Joint dataset analysis and dark matter constraints from dwarf galaxies

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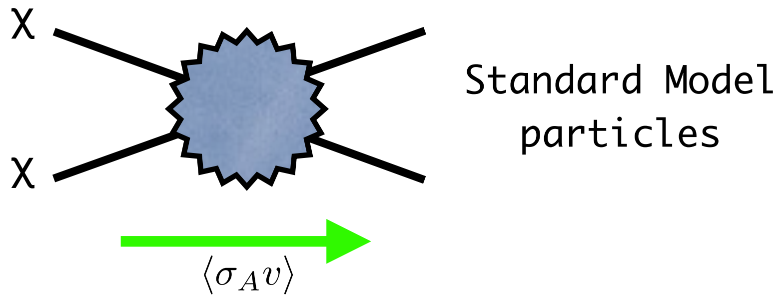
BROWN

Based on Geringer-Sameth & SMK, PRL 107,241303, 2011, PRD 86, 021302(R), 2012, MNRAS 421, 1813 2011, MNRAS 425, 862 2012.

Alex Geringer-Sameth

Thanks to Alex for slides



If it annihilated in the early universe, it annihilates today

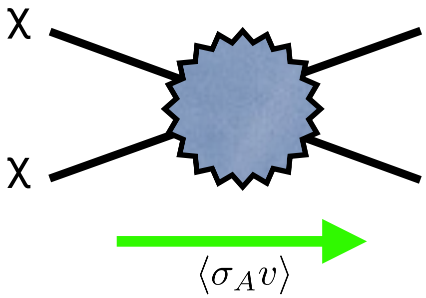
Look nearby, in high density regions: Dwarf galaxies

$$\sigma_\perp \propto f(v_c)$$ Kinematic data

$$v_c \propto f(n[r])$$ Jeans equation

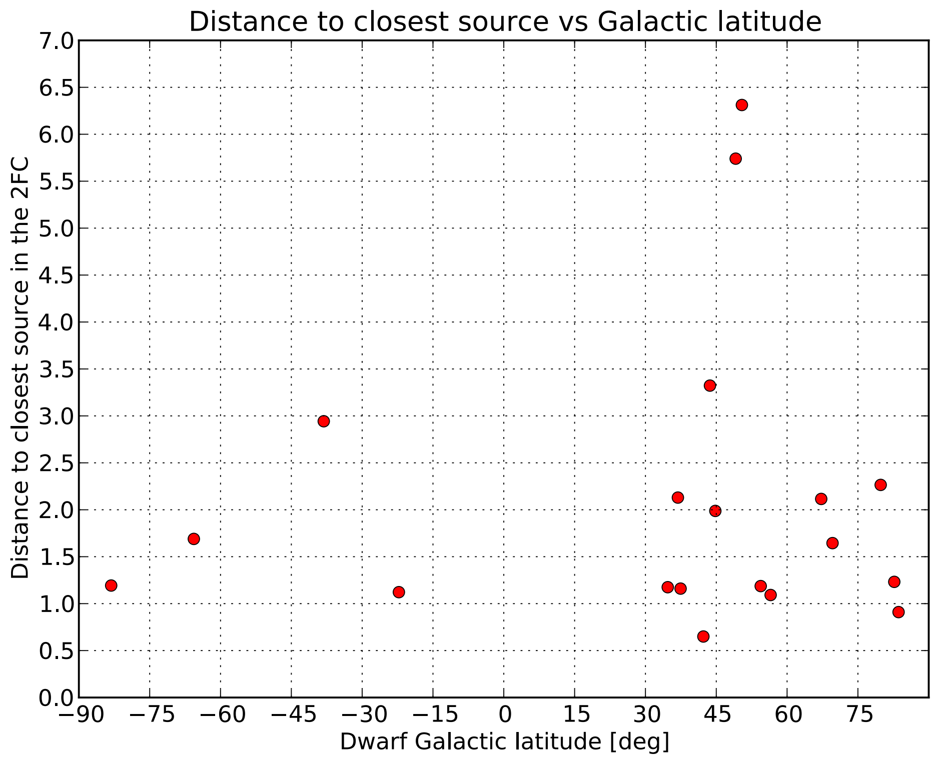
$$\Gamma_{\rm ann} \propto \left[\int_{\rm LOS} n^2(r) d^3 r\right]$$

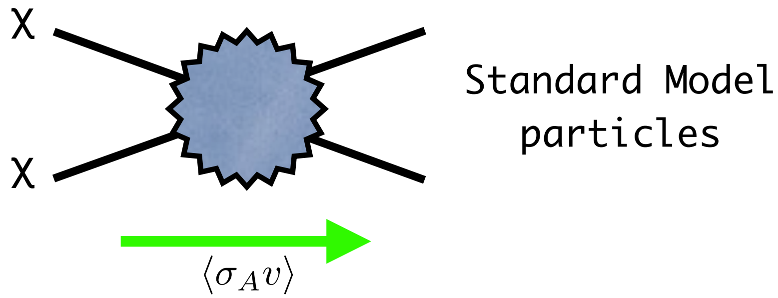
a.k.a. J



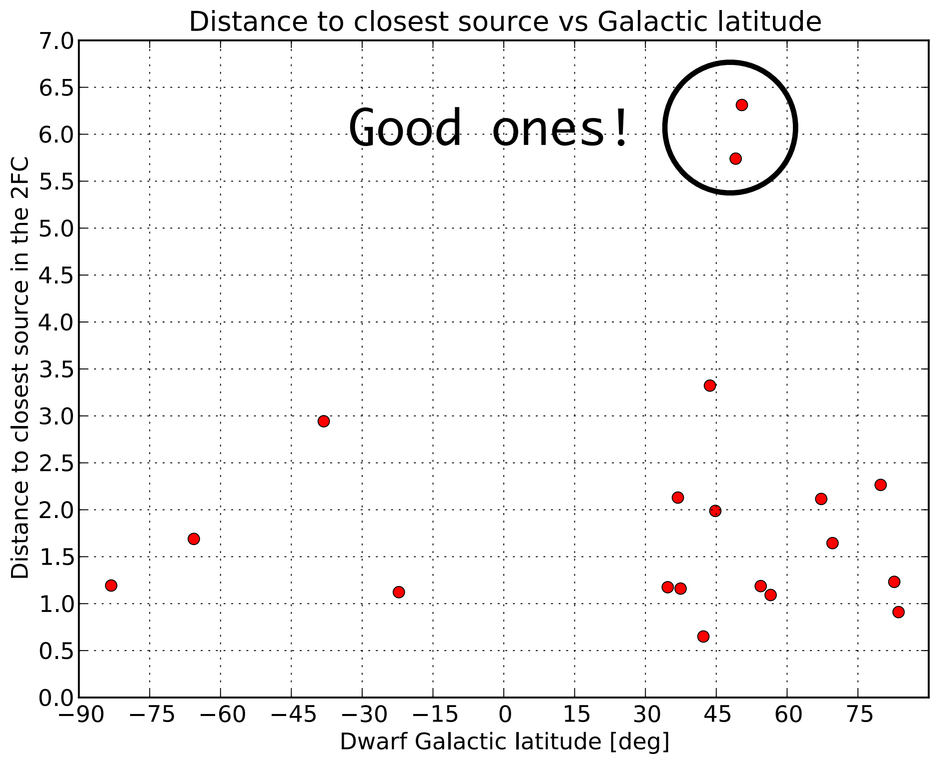
Standard Model
particles

Look nearby, in high density regions: Dwarf galaxies





Look nearby, in high density regions: Dwarf galaxies



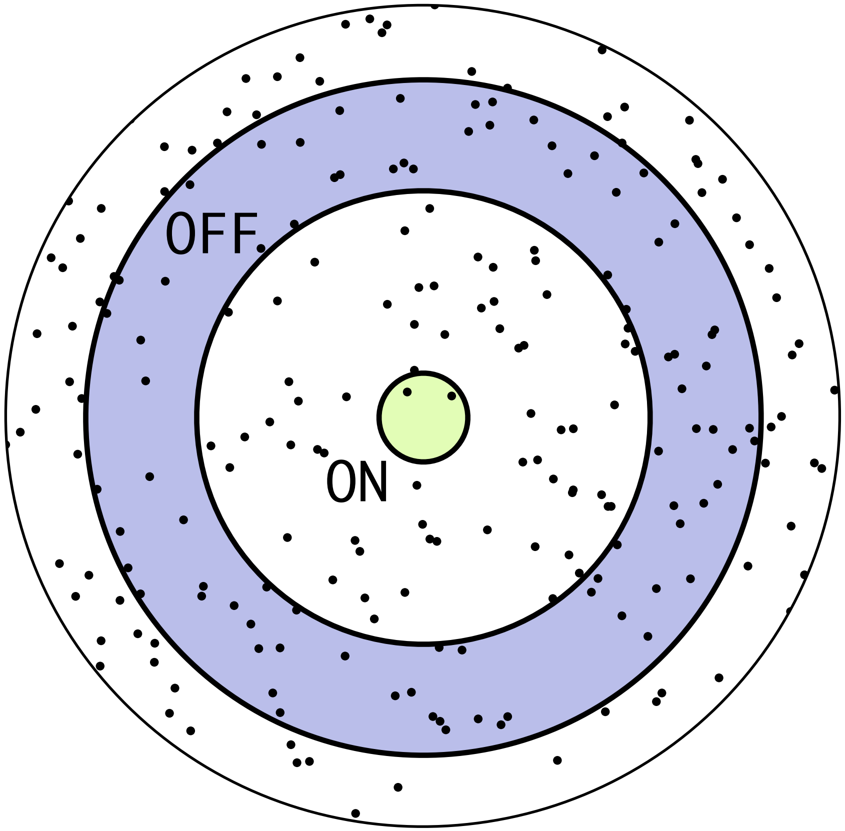
Analysis methods

ON/OFF

Profile likelihood

Photon weighting

ON/OFF method
(ACTs)



Pros

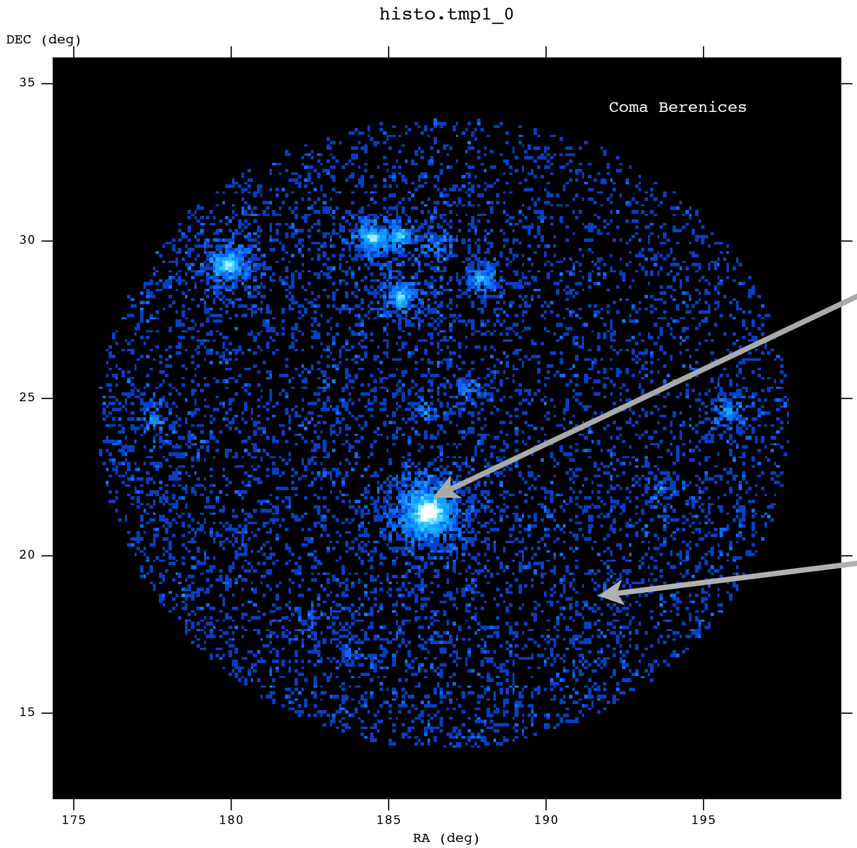
- Model independent

Cons

- One dwarf at a time
- Assumptions on PDFs
- Ignores energy/spatial info
- Ignores DM spectrum
- Choice of ON radius/energy range
- Nearby sources

Profile likelihood method
(e.g Fermi collaboration studies)

1. Construct a theoretical model which in principle characterizes the background
2. Compute the signal/noise ratio (and place bound)



Background at this source

Computed by how much one understands this

See also talk by Alex Drlica-Wagner

Profile likelihood method
(e.g Fermi collaboration studies)

1. Construct a theoretical model which in principle characterizes the background
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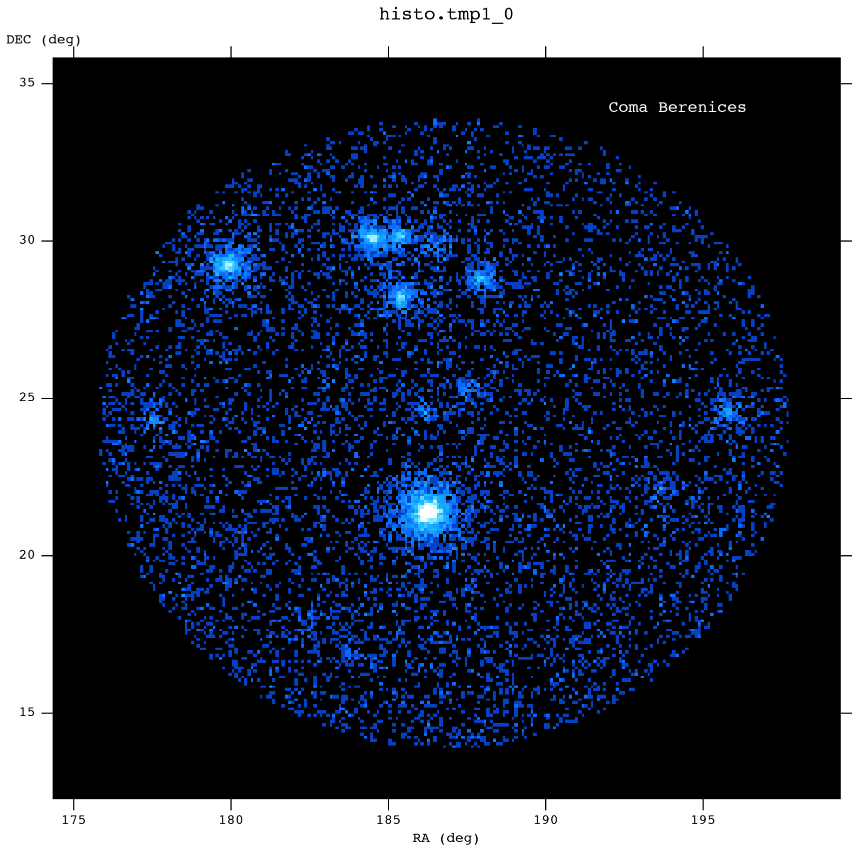


Pros

- Combined analysis of dwarfs is easy
- Uses all information available
- Handles sources, complicated fields of view

Cons

- Model dependent (many free parameters)

Photon weighting

Main assumption:

Whatever the processes are which give rise to the photon events nearby each source, these same processes are also at work along the direction of the dwarf.

Alex Geringer-Sameth & Koushiappas, PRL 107,241303, 2011 & PRD 86, 021302(R) 2012.

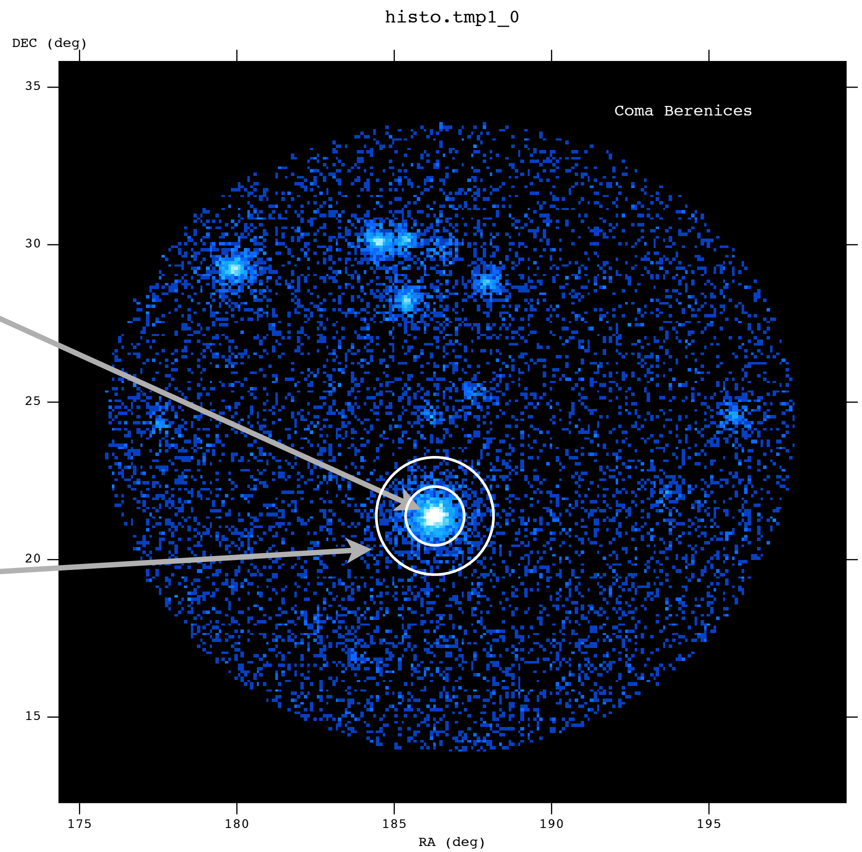
Photon weighting

Main assumption:

Whatever the processes are which give rise to the photon events nearby each source, these same processes are also at work along the direction of the dwarf.

Background at this source

Same as here



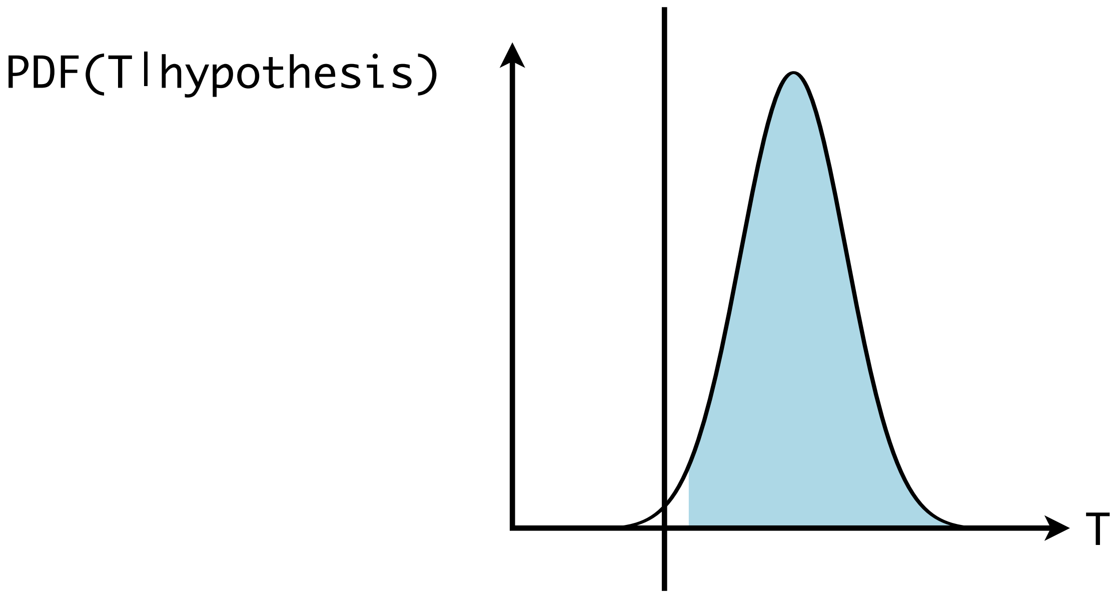
Alex Geringer-Sameth & Koushiappas, PRL 107,241303, 2011 & PRD 86, 021302(R) 2012.

Searches/Limits = Hypothesis testing

Data ⟶ Test statistic, T

(many numbers) (one number)

e.g. T = { number of photons (ON/OFF) ; LR (profile likelihood) }



Choosing a test statistic

Weight dwarfs according to expected signal and expected background

observed counts

$$T = \sum_{i \in \text{dwarfs}} w_i N_i$$

$$w_i \propto \frac{\text{exposure} \times J}{\text{background}}$$

Geringer-Sameth & SMK, PRL 107,241303, 2011

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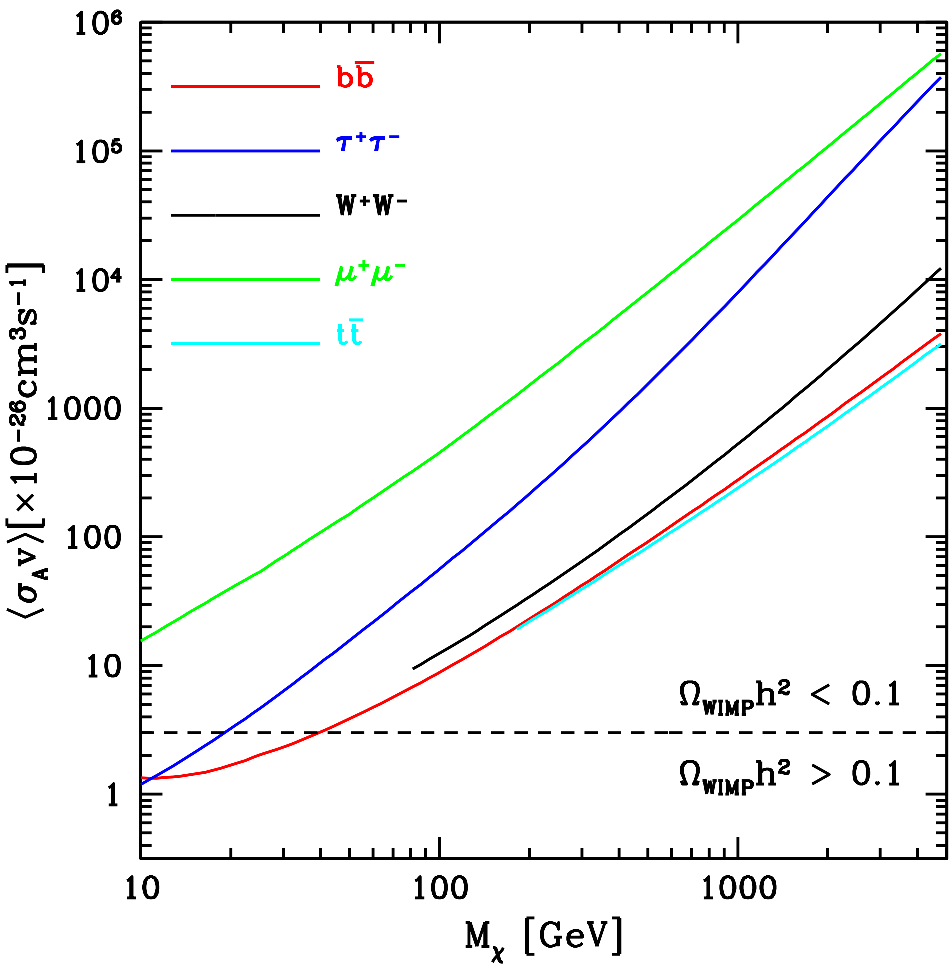

Geringer-Sameth & SMK, PRL 107,241303, 2011

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Geringer-Sameth & SMK, PRL 107,241303, 2011

Include spatial and spectral information:

each photon gets a weight

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

sum over all events from all dwarfs

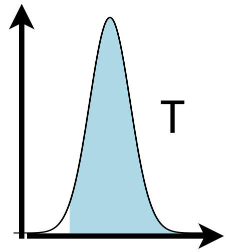
Weight of photon is based on:

- Which dwarf it came from
- Energy
- Angular separation from location of dwarf

(all three together: Q_i)

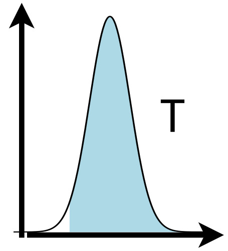
Geringer-Sameth & SMK, PRD 86, 021302(R), 2012

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



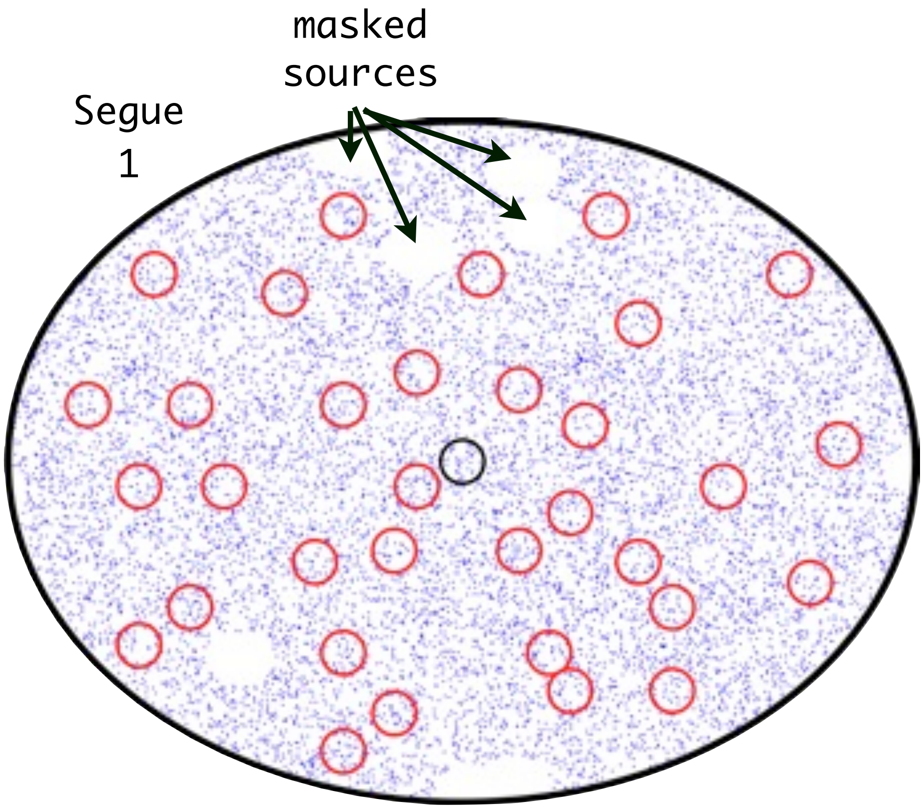
$$T = \sum_{\text{dwarfs}} \left\{ \text{weights of DM photons} + \text{weights of bg photons} \right\}$$

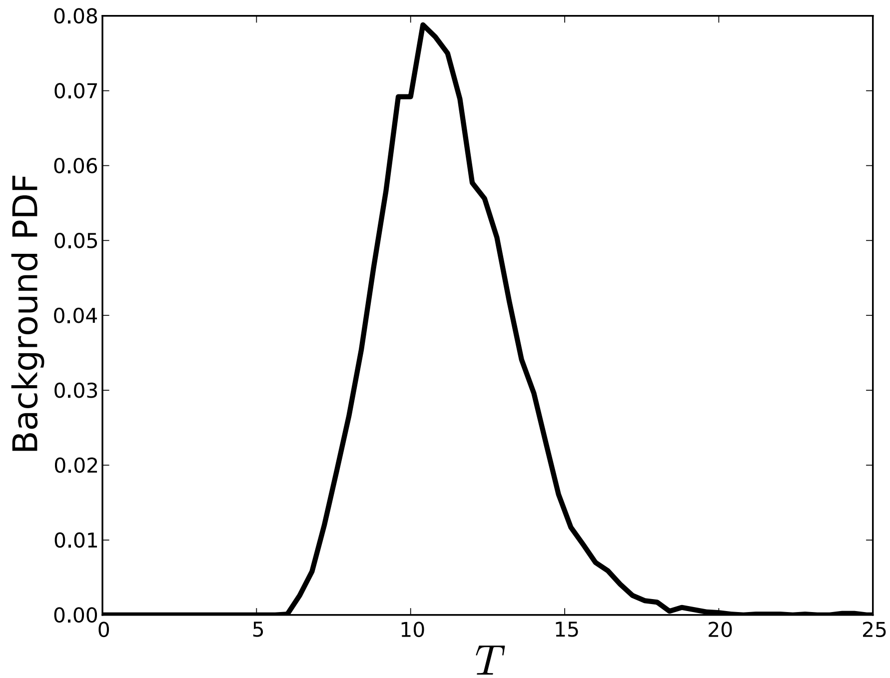
PDF of $T = \sum_{i \in \text{photons}} w(Q_i)$



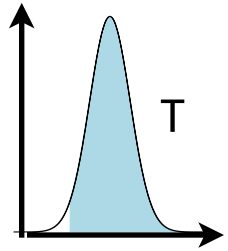
$$T = \sum_{\text{dwarfs}} \left\{ \text{weights of DM photons} + \text{weights of bg photons} \right\}$$

Background found by sampling in region around each dwarf





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



$$T = \sum_{\text{dwarfs}} \left\{ \text{weights of DM photons} + \text{weights of bg photons} \right\}$$

number of DM photons (Poisson random variable)

$$T_{\text{sig}} = \sum_{i=1}^{N} W_i$$

weight of each DM photon (Poisson random variable)

Compound Poisson distribution

Choosing weights

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

signal (s_Q)

background (b_Q)

For each infinitesimal bin in $Q = \{\nu, E, \theta\}$

<u>INGREDIENTS</u>

DM annihilation spectrum
+
Instrument response (effective area, PSF)
+
astrophysical background

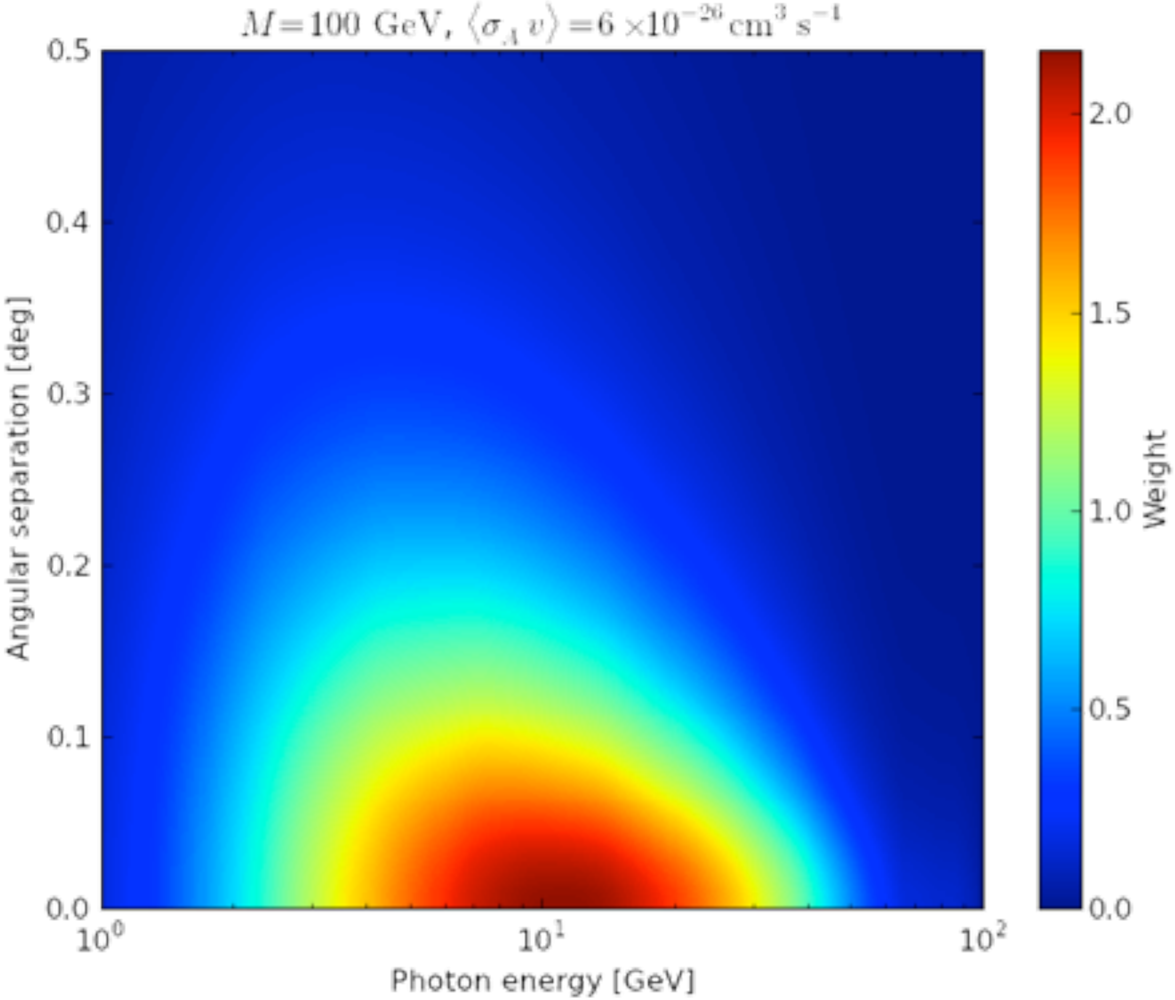
$$s_Q = J \frac{\langle \sigma v \rangle}{8\pi M_\chi^2} \frac{dN_\gamma(E)}{dE} \epsilon(E) \mathrm{PSF}(E,\theta) dE d\Omega(\theta)$$

Choosing weights

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

signal

background



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DM annihilation spectrum
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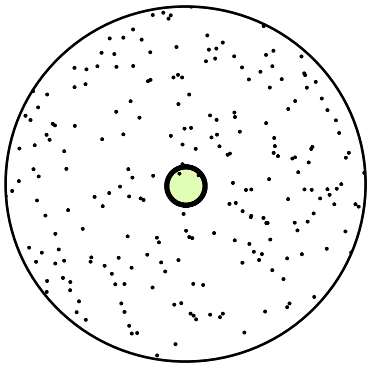
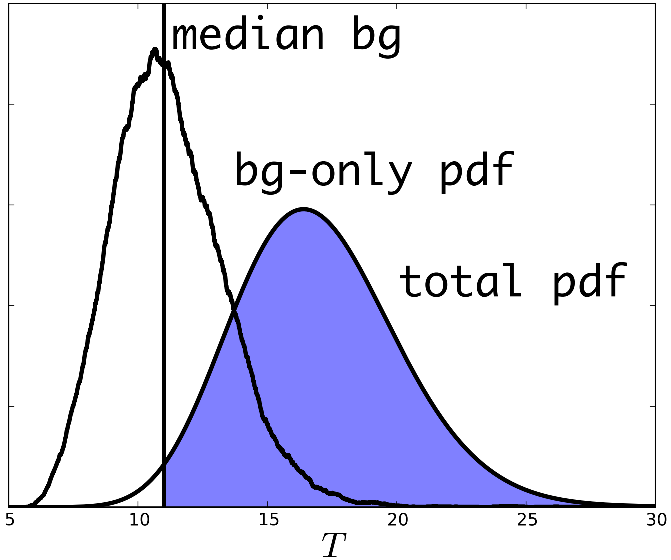
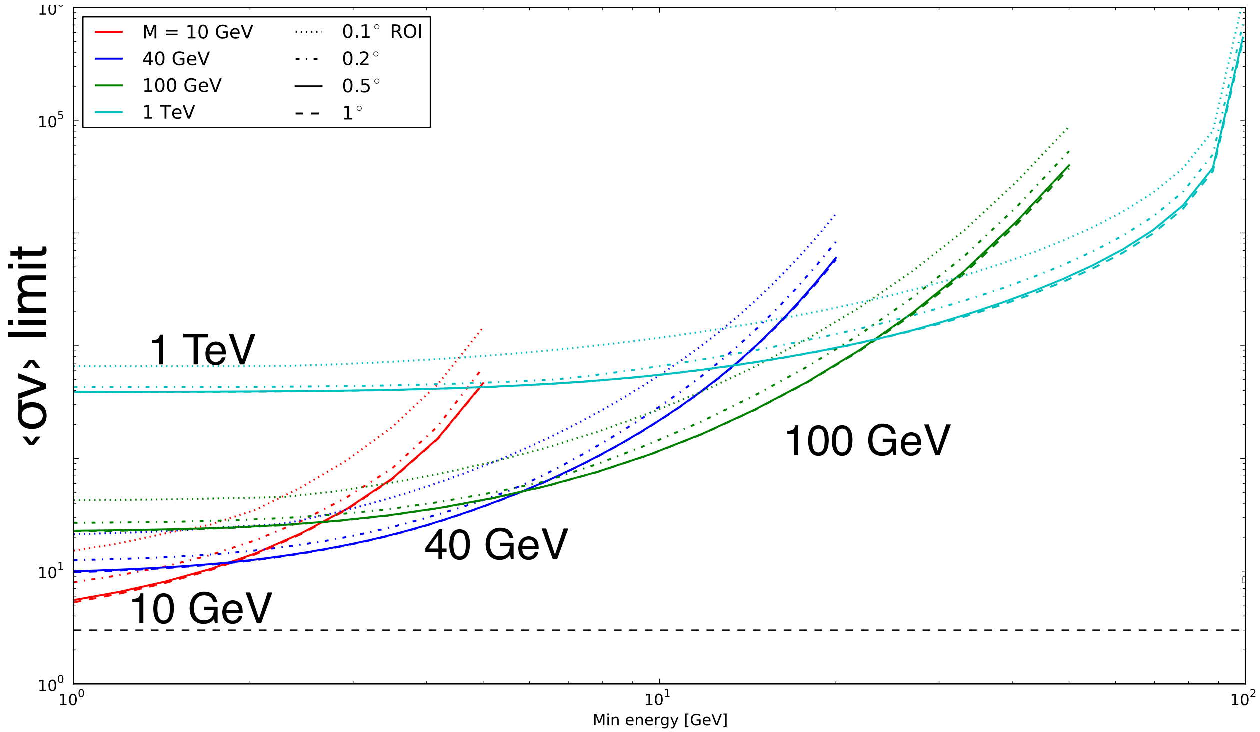
Expected limits





Dependence on energy range and size of central ROI



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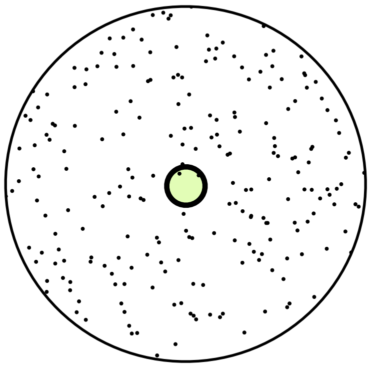
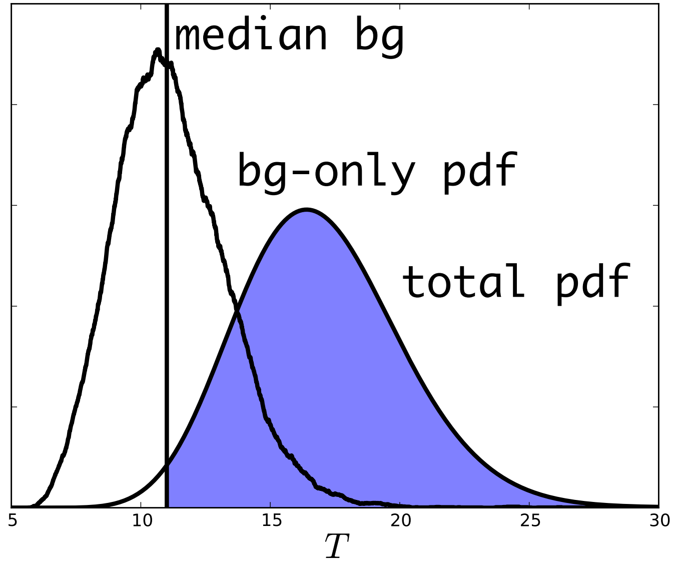
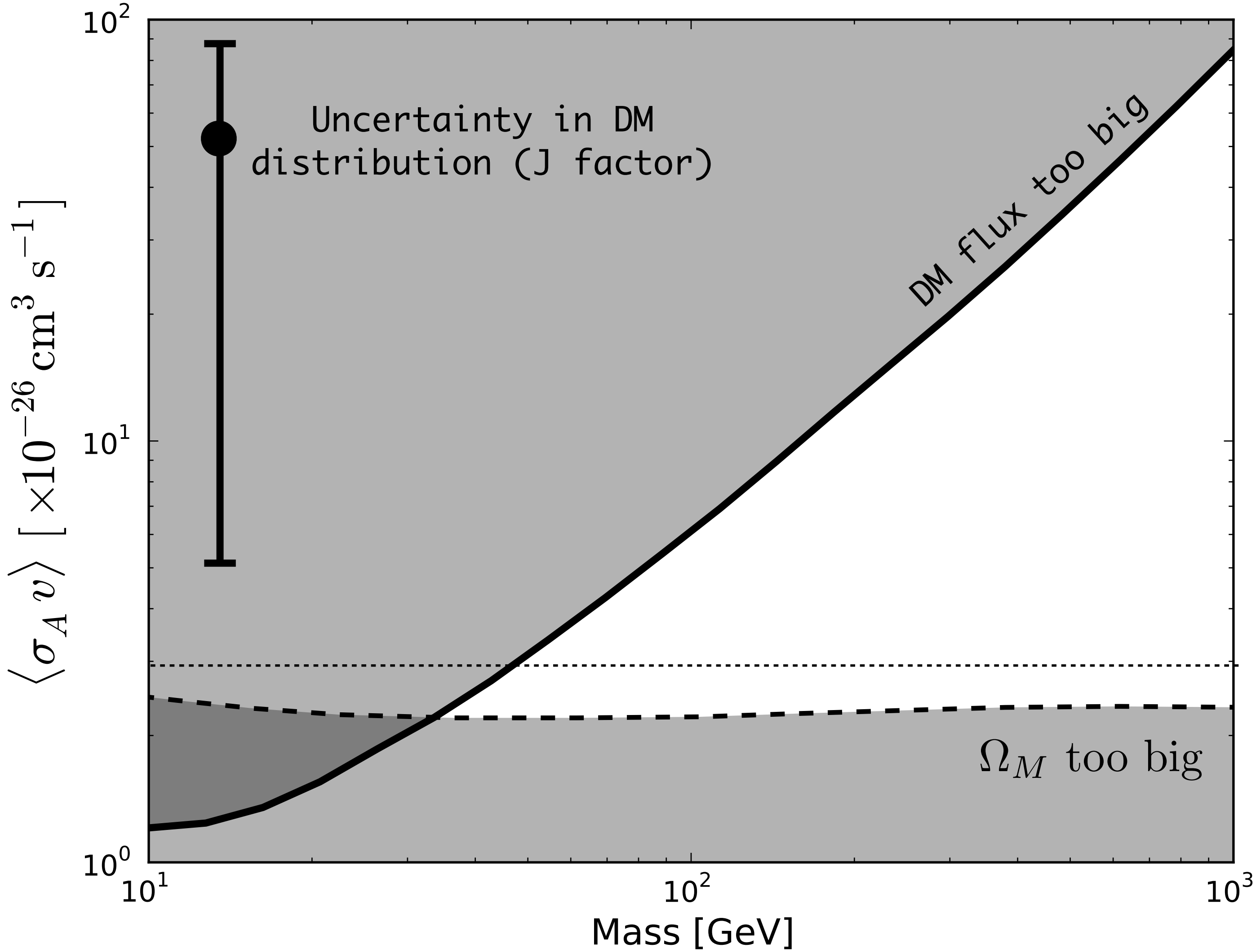




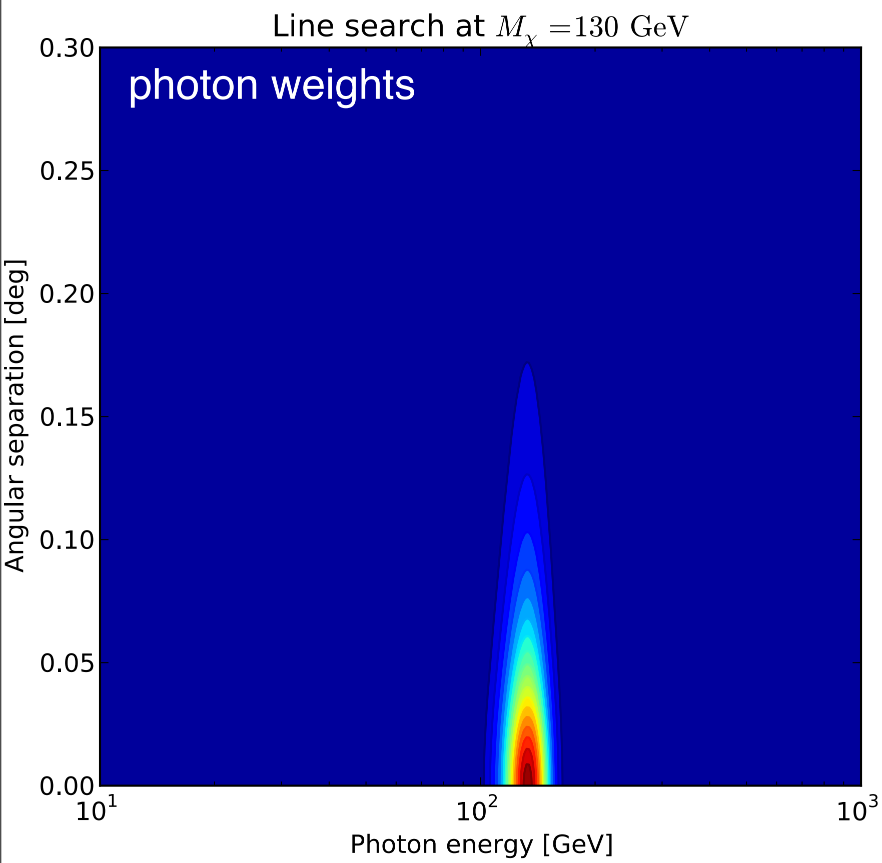
See also the talk by Alex Drlica-Wagner

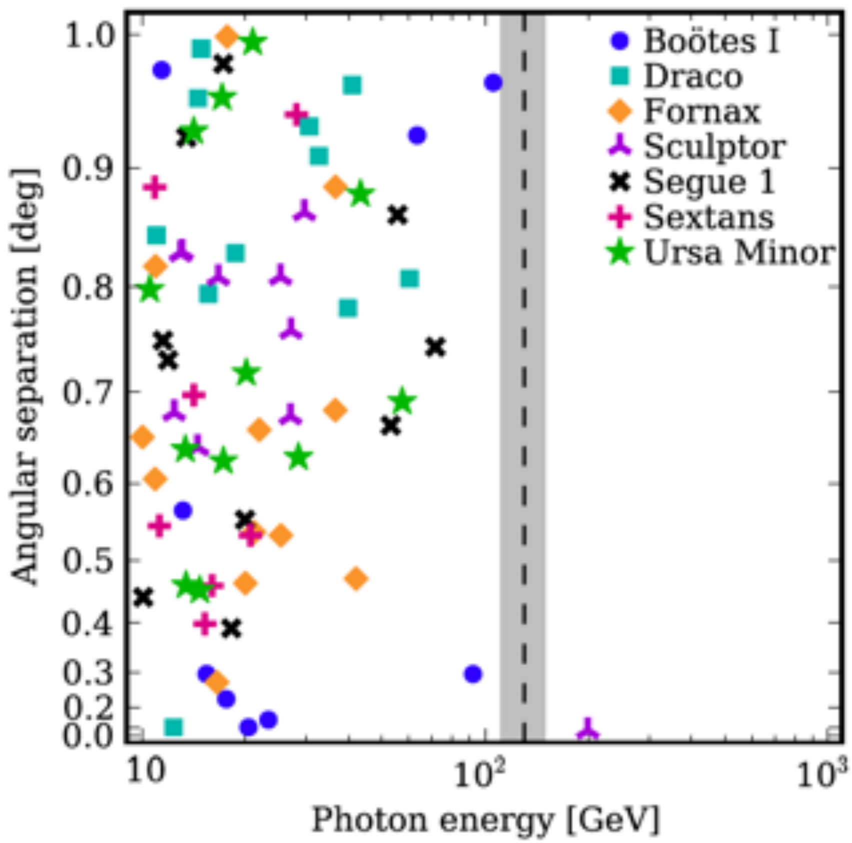
In general:

1. Derive PDF of T under null hypothesis (no dark matter)
2. Sum weights of all photons within central ROI (T*)
3. Significance = Probability that T<T* if null hypothesis is true (e.g., if there is 99.7% chance that T<T* then we have a 3 sigma detection).


Uncertainty in DM
distribution (J factor)
DM flux too big
Ω_M too big
$\langle \sigma_A v \rangle$ [$\times 10^{-26}$ cm^3 s^{-1}]
Mass [GeV]
10^0
10^1
10^2
10^1
10^2
10^3

Change DM spectrum: optimal weights for a line search





Geringer-Sameth & SMK, PRD 86, 021302(R), 2012

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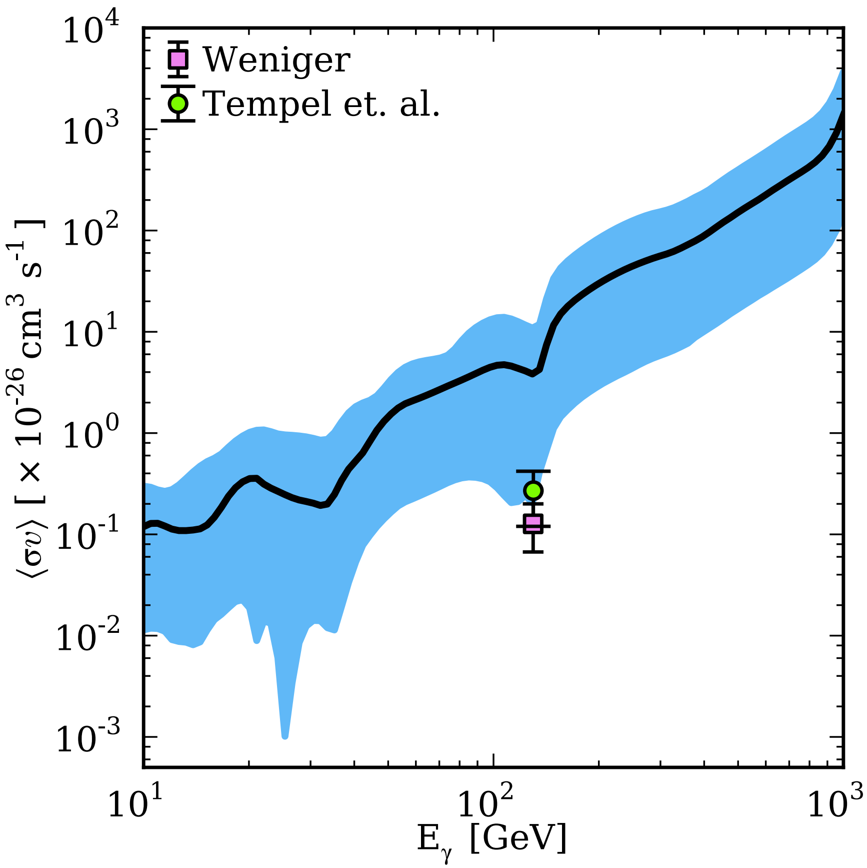
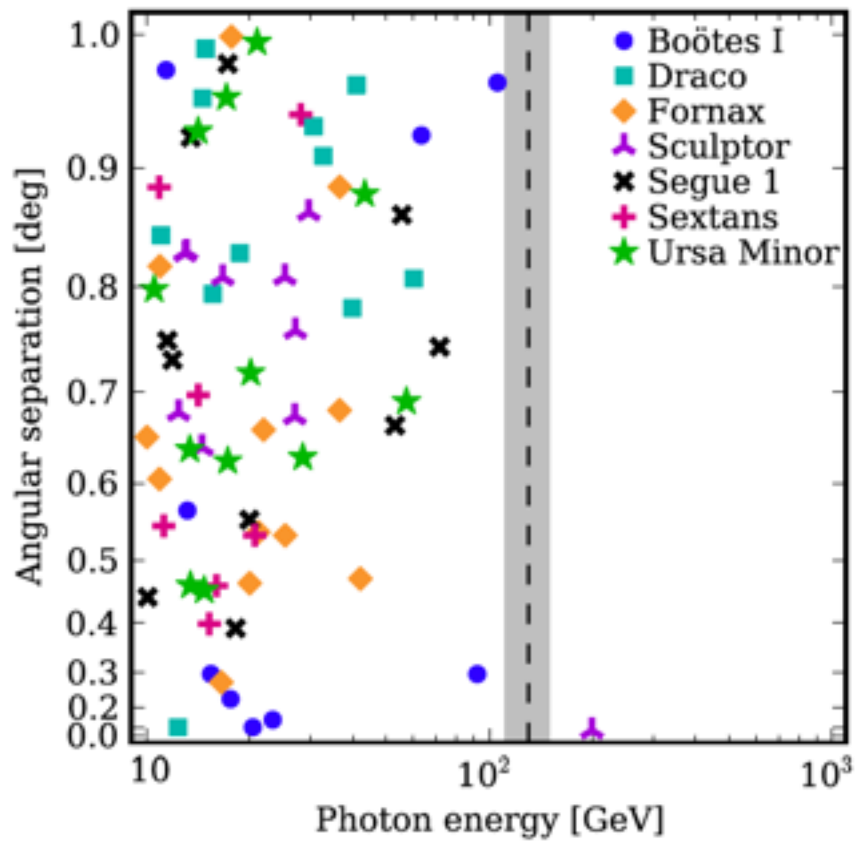
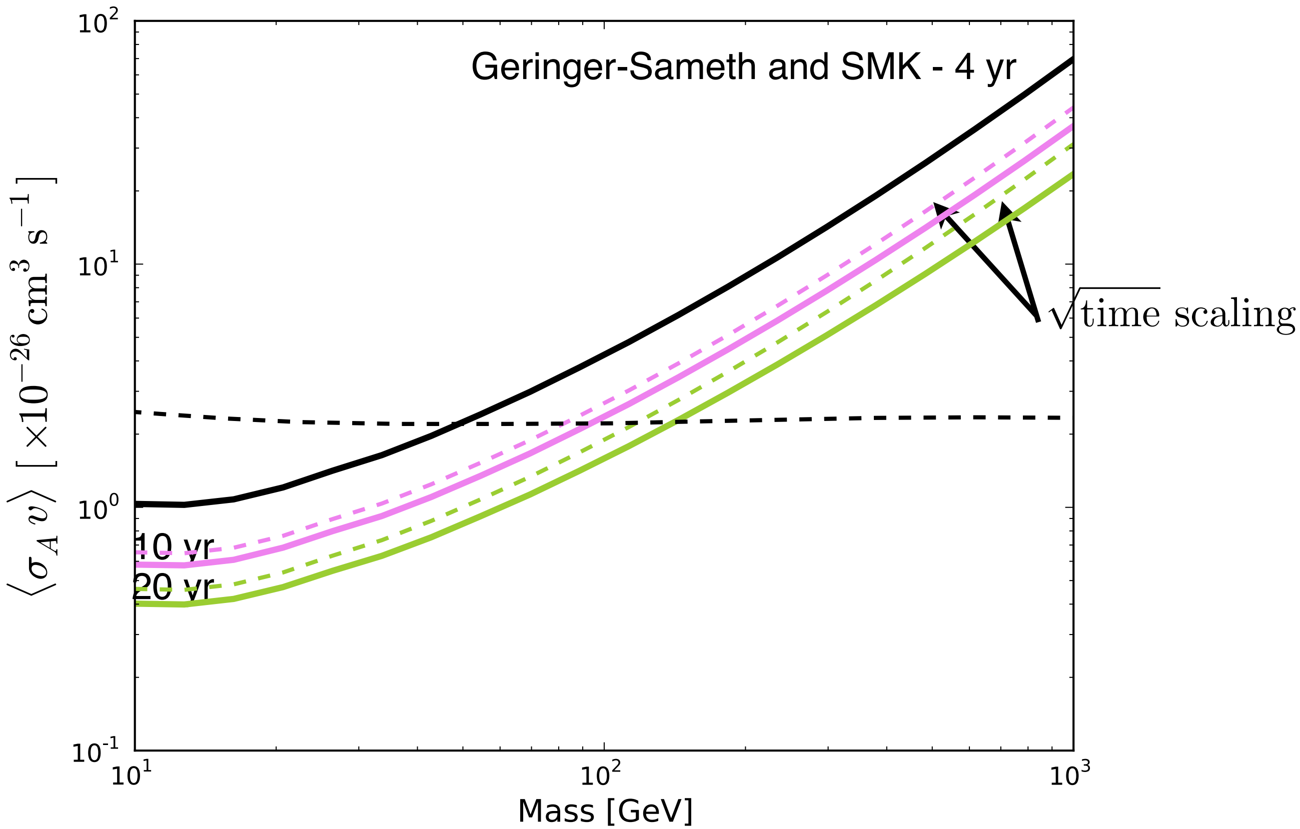




Geringer-Sameth & SMK, PRD 86, 021302(R), 2012

Conclusion and predicting the future



Stay tuned for results in the high-mass (>TeV) regime using a staked dwarf analysis with ***VERITAS***...