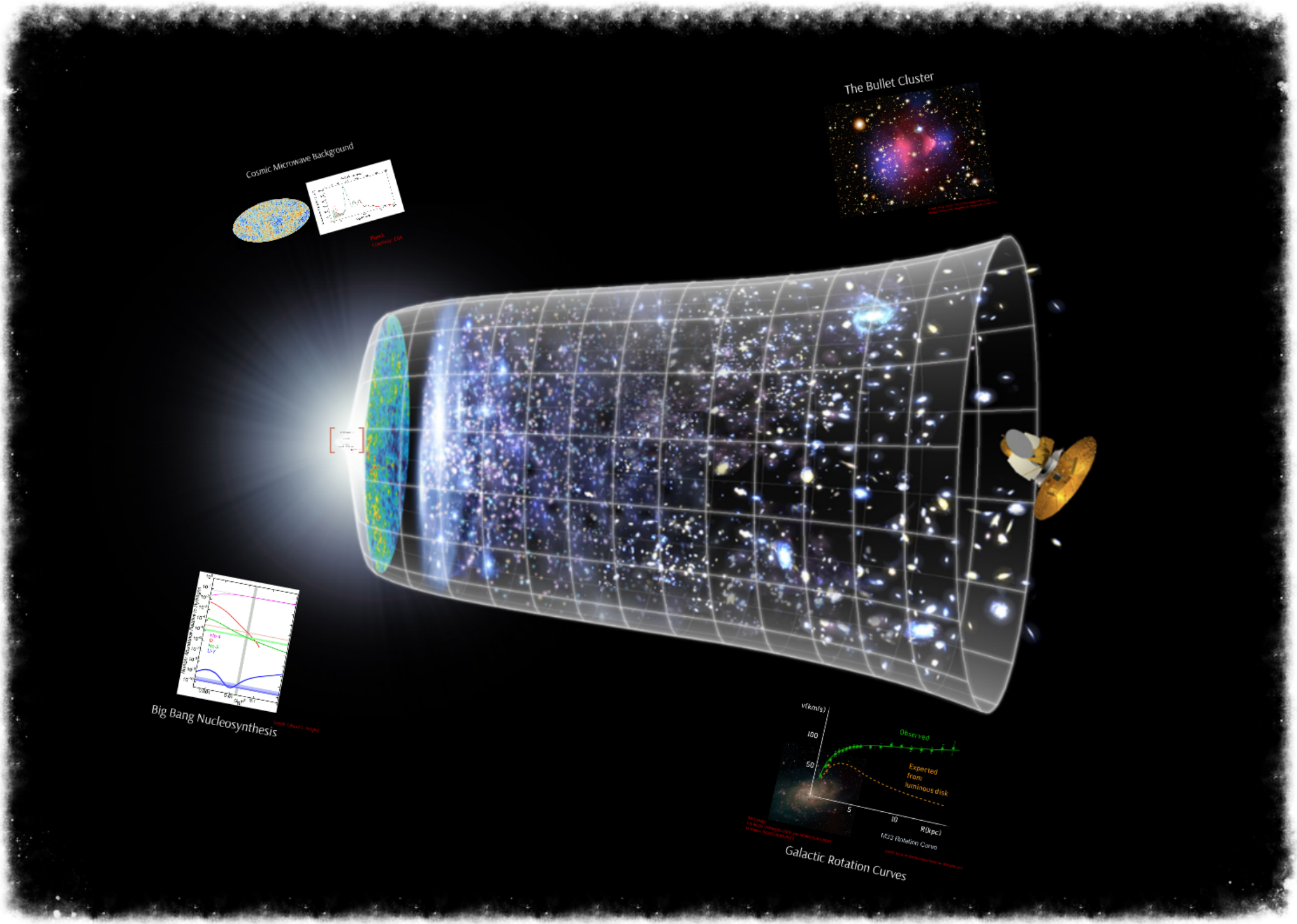
WIMPs@GC.com

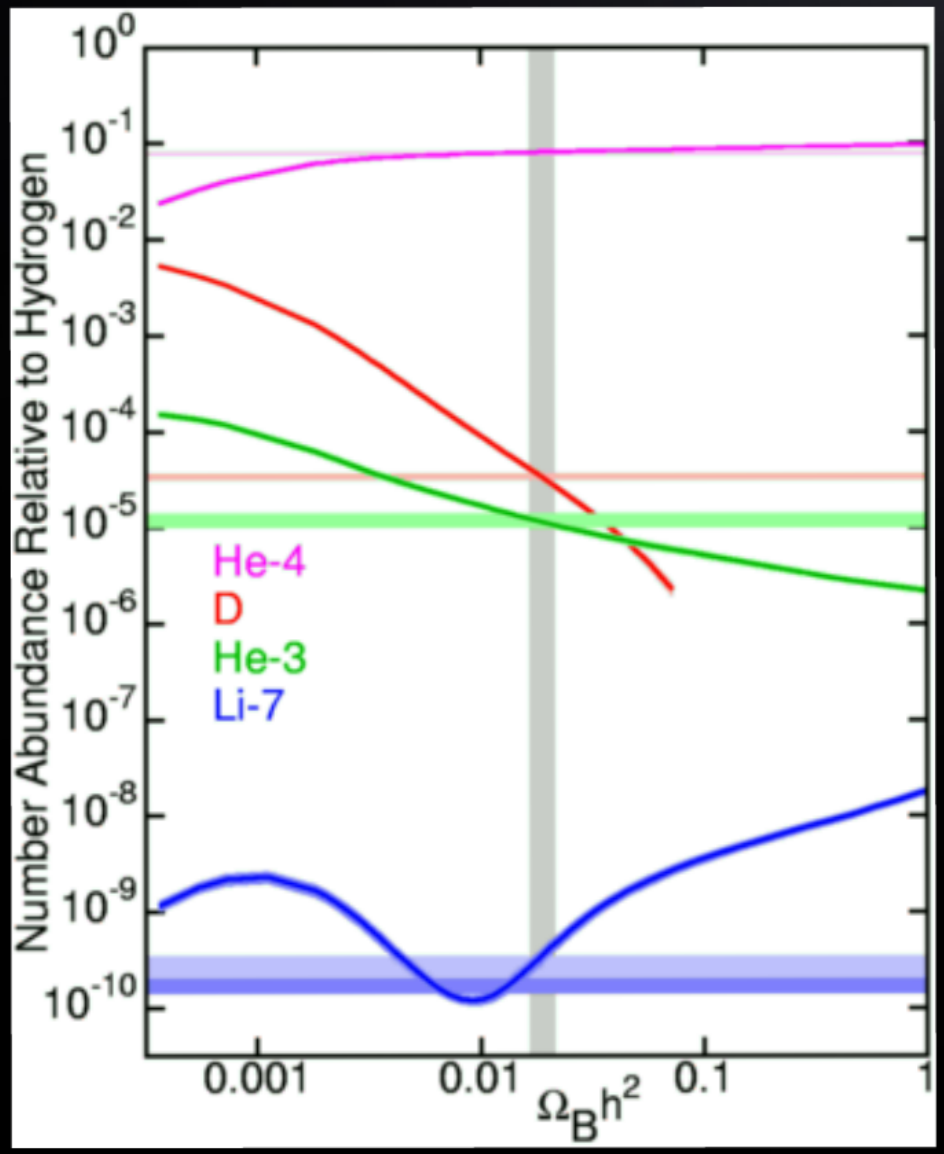
Prateek Agrawal

Fermilab

March 20
MITP Workshop
Effective Theories and Dark Matter

PA, Brian Batell, Patrick J. Fox, Roni Harnik
arXiv:1411.2592

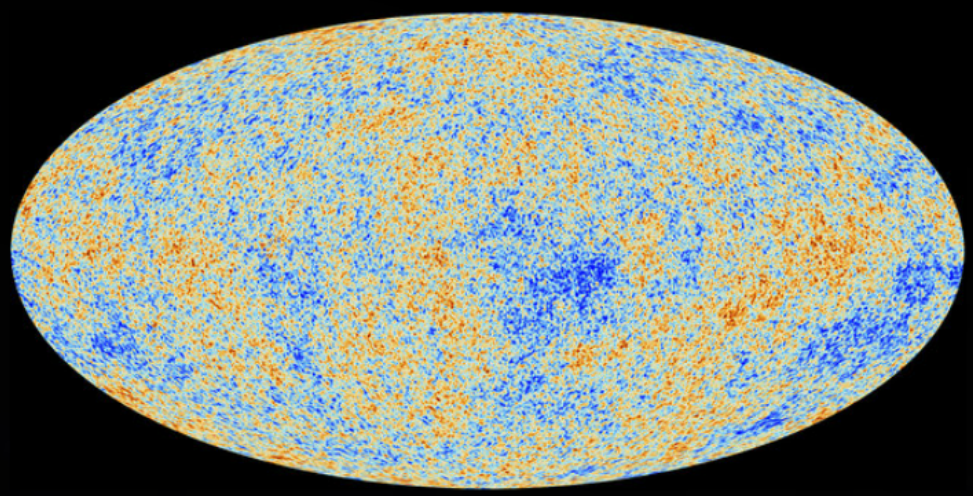

Cosmic Microwave Background
Planck
Courtesy ESA
The Bullet Cluster
Big Bang Nucleosynthesis
v(km/s)
100
50
Observed
Expected
from
luminous disk
5
10
R(kpc)
M33 Rotation Curve
Galactic Rotation Curves

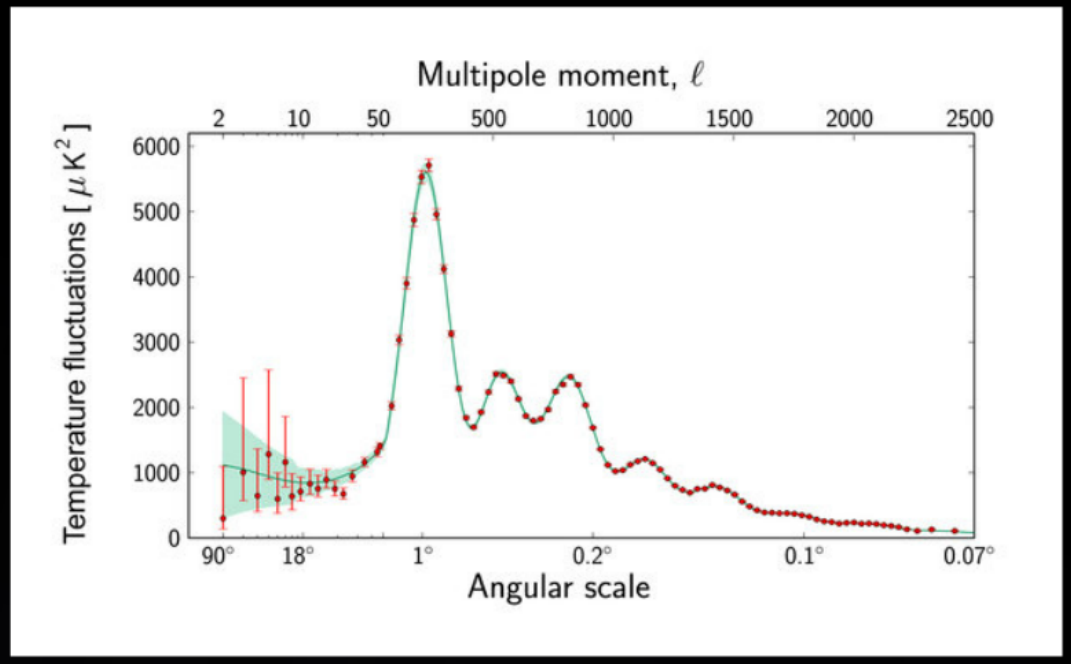


[credit: Edward L. Wright]

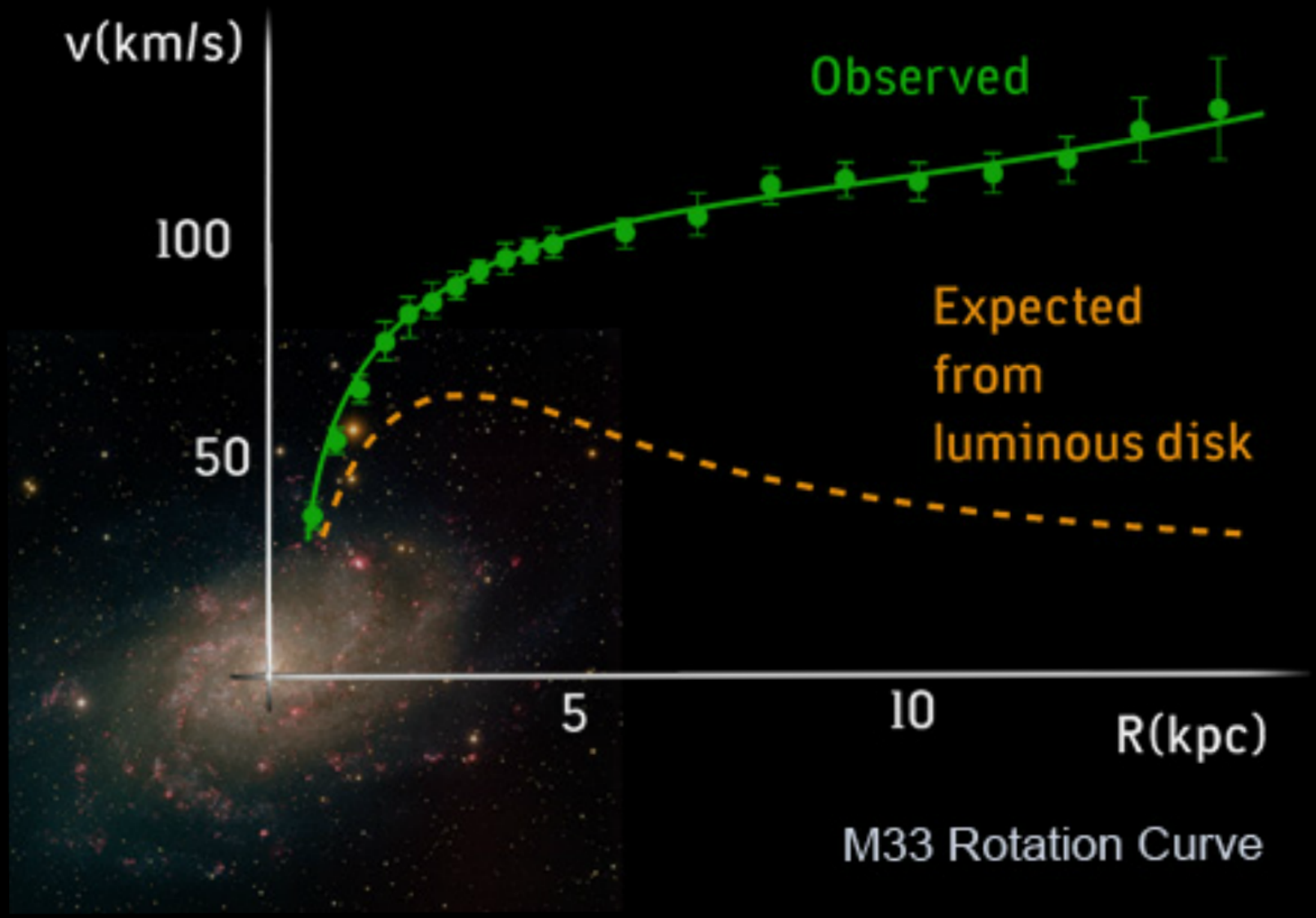
Big Bang Nucleosynthesis

Cosmic Microwave Background





Planck
Courtesy: ESA



M33 image:
T.A.Rector (NRAO/AUI/NSF and NOAO/AURA/NSF)
M.Hanna (NOAO/AURA/NSF)

[credit: Harvard-Smithsonian Center for Astrophysics]

Galactic Rotation Curves

The Bullet Cluster

[Credit: X-ray: NASA/CXC/CfA/M.Markevitch et al.;
Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.]

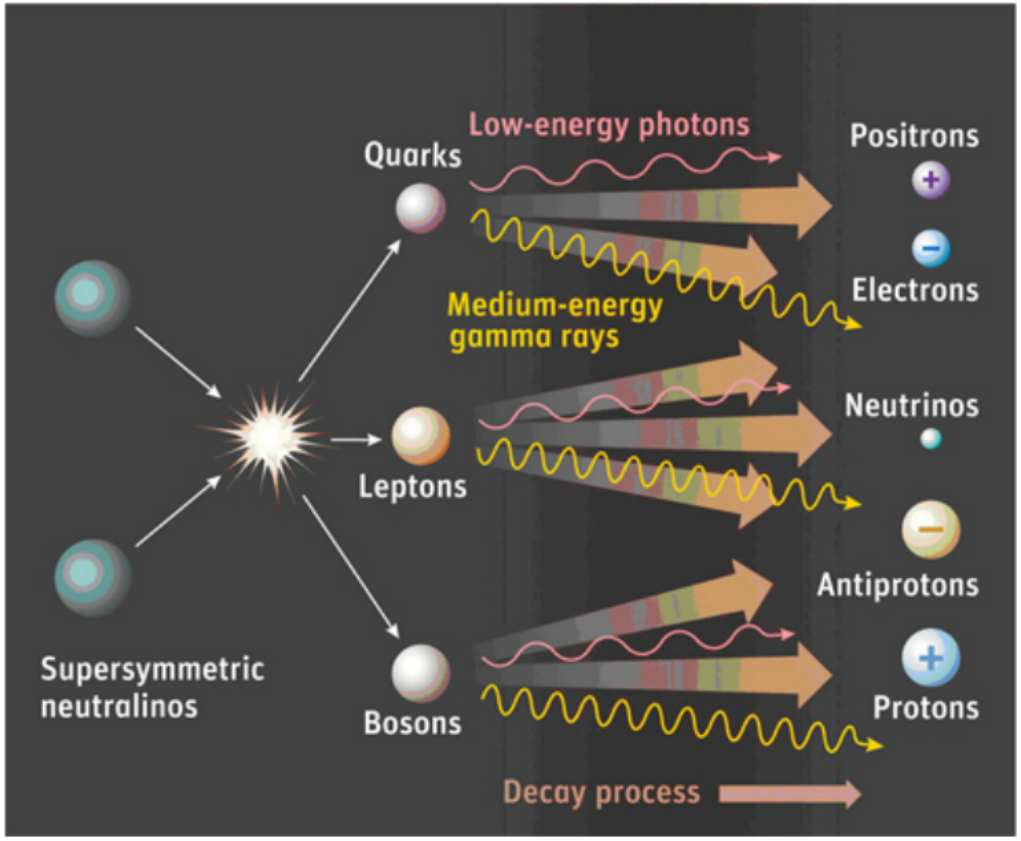
Indirect detection

Dark matter annihilations today might leave visible traces in the sky

The fluxes are often observable in the WIMP parameter space

Backgrounds are unknown, so discovery is challenging

Photons and neutrinos point back to sources, contain more spatial information



Positrons / anti-protons background spectra fall steeply at high energies

[credit: Michele Doro]

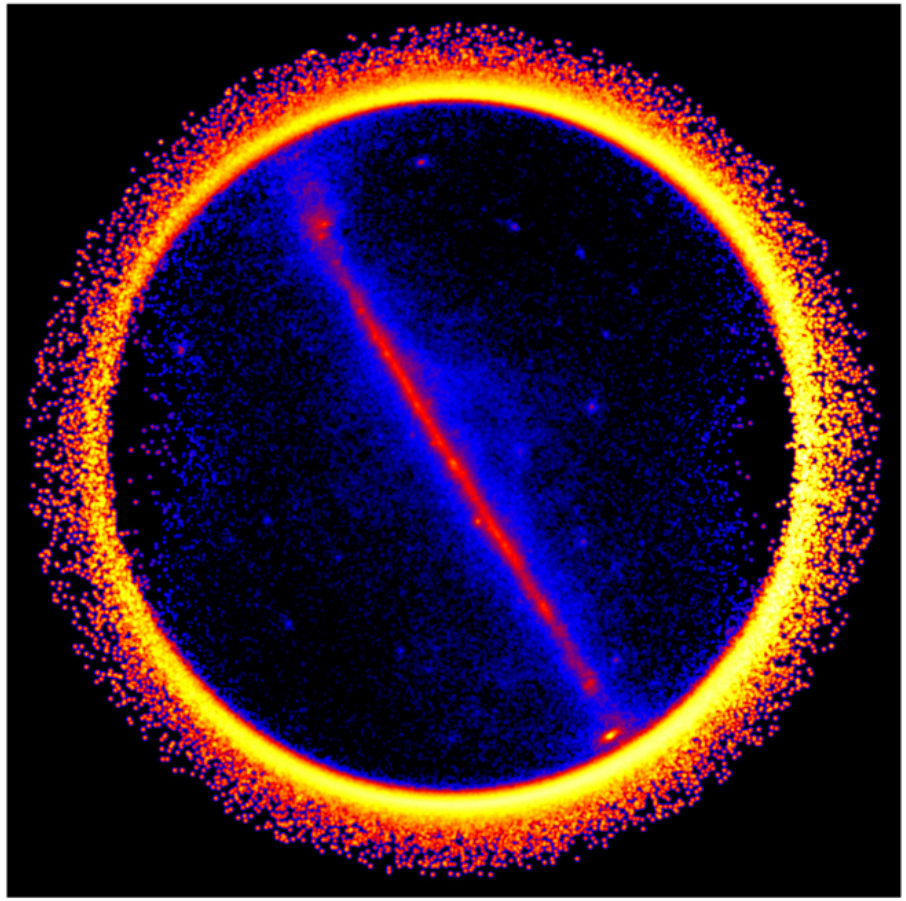
Fermi Large Area Telescope

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

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

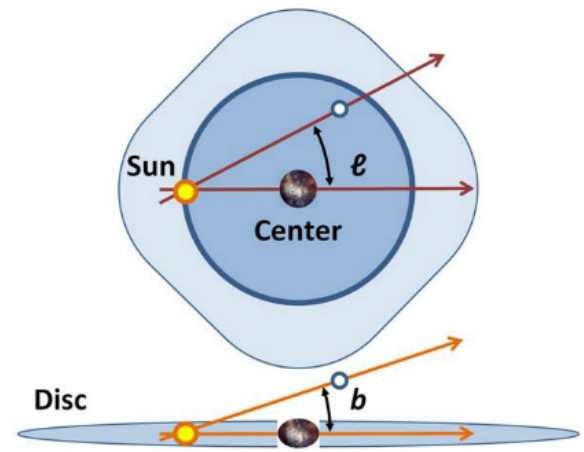
Models

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

*prompt only

Galactic Center is a good place to look for dark matter

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

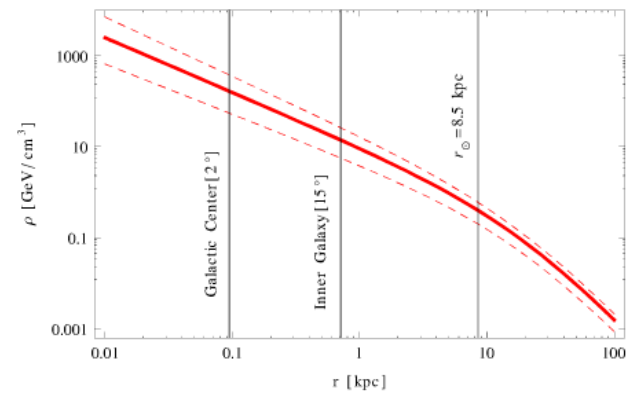


Navarro-Frenk-White profile

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

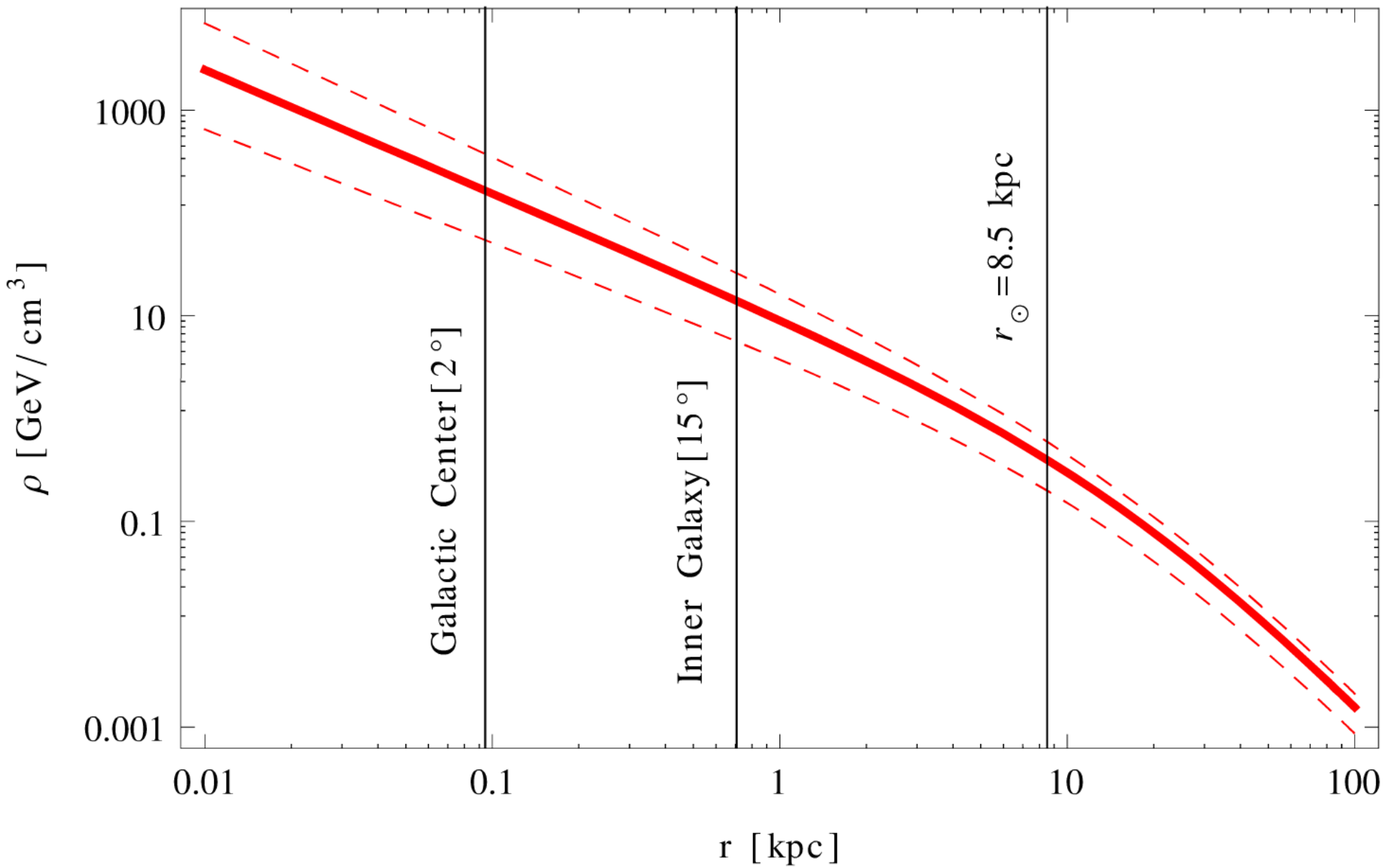
Profile uncertainties are large near GC

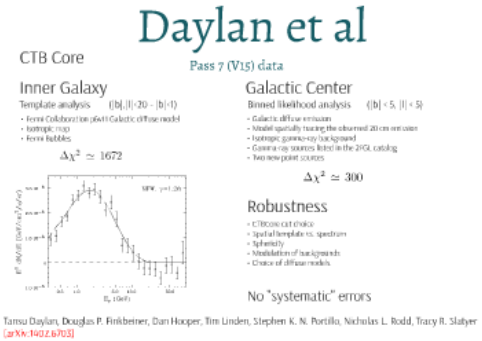
$$\gamma = 1.2 \pm 0.1$$
$$\rho_\odot = 0.4 \pm 0.2$$

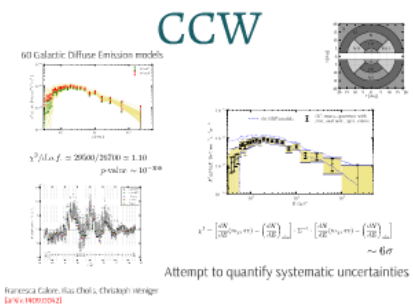


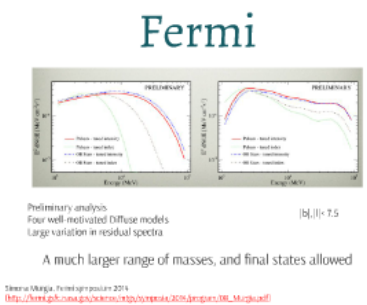
$$\bar{J} = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} J(\psi) d\Omega \equiv \mathcal{J} \times \bar{J}_{\text{canonical}}$$

J-factor


1000
10
0.1
0.001
0.01
0.1
1
10
100
ρ [GeV/cm³]
r [kpc]
Galactic Center [2°]
Inner Galaxy [15°]
r⊙=8.5 kpc







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

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D. Hooper and T. R. Slatyer, Phys.Dark Univ. 2, 118 (2013), 1302.6589.
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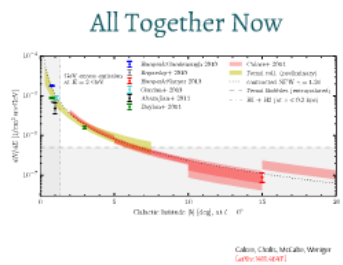


$$\frac{dN}{d\Omega dE}$$

The Galactic Center Analyses

Daylan et al

CTB Core

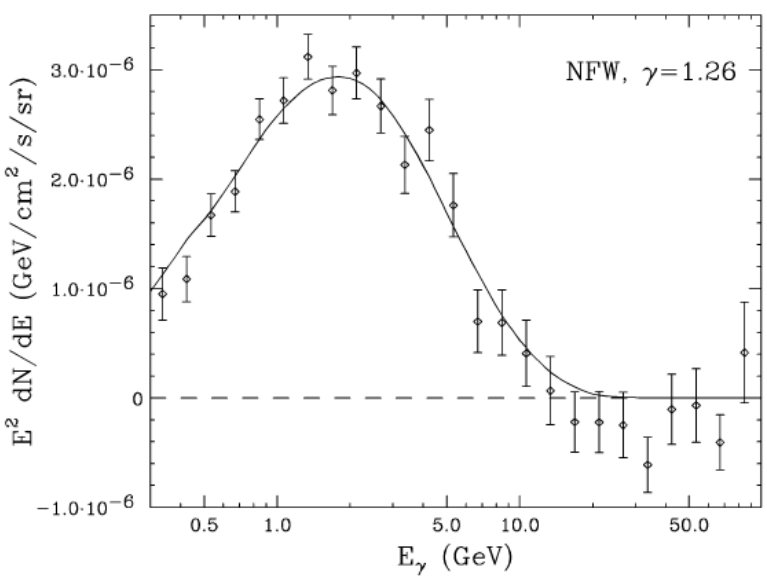
Pass 7 (V15) data

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

$$\Delta\chi^2 \simeq 300$$

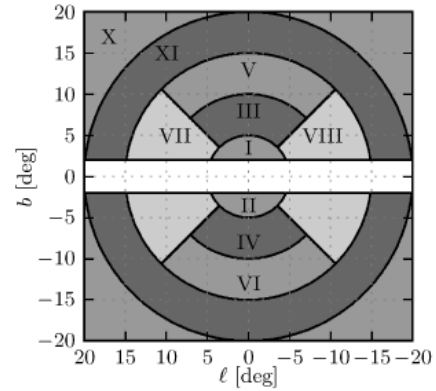
Robustness

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

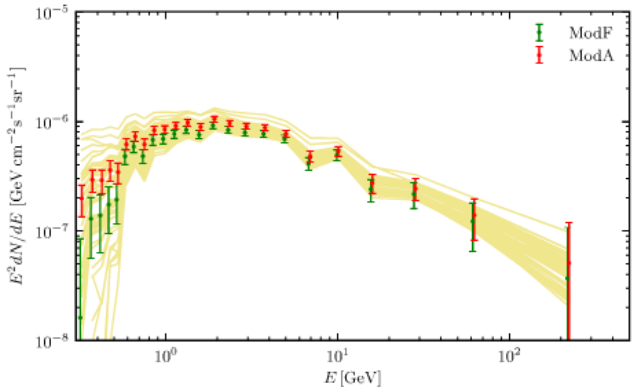
No "systematic" errors

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

CCW

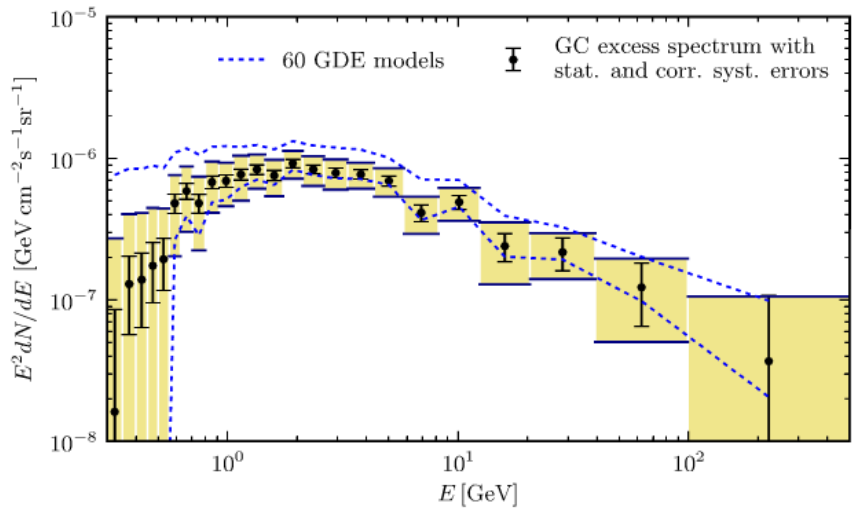


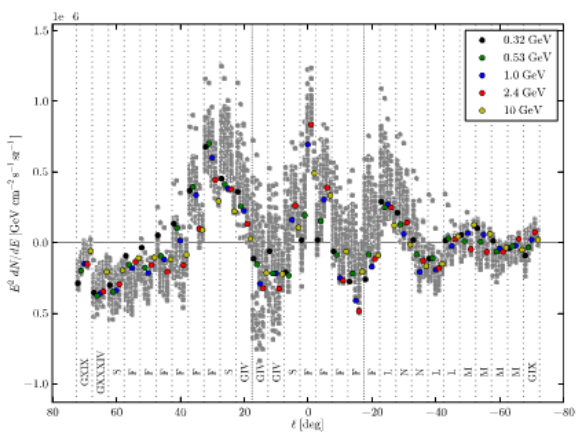
60 Galactic Diffuse Emission models



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

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





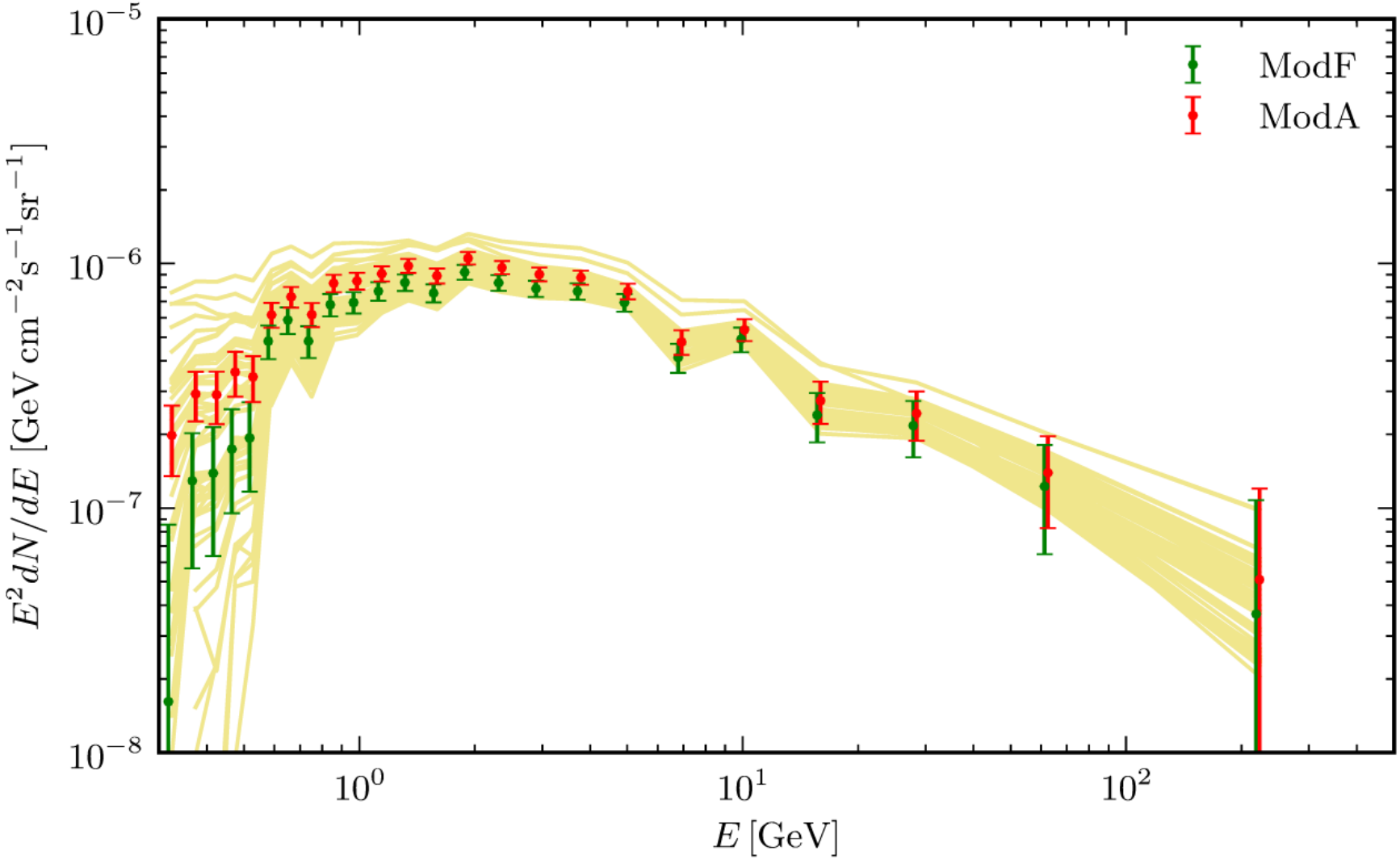
$$\chi^2 = \left[\frac{dN}{dE}(m_\chi, \sigma v) - \left(\frac{dN}{dE}\right)_{obs}\right] \cdot \Sigma^{-1} \cdot \left[\frac{dN}{dE}(m_\chi, \sigma v) - \left(\frac{dN}{dE}\right)_{obs}\right]$$

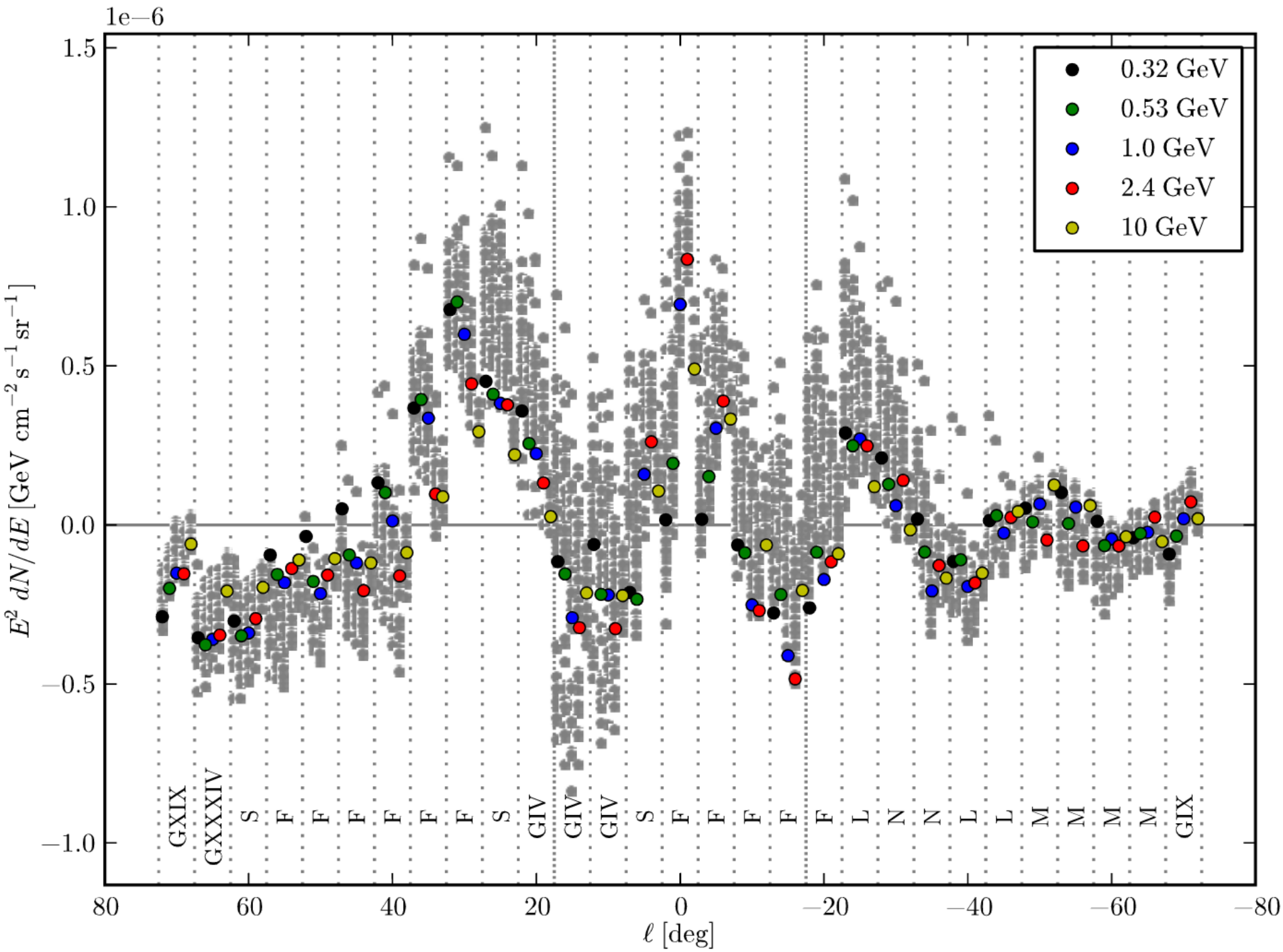
$$\sim 6\sigma$$

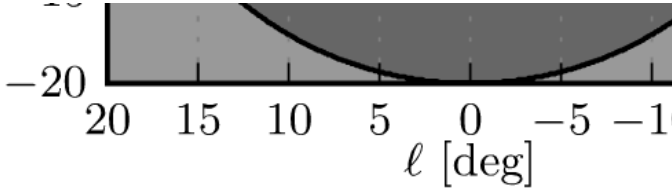
Attempt to quantify systematic uncertainties

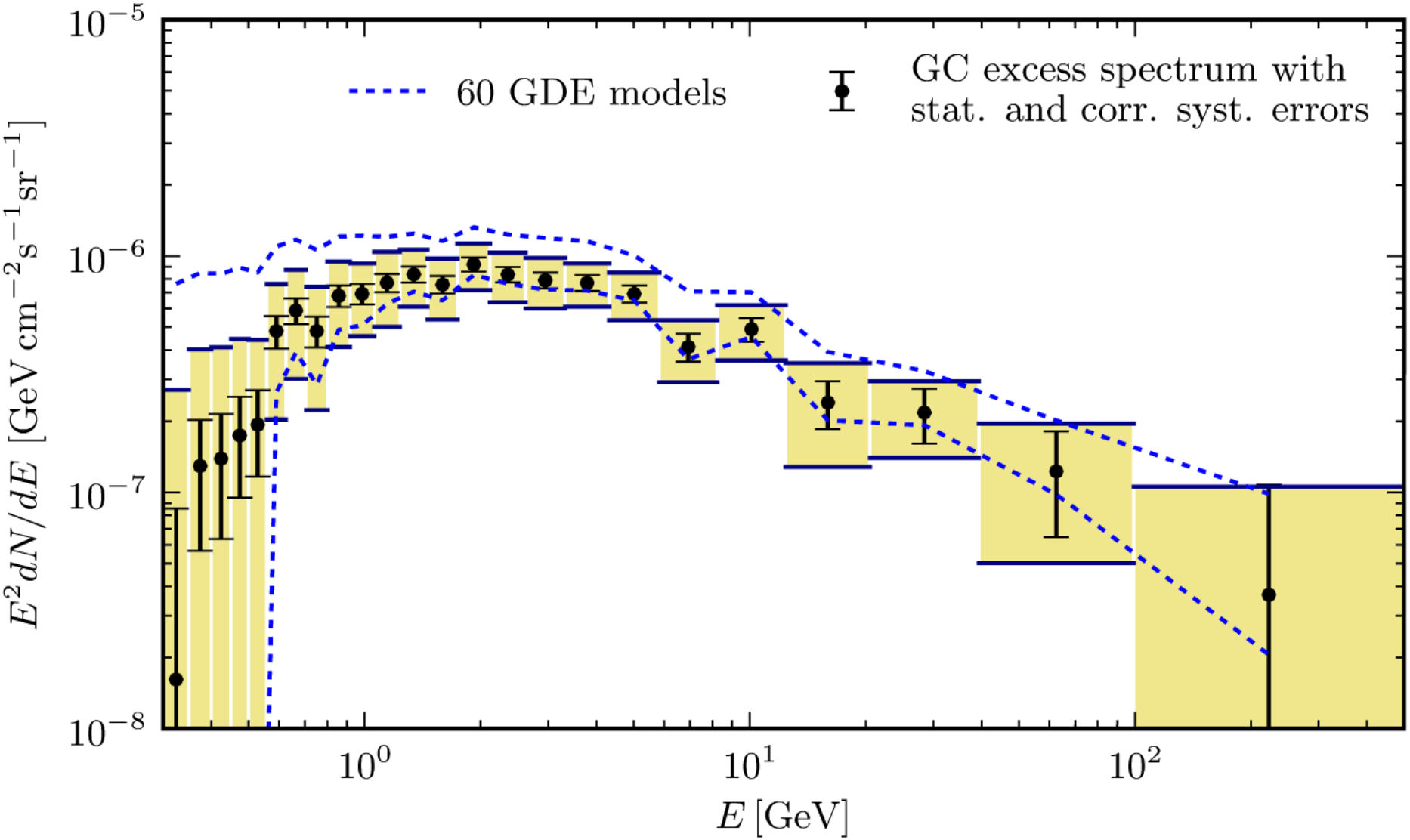
Francesca Calore, Ilias Cholis, Christoph Weniger
[arXiv:1409.0042]

60 Galactic Diffuse Emission models

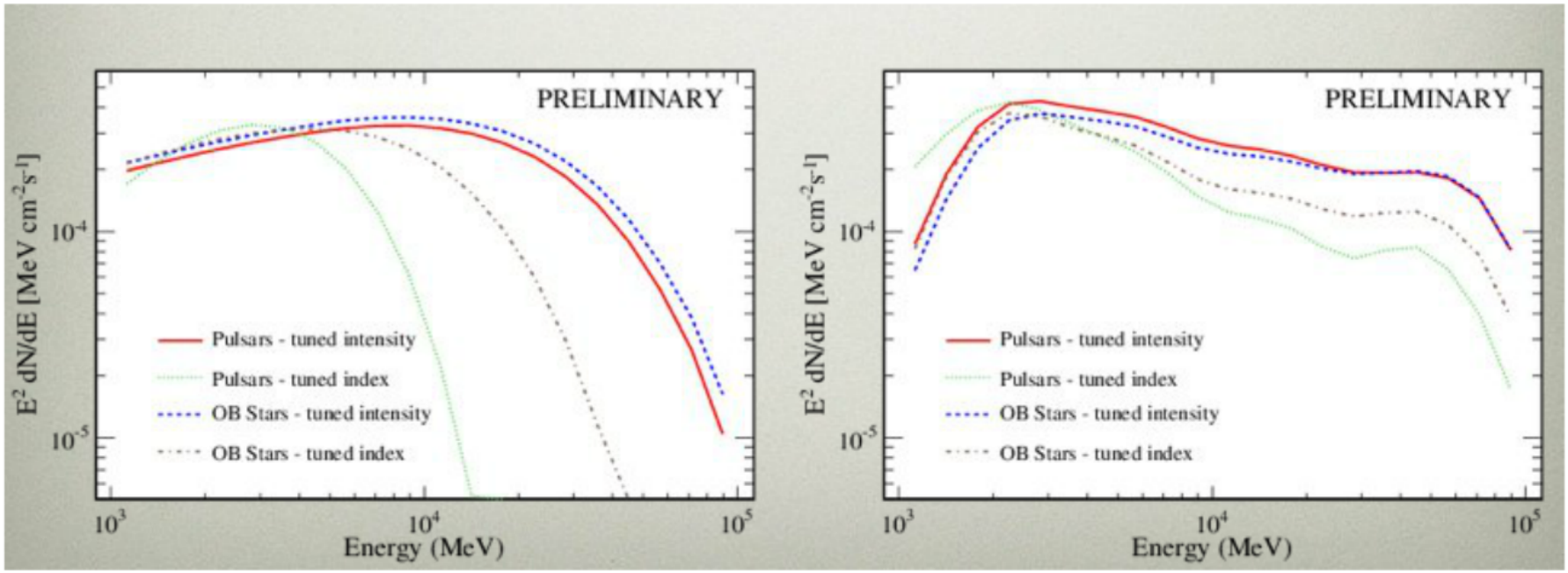



1e−6
1.5
1.0
0.5
0.0
−0.5
−1.0
$E^2\ dN/dE$ [GeV cm^{-2} s^{-1} sr^{-1}]
0.32 GeV
0.53 GeV
1.0 GeV
2.4 GeV
10 GeV
GXIX
GXXXIV
S
F
F
F
F
F
F
S
GIV
GIV
GIV
S
F
F
F
F
F
L
N
N
L
L
M
M
M
M
GIX
80
60
40
20
0
−20
−40
−60
−80
ℓ [deg]


−20
20 15 10 5 0 −5 −1
ℓ [deg]


60 GDE models
GC excess spectrum with
stat. and corr. syst. errors
$E^2 dN/dE$ [GeV cm^{-2}s^{-1}sr^{-1}]
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^0
10^1
10^2
E [GeV]

Fermi



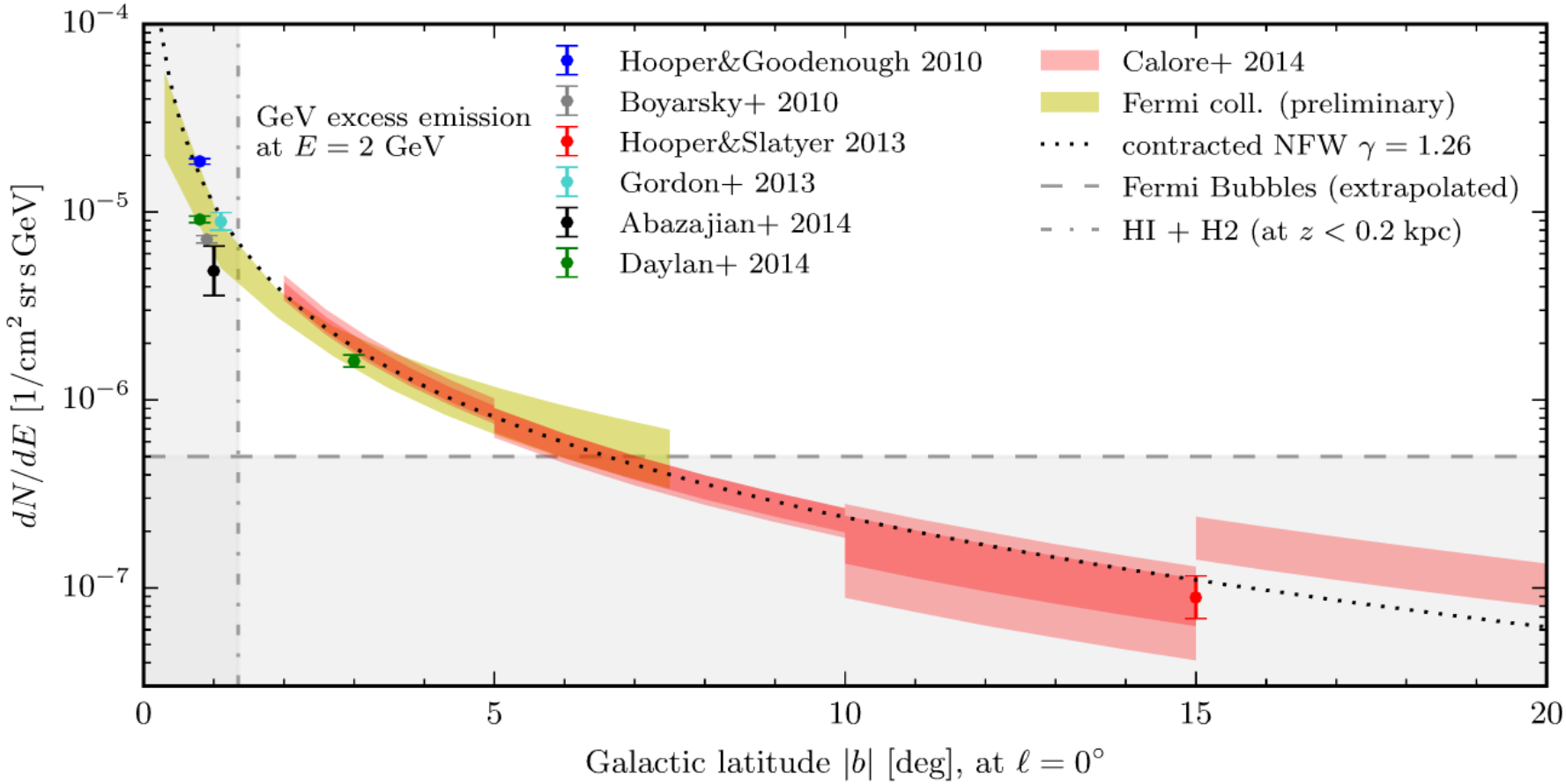
Preliminary analysis
Four well-motivated Diffuse models
Large variation in residual spectra

$|b|,|l| < 7.5$

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

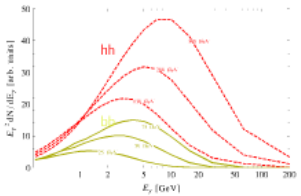


Calore, Cholis, McCabe, Weniger
[arXiv:1411.4647]

Spectrum

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

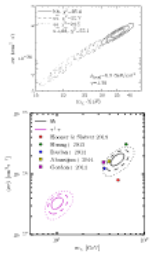
best fits agree with Daylan et al

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

Fermi analysis

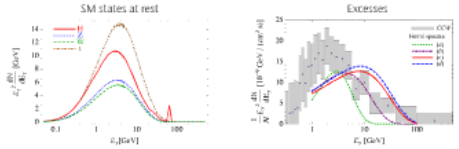
opens up many possibilities in masses and channels

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

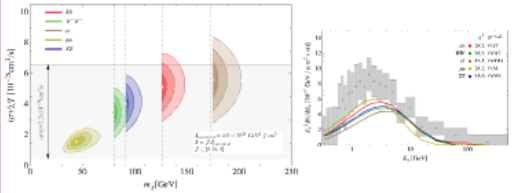
The spectra are boosted for a general dark matter mass

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



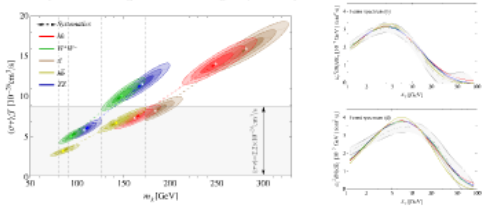
WIMPS at the Galactic center

Fitting to Fermi

Use Fermi spectra (b) and (d)

For each spectrum, find best fit regions using statistical errors only

Span of the fit region estimates range of possibility



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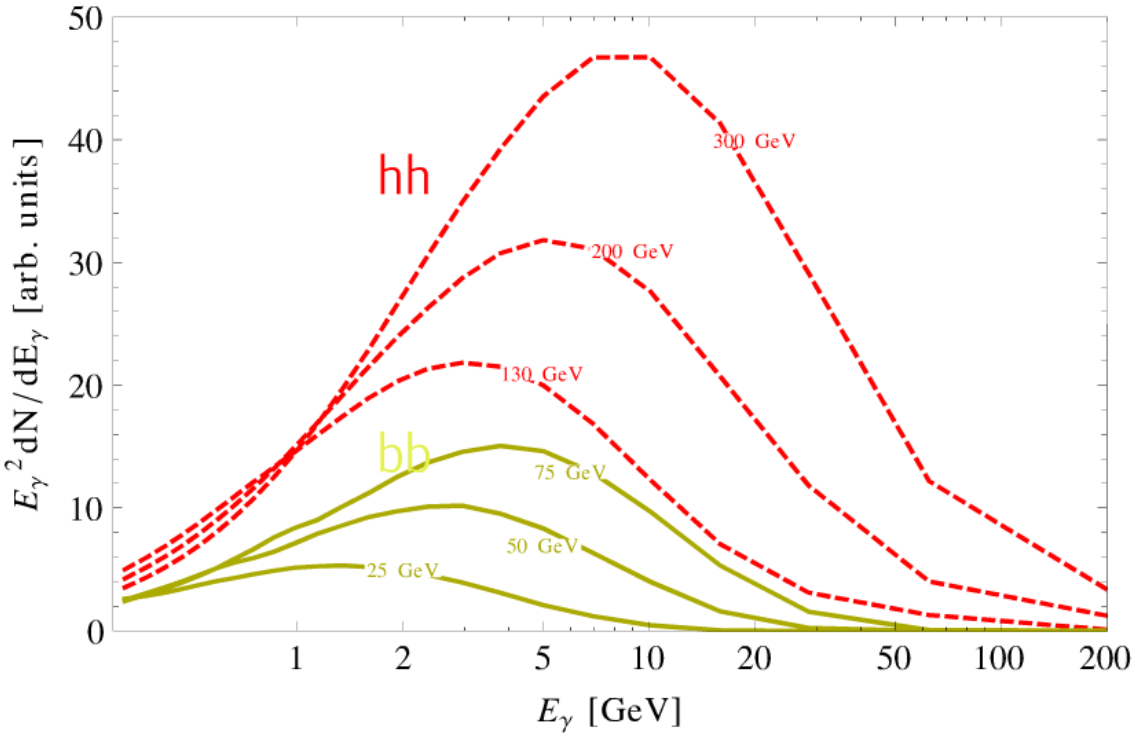

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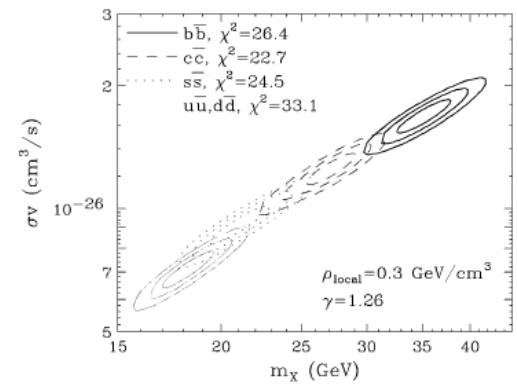

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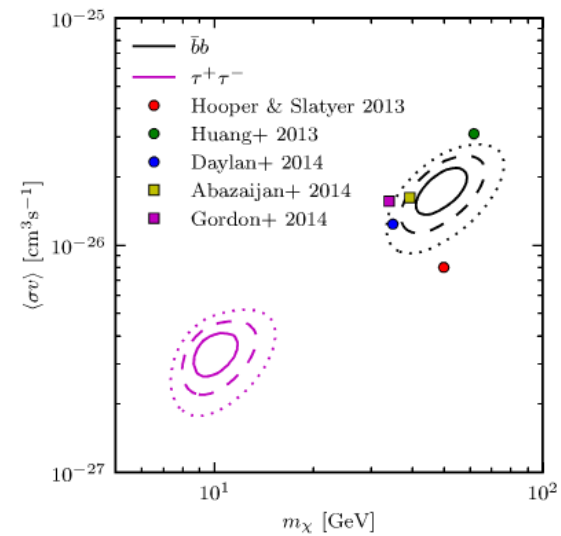

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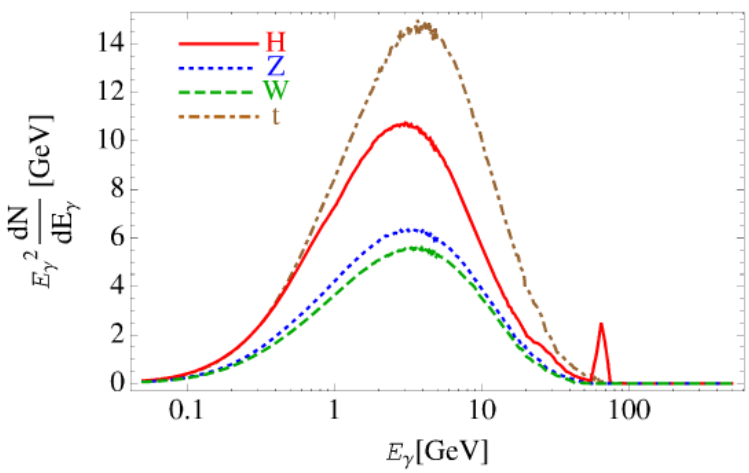
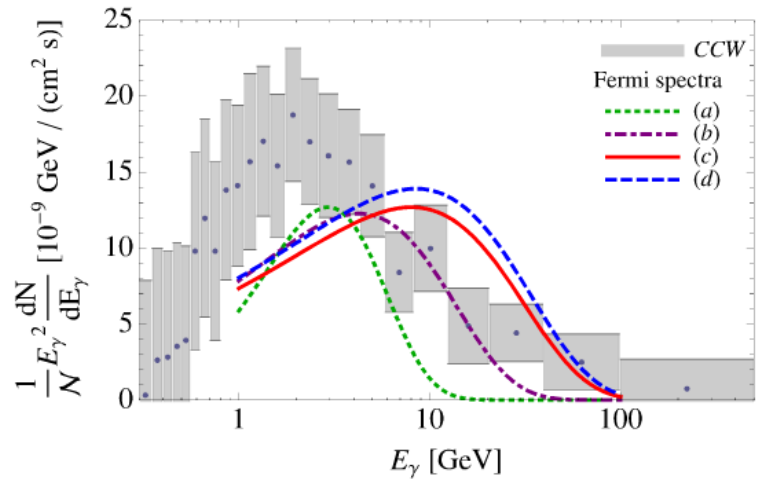
Spectrum of photons from many SM final states similar to the excess

SM states at rest



Excesses



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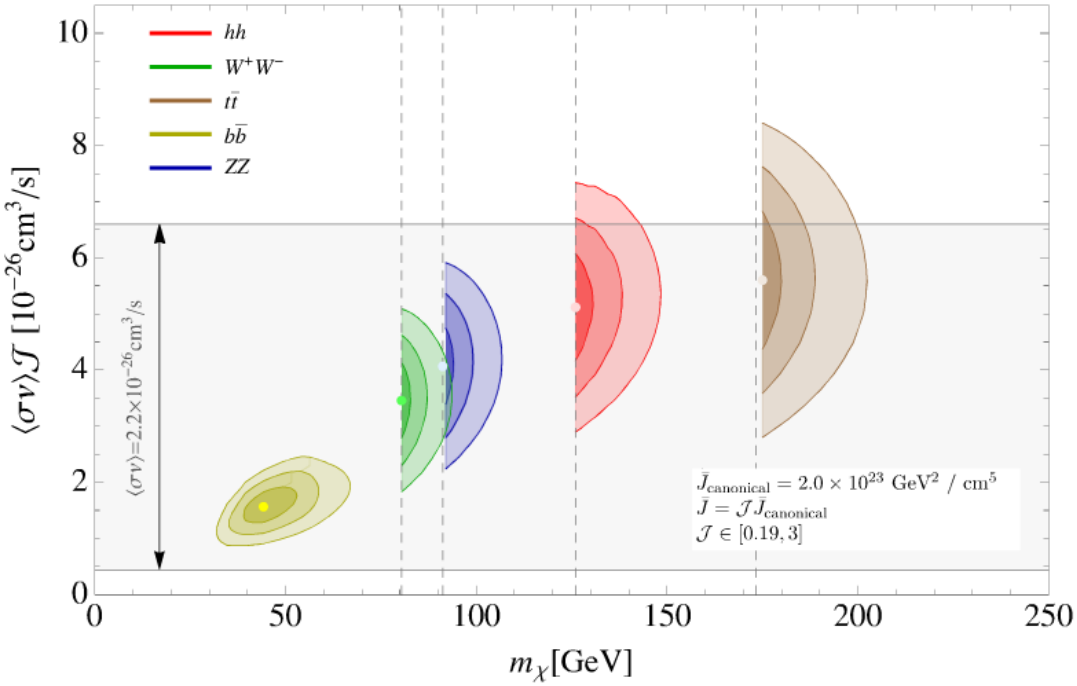
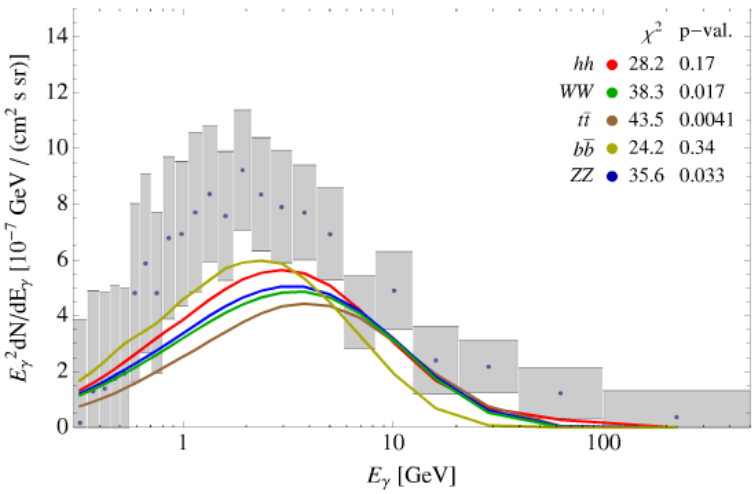
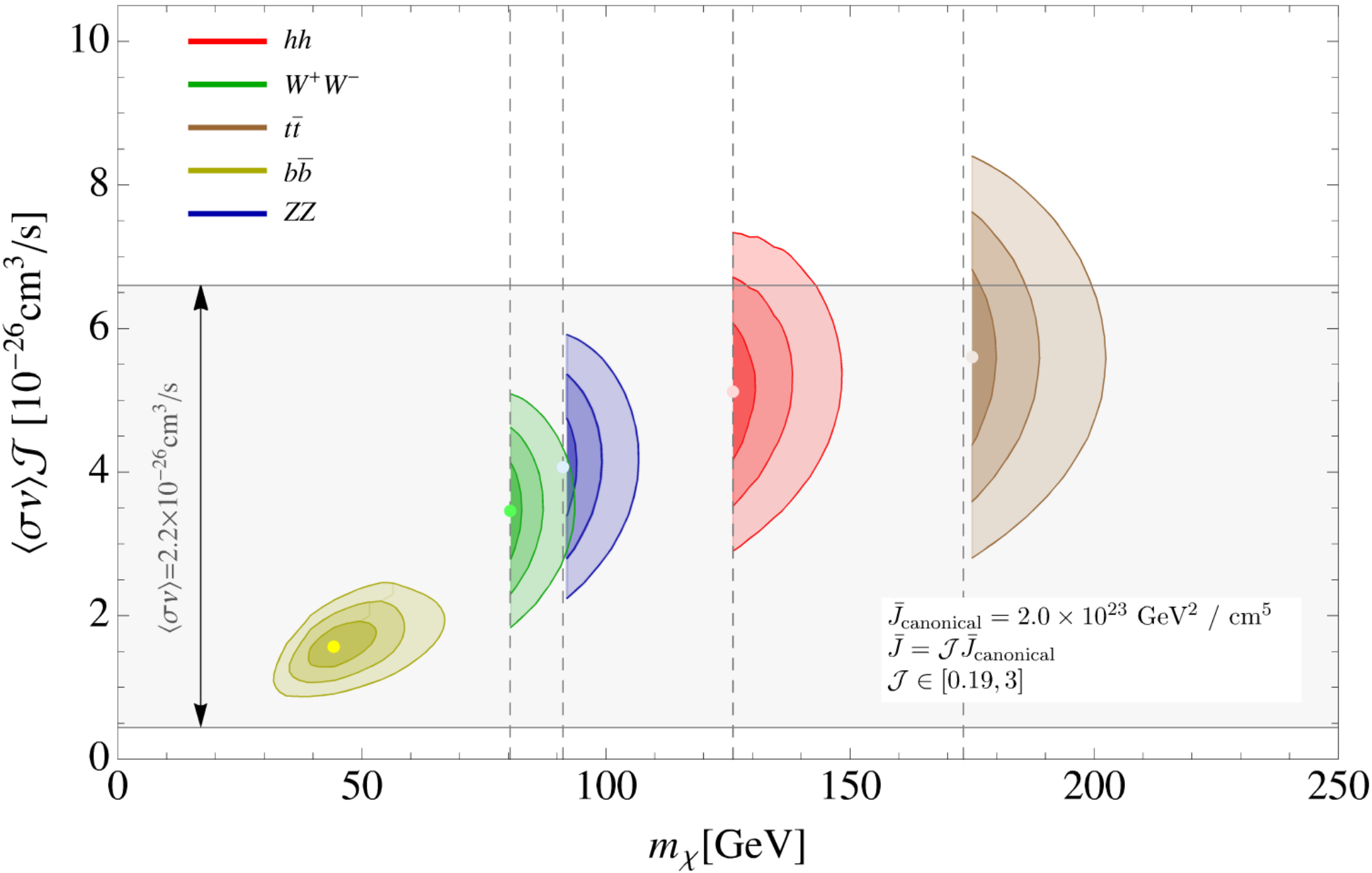
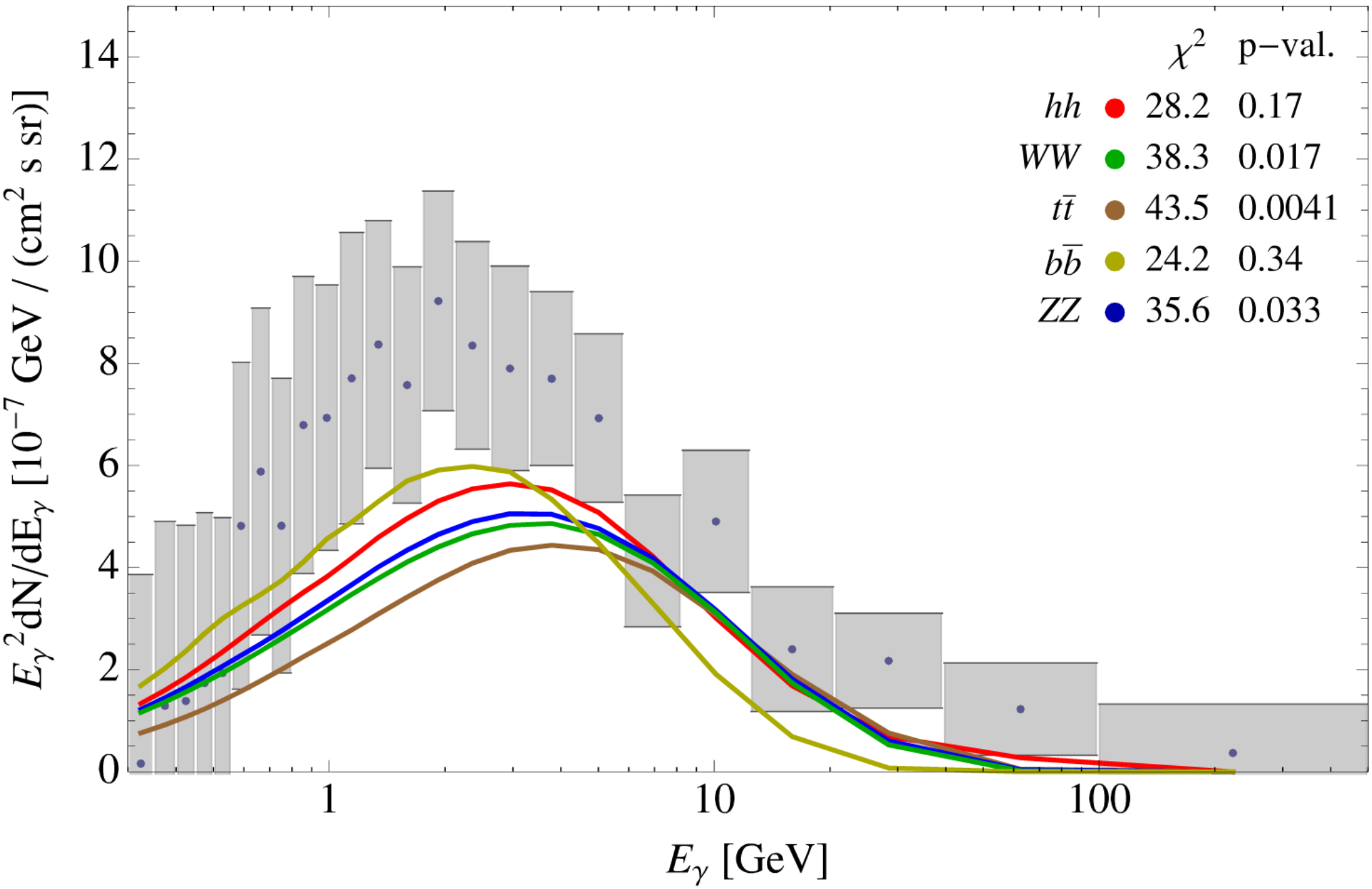





hh
W+W−
tt̄
bb̄
ZZ
⟨σv⟩=2.2×10−26cm3/s
⟨σv⟩𝒥 [10−26cm3/s]
mχ[GeV]
J̄canonical = 2.0 × 1023 GeV2 / cm5
J̄ = 𝒥 J̄canonical
𝒥 ∈ [0.19, 3]
0
2
4
6
8
10
0
50
100
150
200
250


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

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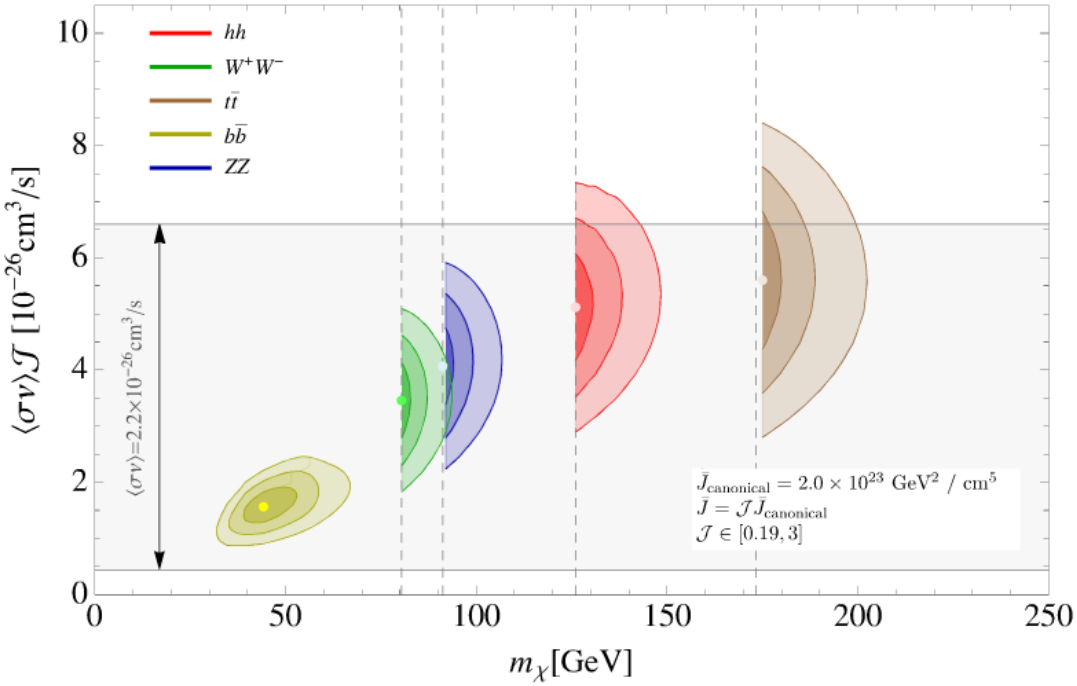
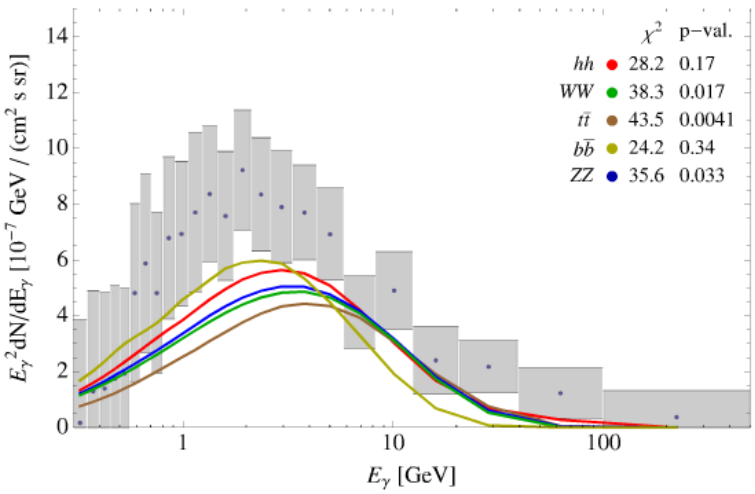
Mass of dark matter and SM final state need to be close





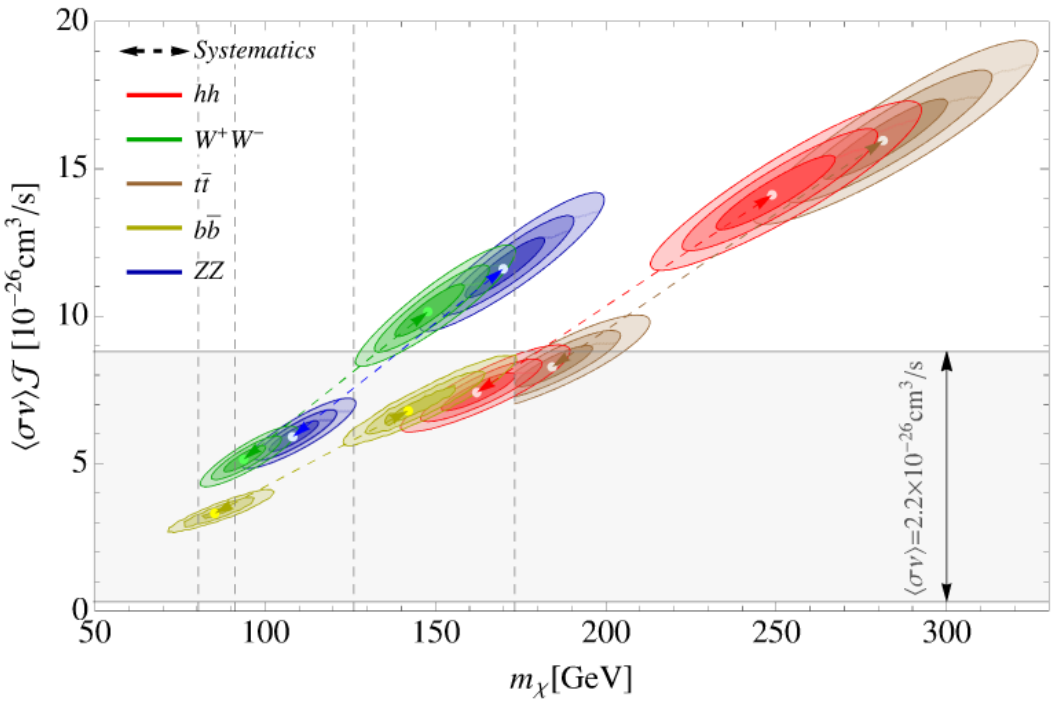
WIMPS at the Galactic center

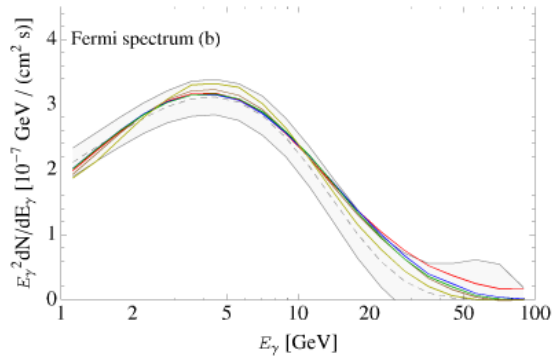
Fitting to Fermi

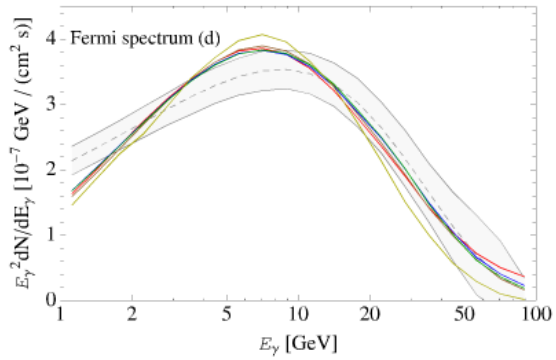
Use Fermi spectra (b) and (d)

For each spectrum, find best fit regions using statistical errors only

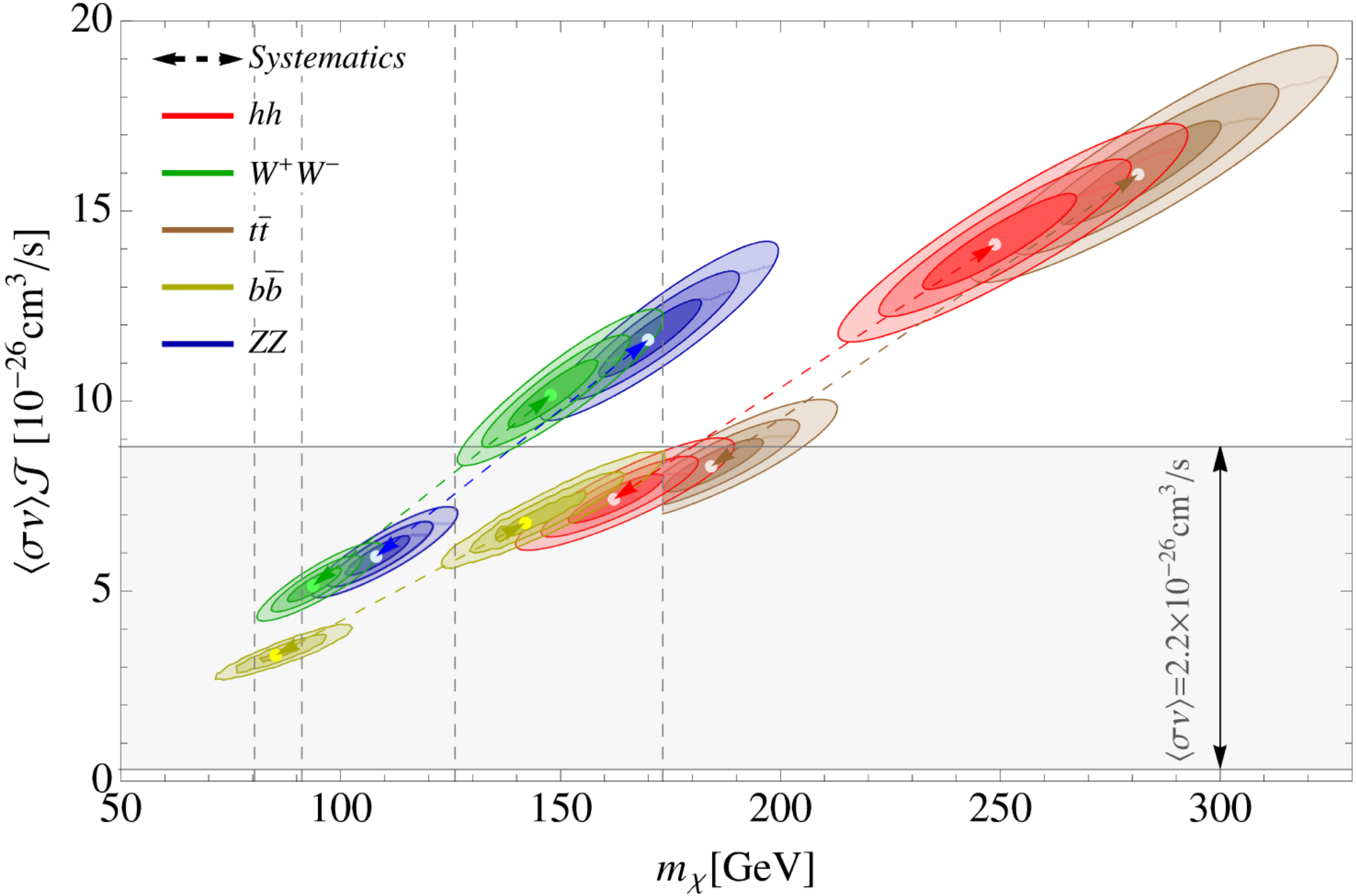
Span of the fit region estimates range of possibility

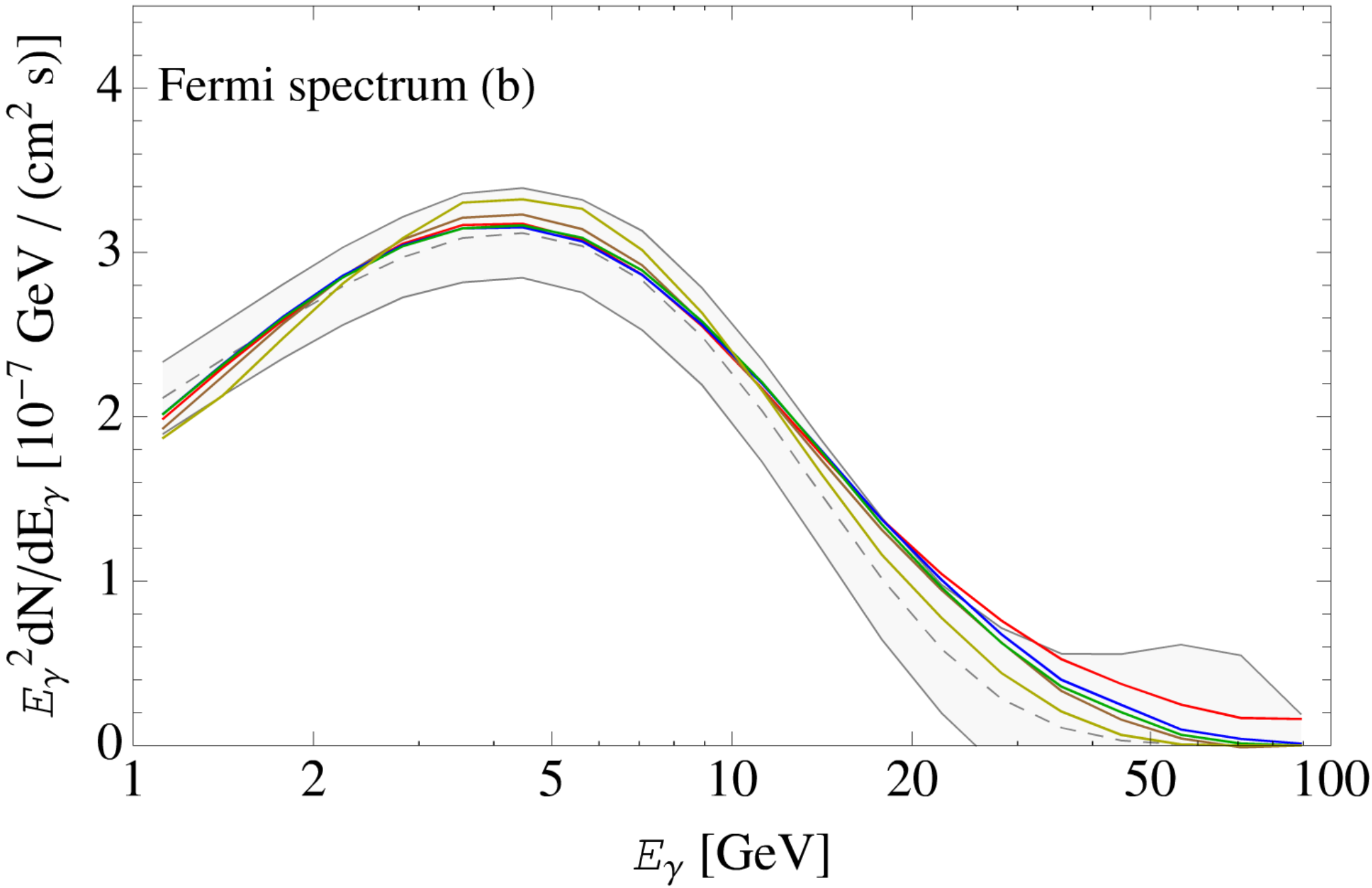






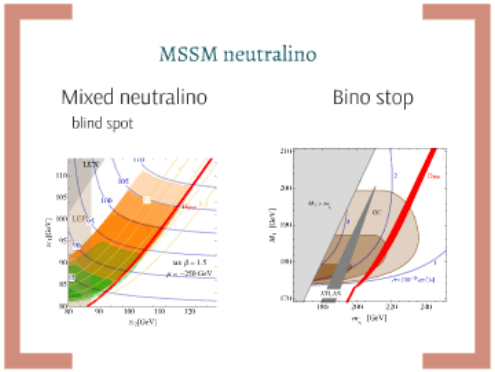
Span of the fit region estimates range of possibility

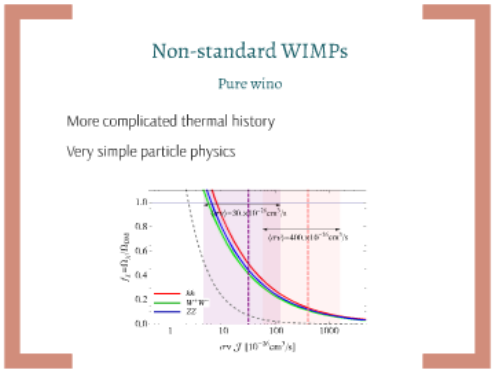


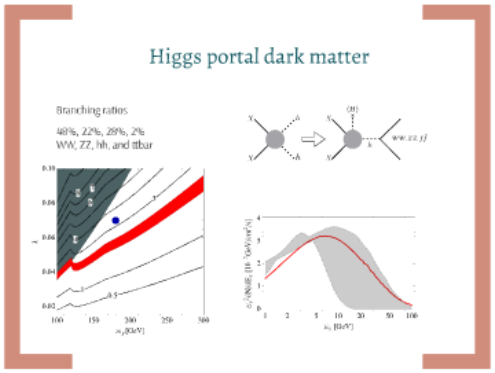

Fermi spectrum (b)
$E_\gamma^2 dN/dE_\gamma$ [10^{-7} GeV / (cm^2 s)]
E_γ [GeV]
0
1
2
3
4
1
2
5
10
20
50
100

Models

WIMPs



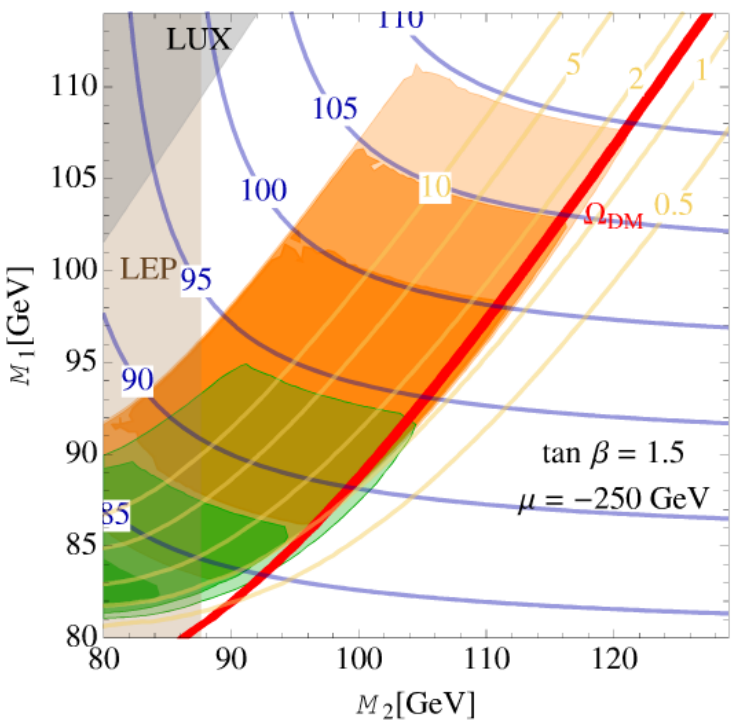




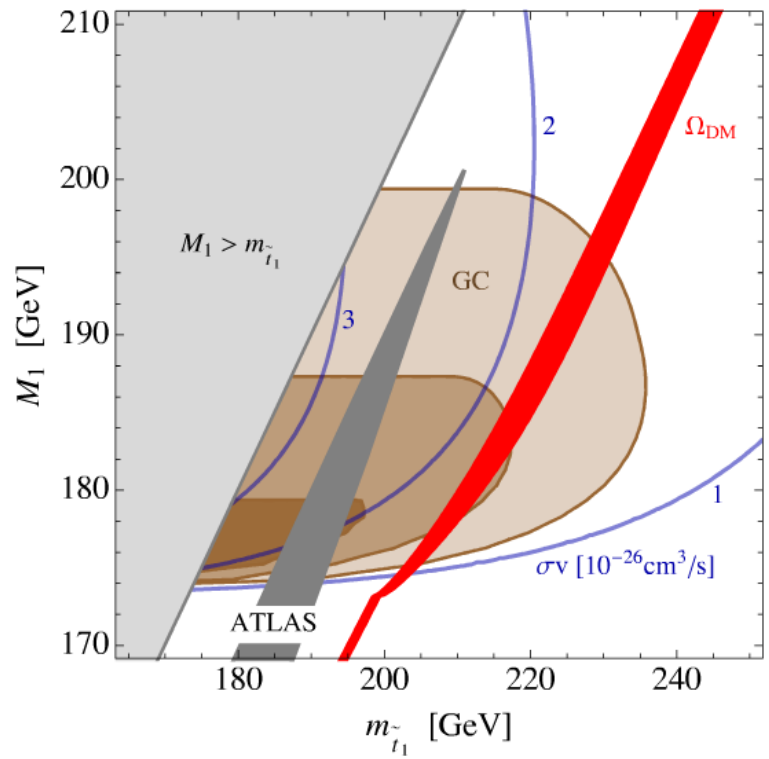
MSSM neutralino

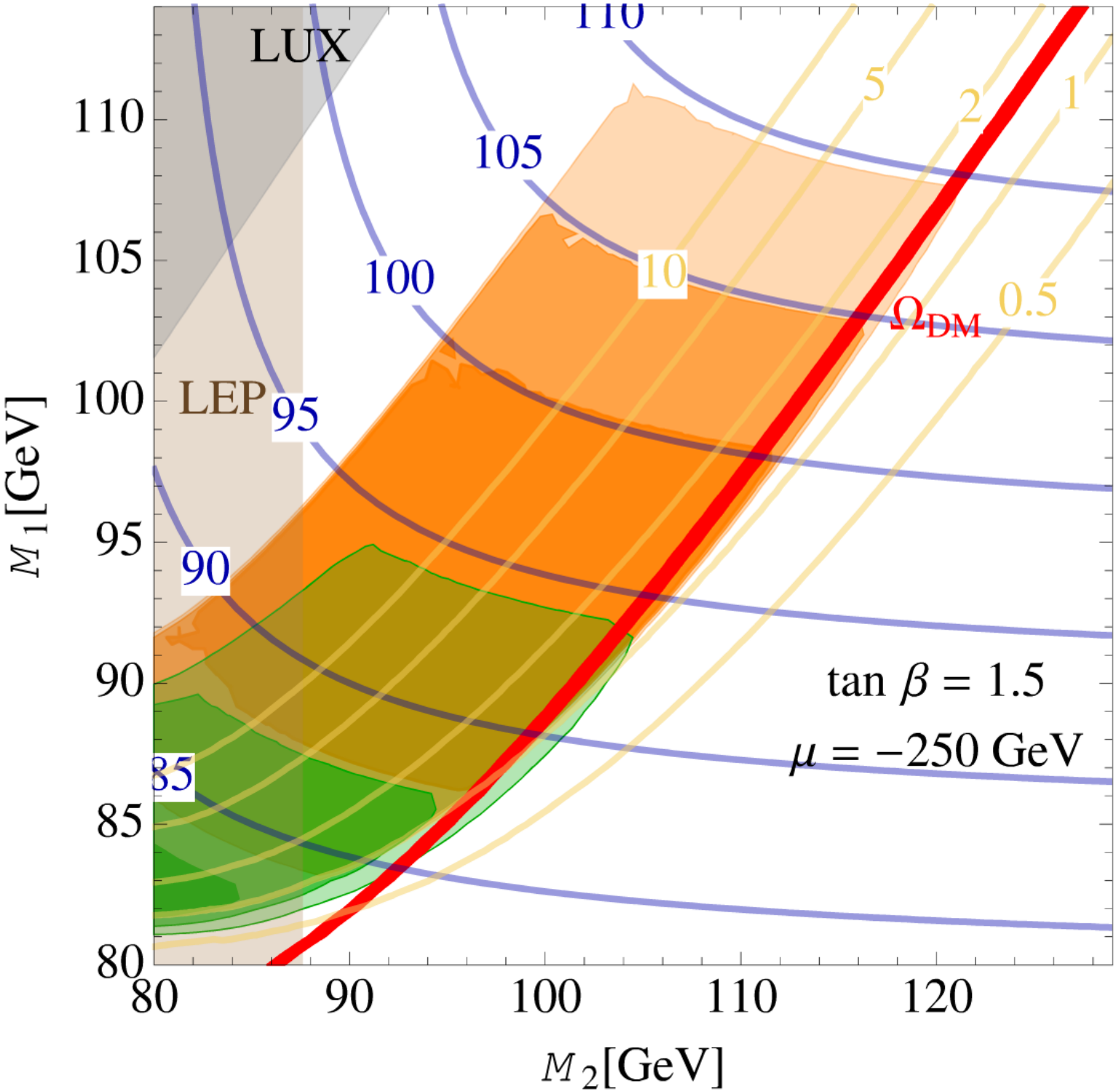
Mixed neutralino

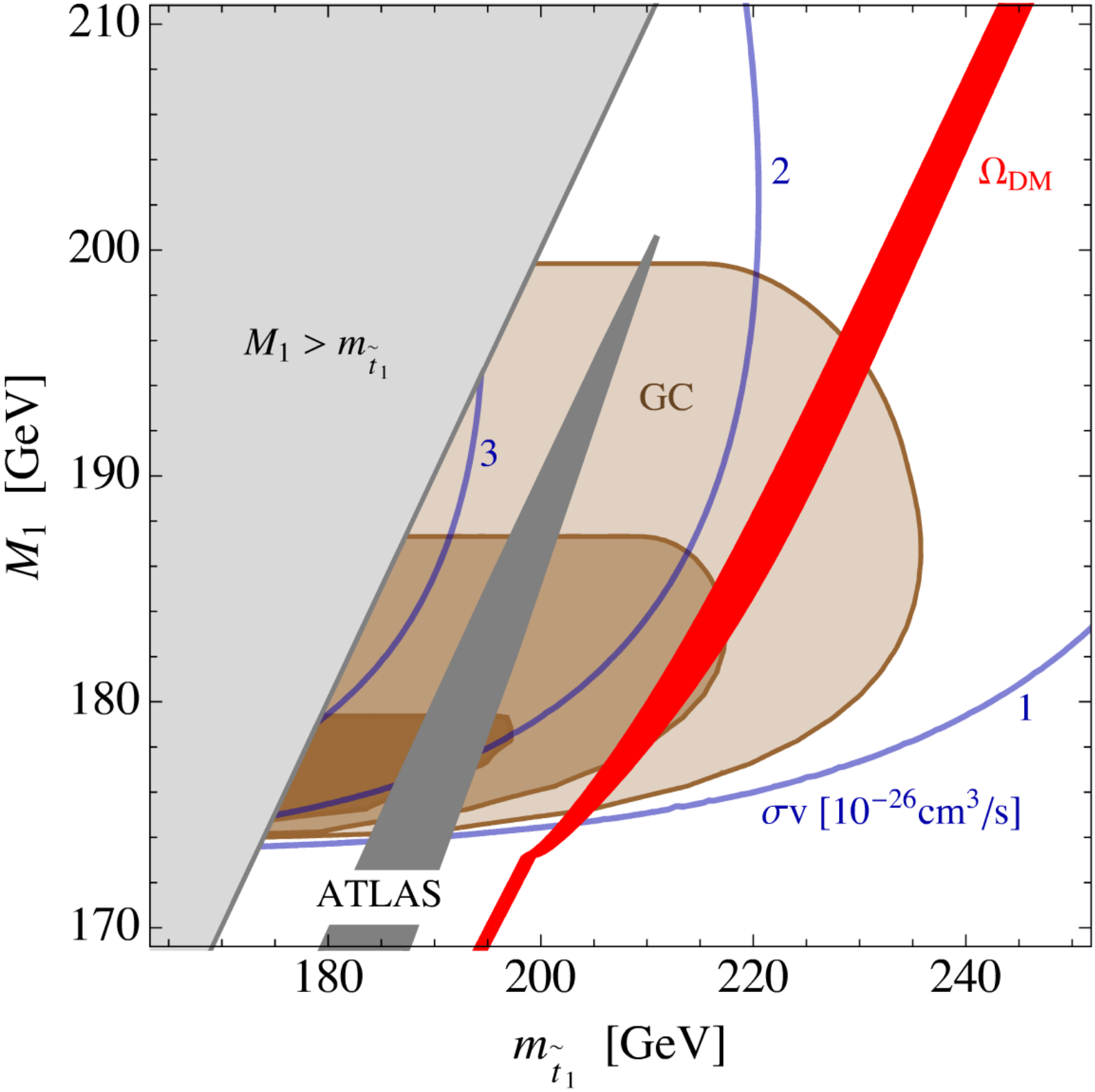
blind spot



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

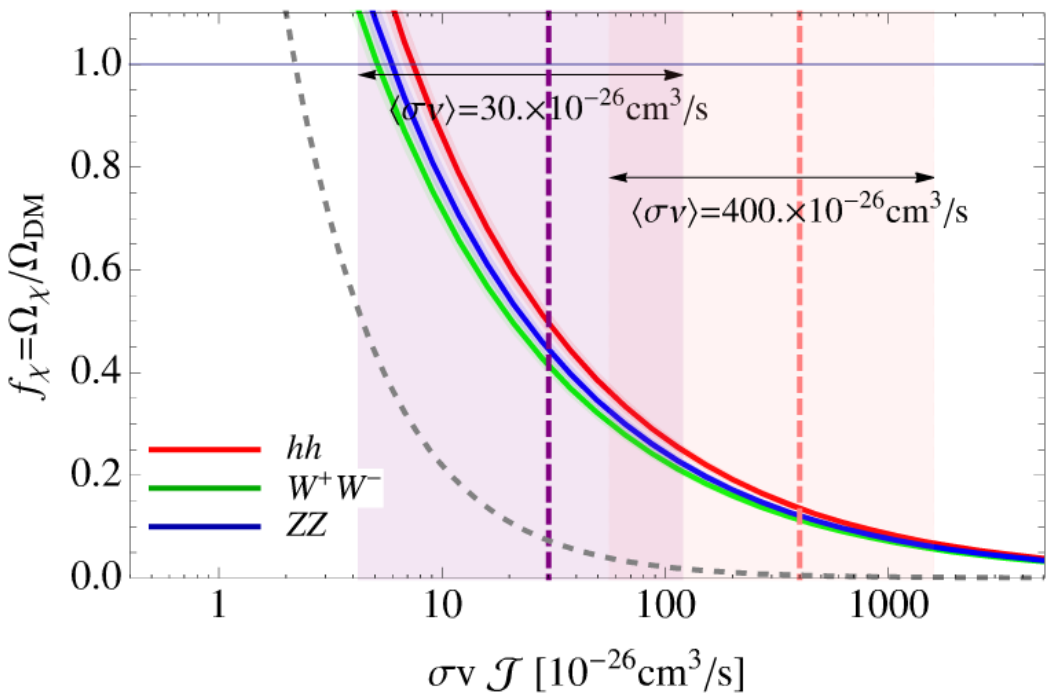

210
200
190
180
170
180
200
220
240
M_1 [GeV]
$m_{\tilde{t}_1}$ [GeV]
$M_1 > m_{\tilde{t}_1}$
GC
ATLAS
Ω_{DM}
2
3
1
σv [10^{-26}cm^3/s]

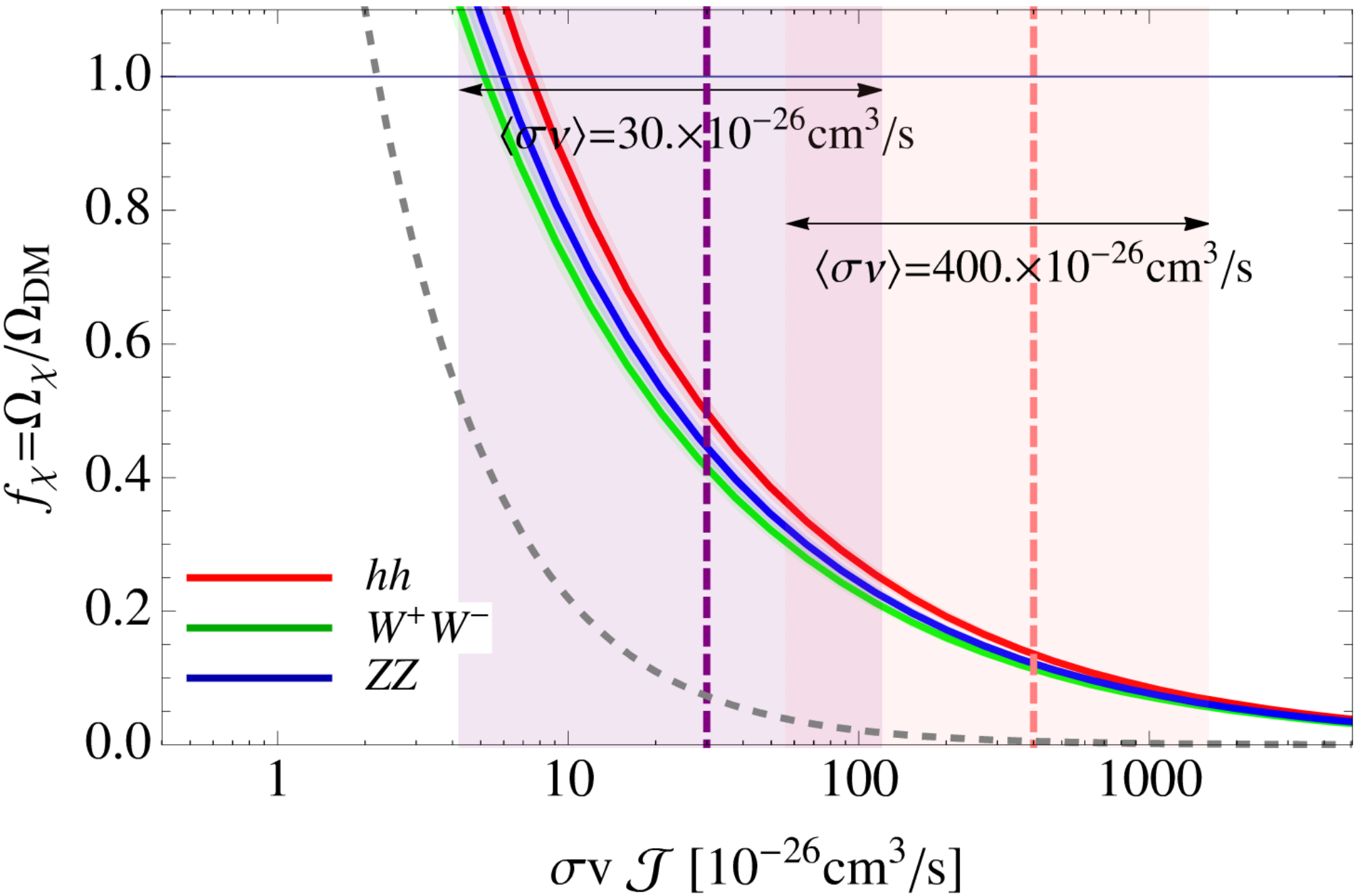
Non-standard WIMPs

Pure wino

More complicated thermal history

Very simple particle physics

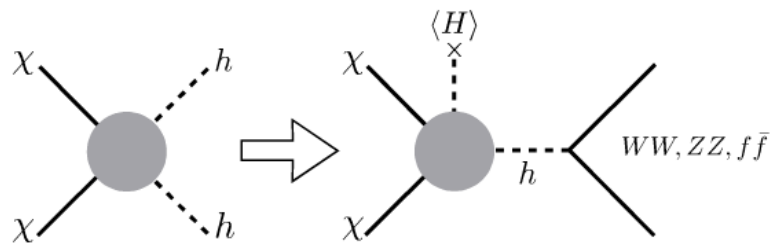


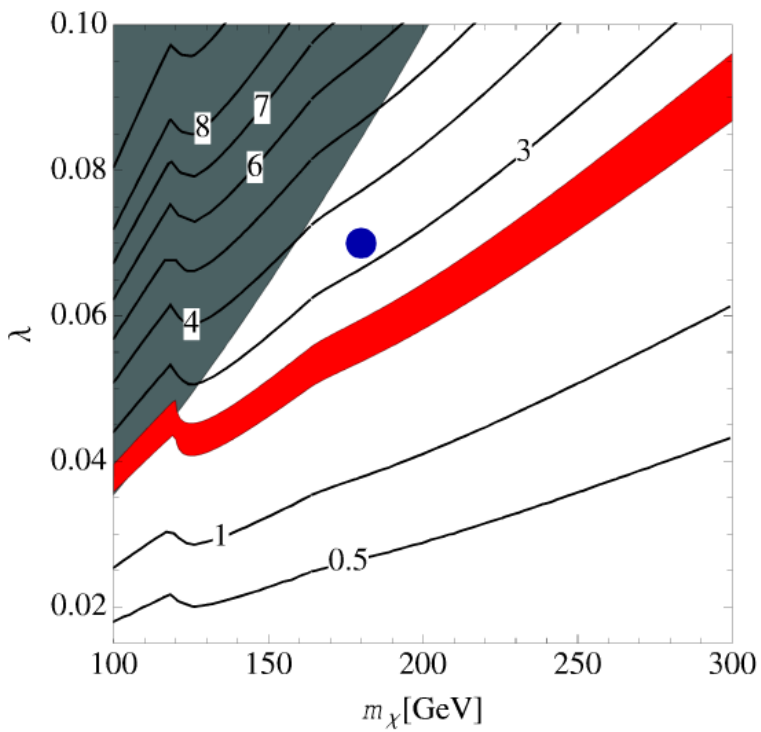

1.0
0.8
0.6
0.4
0.2
0.0
$f_\chi = \Omega_\chi / \Omega_{\rm DM}$
$\langle \sigma v \rangle = 30. \times 10^{-26} {\rm cm}^3/{\rm s}$
$\langle \sigma v \rangle = 400. \times 10^{-26} {\rm cm}^3/{\rm s}$
hh
W^+W^-
ZZ
1
10
100
1000
$\sigma {\rm v}\, \mathcal{J}\ [10^{-26} {\rm cm}^3/{\rm s}]$

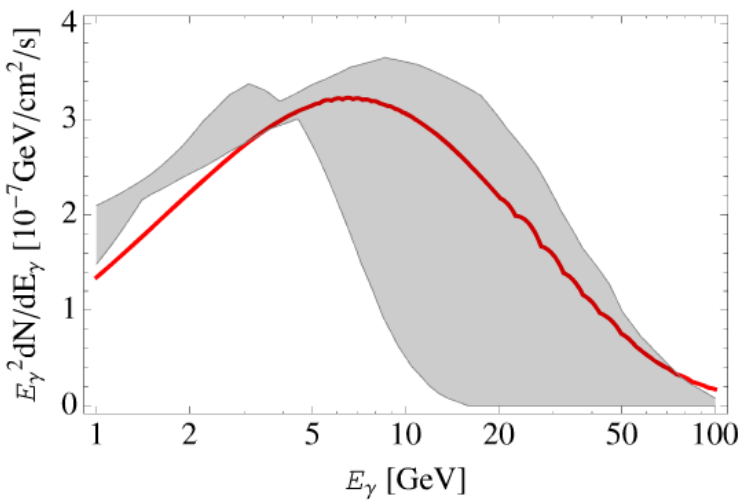
Higgs portal dark matter

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

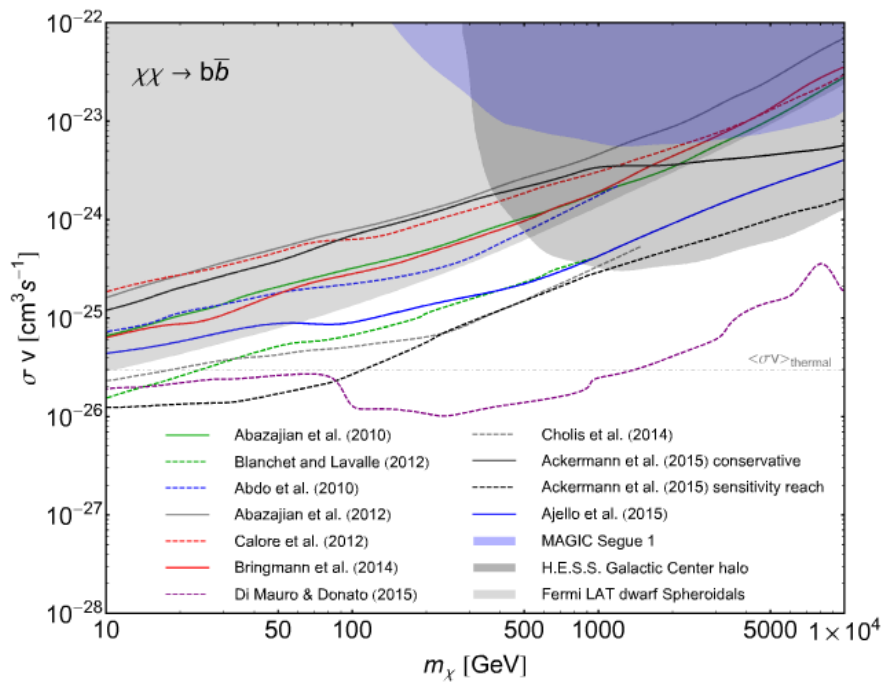
Characterizing the signal and error-bars rigorously challenging

Limits from many analyses are getting competitive

- Dwarf Spheroidals
- Diffuse emission
- Isotropic emission

Hints of new signals, possible new dwarves

Watch this space!



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