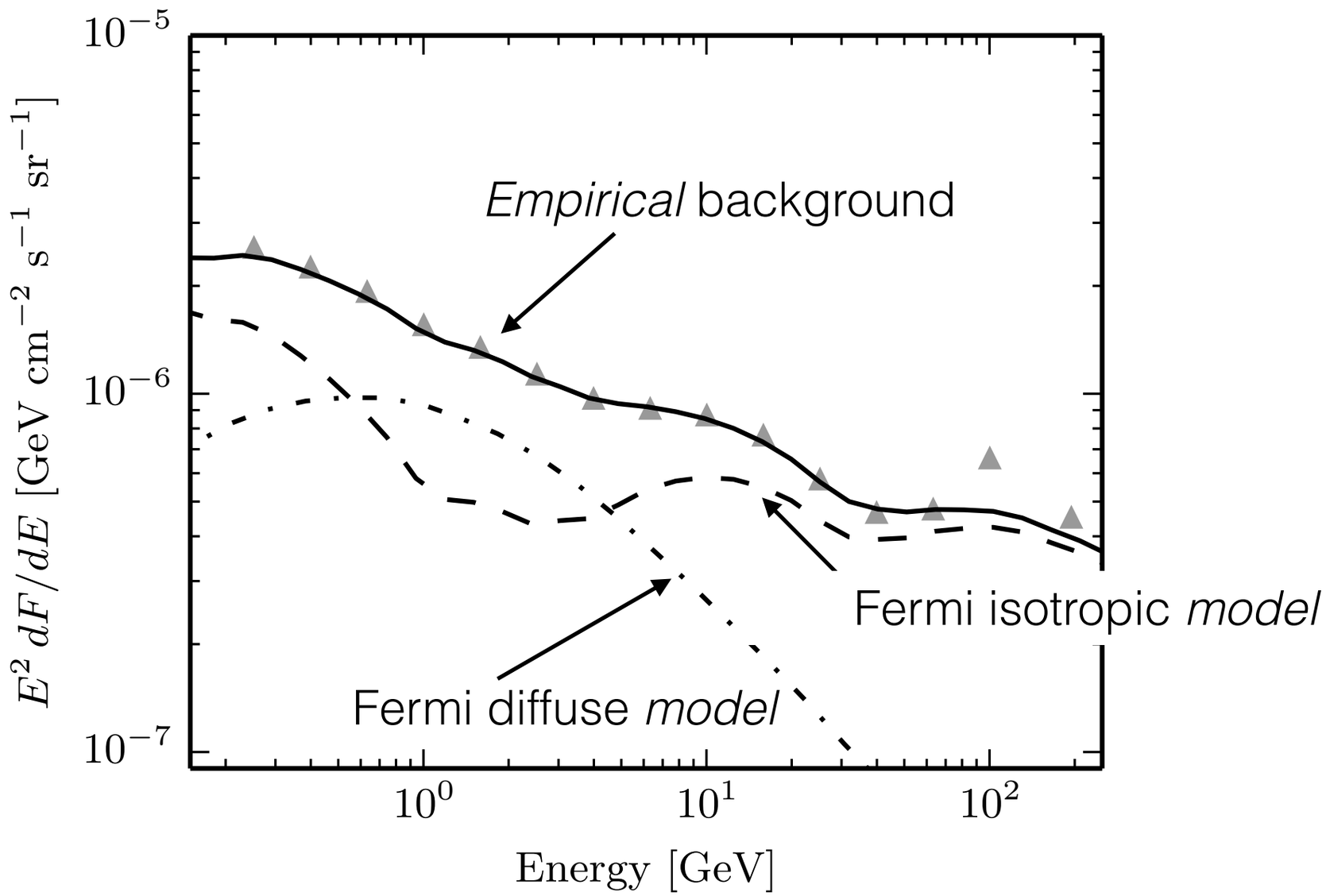

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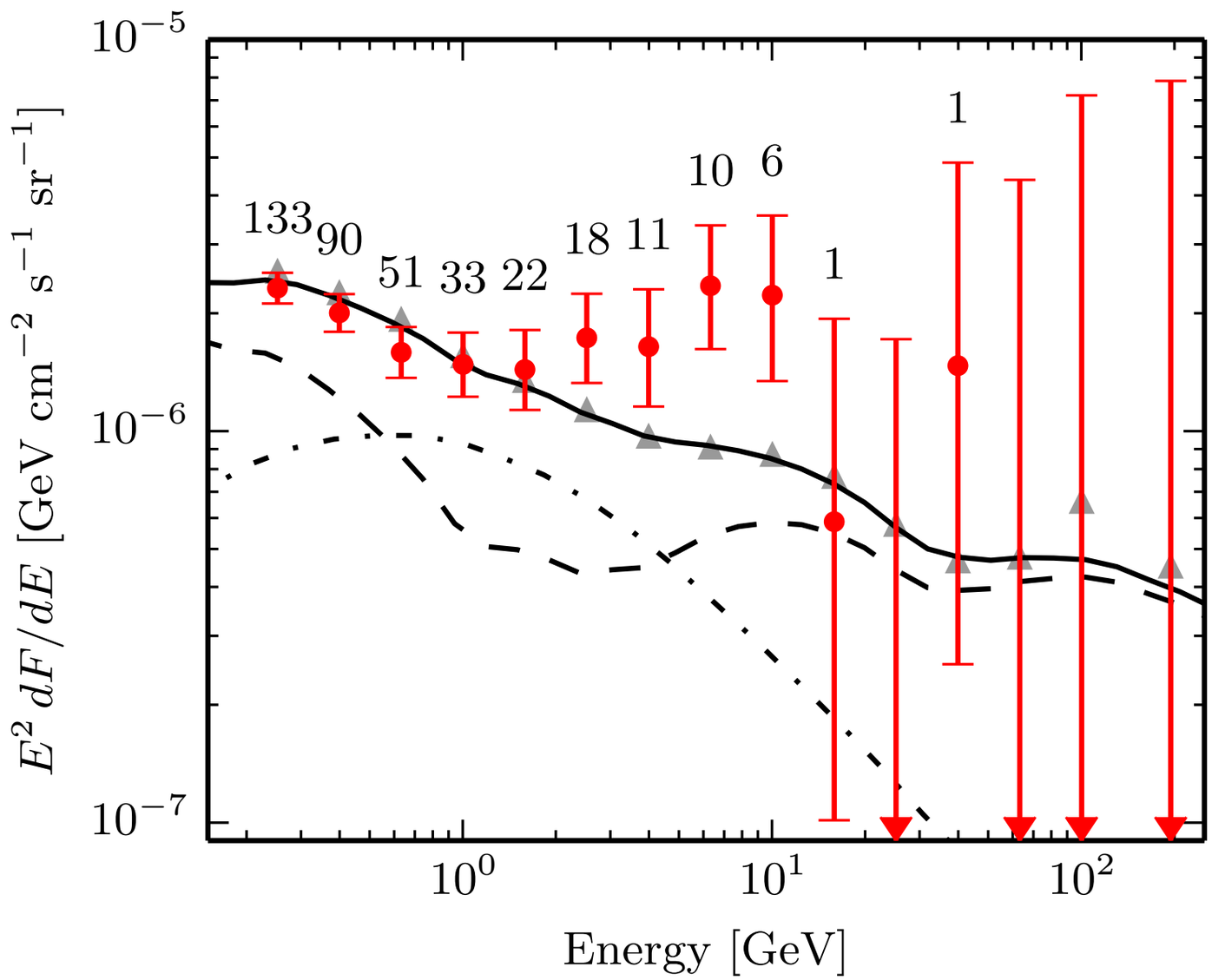


Events within 0.5° of Ret2

AGS et. al. arXiv:1503.02320

Statistical procedure

Need to quantify the significance of the signal (e.g. *p*-value)

Each photon gets a weight

$$T = \sum_{i \in \text{photons}} w(Q_i)$$

sum over all observed events

$$w_Q = \log\left(1 + \frac{s_Q}{b_Q}\right)$$

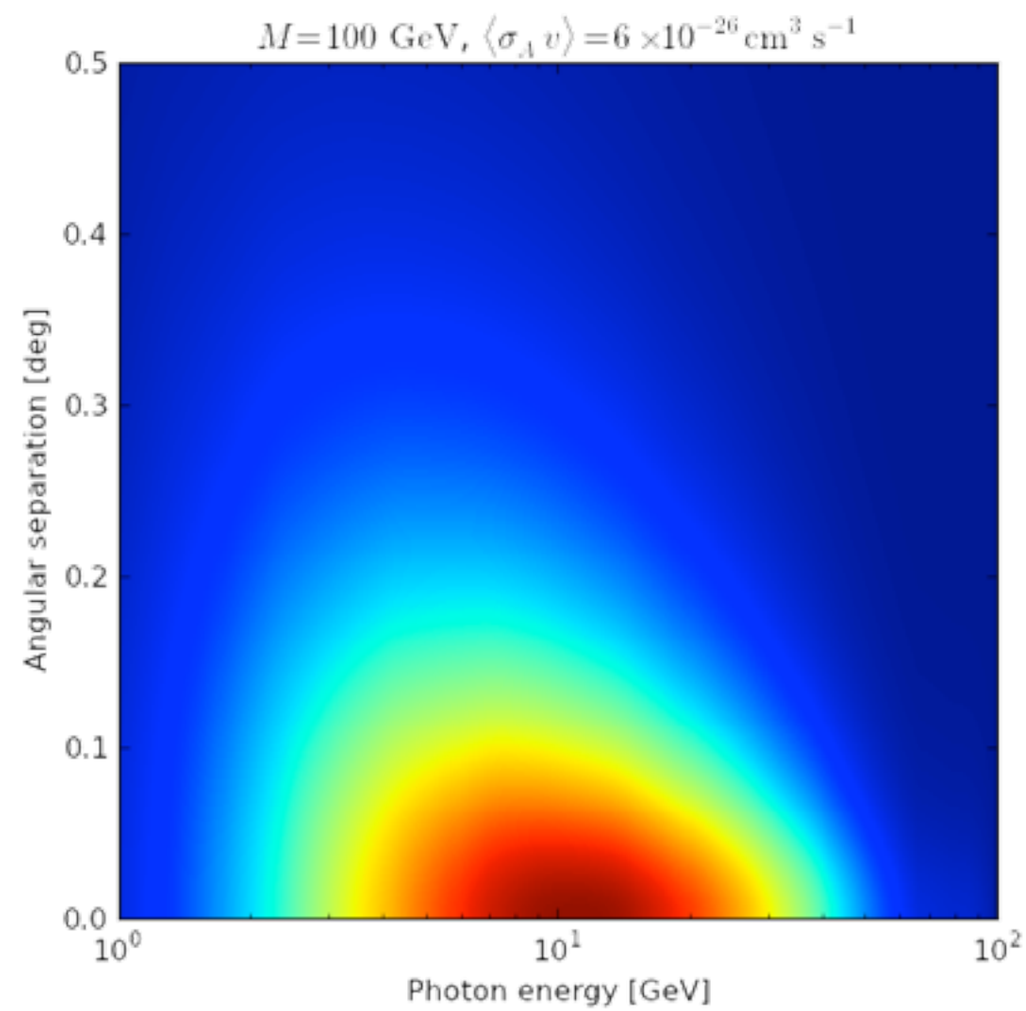
signal

background

Weight of photon is based on:

- Energy
- Angular separation from location of dwarf

$\Big\}\ Q_i$

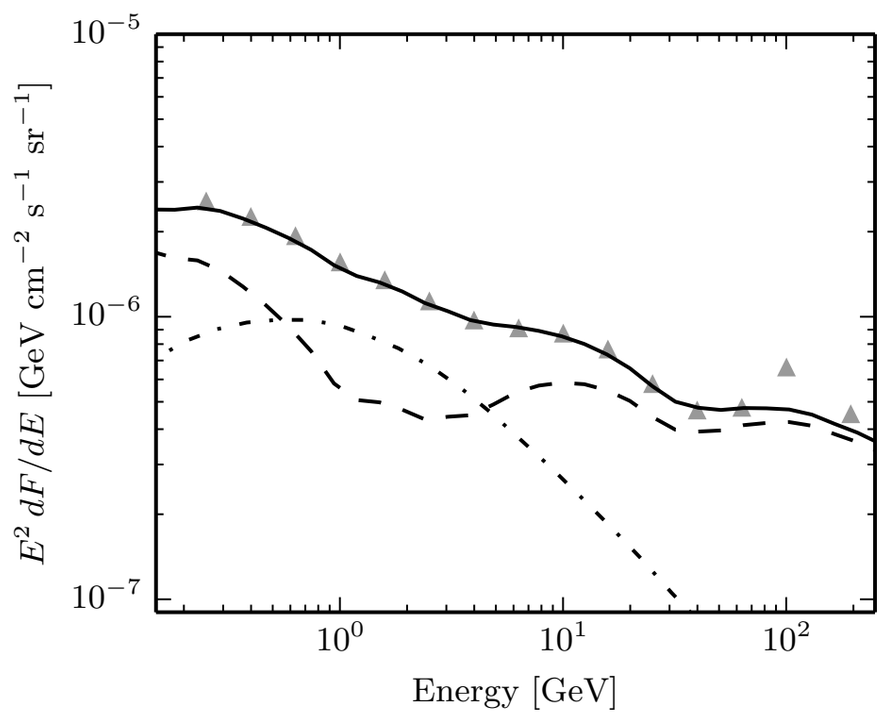


AGS, Koushiappas, Walker 1410.2242 (PRD accepted)

Background modeling

Poisson process background:

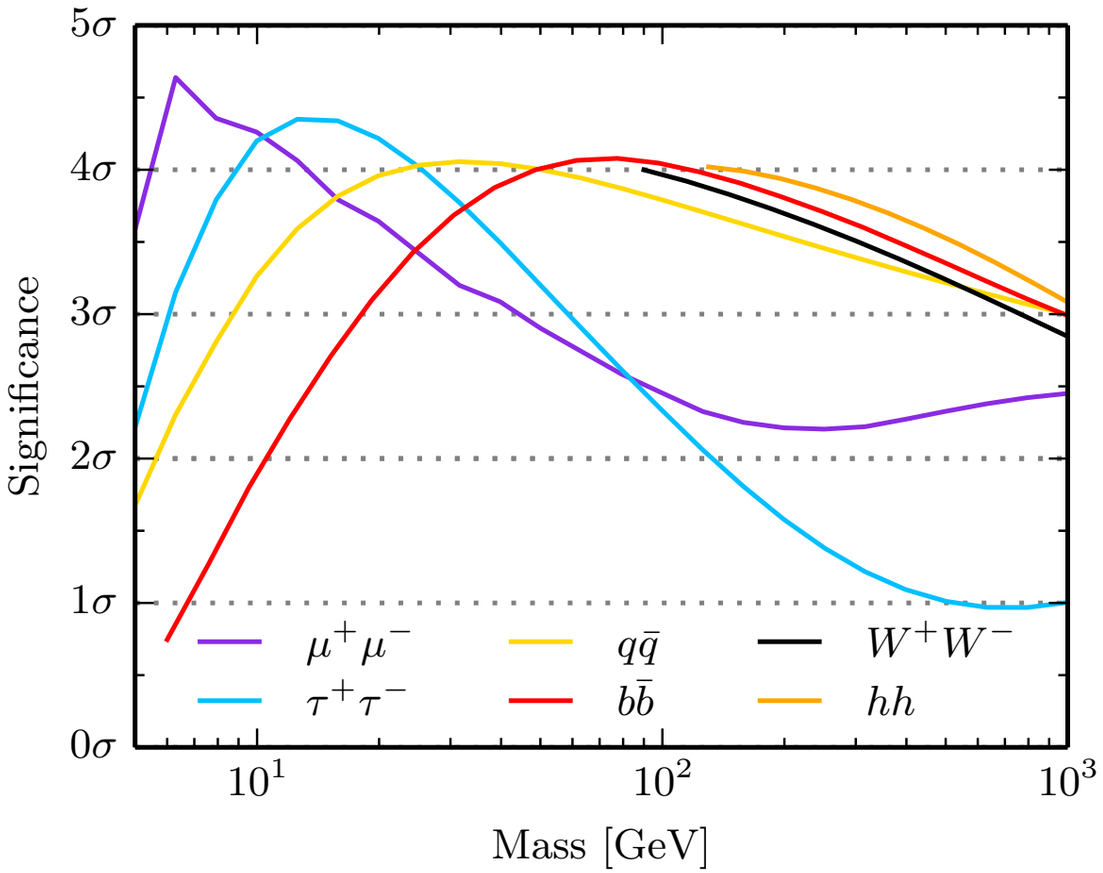
- Number of events is a Poisson variable
- Isotropic within 0.5° of Ret2
- Event energies are independent draws from some energy spectrum

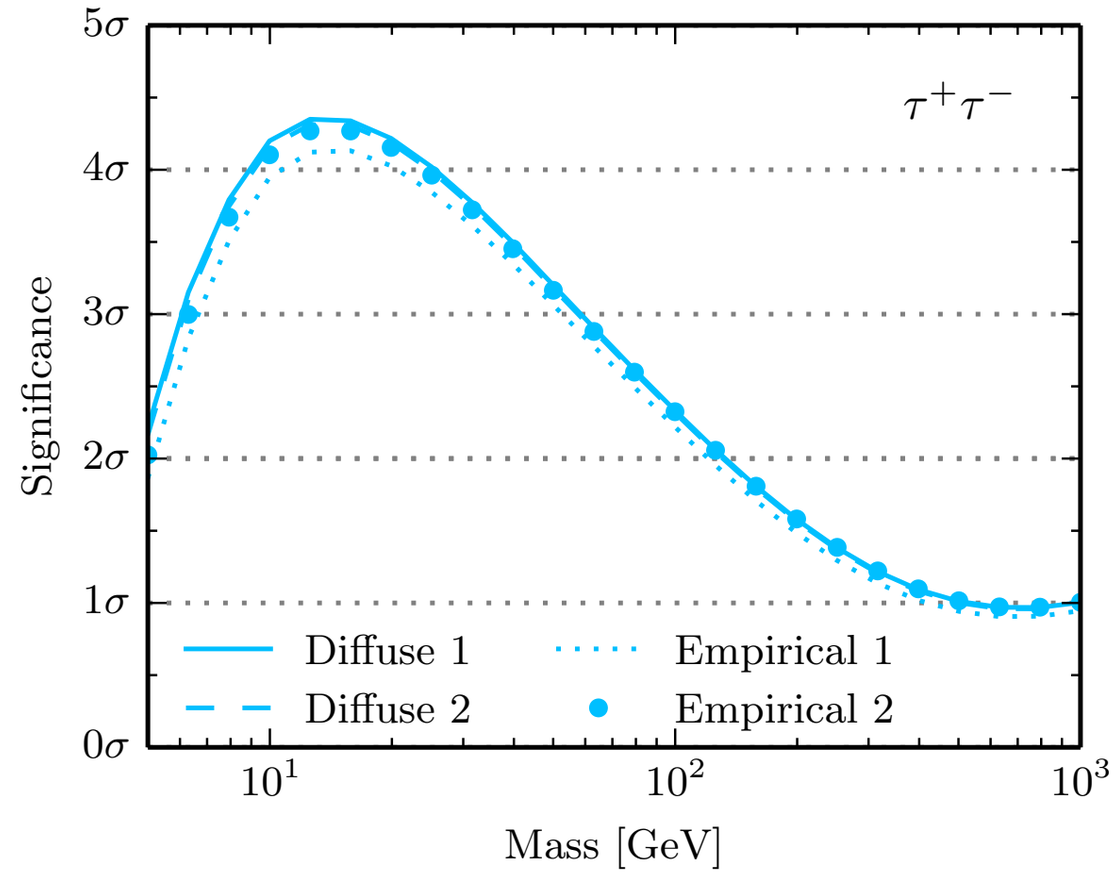


$$T = \sum_{i \in \text{photons}} w(Q_i)$$ follows a compound Poisson distribution which we can compute exactly

AGS, Koushiappas, Walker 1410.2242 (PRD accepted)

Results





Local *p*-value < 3 ×10^{-5} (4σ) in every channel

Robust to different background spectra

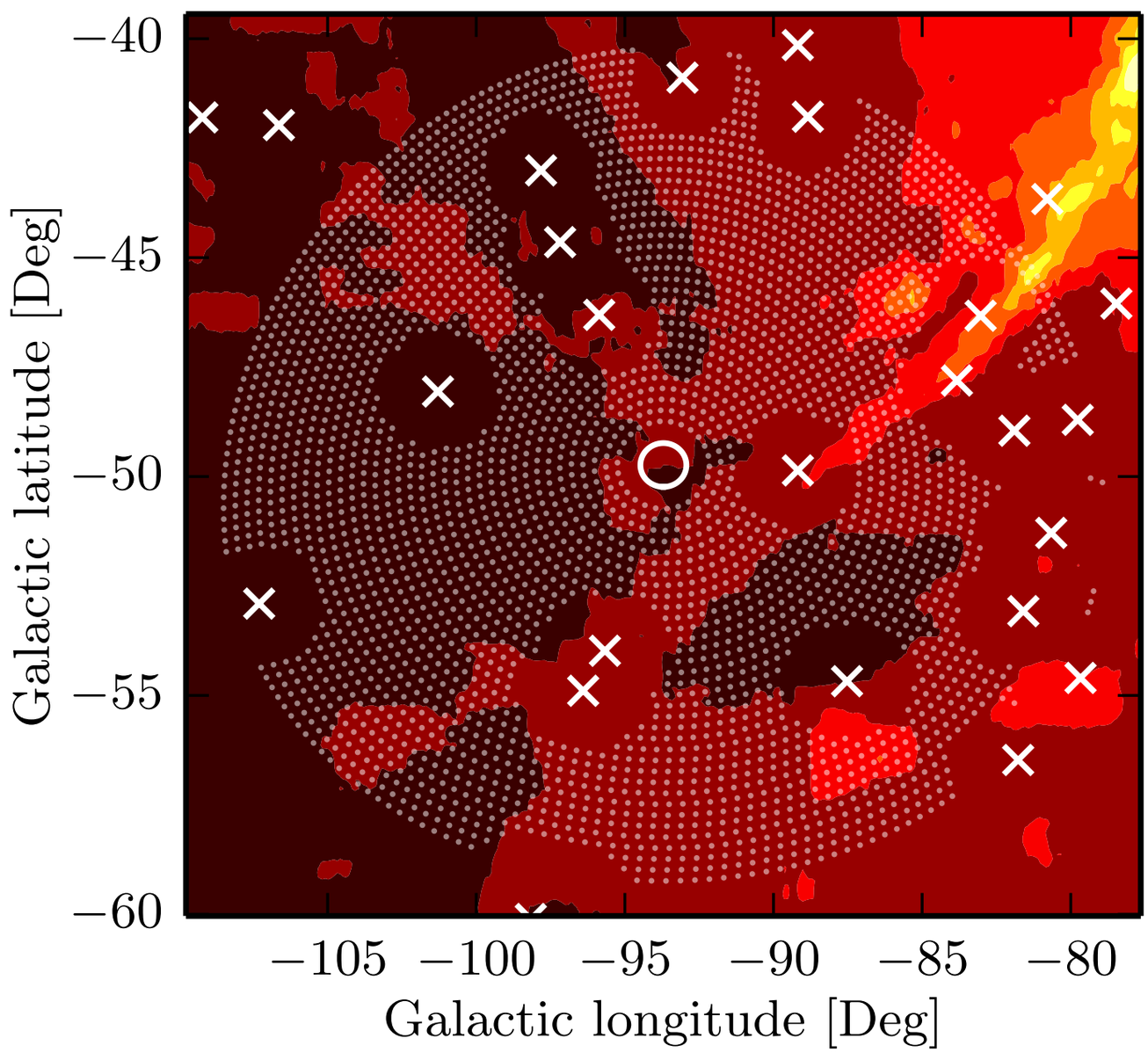
Searching over dark matter masses = multiple hypothesis tests

$p_{global} < 9.8 \times 10^{-5}$

Empirical background sampling

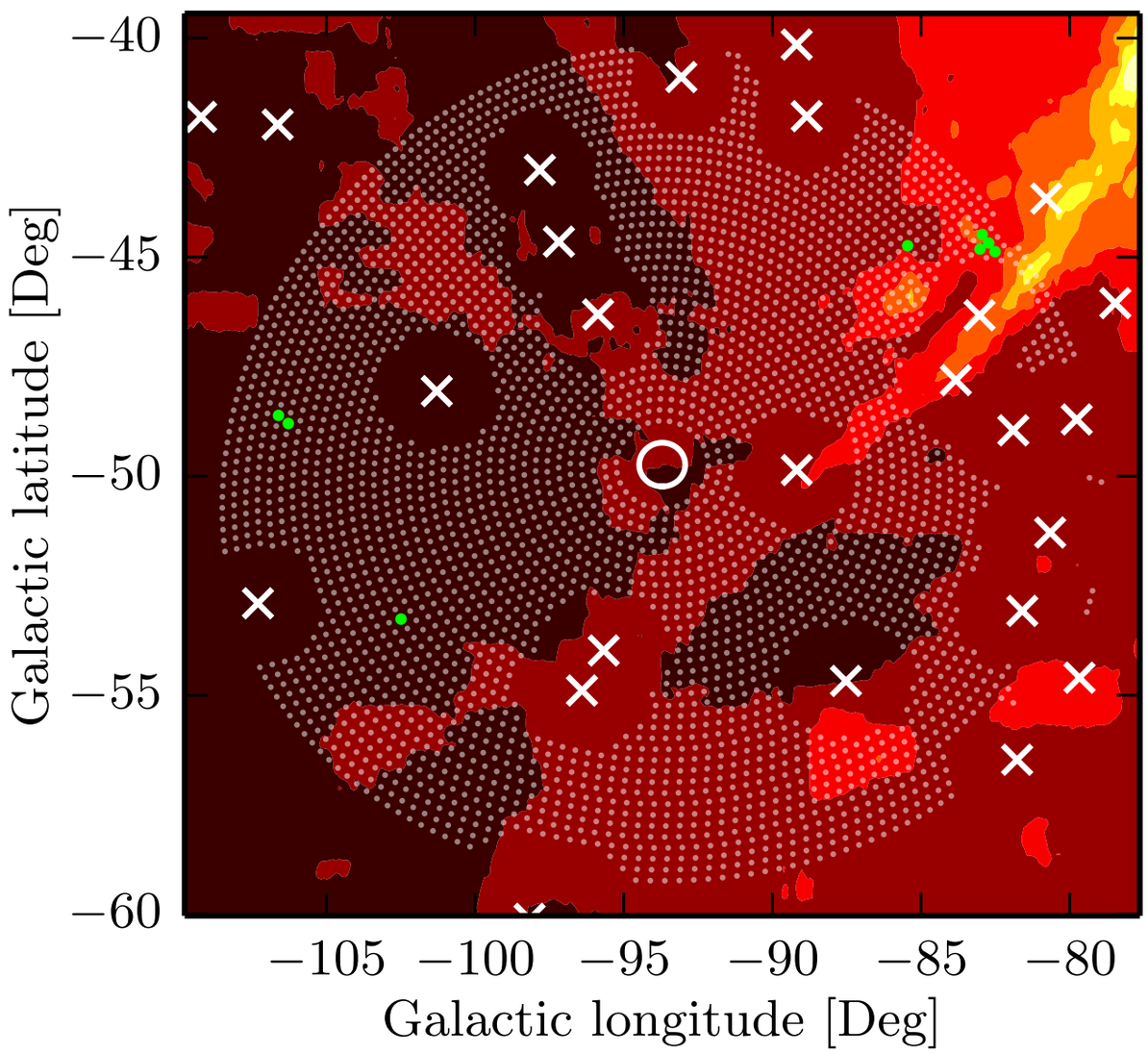
No assumptions about background

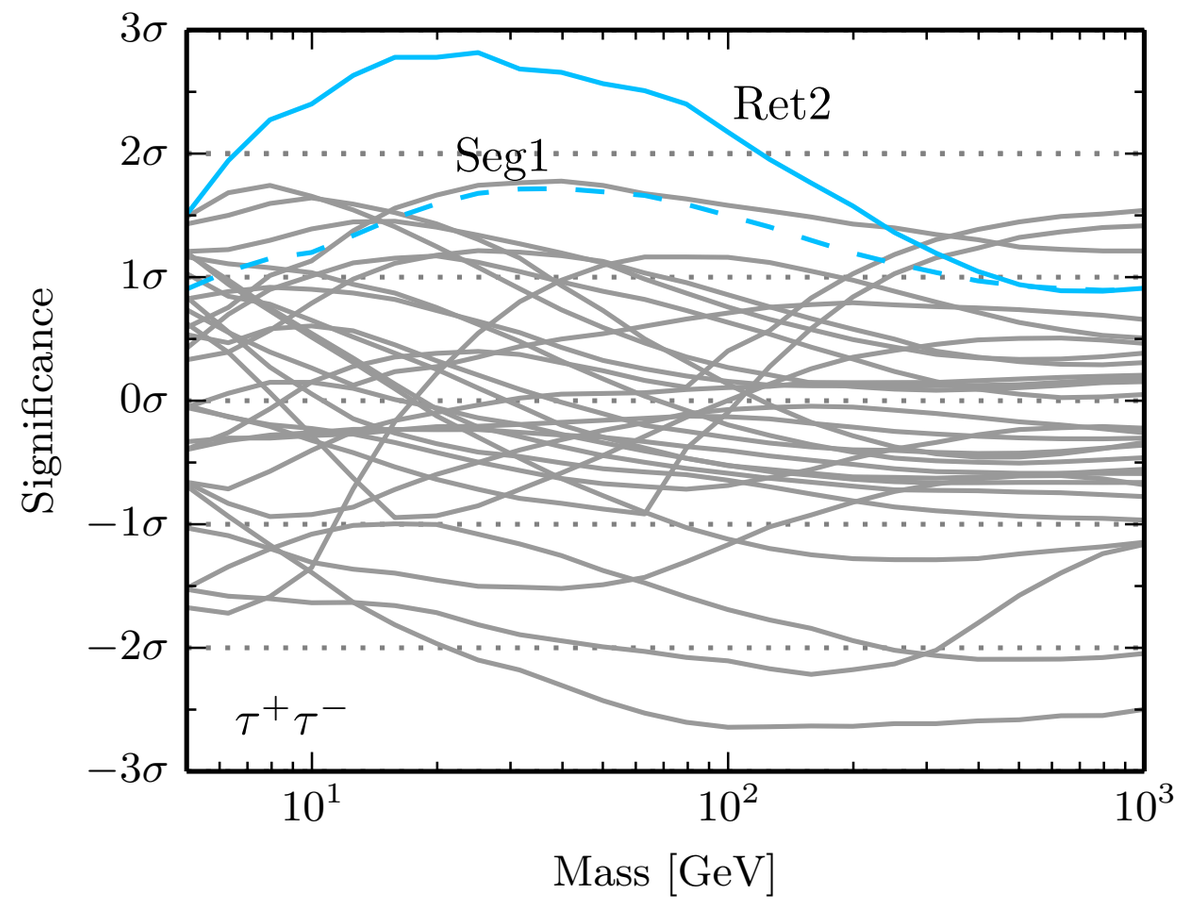
How many background ROIs have *T* larger than Ret2?



Empirical background sampling

Results





Local *p*-value of 8/3306 = 0.0024 (2.8σ)

Global *p*-value of 32/3306 = 0.0097 (2.3σ)

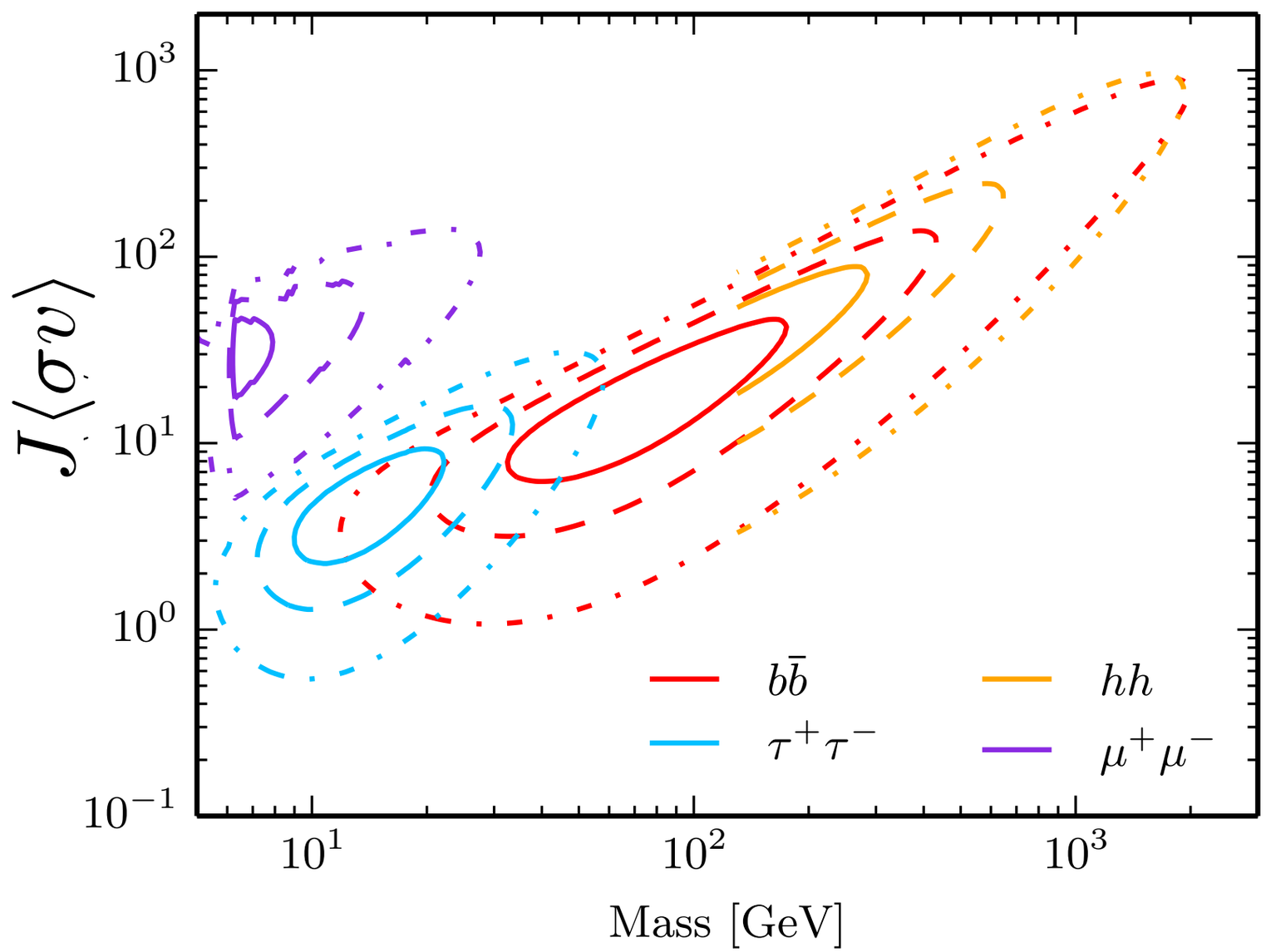
Fundamental limitation: strong signal = very few samples in tail

If signal is due to dark matter annihilation
what can we say about the dark matter particle?

$$\log \frac{P(\text{data} \mid \text{DM} + \text{bg})}{P(\text{data} \mid \text{bg})} = \sum_i \log(1 + s_i/b_i) - \int_{E,\theta} s(E,\theta)$$

sum of weights expected number of DM photons

χ^2 with 2 dof

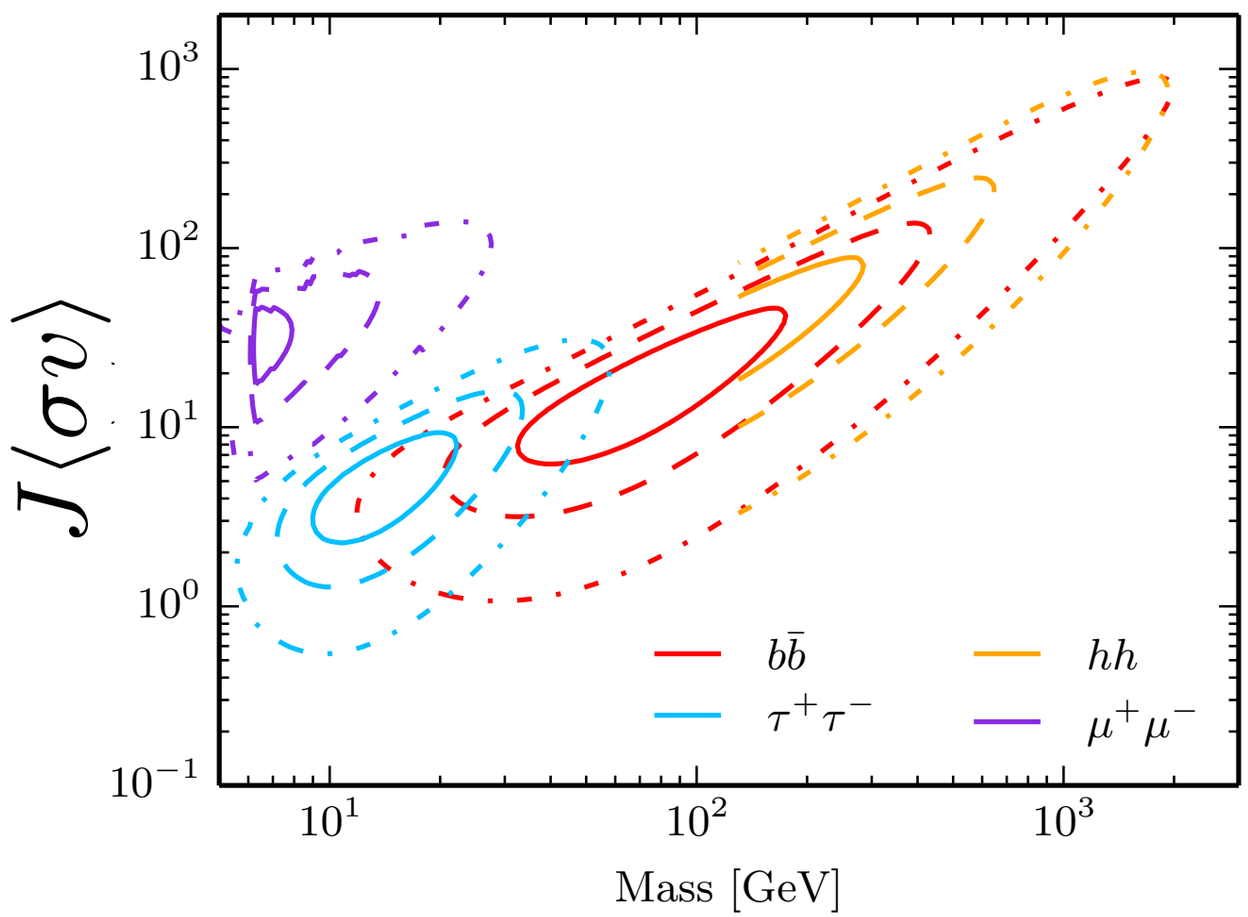


Can only constrain product $J\langle\sigma v\rangle$

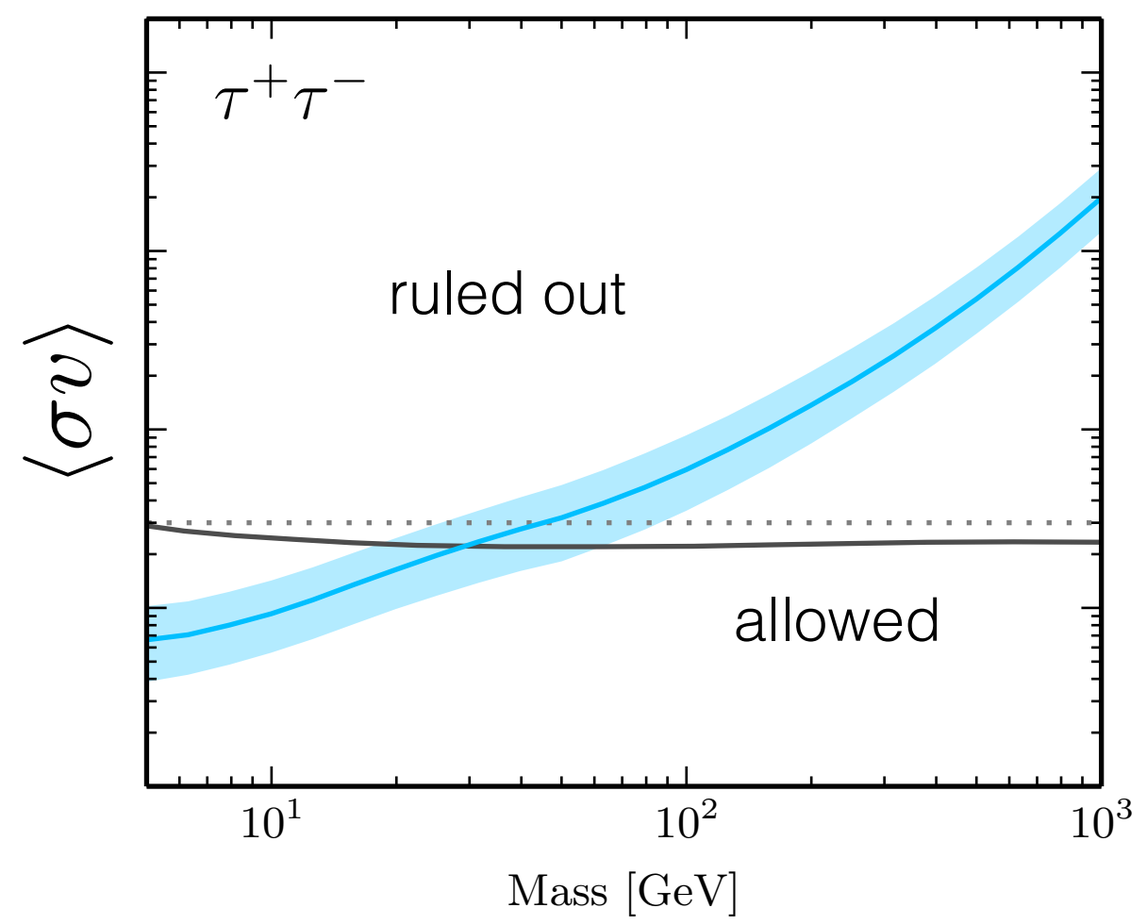
$\langle\sigma v\rangle$ = Strength of interaction (particle physics)

J = Dark matter content of Ret2 (astrophysics)

Reticulum 2



Other dwarfs



AGS, Koushiappas, Walker 1410.2242 (PRD accepted)

<*σv*> upper limits from other dwarfs gives a *prediction* for Ret2's *J* value

$$\log_{10} J \gtrsim 19.6 \pm 0.3$$

Path forward…

1. Gamma-ray data is inconsistent with background ✓

2. Consistent with dark matter annihilation

3. Inconsistent with any other possible source

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   Dark matter halo of Ret2 **??** — will know soon

   Energy spectrum of signal ✓

   Other indirect, direct, and collider searches

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Path forward…

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   Dark matter halo of Ret2 **??** — will know soon

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   Population of sources inside Ret2 (pulsars?) ✓

   Distant source coincidentally in same direction **??** — related to (1)

   Instrumental/data systematics **??** Drlica-Wagner+ (Fermi,DES) 1503.02632
   Hooper & Linden 1503.06209