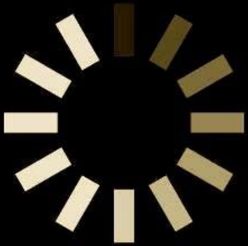
CAFFEINE LOADING...



PLEASE WAIT

Caffeine free version

- Since 2009 observation of an excess of gamma ray photons in 3-4 GeV range from the galactic center by Fermi LAT
- Possible interpretation as annihilating dark matter
- Use Fermi data: Good fit results for MSSM
- Strong constraints from direct detection

Saving the MSSM from the GCE

A. Butter [1] with S.Murgia [2], T. Plehn [1] and T. M. P. Tait [2]

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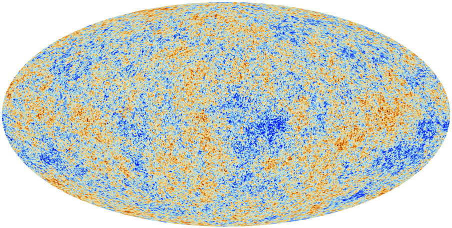
[2]Department of Physics and Astronomy, University of California, Irvine, USA

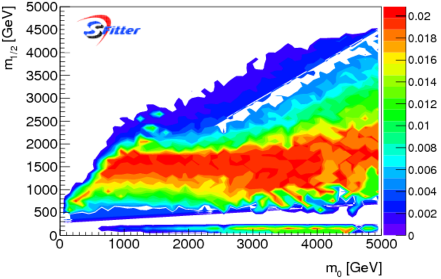
arXiv:1612.07115
to be published in PRD

There is physics beyond the Standard Model!

- 26.8% dark matter
- strong constraining power on the parameterspace



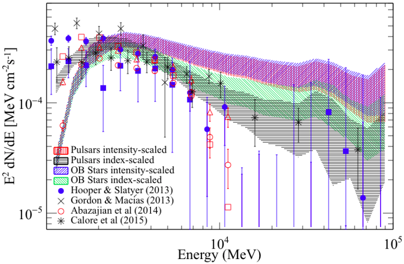
CMB as observed by Planck (Planck Collaboration)



SFitter likelihood Fit, mSUGRA

There is more...?

- Since 2009 observation of an excess of gamma ray photons in 3-4 GeV range from the galactic center by Fermi LAT [Hooper et al., Calore et al., Murgia for Fermi Collaboration]

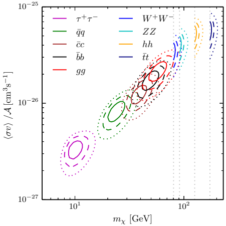


Fermi collaboration, arXiv:1511.02938

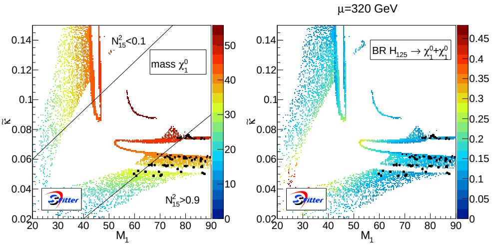
- Fermi LAT analysis settings:
  - NFW profile ($\alpha = 1., \beta = 3., \gamma = 1.2$)
  - 15×15 degree region around galactic center

Previous work within NMSSM

- Best fit results by Calore et al. for light dark matter
- easier in NMSSM
- Connection with invisible Higgs decay



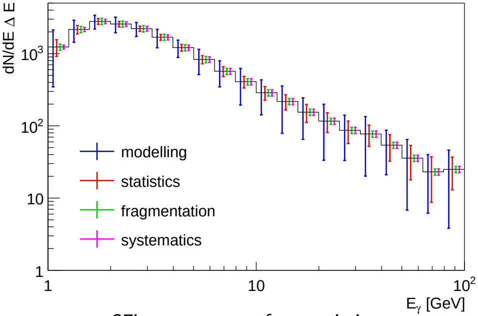
Calore, Cholis, McCabe, Weniger,
arXiv:1411.4647



- End of 2015 Fermi LAT publish their own analysis

A closer look at the data

- Poisson distribution for statistic treatment
- correlated Gaussian for instrumental systematics (effective area)
- uncorrelated Gaussian uncertainties for spectrum
- flat theory uncertainties for background models (envelope)
  $\rightarrow$ spatial distribution of cosmic ray sources (OB-stars, Pulsars)

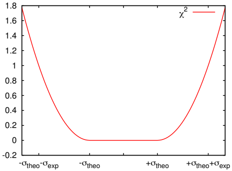


SFitter treatment of uncertainties

Likelihood function

Gauss:

$$\sqrt{-2\log\mathcal{L}_{Gauss}} = \begin{cases} \dfrac{s-(\tilde{s}+\sigma_{theo})}{\sigma_{sys,s}} & \text{for } \sigma_{theo} < s-\tilde{s} \\ 0 & \text{for } \sigma_{theo} > |s-\tilde{s}| \\ \dfrac{s-(\tilde{s}-\sigma_{theo})}{\sigma_{sys,s}} & \text{for } \sigma_{theo} < \tilde{s}-s \end{cases}$$



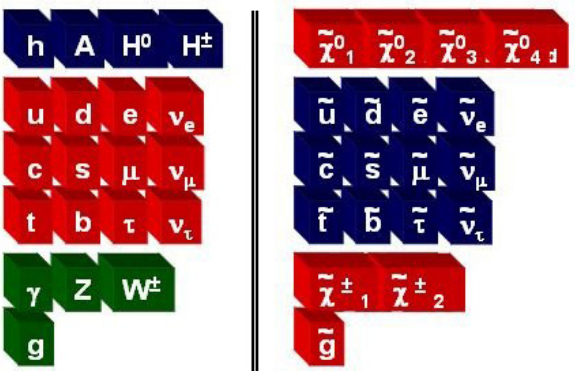
Poisson:

$$\mathcal{L}_{\text{Poiss},d} = \frac{P(d|\tilde{d})}{P(\tilde{d}|\tilde{d})} = \frac{\tilde{d}!}{d!}\,\tilde{d}^{d-\tilde{d}}$$

Combination:

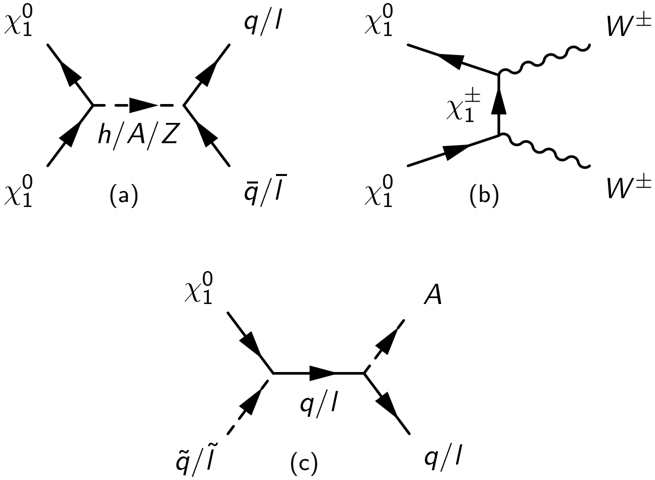
$$\frac{1}{\log\mathcal{L}} = \frac{1}{\log\mathcal{L}_{Gauss}} + \frac{1}{\log\mathcal{L}_{Poiss}}$$

The MSSM particle content



Annihilation channels I

$\gamma-$rays radiated of SM particles during annihilation process



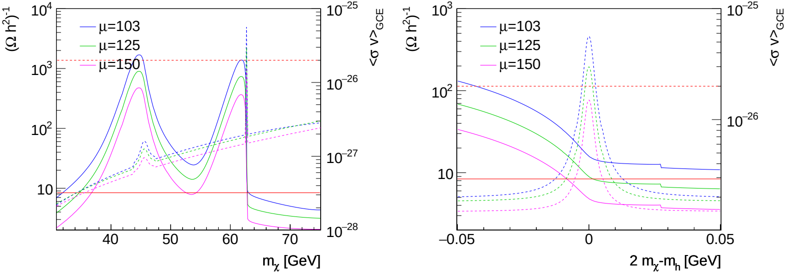
Annihilation channels II

process	channel	σv
$\chi\chi \to A \to q\bar{q}$	s-channel	$c\lambda^4 \frac{m_\chi^2}{(M_A^2-4m_\chi^2)^2}$
$\chi\chi \to h \to q\bar{q}$	s-channel	$c\lambda^4 \frac{v^2 m_\chi^2}{(M_h^2-4m_\chi^2)^2}$
$\chi\chi \to Z \to q\bar{q}$	s-channel	$c\lambda^2 \left[\frac{\lambda_{qZ_{ax}}^2 m_q^2}{M_Z^4} + \frac{v^2(\lambda_{qZ_{ax}}^2+\lambda_{qZ_v}^2)m_\chi^2}{3(M_Z^2-4m_\chi^2)^2}\right]$
$\chi\chi \to \chi\tilde{q}\bar{q} \to q\bar{q}$	t-channel	$c\lambda^4 \frac{(m_q+m_\chi)^2}{(M_{\tilde{q}}^2-m_q^2+m_\chi^2)^2}$

Table: Examples for simplified annihilation cross sections expanded in powers of v^2 assuming Majorana dark matter and light final states.

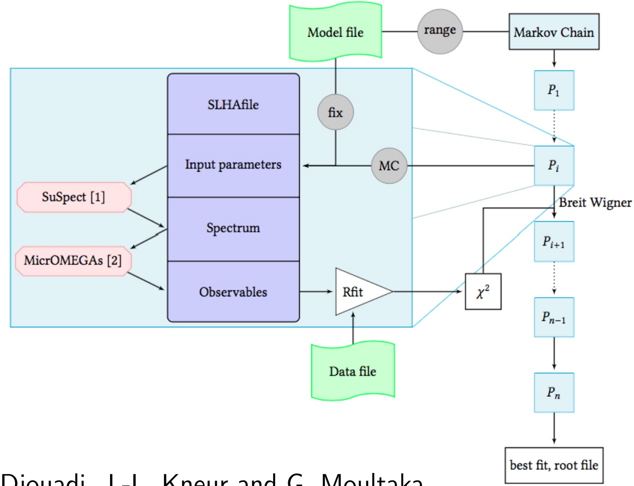
$\chi\chi \to b\bar{b}$

Illustration of the velocity dependence



Inverse relic density (solid, left axis) and annihilation rate in the GC (dashed, right axis)

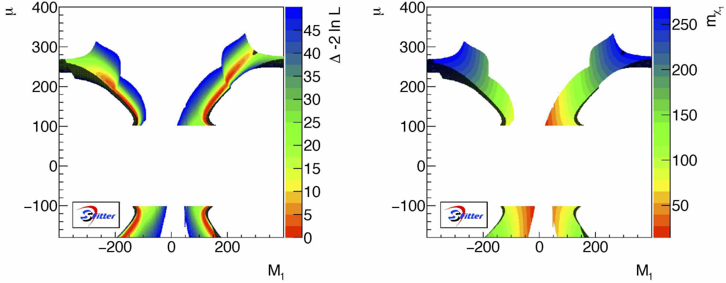
The Fit



[1] A. Djouadi, J.-L. Kneur and G. Moultaka
[2] G. Bélanger, F. Boudjema, A. Pukhov and A. Semenov

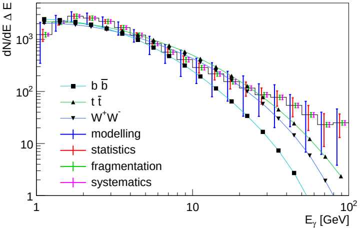
Fitting the Fermi LAT spectrum I

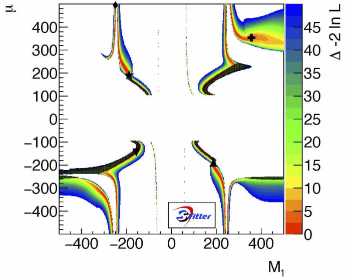
- $M_2 = 700$ GeV, sfermions and heavy Higgs decoupled
- A_t to adjust SM-like Higgs mass
- dwarf limits included
- likelihood map determined by LSP mass and coupling
- WW, $t\bar{t}$ final states

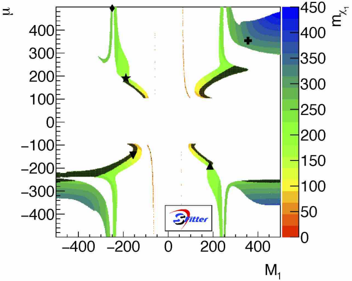


Fitting the Fermi LAT spectrum II

- annihilation spectra for $\chi\chi \to b\bar{b}/t\bar{t}/WW$ for local best fit points
- $m_A = 500$ GeV
- additional annihilation via pseudoscalar

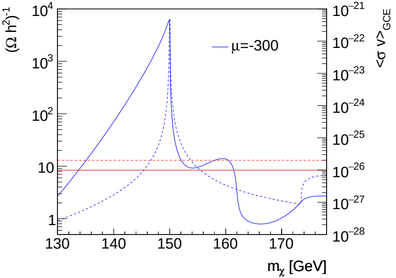






Why not $\chi\chi \to hh$?

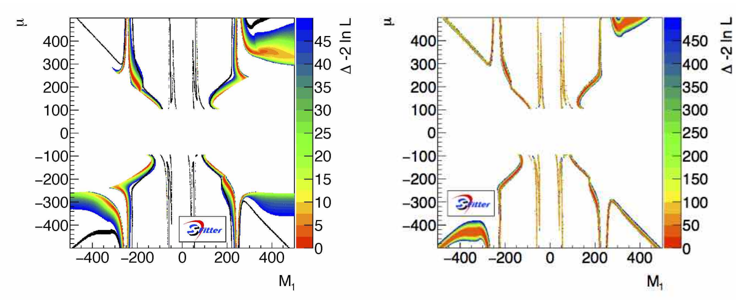
- t-channel annihilation dominated by $\chi\chi \to WW$



- $m_A = 300$ GeV, $m_H = 320$ GeV
- annihilation to hh only possible via $\chi\chi \to H \to hh$

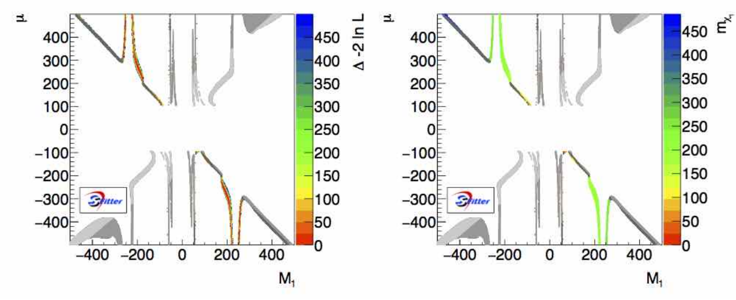
Fitting the Fermi LAT spectrum and the relic density

- left: likelihood map with black dots indicating the correct relic density
- the relic density favors smaller couplings
- right: fit including the relic density



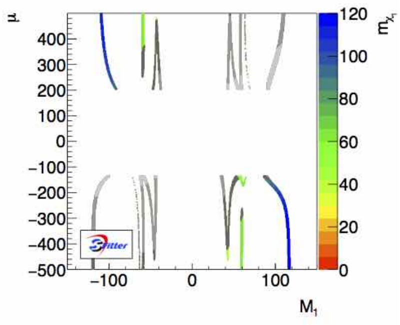
Direct detection

- exclusion limits from direct detection experiments
- light to dark: Xenon100, PandaX, LUX



Direct detection

- low $M_2 = 120$ GeV $\rightarrow$ wino dark matter
- smaller coupling to light Higgs $\rightarrow$ avoids direct detection
- allowed masses $m_\chi \approx 45$ GeV, 63 GeV, 100 - 120 GeV

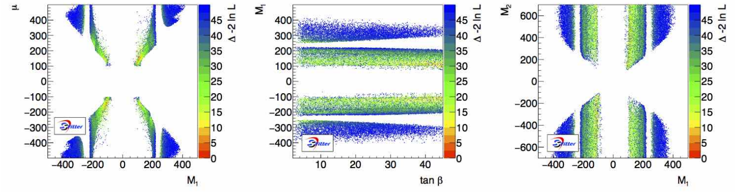


A global analysis assuming $m_A = 500$ GeV

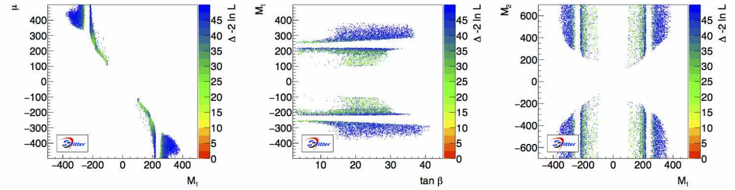
Parameters:

$$|M_1| < 500\ GeV \qquad |M_2| < 700\ GeV \qquad |\mu| < 500\ GeV$$

$$|A_t| < 7\ TeV \qquad \tan\beta = 2\ ...\ 45\ .$$



Including LUX limits:



Conclusion

- γ-ray excess observed in GC can be explained by annihilating dark matter
- Small tension between relic density and GCE can be resolved in MSSM
- Direct detection experiments can rule out most of the parameter space
- Future direct detection experiments will probe the remaining low mass regime

BACK UP

Couplings

$$g_{W\chi_1^0\chi_1^\pm} = \frac{g\sin\theta_w}{\cos\theta_w}\left(\frac{1}{\sqrt{2}}N_{14}V_{12}^* - N_{12}V_{11}^*\right) \tag{1}$$

$$g_{Z\chi_1^0\chi_i^0} = \frac{g}{2\cos\theta_w}\left(N_{13}N_{i3} - N_{14}N_{i4}\right) \tag{2}$$

$$g_{h\chi_1^0\chi_1^0} = \left(gN_{11} - g'N_{12}\right)\left(\sin\alpha\ N_{13} + \cos\alpha\ N_{14}\right)\ . \tag{3}$$

Constraints

Measurement	Value
m_h	$(125.09 \pm 0.21_{\text{stat}} \pm 0.11_{\text{syst}} \pm 3.0_{\text{theo}})$ GeV
$\Omega_\chi h^2$	$0.1188 \pm 0.0010_{\text{stat}} \pm 0.0120_{\text{theo}}$
a_μ	$(287 \pm 63_{\text{exp}} \pm 49_{\text{SM}} \pm 20_{\text{theo}}) \cdot 10^{-11}$
$\text{BR}(B \to X_s\gamma)$	$(3.43 \pm 0.21_{\text{stat}} \pm 0.07_{\text{syst}}) \cdot 10^{-4}$
$\text{BR}(B_s^0 \to \mu^+\mu^-)$	$(3.2 \pm 1.4_{\text{stat}} \pm 0.5_{\text{syst}} \pm 0.2_{\text{theo}}) \cdot 10^{-9}$
$m_{\chi_1^+}$	> 103 GeV

Table: Data used for the fit including their systematic, statistical, and theoretical uncertainties, as appropriate.