Fitting Dark Matter

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Student lecture

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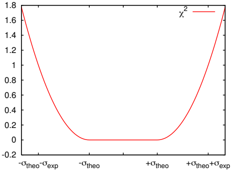
Outline

1. Revision
2. Dark Matter annihilation channels
3. Fitting the Galactic center excess

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:

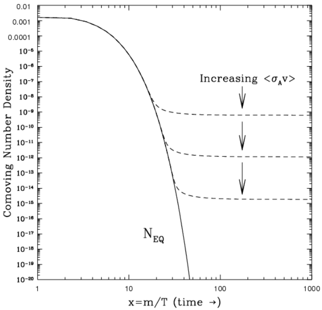
$$\frac{1}{\log\mathcal{L}} = \frac{1}{\log\mathcal{L}_{Gauss}} + \frac{1}{\log\mathcal{L}_{Poiss,d}} + \frac{1}{\log\mathcal{L}_{Poiss,b}}$$

Dark Matter

Boltzmann equation:

$$\frac{dN_\chi}{dt} = \Gamma(f\bar{f} \to \chi\chi) - \Gamma(\chi\chi \to f\bar{f}) + \Gamma_{other}$$

Freeze-out:



Relic density:

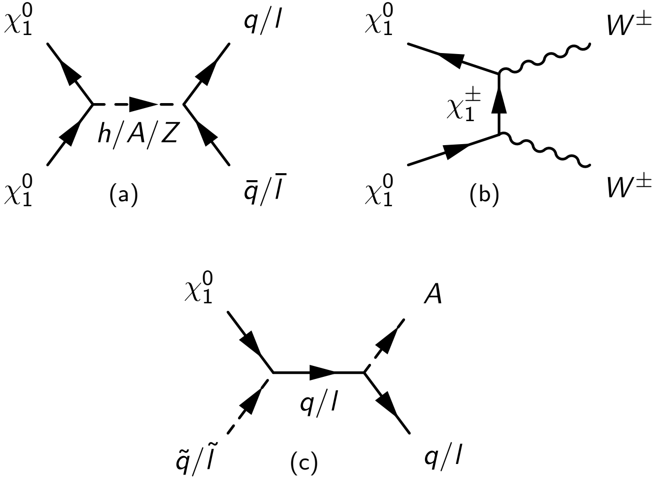
$$\Omega h^2 = \frac{\rho}{\rho_{crit}} h^2 \approx \frac{2.510^{-27} \frac{cm^3}{sec}}{< \sigma_{ann} v_{rel} >}$$

SUSY

- Symmetry connecting fermions and bosons
- Hierarchy problem
- Dark matter candidates: neutralino, sneutrino, gravitino
- gauge coupling unification

	SM Particle (R=+1)		SUSY Partner(R=-1)	
Names	Gauge ES	Mass ES	Gauge ES	Mass ES
neutralinos	W^0, B^0 H_u^0, H_d^0	Z^0, γ h_1^0, h_2^0, A_1^0	$\tilde{W}^0, \tilde{B}^0$ $\tilde{H}_u^0, \tilde{H}_d^0$	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$
charginos	$W^\pm$ H_u^+, H_d^-	$W^\pm$ $H^\pm$	$\tilde{W}^\pm$ $\tilde{H}_u^+, \tilde{H}_d^-$	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$

Annihilation channels I



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.

Annihilation channels III

Illustration of the velocity dependence

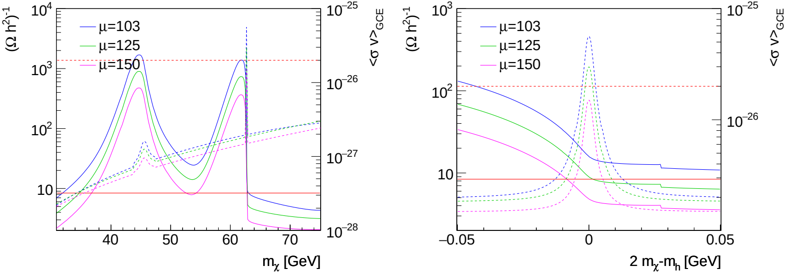
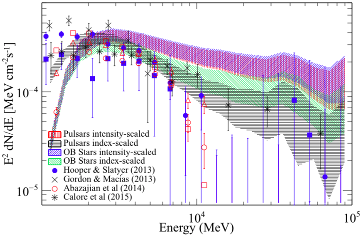
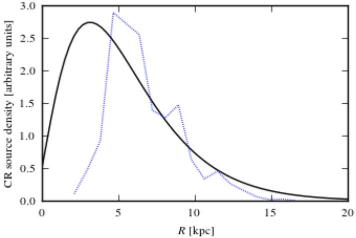


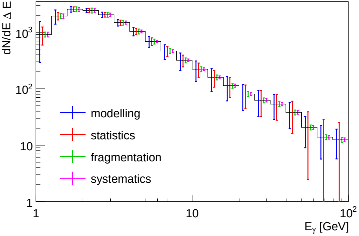
Figure: Inverse relic density (dashed, left axis) and annihilation rate in the GC (solid, right axis) for an MSSM parameter point where the annihilation is dominated by $\chi_1^0\chi_1^0 \to b\bar{b}$.

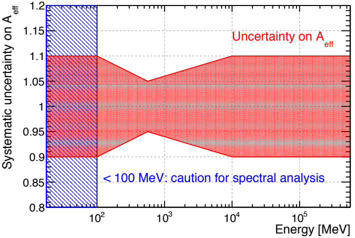
The Fermi LAT spectrum

γ ray spectrum from the galactic center observed by Fermi LAT [arXiv:1511.02938]



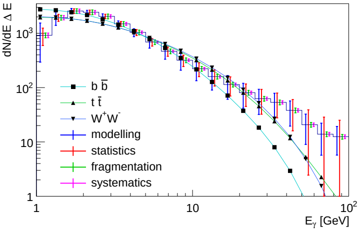


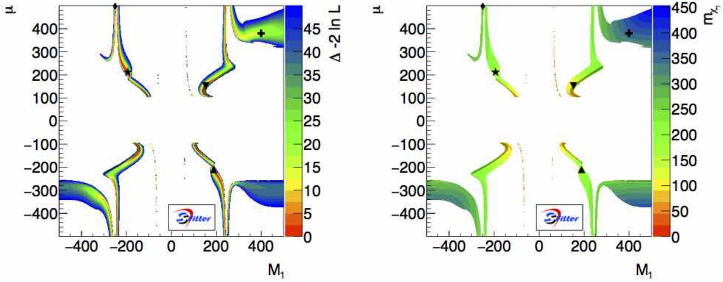




Fitting the Fermi LAT spectrum

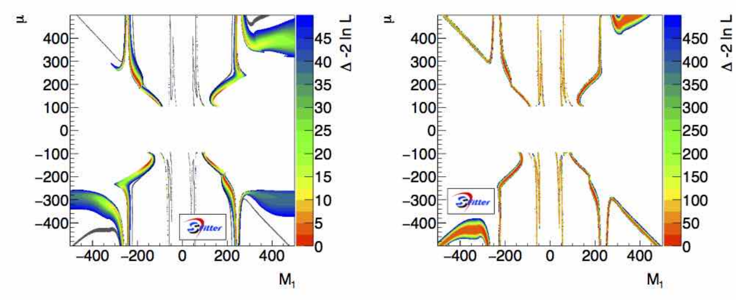
- annihilation spectra for $\chi\chi \to b\bar{b}/t\bar{t}/WW$ for local best fit points
- $m_A = 500$ GeV
- likelihood map determined by LSP mass and coupling





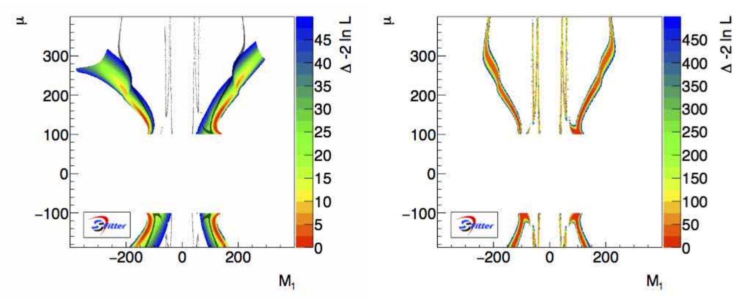
Fitting the Fermi LAT spectrum and the relic density

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



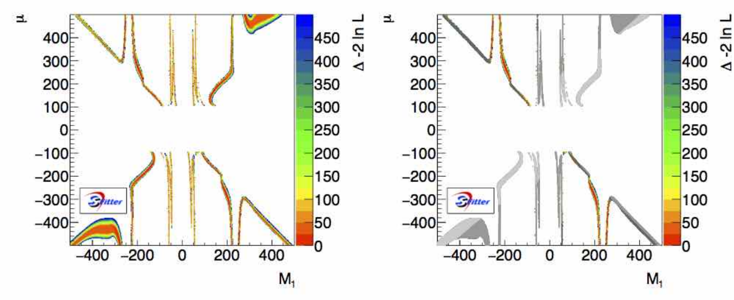
Another example

- $\tan\beta = 45$, $m_A = 1\text{TeV}$ (di lepton limits)



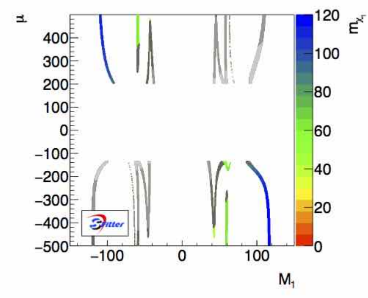
Direct detection

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



Direct detection

- low $M_2 = 120$ GeV $\rightarrow$ wino
- smaller coupling to light Higgs $\rightarrow$ avoids direct detection



5 things to keep in mind

- careful treatment of uncertainties and correlation to built a likelihood function
- γ-ray excess observed in GC can be explained by annihilating dark matter
- strongest constraint from relic density
- small tension between relic density and GCE can be resolved in MSSM
- direct detection experiments can rule out most of the parameter space

For further reading

- Statistik lecture notes
  - T. Plehn
    http://www.thphys.uni-heidelberg.de/~plehn/pics/lhc.pdf
  - K. Cranmer (NYU)
    http://arxiv.org/abs/1503.07622
  - Glen Cowan
    https://www.pp.rhul.ac.uk/~cowan/stat_course.html
- Dark Matter lecture notes
  - T. Plehn
    http://www.thphys.uni-heidelberg.de/~plehn/pics/dark_matter.pdf
  - J. Kopp (Mainz)
    http://www.staff.uni-mainz.de/jkopp/astroparticle2013.html
- others
  - S. P. Martin, "A Supersymmetry primer"
  - E.W. Kolb & M. S. Turner, "The Early Universe"
  - Butter et al., "Saving the MSSM from the GCE"
    https://arxiv.org/abs/1612.07115