WIMPs at the Galactic Center

Prateek Agrawal

Fermilab

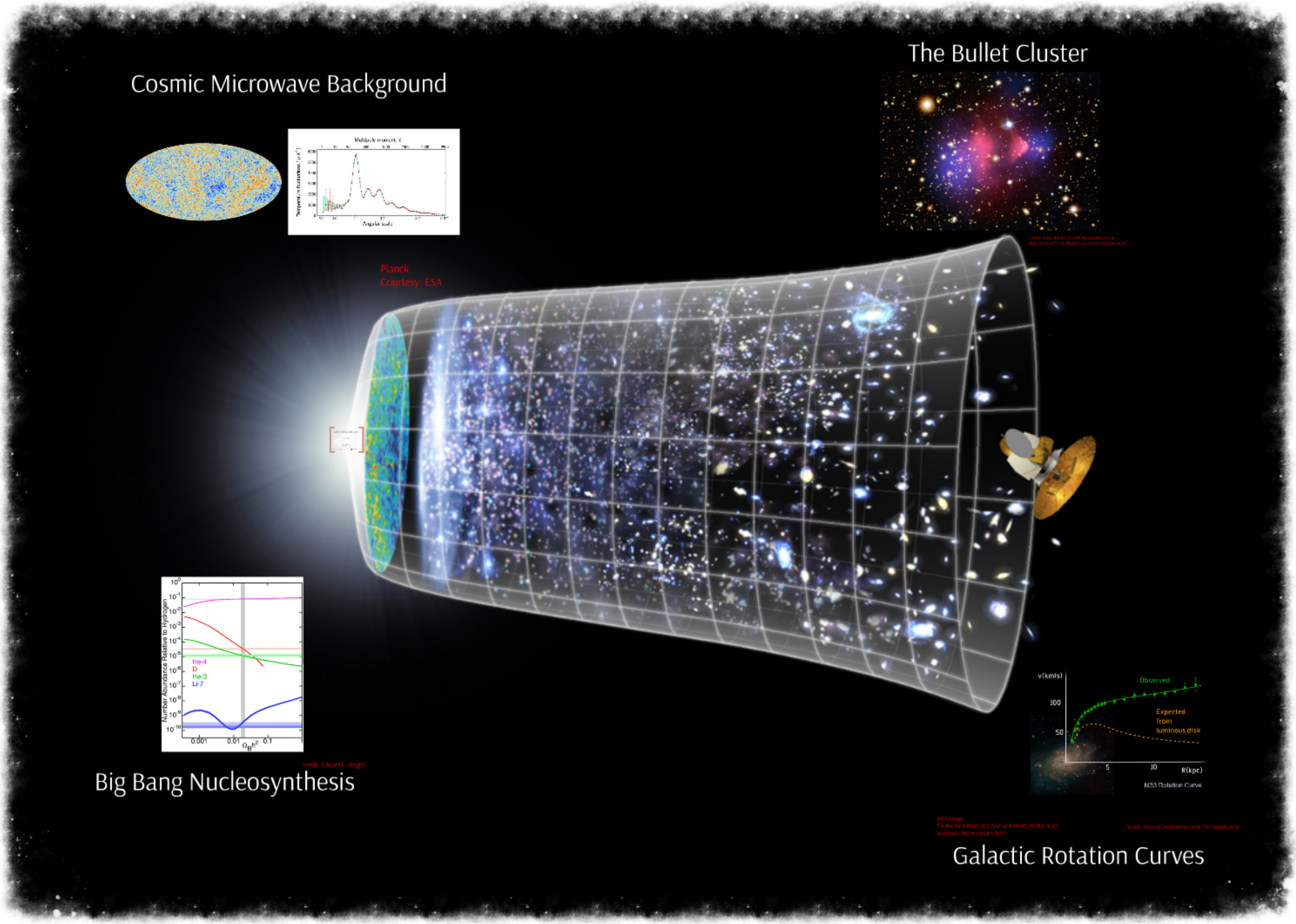
Mitchell Workshop

Texas A&M University

Prezi version online: http://bit.ly/1dl06xv

PA, Brian Batell, Patrick J. Fox, Roni Harnik

arXiv:1411.2592

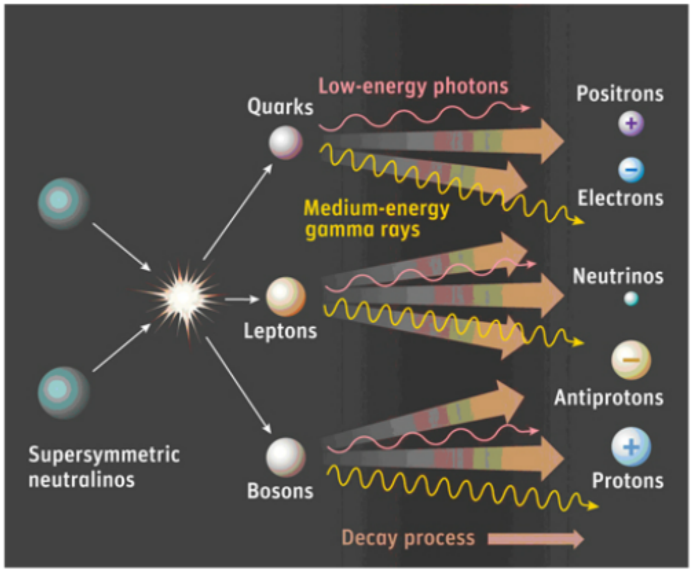

Cosmic Microwave Background
Multipole moment, ℓ
Temperature fluctuations
Angular scale
Planck
Courtesy: ESA
The Bullet Cluster
Number Abundance Relative to Hydrogen
He-4
D
He-3
Li-7
0.001
0.01
0.1
1
Big Bang Nucleosynthesis
v(km/s)
Observed
Expected
from
luminous disk
100
50
5
10
R(kpc)
M33 Rotation Curve
Galactic Rotation Curves

Indirect detection

Dark matter annihilation today might leave visible traces in the sky

Size of signal flux is predicted for WIMPs

$$\langle \sigma_A v \rangle \sim 3 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}$$



[credit: Michele Doro]

Backgrounds are unknown, discovery is challenging

Photons point back to sources, contain more spatial information

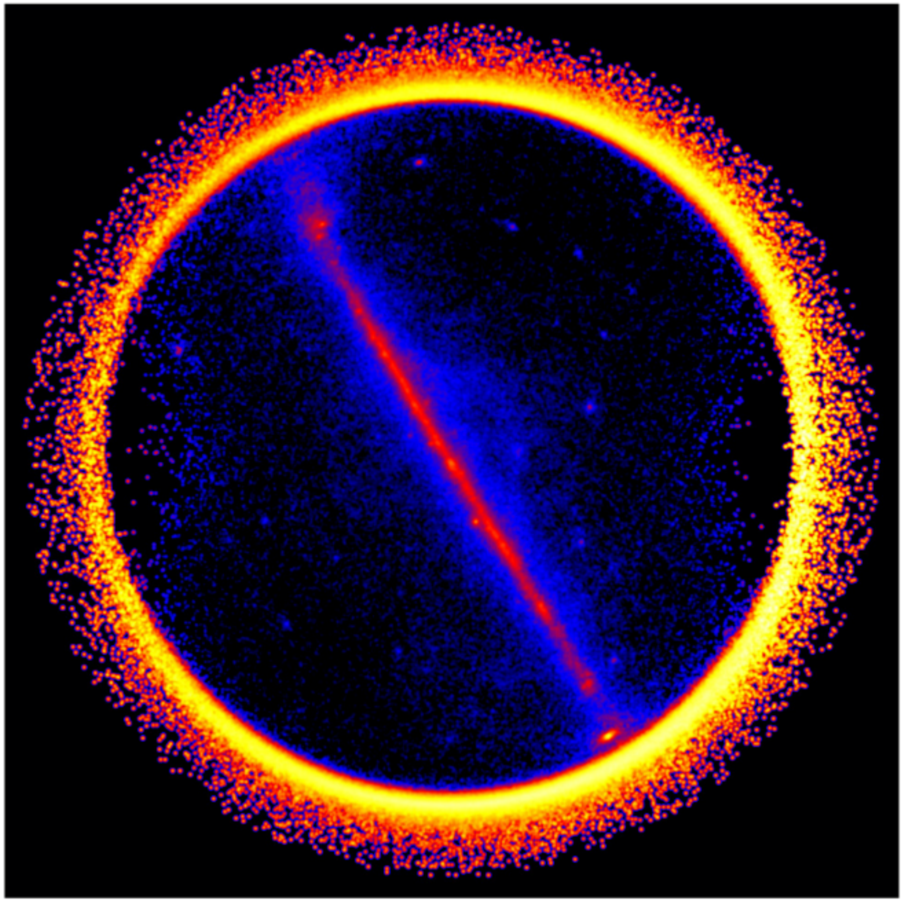
Fermi Large Area Telescope

Maps out the gamma ray sky
from 20 MeV to 300 GeV

Covers full sky every three hours

Data publicly available

http://fermi.gsfc.nasa.gov/ssc/data/



J-factor

Spectrum

$$\frac{dN}{d\Omega dE}^{*}(\psi) = \frac{1}{4\pi\eta}\frac{f_\chi^2 J(\psi)}{m_\chi^2}\sum_i \langle\sigma v\rangle_i \frac{dN^i}{dE_\gamma}$$

Models

$$\left[\, f_\chi = \frac{\Omega_\chi}{\Omega_{DM}} \,\right]$$

*prompt only

Daylan et al

CTB Core

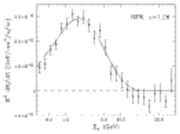
Pass 7 (V15) data

Inner Galaxy

Template analysis (|b|,|l|<20 - |b|<1)

- Fermi Collaboration p6v11 Galactic diffuse model
- Isotropic map
- Fermi Bubbles

$\Delta\chi^2 \simeq 1672$



Galactic Center

Binned likelihood analysis (|b| < 5, |l| < 5)

- Galactic diffuse emission
- Model spatially tracing the observed 20 cm emission
- Isotropic gamma-ray background
- Gamma-ray sources listed in the 2FGL catalog
- Two new point sources

$\Delta\chi^2 \simeq 300$

Robustness

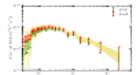
- CTBCore cut choice
- Spatial template vs. spectrum
- Sphericity
- Modulation of backgrounds
- Choice of diffuse models

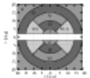
No "systematic" errors

Tansu Daylan, Douglas P. Finkbeiner, Dan Hooper, Tim Linden, Stephen K. N. Portillo, Nicholas L. Rodd, Tracy R. Slatyer [arXiv:1402.6703]

CCW

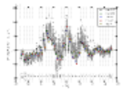
60 Galactic Diffuse Emission models

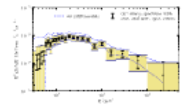




$\chi^2/d.o.f. \simeq 29500/26700 \simeq 1.10$

p-value $\sim 10^{-300}$





$\sim 6\sigma$

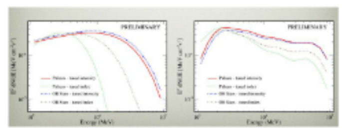
Attempt to quantify systematic uncertainties

Francesca Calore, Ilias Cholis, Christoph Weniger [arXiv:1409.0042]

L. Goodenough and D. Hooper (2009), 0910.2998.

D. Hooper and L. Goodenough, Phys.Lett. B697, 412(2011), 1010.2752.
A. Boyarsky, D. Malyshev, and O. Ruchayskiy, Phys.Lett. B705, 165 (2011), 1012.5839.
D. Hooper and T. Linden, Phys.Rev. D84, 123005 (2011), 1110.0006.
K. N. Abazajian and M. Kaplinghat, Phys.Rev. D86,083511 (2012), 1207.6047.
C. Gordon and O. Macias, Phys.Rev. D88, 083521 (2013), 1306.5725.
K. N. Abazajian, N. Canac, S. Horiuchi, and M. Kaplinghat (2014), 1402.4090.
D. Hooper and T. R. Slatyer, Phys.Dark Univ. 2, 118 (2013), 1302.6589.
W.-C. Huang, A. Urbano, and W. Xue (2013), 1307.6862.
K. N. Abazajian, JCAP 1103, 010 (2011), 1011.4275.
D. Hooper, I. Cholis, T. Linden, J. Siegal-Gaskins, and T. R. Slatyer, Phys.Rev. D88, 083009 (2013), 1305.0830

Fermi



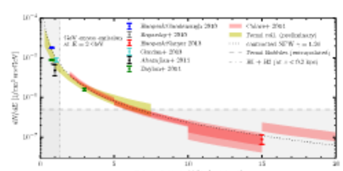
Preliminary analysis
Four well-motivated Diffuse models
Large variation in residual spectra

|b|,|l|< 7.5

A much larger range of masses, and final states allowed

Simona Murgia, Fermi symposium 2014
(http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2014/program/08_Murgia.pdf)

All Together Now



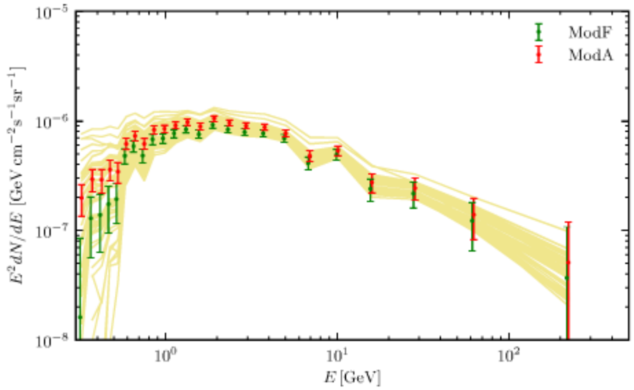
Calore, Cholis, McCabe, Weniger
[arXiv:1411.4647]

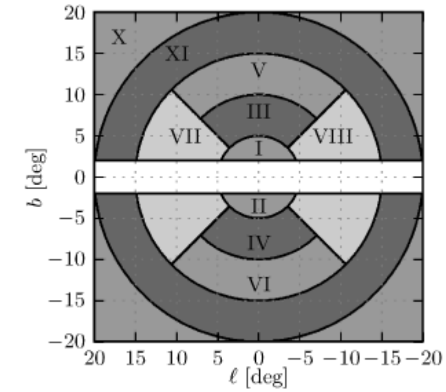
$$\frac{dN}{d\Omega dE}$$

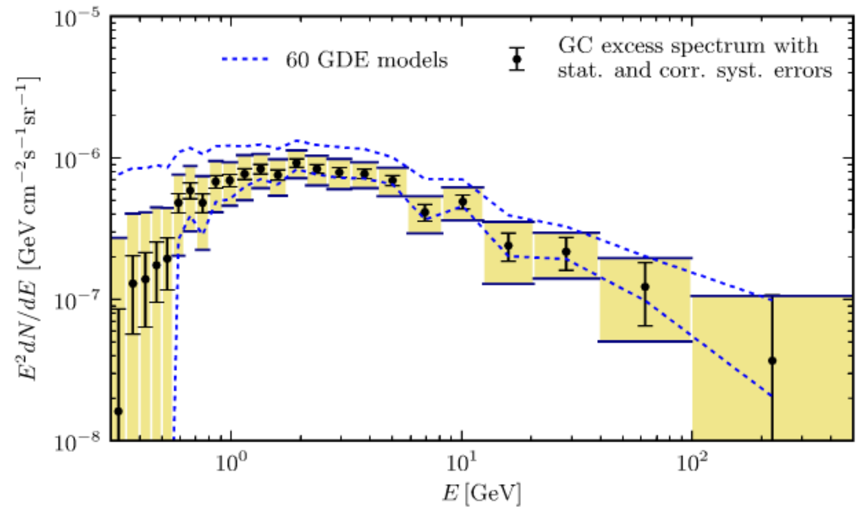
The Galactic Center Analyses

CCW

60 Galactic Diffuse Emission models







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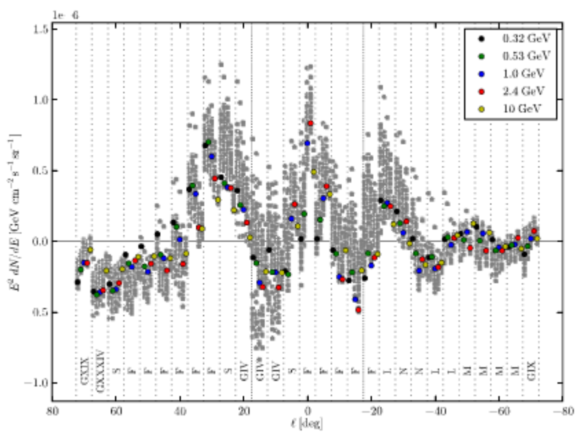
$$p\text{-value} \sim 10^{-300}$$



$$\chi^2 = \left[\frac{dN}{dE}(m_\chi, \sigma v) - \left(\frac{dN}{dE}\right)_{obs}\right] \cdot \Sigma^{-1} \cdot \left[\frac{dN}{dE}(m_\chi, \sigma v) - \left(\frac{dN}{dE}\right)_{obs}\right]$$

$$\sim 6\sigma$$

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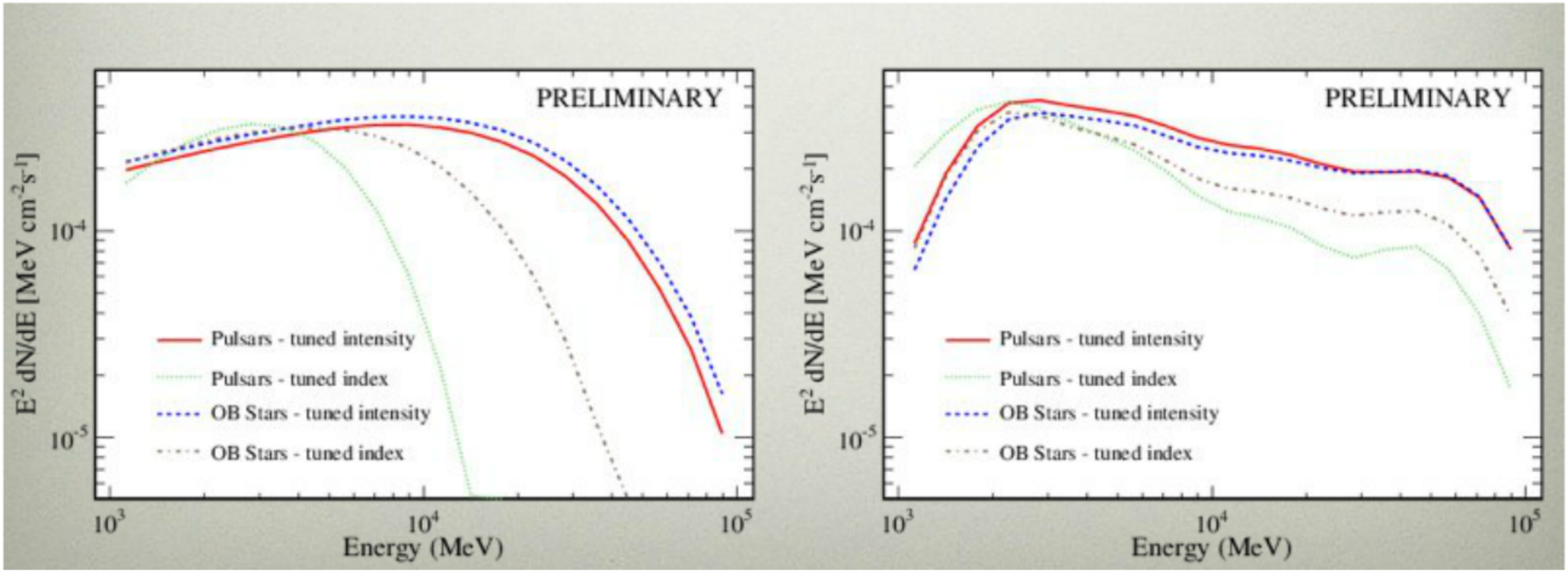
Fermi



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Simona Murgia, Fermi symposium 2014
[http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2014/program/08_Murgia.pdf]

Galactic Center is a good place to look for dark matter

$$J(\psi) = \int_{\text{l.o.s.}} ds\, \rho(r)^2$$

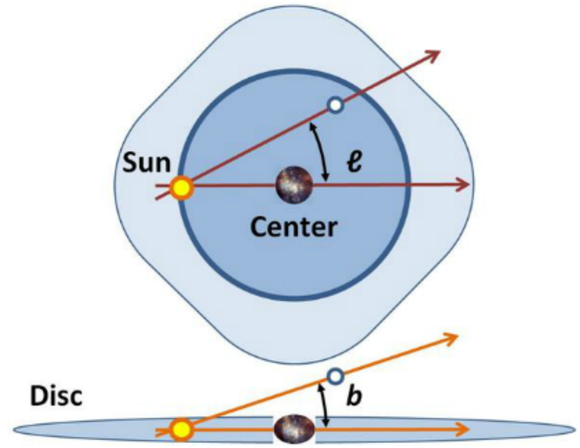
Navarro-Frenk-White profile

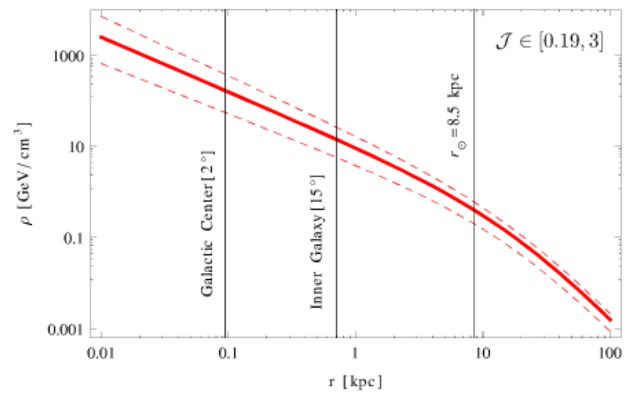
$$\rho(r) = \rho_0 \frac{(r/r_s)^{-\gamma}}{(1 + r/r_s)^{3-\gamma}}$$

Profile uncertainties are large near GC

$$\gamma = 1.2 \pm 0.1$$
$$\rho_\odot = 0.4 \pm 0.2$$

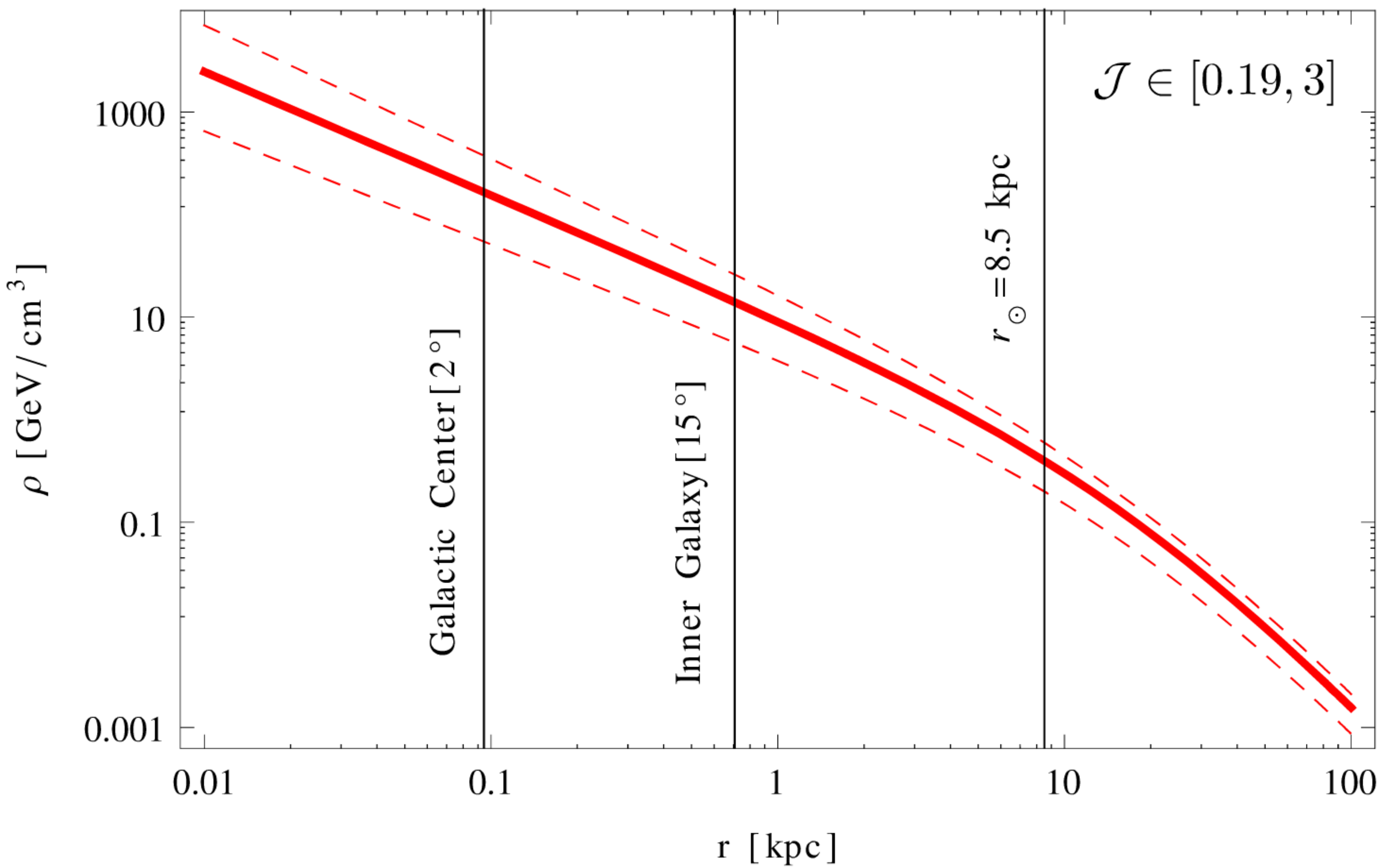
$$\bar{J} = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} J(\psi) d\Omega \equiv \mathcal{J} \times \bar{J}_{\text{canonical}}$$





Miguel Pato, Fabio Iocco, Gianfranco Bertone
[arXiv:1504.06324]

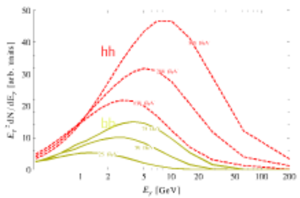
J-factor



$\mathcal{J} \in [0.19, 3]$
ρ [GeV / cm^3]
1000
10
0.1
0.001
Galactic Center [2°]
Inner Galaxy [15°]
$r_\odot$=8.5 kpc
0.01
0.1
1
10
100
r [kpc]

Spectra from SM final states

Photons arise from hadronization and Bremsstrahlung



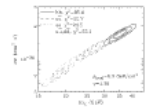
Can potentially be used to discriminate models

Fitting the excess

Daylan et al

prefer a $\bar{b}b$ final state

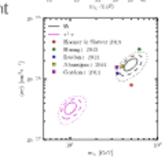
Direct detection limits are typically stringent



CCW

best fits agree with Daylan et al

added systematic errors allow $\tau^+\tau^-$



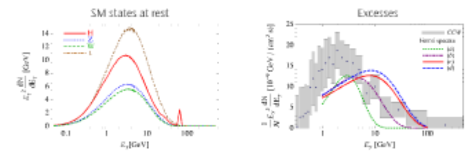
Fermi analysis

opens up many possibilities in masses and channels

Preliminary, hard to ascribe rigorous significance

WIMPS at the Galactic center

Spectrum of photons from many SM final states similar to the excess



H,Z,W final states are generic when dark matter is charged under Weak interactions

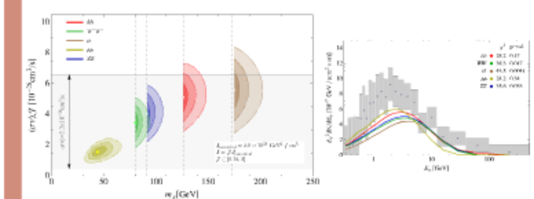
The spectra are boosted for a general dark matter mass

WIMPS at the Galactic center

Fitting to CCW

Other final states provide a "reasonable" fit

Mass of dark matter and SM final state need to be close



Spectrum

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Fitting to Fermi

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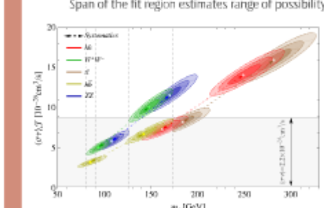

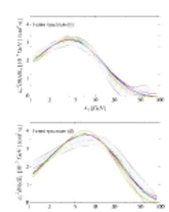

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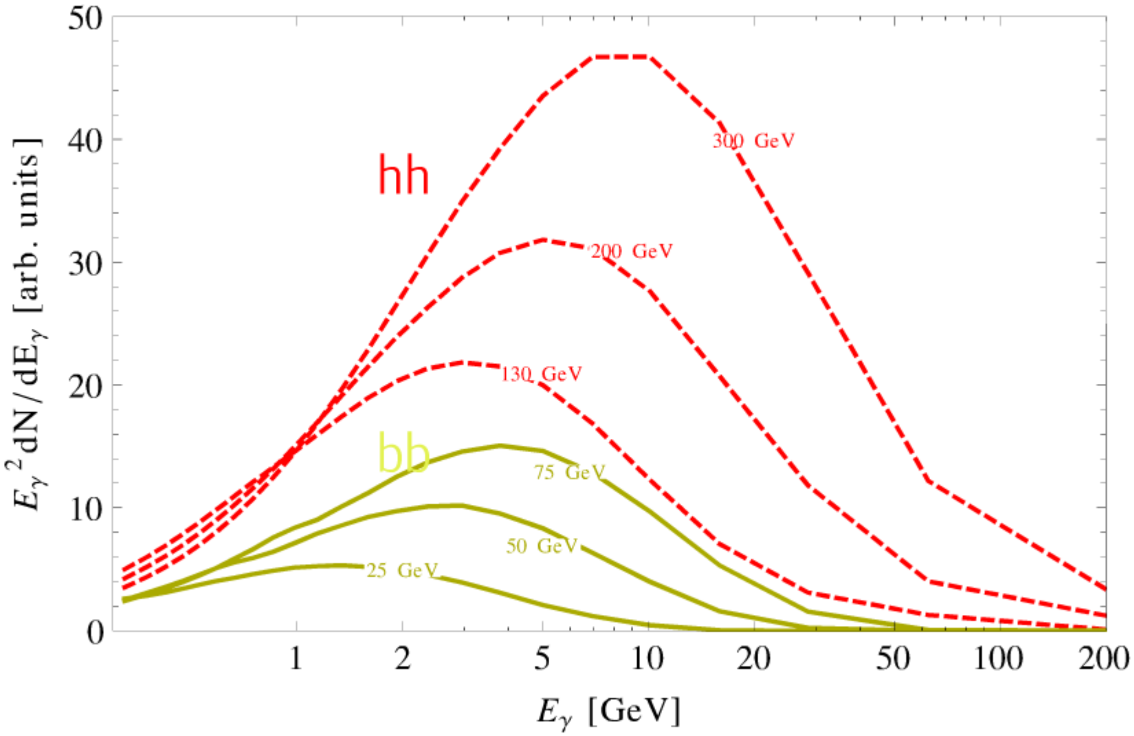

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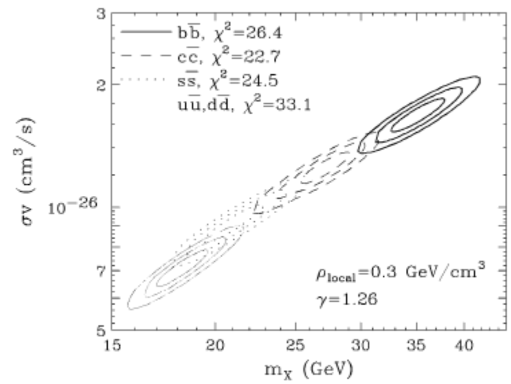
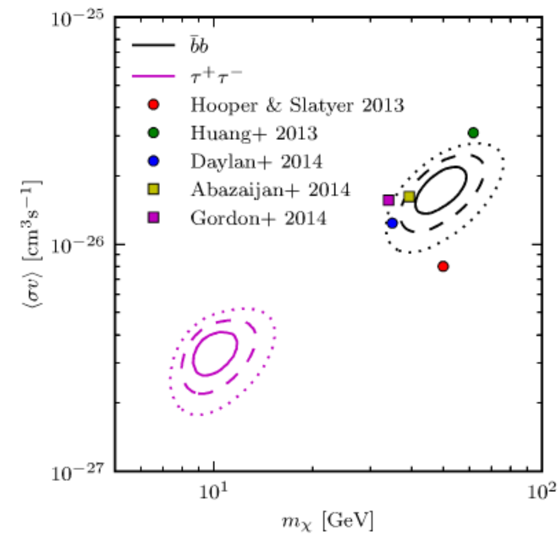


Daylan et al

- prefer a $\bar{b}b$ final state
- Direct detection limits are typically stringent



CCW

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- opens up many possibilities in masses and channels
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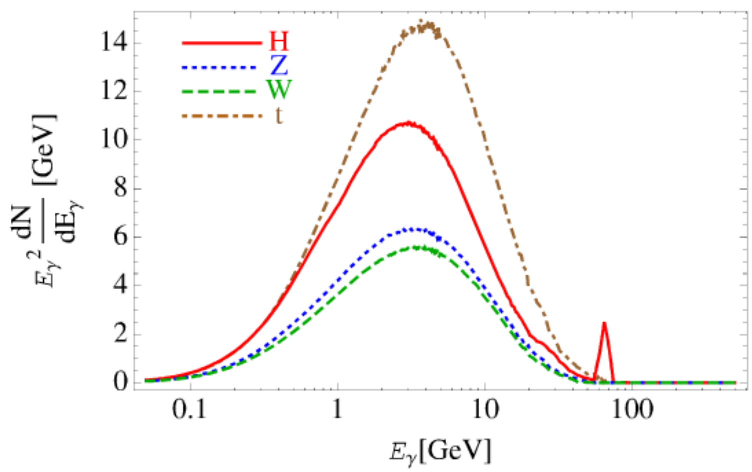
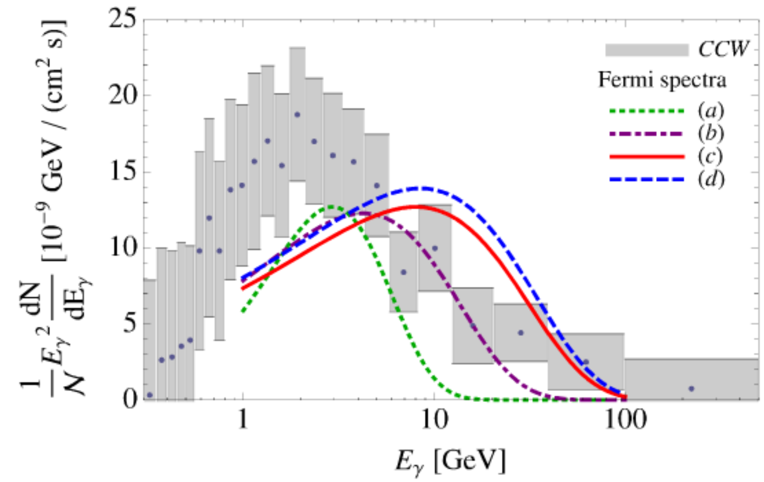
SM states at rest



Excesses



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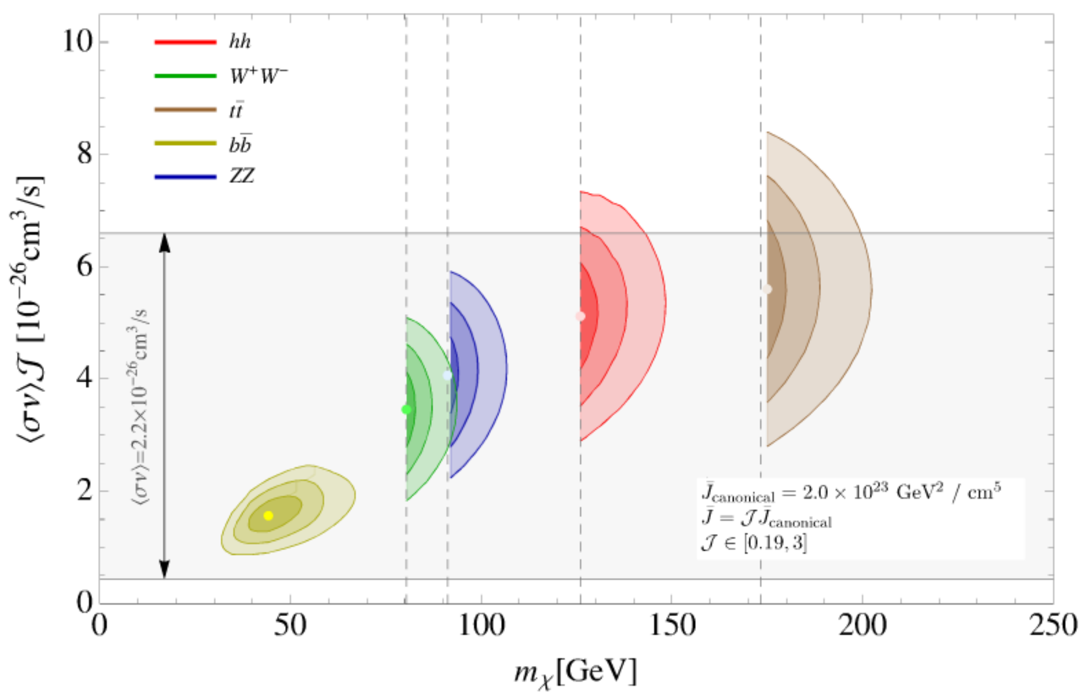
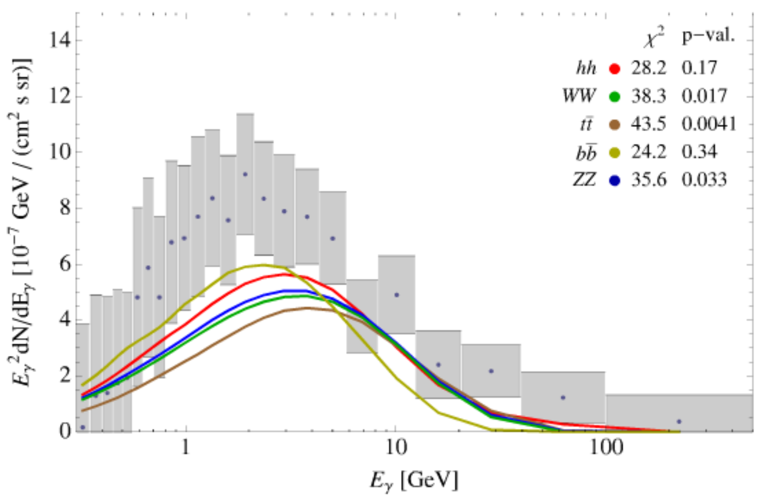
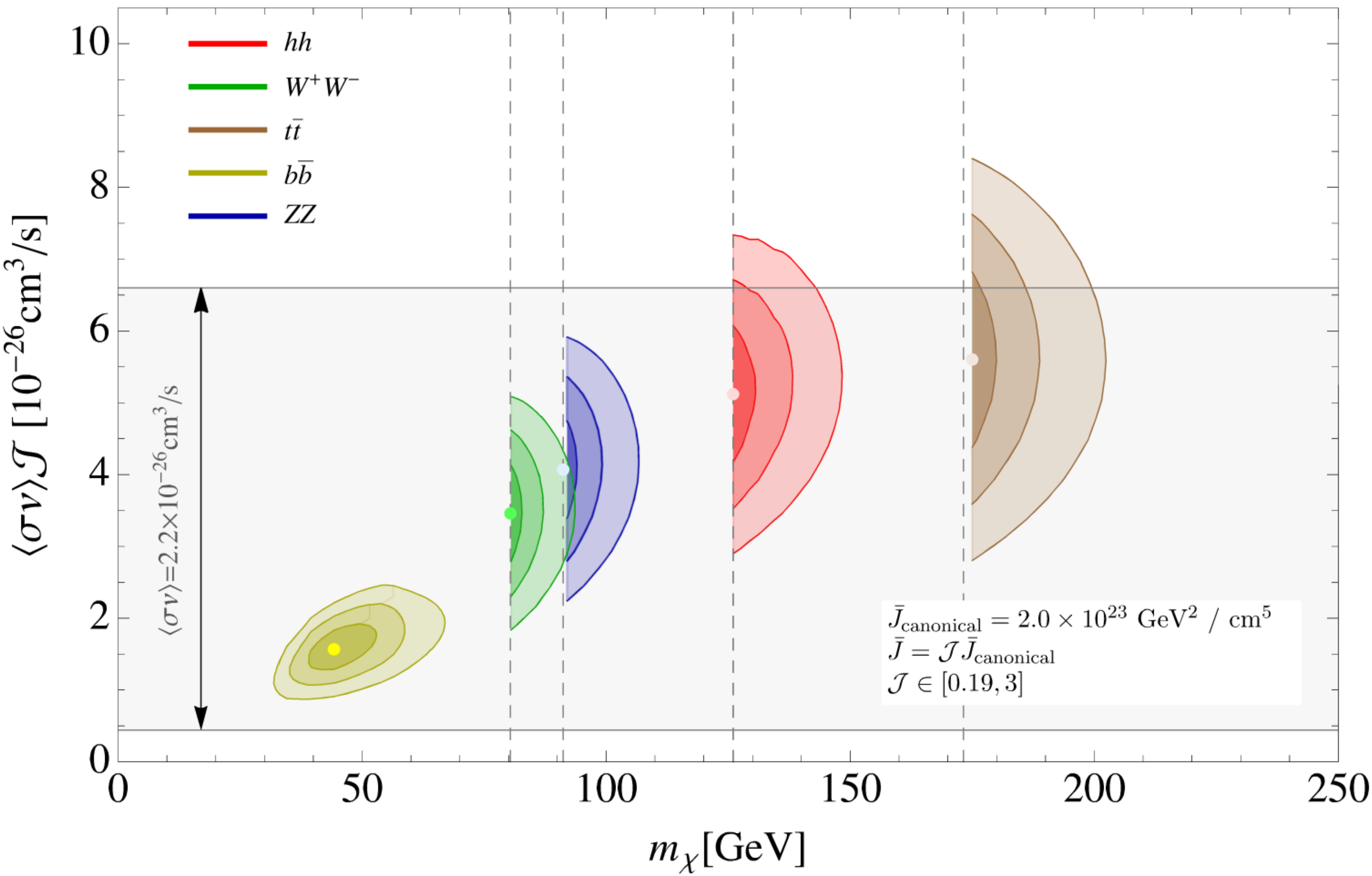
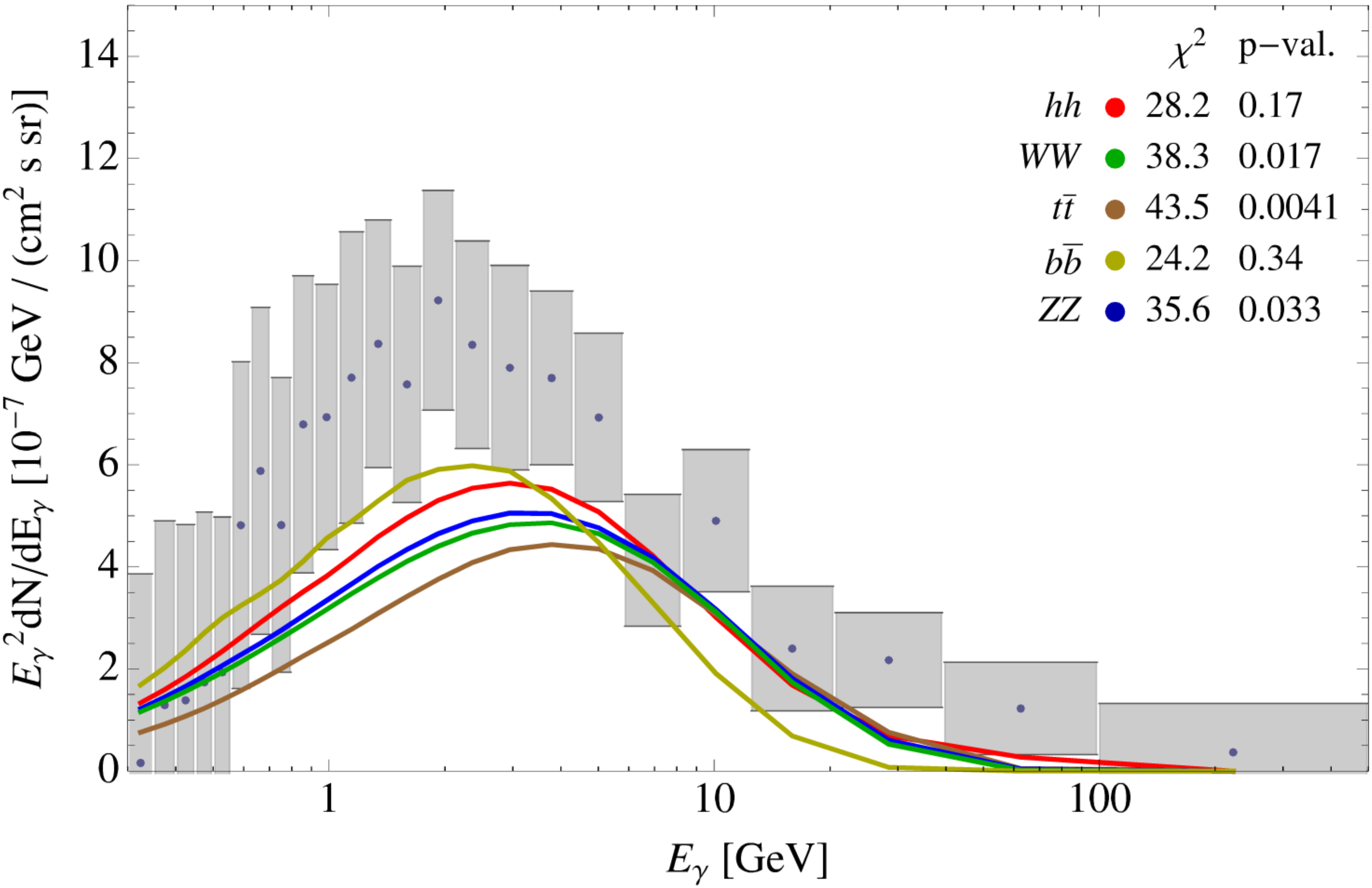






hh
W^+W^-
$t\bar{t}$
$b\bar{b}$
ZZ
$\langle\sigma v\rangle\mathcal{J}$ [10^{-26}cm^3/s]
$\langle\sigma v\rangle$=2.2×10^{-26}cm^3/s
$\bar{J}_{\rm canonical} = 2.0 \times 10^{23}$ GeV^2 / cm^5
$\bar{J} = \mathcal{J}\,\bar{J}_{\rm canonical}$
$\mathcal{J} \in [0.19, 3]$
m_χ[GeV]
0
50
100
150
200
250
2
4
6
8
10



χ^2 p−val.
hh 28.2 0.17
WW 38.3 0.017
$t\bar{t}$ 43.5 0.0041
$b\bar{b}$ 24.2 0.34
ZZ 35.6 0.033
$E_\gamma{}^2 dN/dE_\gamma$ [10^{-7} GeV / (cm^2 s sr)]
E_γ [GeV]
0
2
4
6
8
10
12
14
1
10
100

WIMPS at the Galactic center

Fitting to CCW

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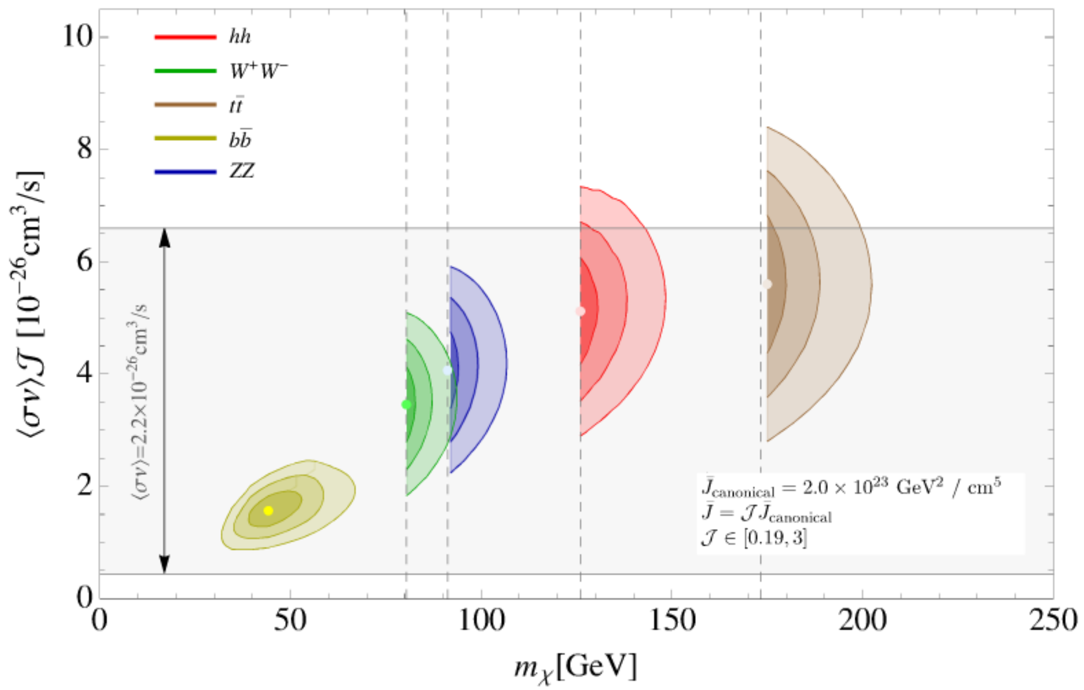

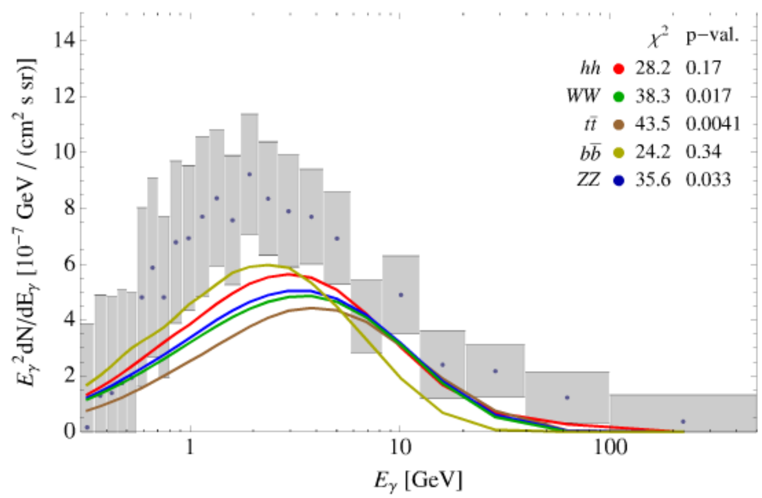

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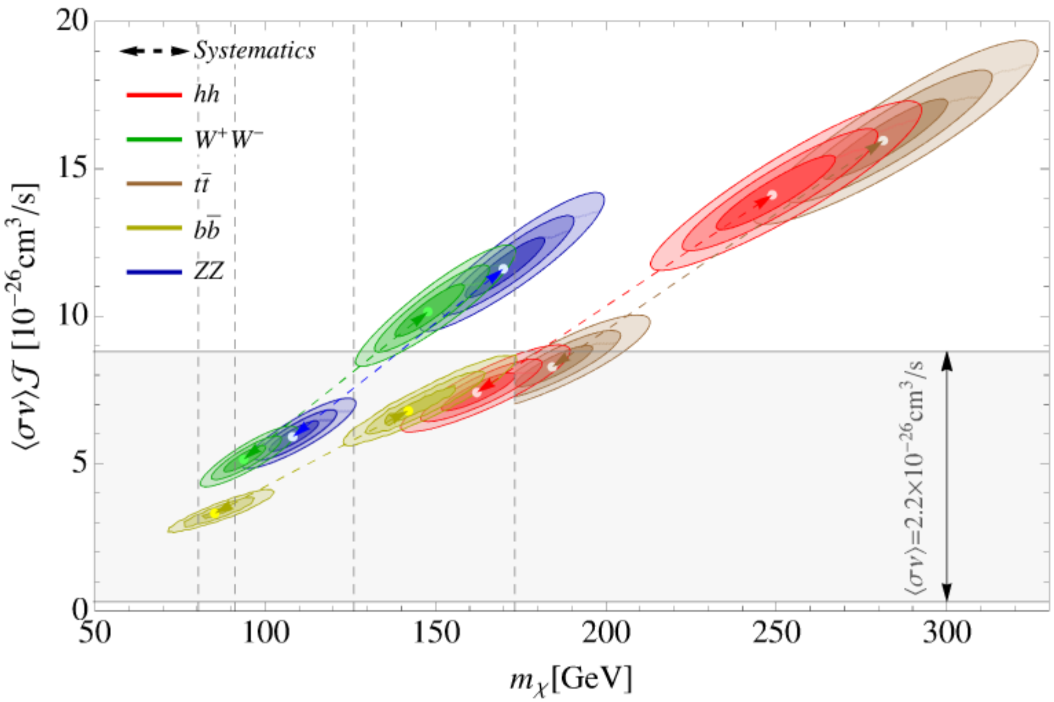
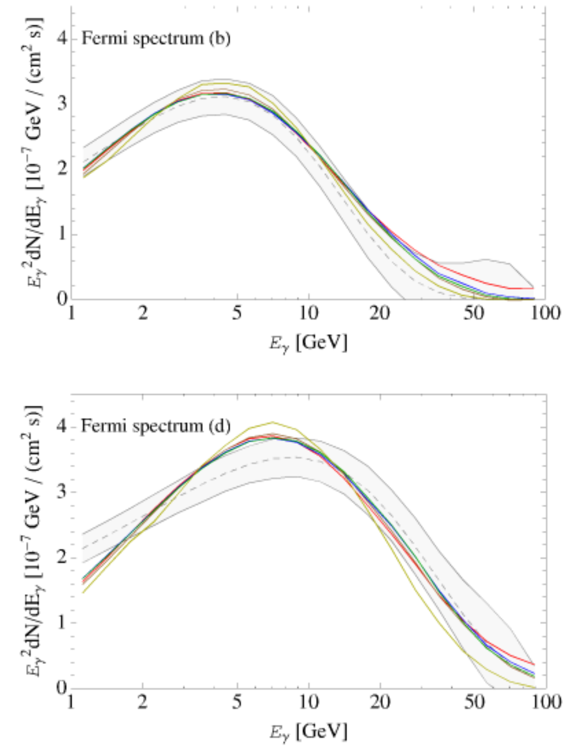
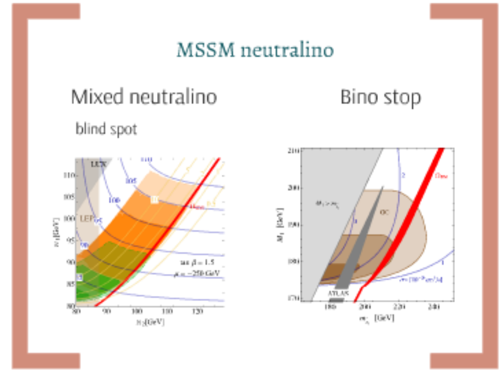
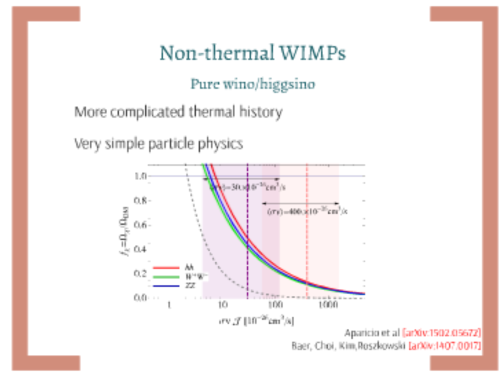
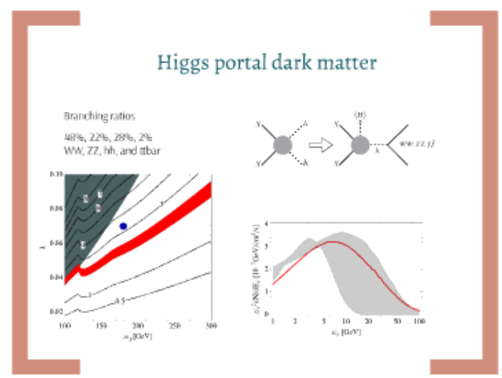




Models





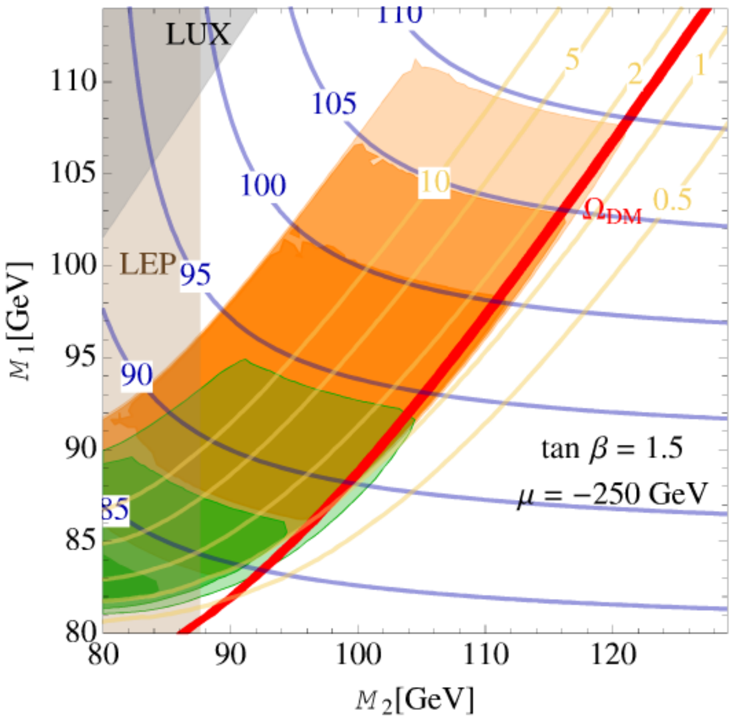


WIMPs

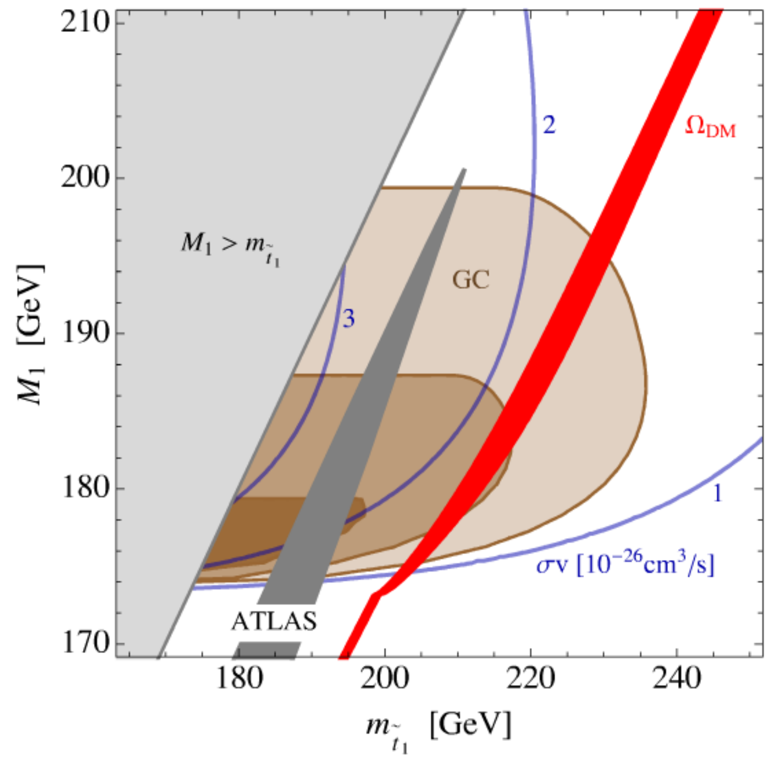
MSSM neutralino

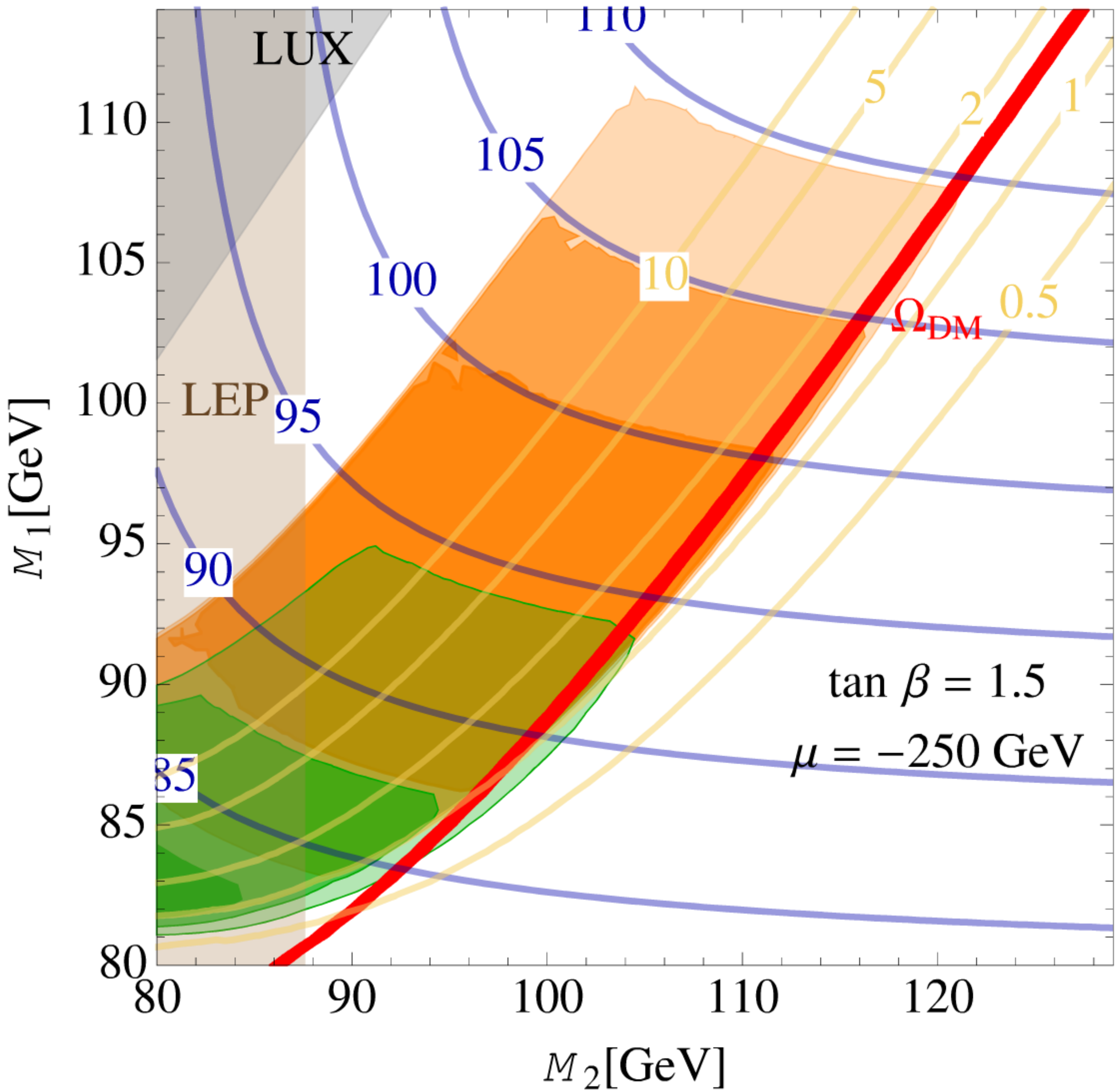
Mixed neutralino

blind spot

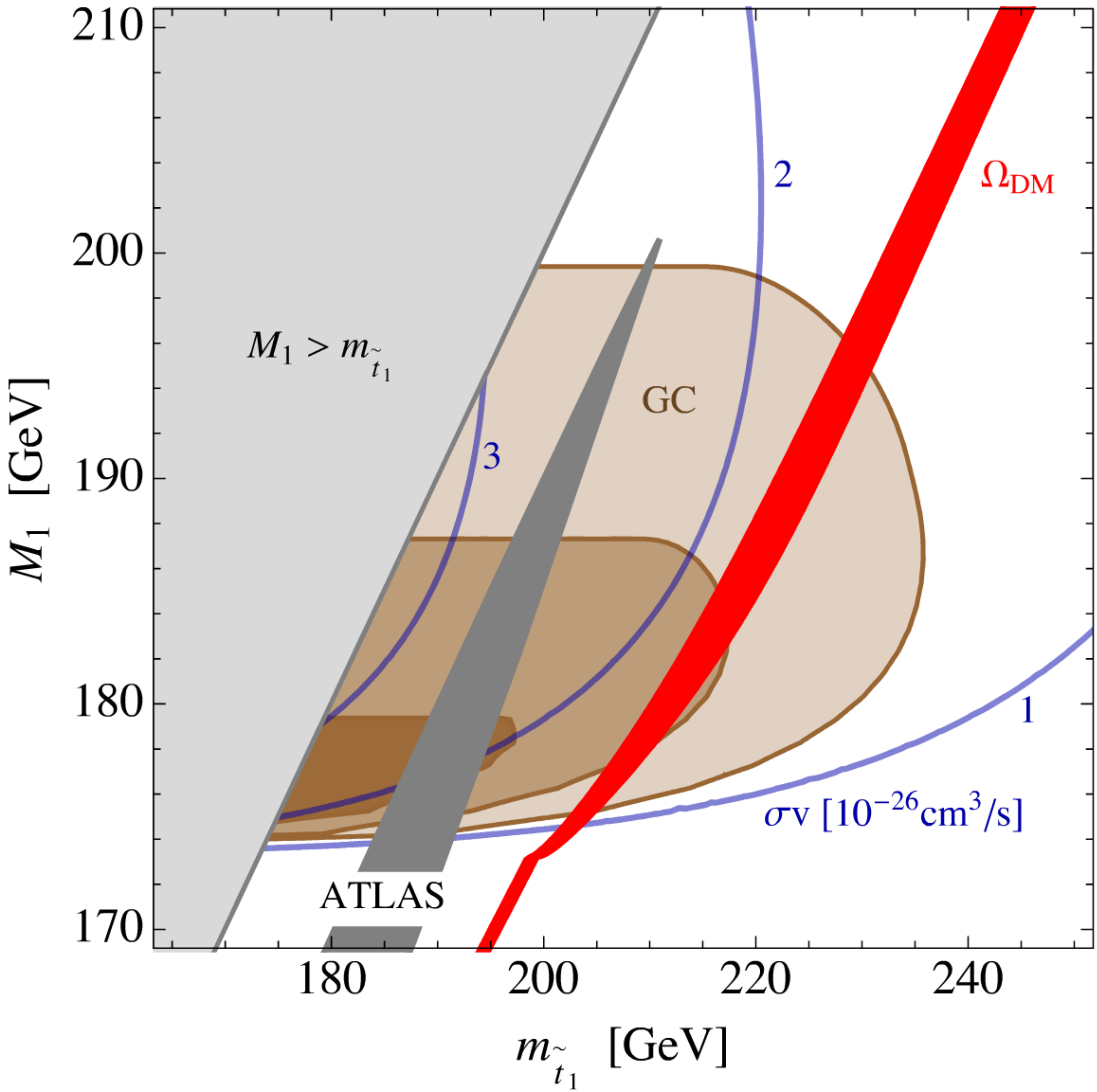


Bino stop





LUX
LEP
110
105
100
95
90
85
5
2
1
10
0.5
Ω_{DM}
tan β = 1.5
μ = −250 GeV
M_1[GeV]
M_2[GeV]
80
90
100
110
120



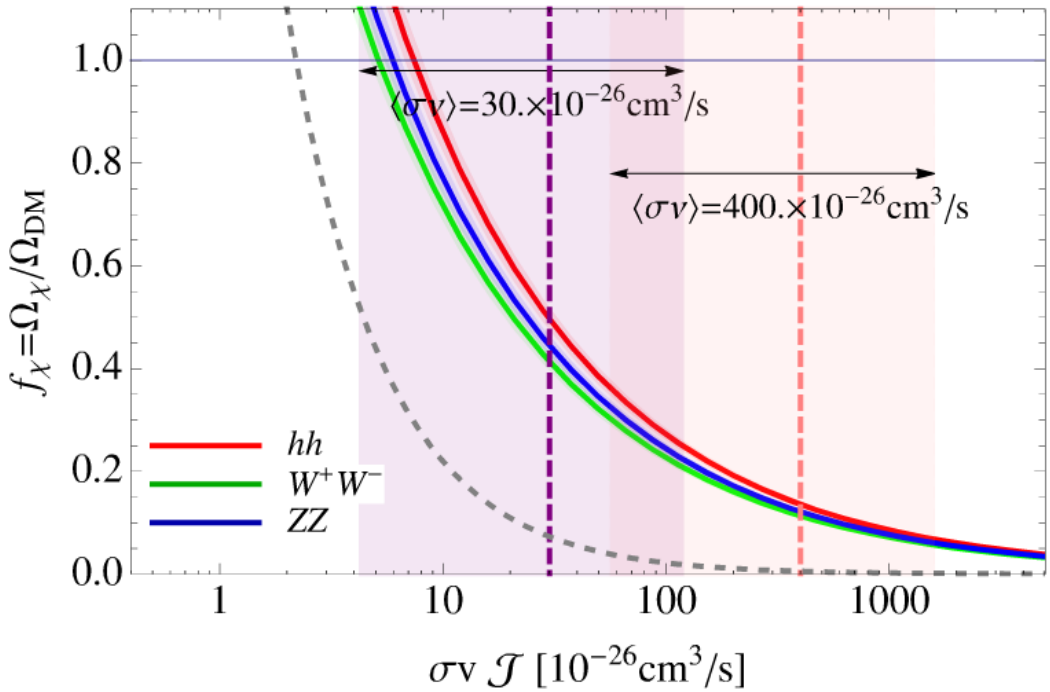
210
200
190
180
170
180
200
220
240
M_1 [GeV]
$m_{\tilde{t}_1}$ [GeV]
$M_1 > m_{\tilde{t}_1}$
GC
ATLAS
Ω_{DM}
3
2
1
σv [10^{-26}cm^3/s]

Non-thermal WIMPs

Pure wino/higgsino

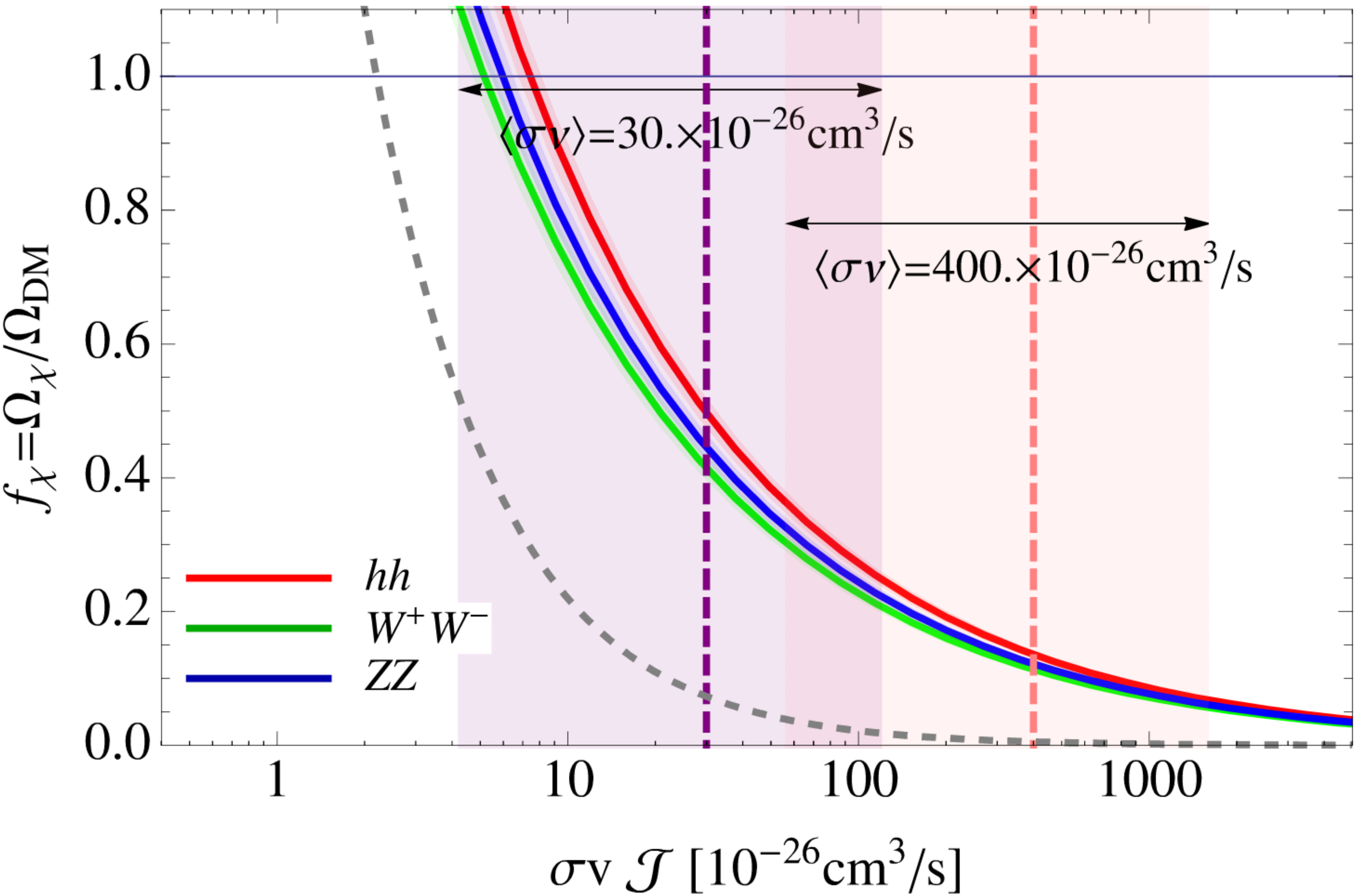
More complicated thermal history

Very simple particle physics



Aparicio et al [arXiv:1502.05672]

Baer, Choi, Kim,Roszkowski [arXiv:1407.0017] mple particle physics

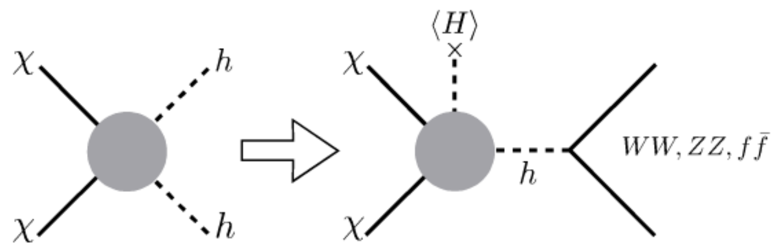


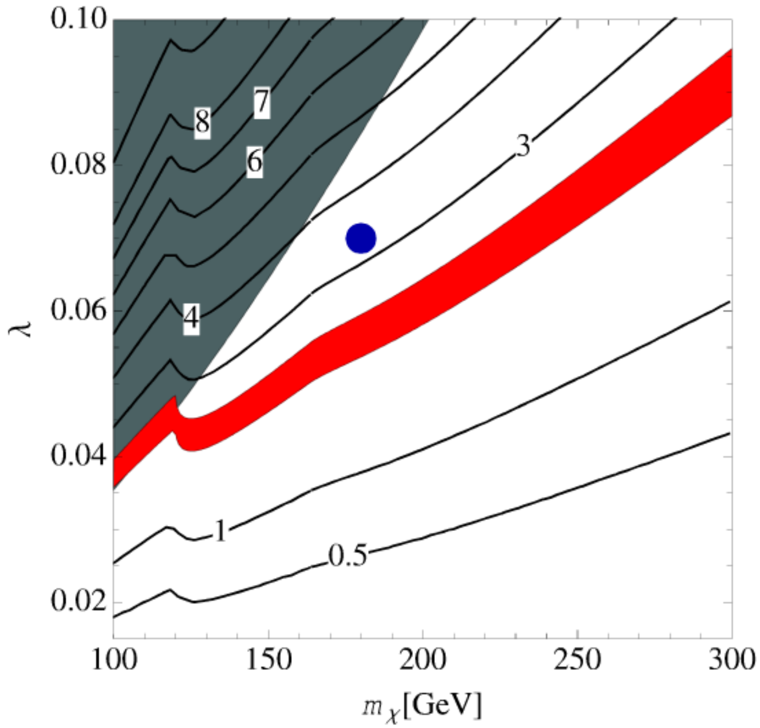
Aparicio

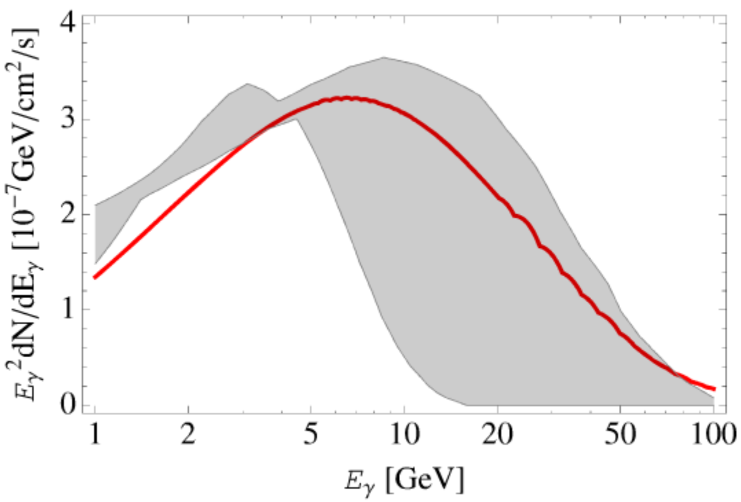
Higgs portal dark matter

Branching ratios

48%, 22%, 28%, 2%
WW, ZZ, hh, and ttbar







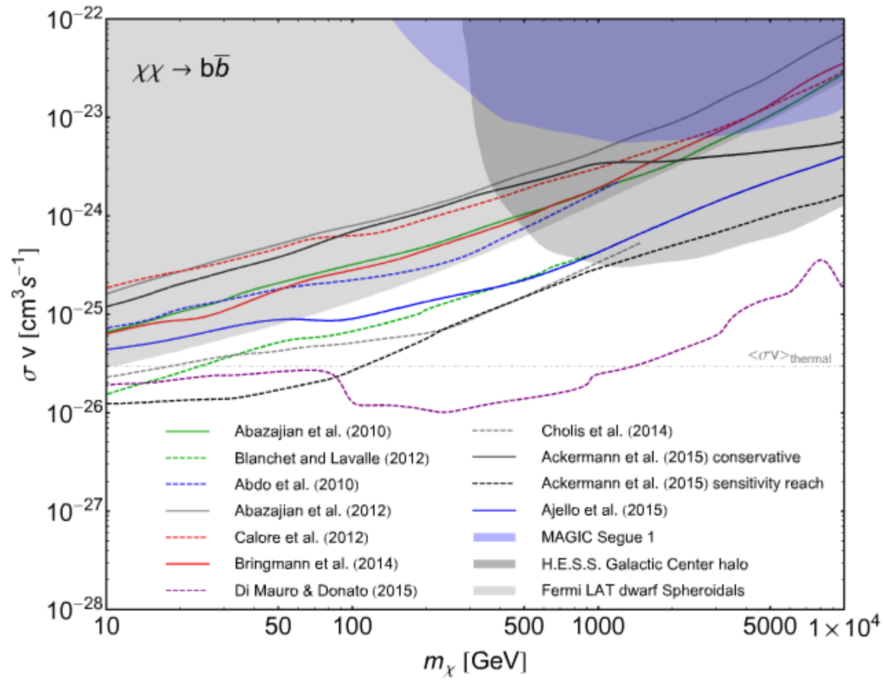
Conclusions

The Galactic Center Excess has held up to scrutiny;
Tantalizing possibility that its origin is dark matter

Characterizing the signal and error-bars rigorously challenging

Limits from many analyses are getting competitive

- Dwarf Spheroidals
- Diffuse emission
- Isotropic emission



Hints of new signals, new dwarf candidates

Mattia Fornasa, Miguel A. Sanchez-Conde
[arXiv:1502.02866]

Watch this space!