

# Dark matter with light mediators

Mathias Garny

Les Houches, 08.11.2013

- QFT out of equilibrium and application to leptogenesis

*M. M. Müller, A. Hohenegger, A. Kartavtsev, M. Lindner, B. Garbrecht*

- Decaying/annihilating dark matter

*A. Ibarra, D. Tran, C. Weniger, A. de Simone, S. Vogl, M. Pato, W. Buchmüller*

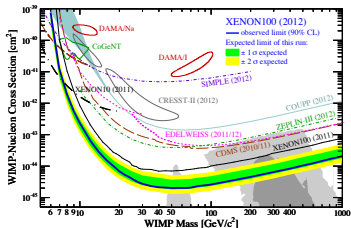
- Cosmological perturbation theory

*T. Konstandin, D. Blas*

- ...

# WIMP Dark Matter

Xenon100 1207.5988; LUX 1310.8214

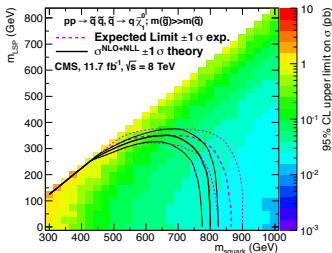
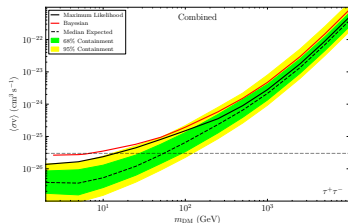
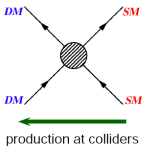


$$\Omega_\chi h^2 \simeq 0.1 \text{ pb} \cdot c / \langle \sigma v \rangle$$

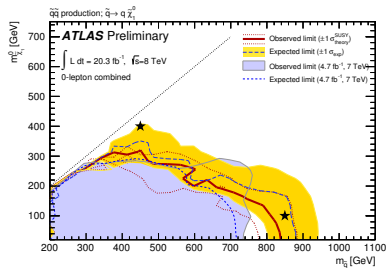
Fermi 1310.0828

thermal freeze-out (early Univ.)  
indirect detection (now)

direct detection



CMS 1303.2985



ATLAS CONF-2013-047

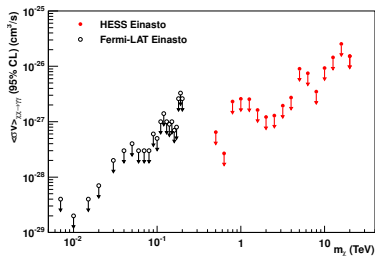
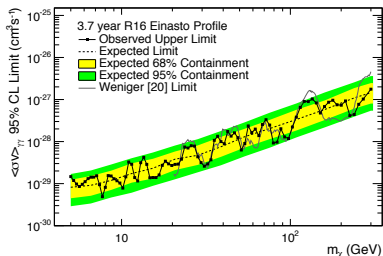
# Searches for spectral features in $\gamma$ -rays

- Fermi LAT GC data 5 – 300 GeV

*Fermi coll. 1305.5597 (Bringmann, Huang, Ibarra, Vogl, Weniger 1203.1312; Weniger 1204.2797)*

- H.E.S.S. CGH (bkg residual  $p$ ) 500 GeV-25 TeV

*H.E.S.S. coll. 1301.1173*



- $\sigma v \lesssim 10^{-29} \dots 10^{-26} \text{cm}^3/\text{s}$  over the range 10 GeV - 10 TeV
- H.E.S.S. II, GAMMA-400, CTA  $\neq$  5 – 10

*Bringmann, Calore, Vertongen, Weniger 1106.1874; Bergstrom, Bertone, Conrad, Farnier, Weniger 1207.6773; Aleksic, Rico, Martinez 1209.5589*

# Interplay of Dark Matter searches

- Interplay: full models (MSSM) or 'simplified models'
- SM+ $\chi$  (eff. op./portals) or SM+ $\chi$  + mediator  $\eta$ , ...

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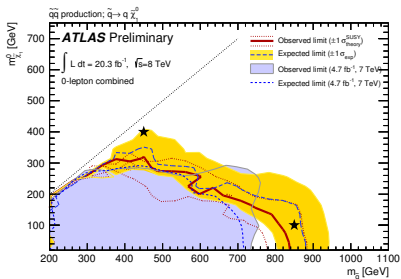
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- Here: Majorana DM  $\chi$ , colored/charged t-channel mediator  $\eta$

$$\mathcal{L} = f\bar{\chi}\psi\eta, \quad \psi \in q, \ell, \quad (f_{susy} = \sqrt{2}g' Y_\psi)$$

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ATLAS-CONF-2013-047

- Difficult for LHC when  $m_\chi \sim m_{\tilde{q}}$
- Nice complementarity to ID and DD

# Indirect detection

- $2 \rightarrow 2$  annihilation

$$\sigma_{\chi\chi \rightarrow q\bar{q}} = \left[ \mathcal{O}(v^0) \mathcal{O}\left(\frac{m_q}{m_{DM}}\right)^2 + \mathcal{O}(v^2) \right] \mathcal{O}\left(\frac{m_{DM}}{m_\eta}\right)^4$$

- $2 \rightarrow 3$  annihilation via FSR from nearly on-shell  $q$  (soft/collinear)

$$\sigma_{\chi\chi \rightarrow q\bar{q}\gamma}^{FSR} \simeq \frac{\alpha_{em}}{\pi} \int_0^1 dx \frac{1-x}{x} \log[4m_{DM}^2(1-x)/m_q^2] \times \sigma_{\chi\chi \rightarrow q\bar{q}}$$

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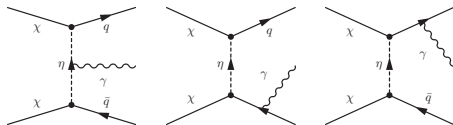
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- $2 \rightarrow 3$  annihilation via VIB and FSR from off-shell  $q$

$$\sigma_{\chi\chi \rightarrow q\bar{q}\gamma}^{VIB/FSR} = \frac{\alpha_{em}}{\pi} \left[ \mathcal{O}(v^0) \mathcal{O}\left(\frac{m_{DM}}{m_\eta}\right)^4 + \mathcal{O}(v^2) \right] \mathcal{O}\left(\frac{m_{DM}}{m_\eta}\right)^4$$



Hard  $\gamma$  spectrum peaked at  $0.8..0.95 \cdot m_{DM}$  (similar to  $\gamma$ -line within LAT energy resolution)

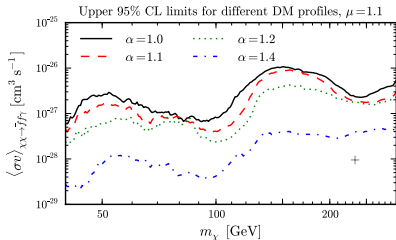
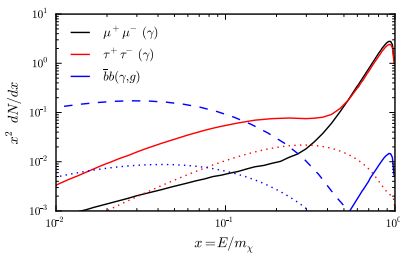
*Bergstrom 89; Bergstrom, Bringmann, Edsjo 0710.3169*



# Constraints on spectral feature from $\chi\chi \rightarrow f\bar{f}\gamma$

- Spectral gamma-ray feature on top of smoothly varying background
- Optimized search region close to GC
- Fermi LAT GC data 40 – 300 GeV

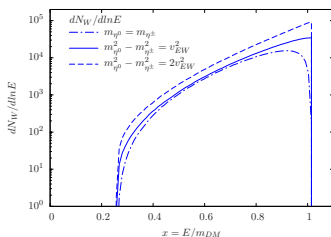
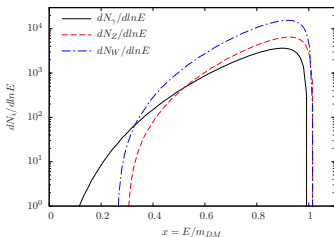
Bringmann, Huang, Ibarra, Vogl, Weniger 1203.1312



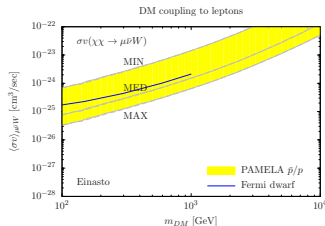
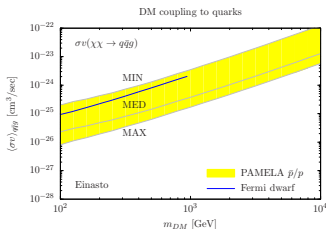
# Constraints from electroweak/strong IB

$$\chi\chi \rightarrow f\bar{f}V, \quad V = W, Z, g$$

MG, Ibarra, Vogl 1105.5367 1112.5155; cf. Ciafaloni et al 1104.2996; Bell et al 1104.3823; Asano et al 1112.5158



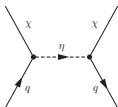
## Antiprotons (PAMELA) and Secondary gamma rays (Fermi dwarf)



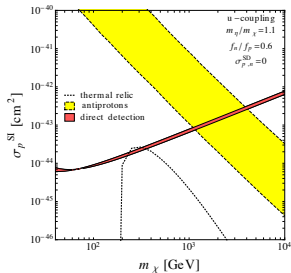
# Direct detection

- Scattering off Xe nuclei (XENON100), resonant enhancement

Hisano, Ishiwata, Nagata 1110.3719; Drees, Nojiri 93; Jungman et al 95



$$\sigma^{SI(SD)} \propto \frac{1}{[m_\eta^2 - (m_\chi + m_q)^2]^{4(2)}}$$

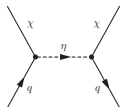


MG, Ibarra, Pato, Vogl 1207.1431

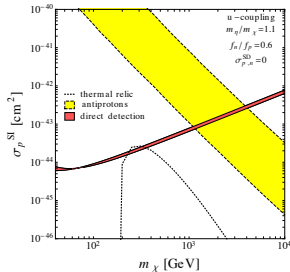
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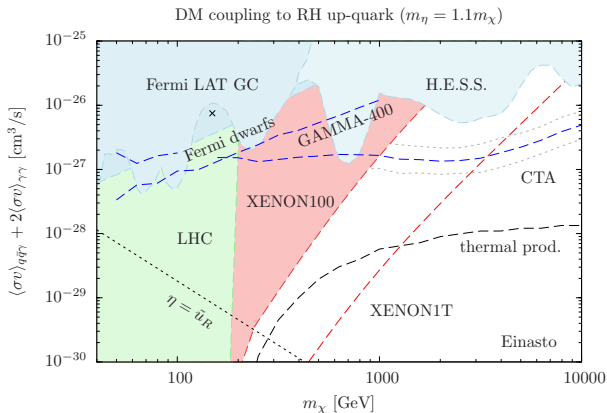
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MG, Ibarra, Pato, Vogl 1207.1431

- Convert into constraints on Yukawa coupling  $f$ , using  $\alpha_s(m_\chi)$ , and conservative assumptions on nuclear uncertainties for DD, and then convert into upper limit on  $\sigma v_{q\bar{q}\gamma} + 2\sigma v_{\gamma\gamma}$

# Current constraints and prospects

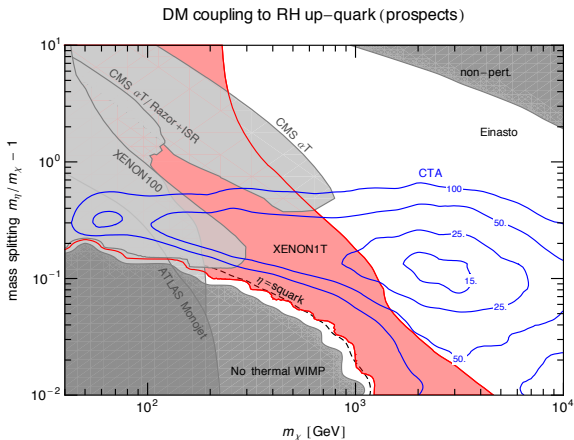


MG, Ibarra, Pato, Vogl 1306.6342

spectral analysis of Fermi LAT GC and H.E.S.S. CGH data with  
 $\text{IB}(q\bar{q}\gamma) + \text{line}(\gamma\gamma)$

# ID vs DD vs LHC

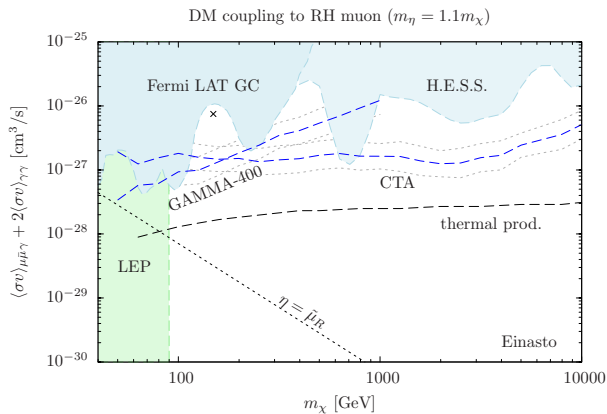
Exclusion/expected reach (95% C.L.) assuming thermal production



MG, Ibarra, Pato, Vogl 1306.6342

→ LHC(13)?

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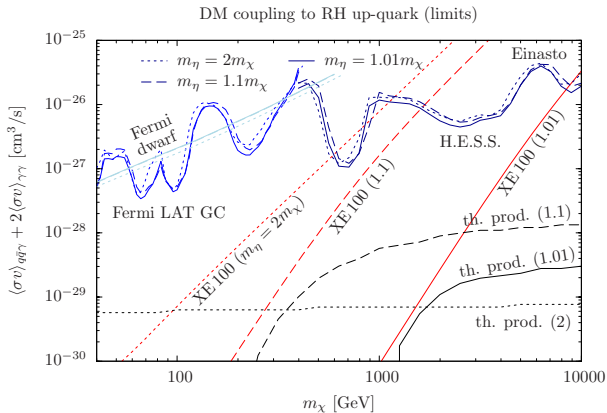


MG, Ibarra, Pato, Vogl 1306.6342

- Internal bremsstrahlung signatures in light of direct dark matter searches MG, A. Ibarra, M. Pato, S. Vogl, 1306.6342
- Decaying vs Annihilating Dark Matter in Light of a Tentative Gamma-Ray Line, W. Buchmüller, MG, 1206.7056
- Antiproton constraints on dark matter annihilations from internal electroweak bremsstrahlung MG, A. Ibarra, S. Vogl, 1105.5367
- Cosmological perturbation theory at three-loop order, D. Blas, MG, T. Konstandin, 1309.3308; 1304.1546
- Leptogenesis from first principles in the resonant regime, MG, A. Kartavtsev, A. Hohenegger, 1112.6428
- Systematic approach to leptogenesis in nonequilibrium QFT, MG, A. Hohenegger, A. Kartavtsev, M. Lindner, 0911.4122; 0909.1559



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MG, Ibarra, Pato, Vogl 1306.6342

$\sigma\nu(\chi\chi \rightarrow X)/\sigma\nu(\chi\chi \rightarrow \gamma f\bar{f})$  for  $m_{\eta^u} = m_{\eta^d}$  and  $m_{DM} = 300\text{GeV}$

DM $\chi = (1, 1, 0)$	$\eta$	$W\bar{f}f'$	$Z\bar{f}f$	$g\bar{f}f$
DM coupling to $L_e$	(1,2,1/2)	4.32	1.82	-
DM coupling to $e_R$	(1,1,1)	-	0.30	-
DM coupling to $q_L$	(3,2,1/6)	7.79	3.02	61.4
DM coupling to $u_R$	(3,1,2/3)	-	0.30	38.4
DM coupling to $d_R$	(3,1,-1/3)	-	0.30	154

*Ciafaloni et al 1104.2996*

*Bell et al 1104.3823*

*MG, Ibarra, Vogl 1105.5367*

[1112.5155](#)

*Bringmann et al 1308.1089*

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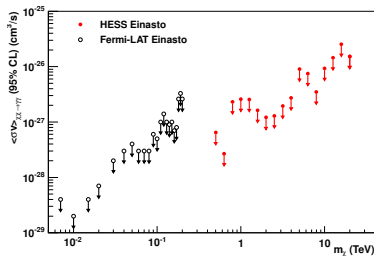
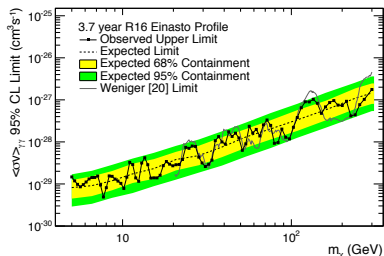
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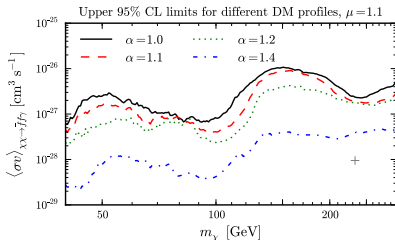
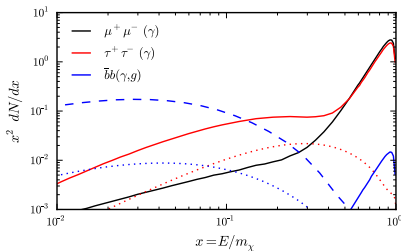
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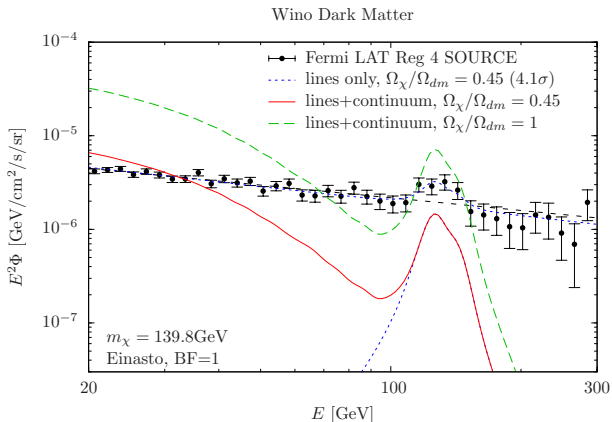
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H.E.S.S. coll. 1301.1173

# Gamma-ray line vs secondaries

$\sigma v_{\gamma\gamma, \gamma Z} \propto (\alpha_{em}/\pi)^2$  loop suppressed

→ continuous  $\gamma$ 's from  $\chi\chi \rightarrow WW, ZZ, b\bar{b}, \dots$  (plus  $\bar{p}, \dots$ )



need  $\text{BR}_{\gamma\gamma} + 0.5 \text{BR}_{\gamma Z} \gtrsim 0.5\%$

Buchmüller, MG 1206.7056