Extra U(1) as a source of monochromatic lines from Galactic Center

Alberto Romagnoni

DFT/IFT - UAM

Warsaw - Planck 2012

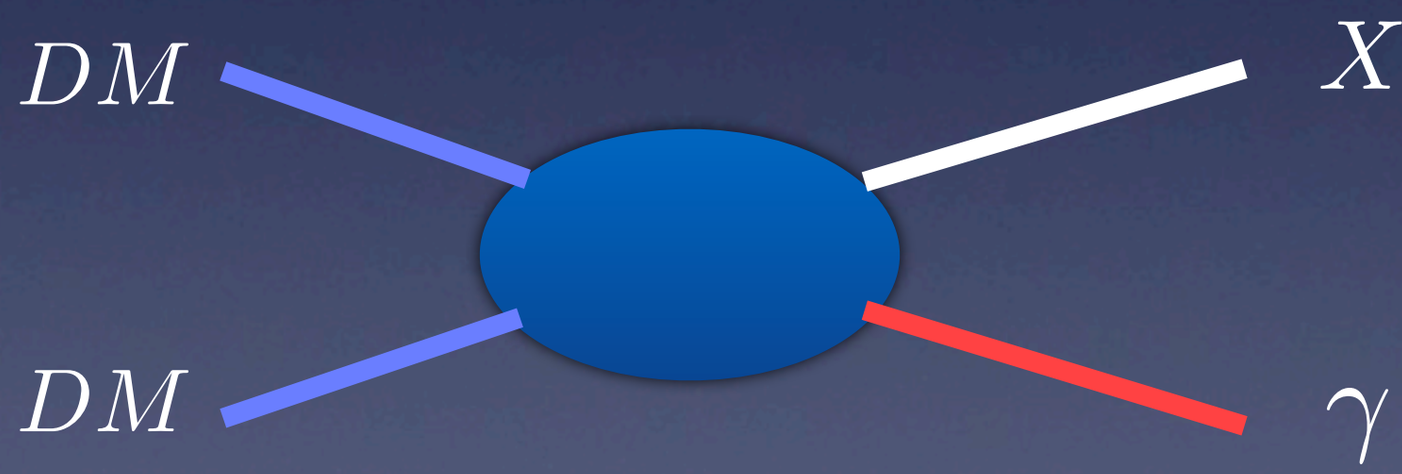
E.Dudas, Y.Mambrini, S.Pokorski, A.R.: arXiv:1205.1520 [hep-ph]

E.Dudas, Y.Mambrini, S.Pokorski, A.R.: JHEP 0908(2009)014

Dark Matter detection

Experiment	Source	Interaction	Channel
Collider	Controlled production	DM pair production	Missing energy
Direct	Local (crossing Earth surface)	DM-nucleus scattering	Phonons
Indirect	Earth, Sun, Galaxy, Cosmos	DM decay/ annihilation	γ, ν, Antimatter

Monochromatic line: A smoking gun!



Since DM is practically at rest:

$$E_\gamma = M_{DM}\left(1 - \frac{m_X^2}{4M_{DM}^2}\right)$$

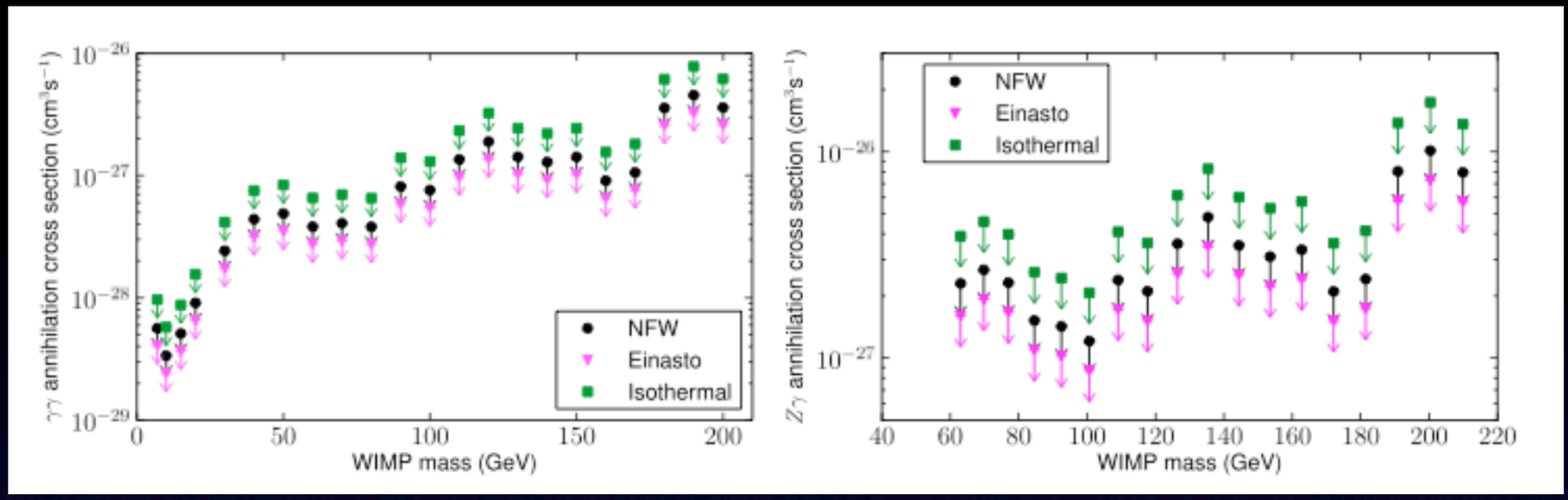
A monochromatic line: From Theory ?

It's quite difficult to obtain it in MSSM, and generically in SUSY models (suppressed with respect to annihilation in fermions)

- Inert Higgs — Gustafsson et al.: Phys.Rev.Lett.99,041301(2007)
- SUSY — Profumo et al.: Phys.Rev.D 78(2008),023507; K.Choi et al.: JCAP 1003(2010)028
- Trilinear Vector Couplings with a Z' — E.Dudas, Y.Mambrini, S.Pokorski, A.R.: JHEP 0908(2009)014; Y.Mambrini: JCAP 0912(2009)005
- Higgs in space — Jackson et al.:JCAP 1004(2010)004
- Extra-dim — Bertone et al.:JCAP 1203(2012)020
- Singlet DM — Profumo et al.: Phys.Rev.D 82(2010),123514
- Decaying DM — Arina et al.:JCAP 1003(2010)024
- Including neutrino sector — Aoki et al.: Phys.Rev.D 80(2009),033007
- Effective approach — Goodman et al.: Nucl.Phys.B 844(2011),55

A monochromatic line: From Fermi-LAT data ? (I-yes)

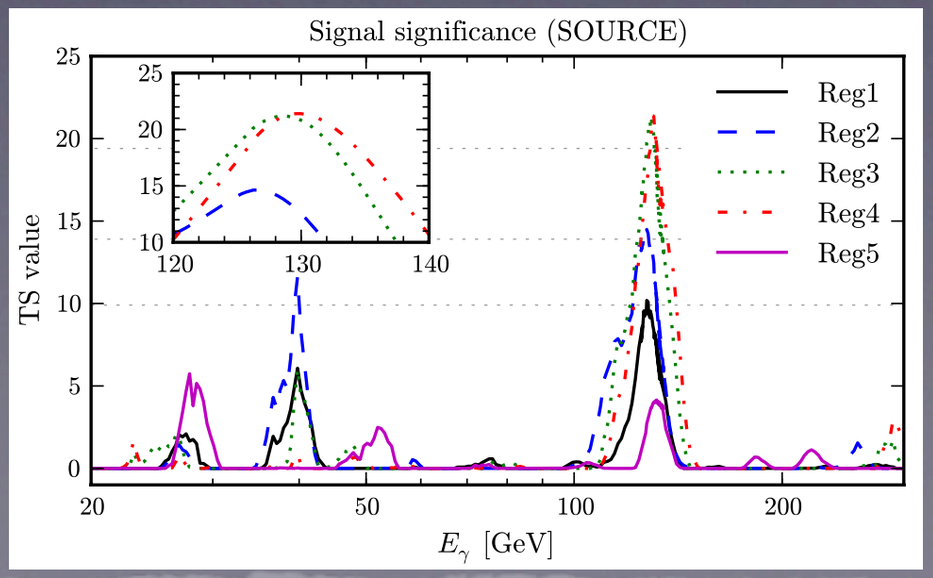
(excluding Galactic Plane)

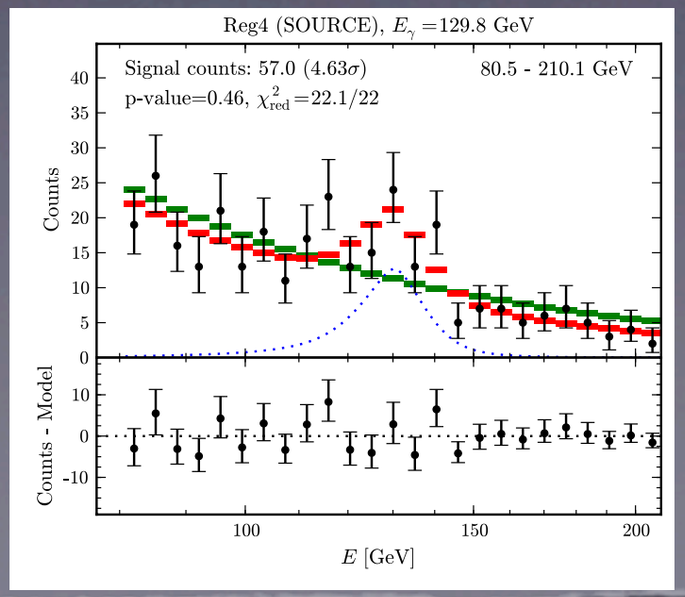


Fermi-LAT: arXiv:1205.2739 [hep-ph]

BUT: Weniger: arXiv:1204.2797 [hep-ph]

Selects optimized target regions depending on the profile of the Galactic DM halo





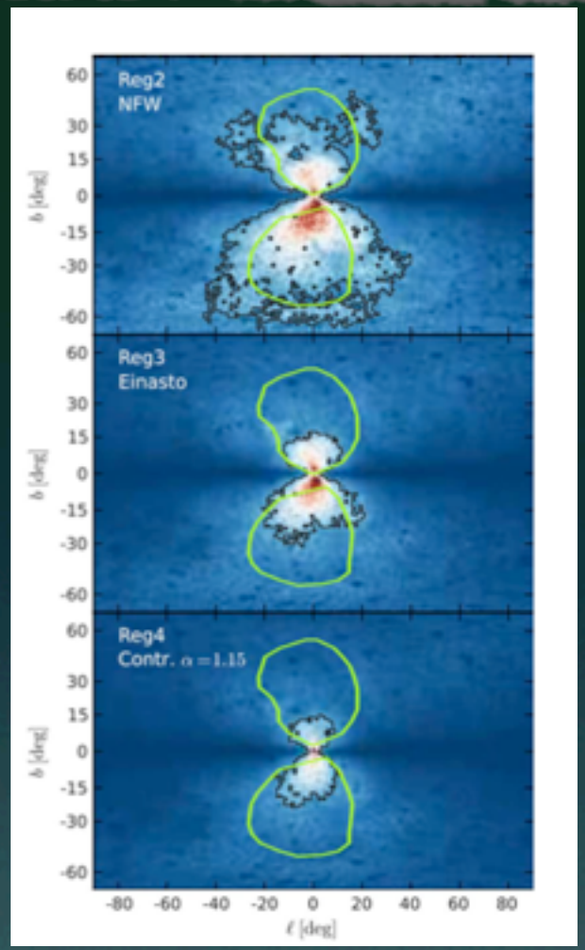
Indication for a monochromatic line from GC

$E_\gamma \simeq 130$ GeV

with significance

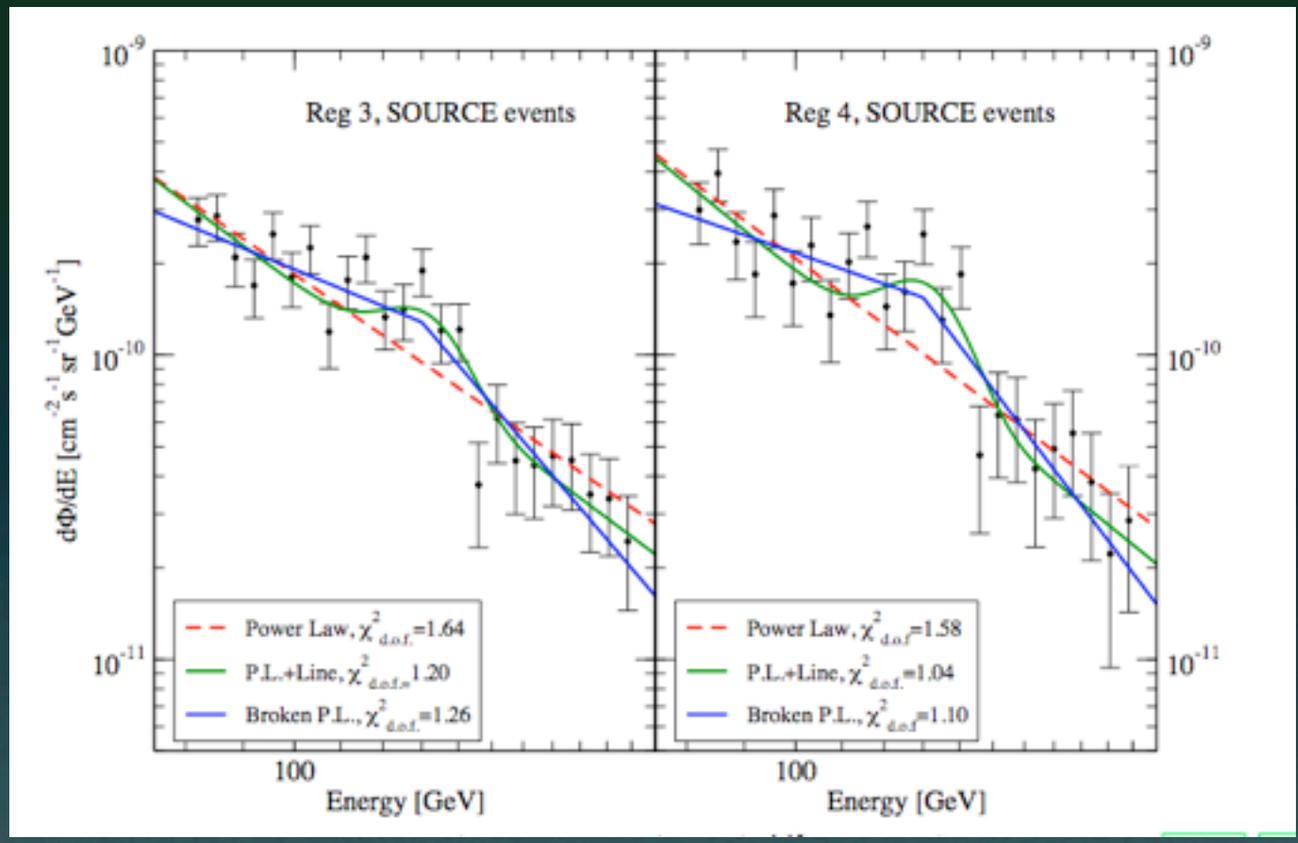
$3.3(4.6)\sigma$

A monochromatic line: From Fermi-LAT data ? (II-no)



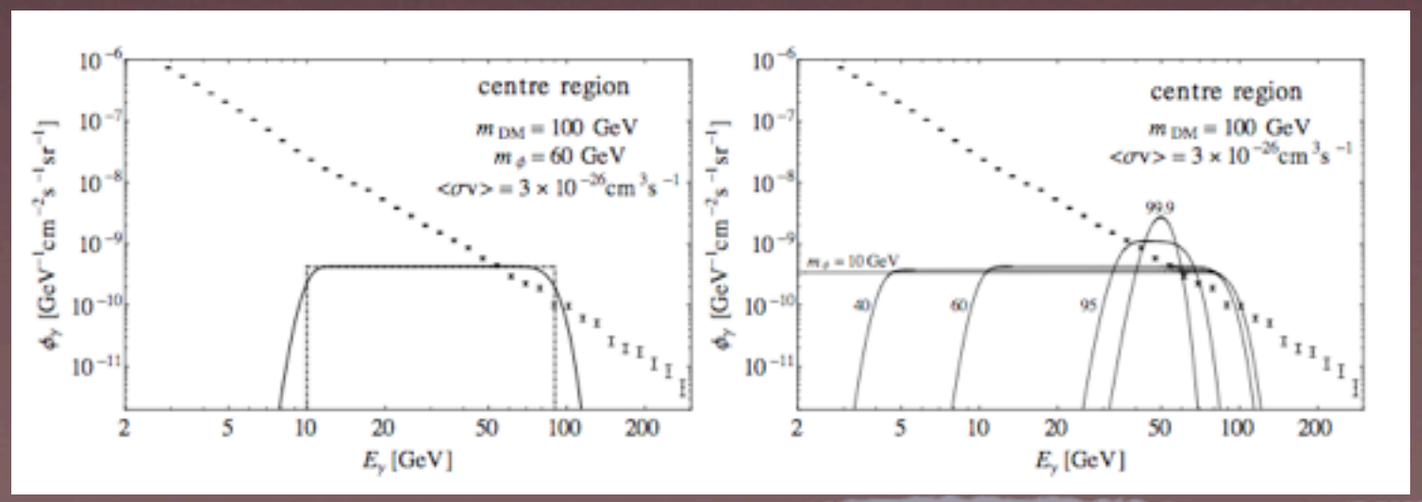
Fermi Bubbles

Profumo et al.: arXiv:1204.6047 [astro-ph.HE]



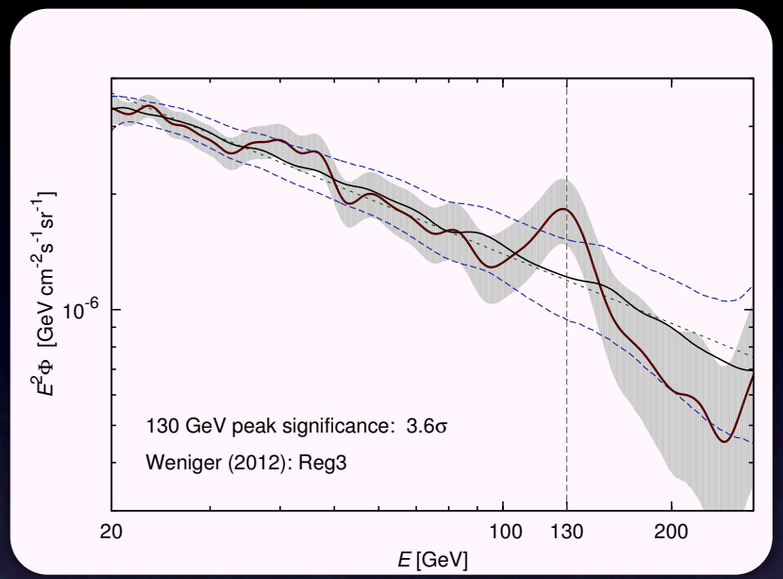
Box-shaped gamma-ray features:
ex) DM DM $\rightarrow$ V V
V $\rightarrow \gamma\gamma$

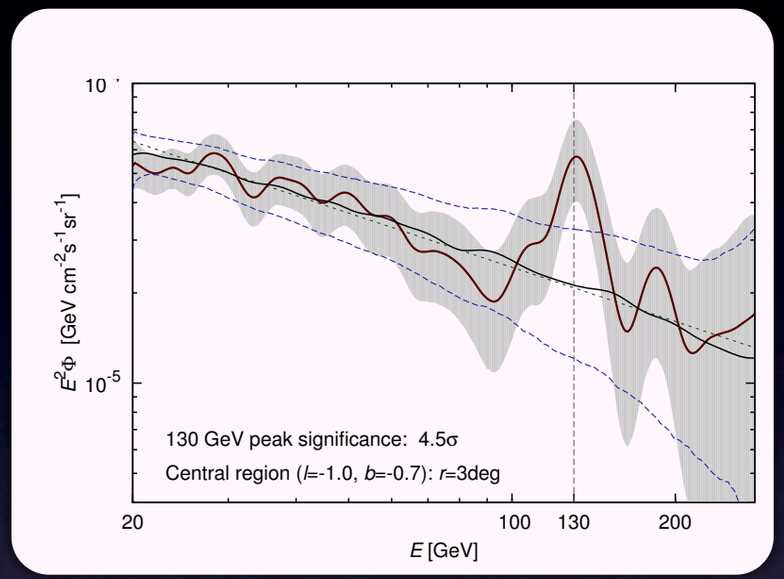
Ibarra et al.: arXiv:1205.0007 [hep-ph]

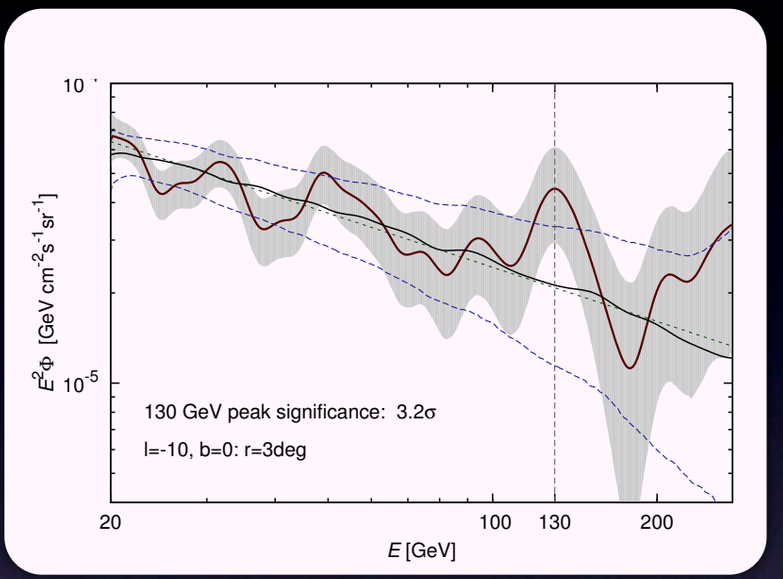


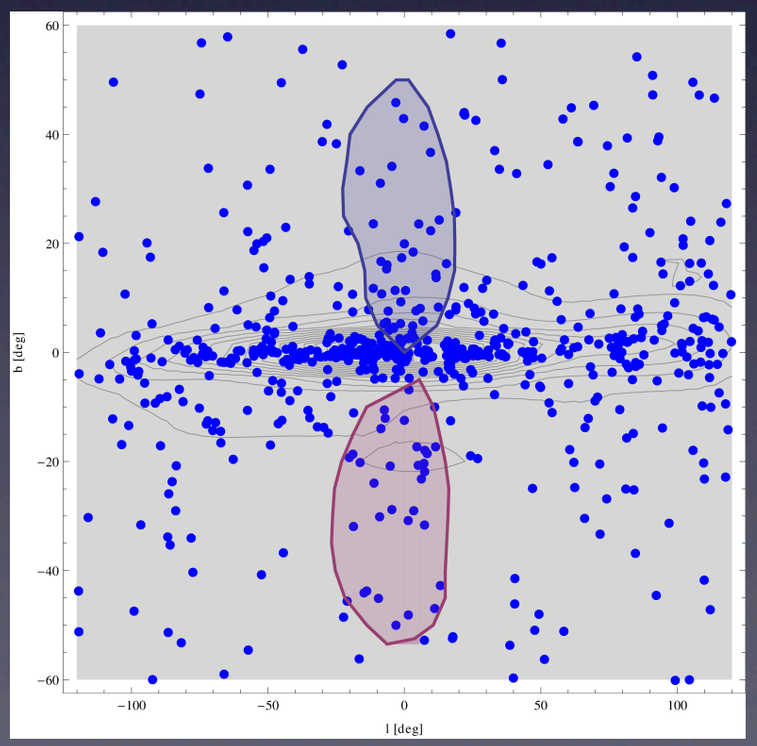
A monochromatic line: From Fermi-LAT data ? (III-yes)

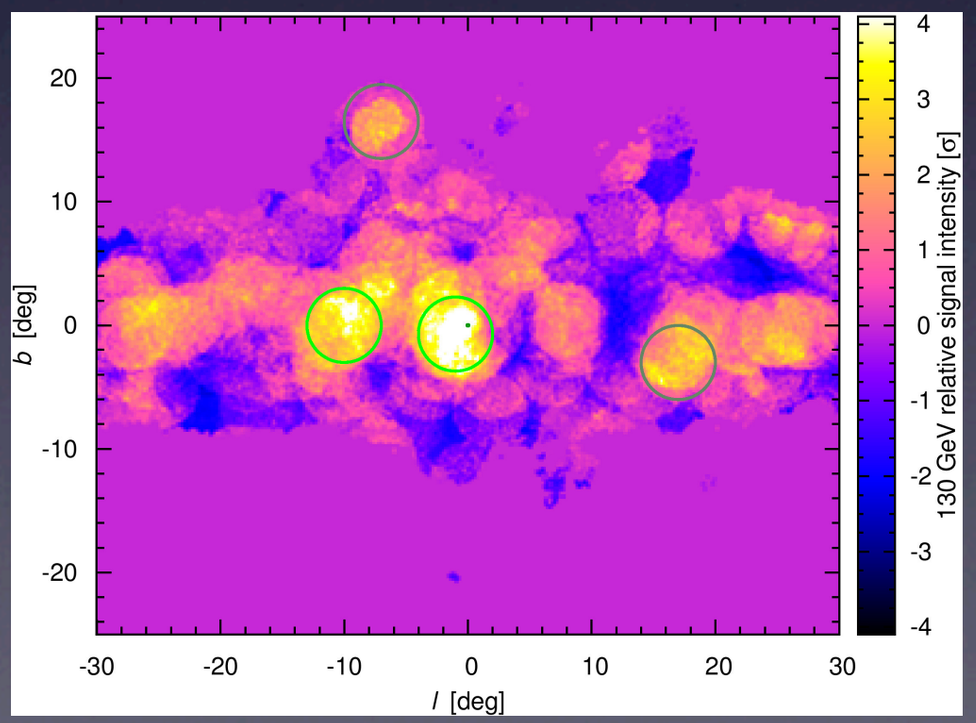
Tempel et al.: arXiv:1205.1045 [hep-ph]







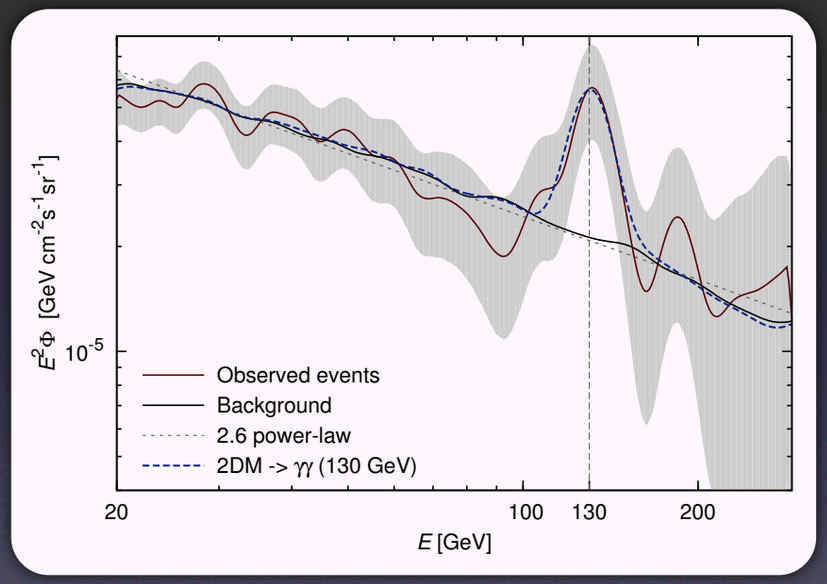


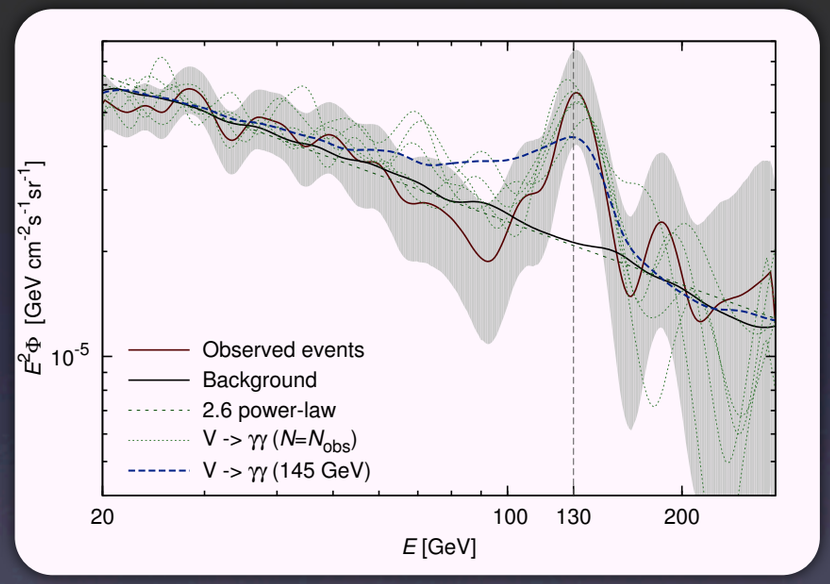


Not a "bubble"-effect:
Other astrophysical objects
or lines from
DM sub-halos?

A monochromatic line: From Fermi-LAT data (IV-yes?)

Tempel et al.: arXiv:1205.1045 [hep-ph]





Most likely
DM DM$\rightarrow \gamma\, X$.

But again... Boyarsky et al.: arXiv:1205.4700 [astro-ph.HE]

If yes, a good model needs a DM candidate with:

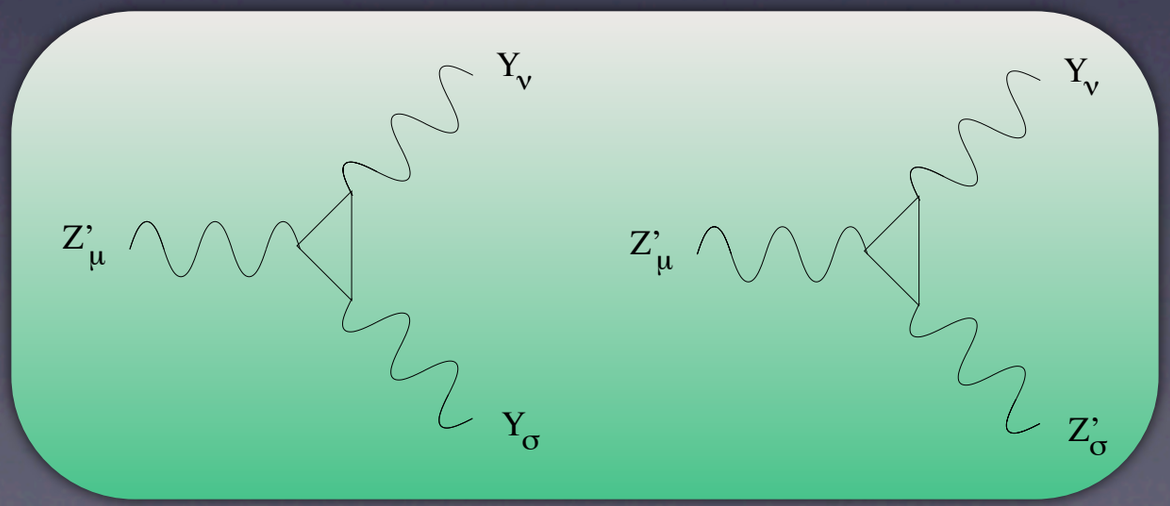
- Cross section for relic density: $\langle\sigma v\rangle \simeq 3 \times 10^{-26} cm^3 s^{-1}$
- Cross section into photon+X: $\langle\sigma v\rangle_{\gamma X} \simeq 2 \times 10^{-27} cm^3 s^{-1}$

Our model: U(1)` and Chern-Simons terms

E.Dudas, Y.Mambrini, S.Pokorski, A.R.: arXiv:1205.1520 [hep-ph]

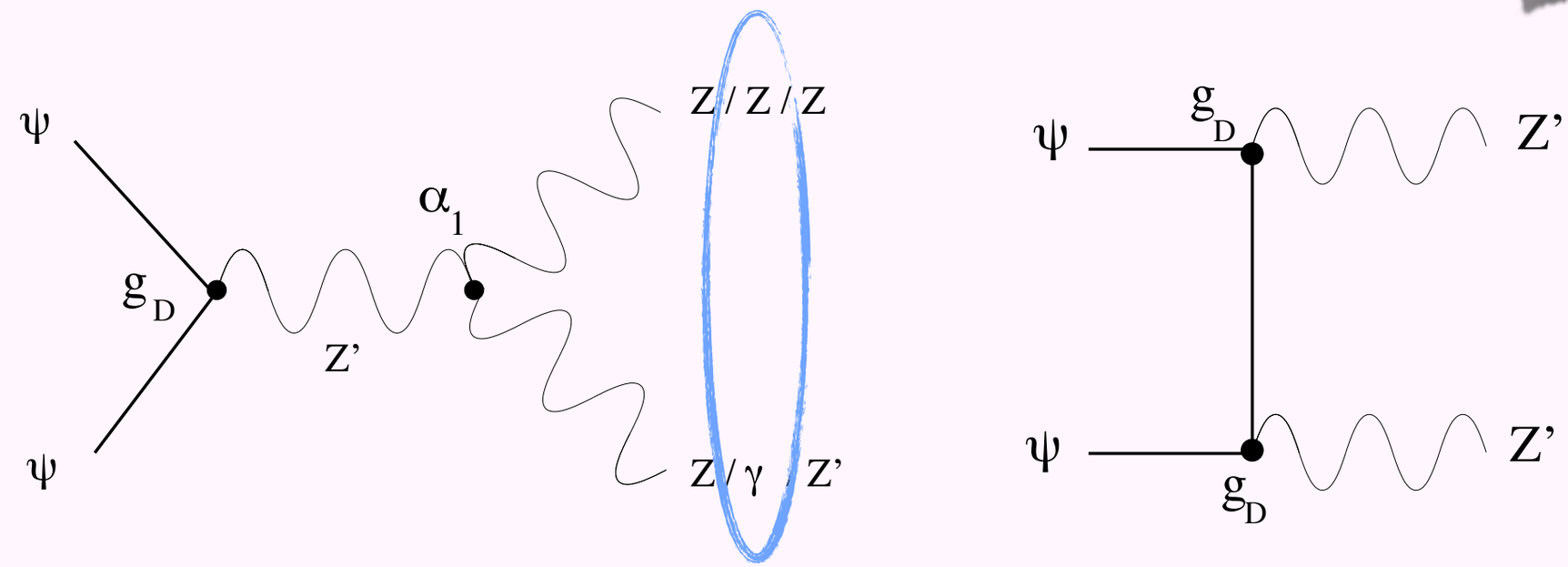
- Extra U(1)`
- DM candidate charged under it [couples to Z`]
- SM particles uncharged under U(1)`
- 1-loop induced Chern-Simons terms [3 gauge boson couplings]

$$\mathcal{L}_{CS} = \alpha_1 \, \epsilon^{\mu\nu\rho\sigma} Z'_\mu Z_\nu F^Y_{\rho\sigma} + \alpha_2 \, \epsilon^{\mu\nu\rho\sigma} Z'_\mu Z_\nu F'_{\rho\sigma}$$



Different scenarios

$m_\psi \simeq 145$ GeV



$< \sigma v >$

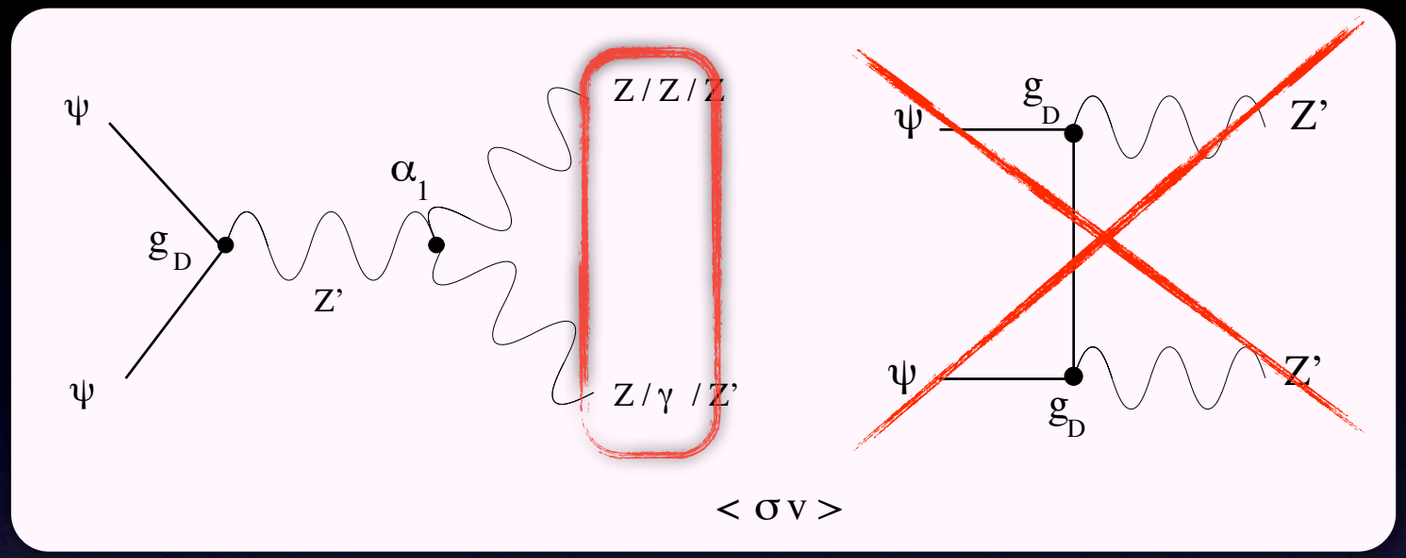
We don't consider here the case of sizeable kinetic mixing

Case A	Case B	Case C
$M_{Z'} > 2m_\psi - M_Z$	$m_\psi < M_{Z'} < 2m_\psi - M_Z$	$M_{Z'} < m_\psi$

Implemented in Micromegas

Case A

$$m_\psi \simeq 145 \text{ GeV}$$
$$M_{Z'} > 2m_\psi - M_Z$$



$$\frac{\langle \sigma v \rangle_{ZZ}}{\langle \sigma v \rangle_{Z\gamma}} \simeq 0.3 \longrightarrow \langle \sigma v \rangle_{Z\gamma} \simeq 2 \times 10^{-26} \text{cm}^3 \text{s}^{-1}$$

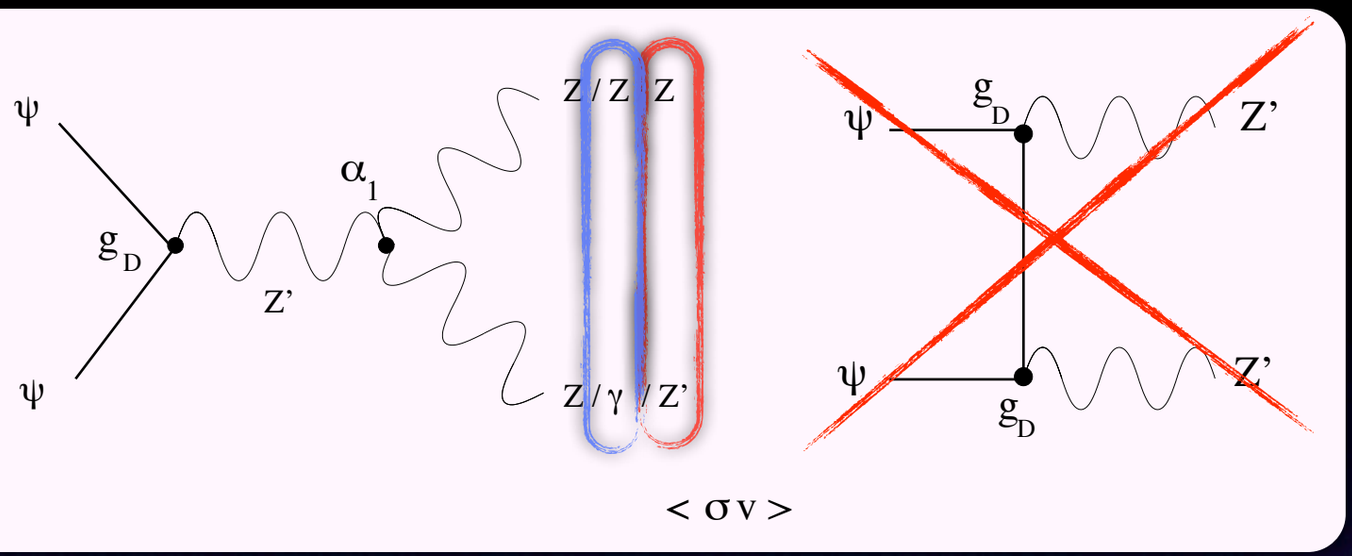
(to have: $\langle \sigma v \rangle \simeq 3 \times 10^{-26} \text{cm}^3 \text{s}^{-1}$)

E.Dudas, Y.Mambrini, S.Pokorski, A.R.: JHEP 0908(2009)014

It seems excluded by Fermi-LAT

Case B

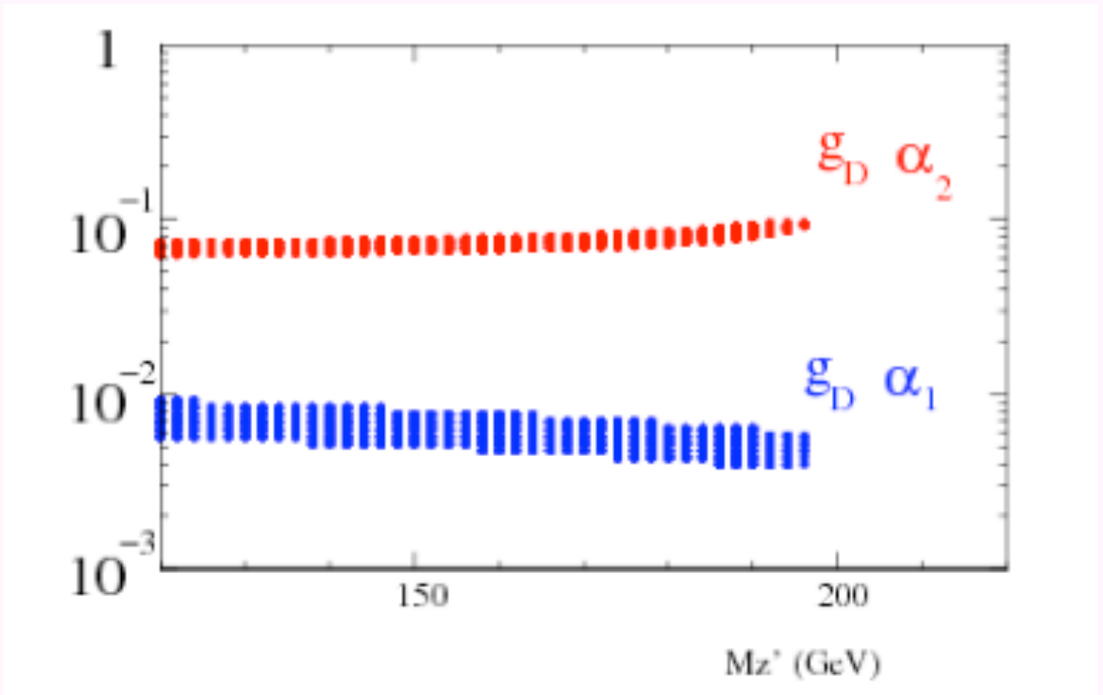
$$m_\psi \simeq 145 \text{ GeV}$$
$$m_\psi < M_{Z'} < 2m_\psi - M_Z$$



The two processes ***can*** decouple:

$$\langle \sigma v \rangle \propto \alpha_2$$

$$\langle \sigma v \rangle_{Z\gamma} \propto \alpha_1$$



Einasto profile

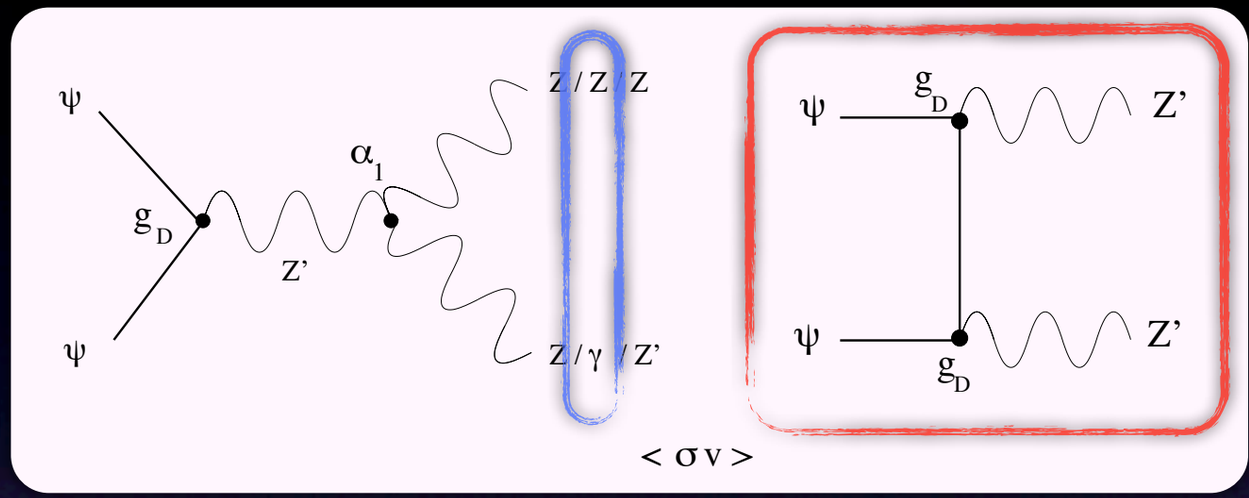
Case C

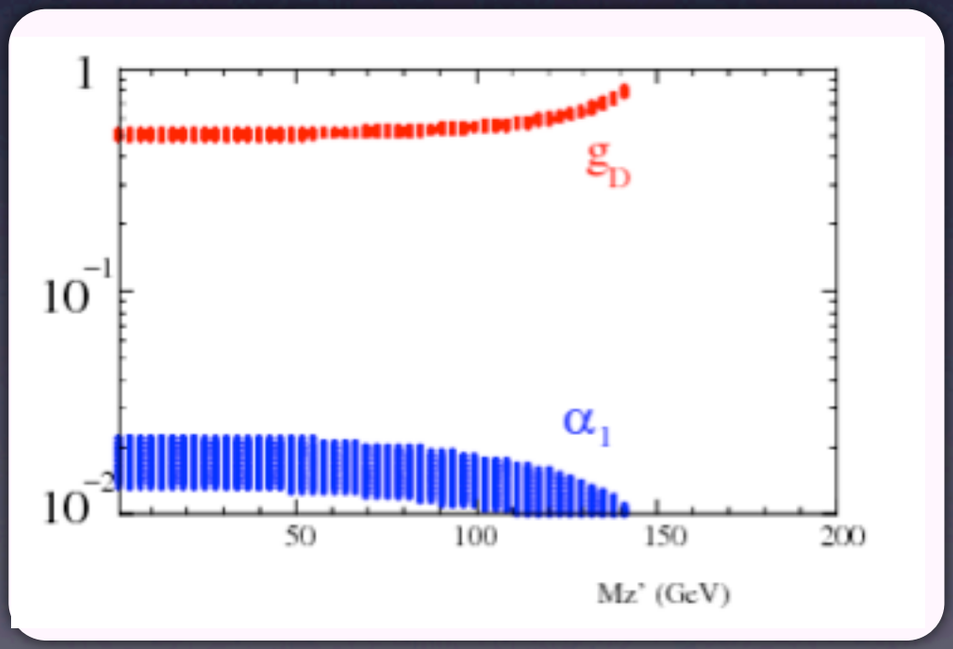
$$m_\psi \simeq 145 \text{ GeV}$$
$$M_{Z'} < m_\psi$$

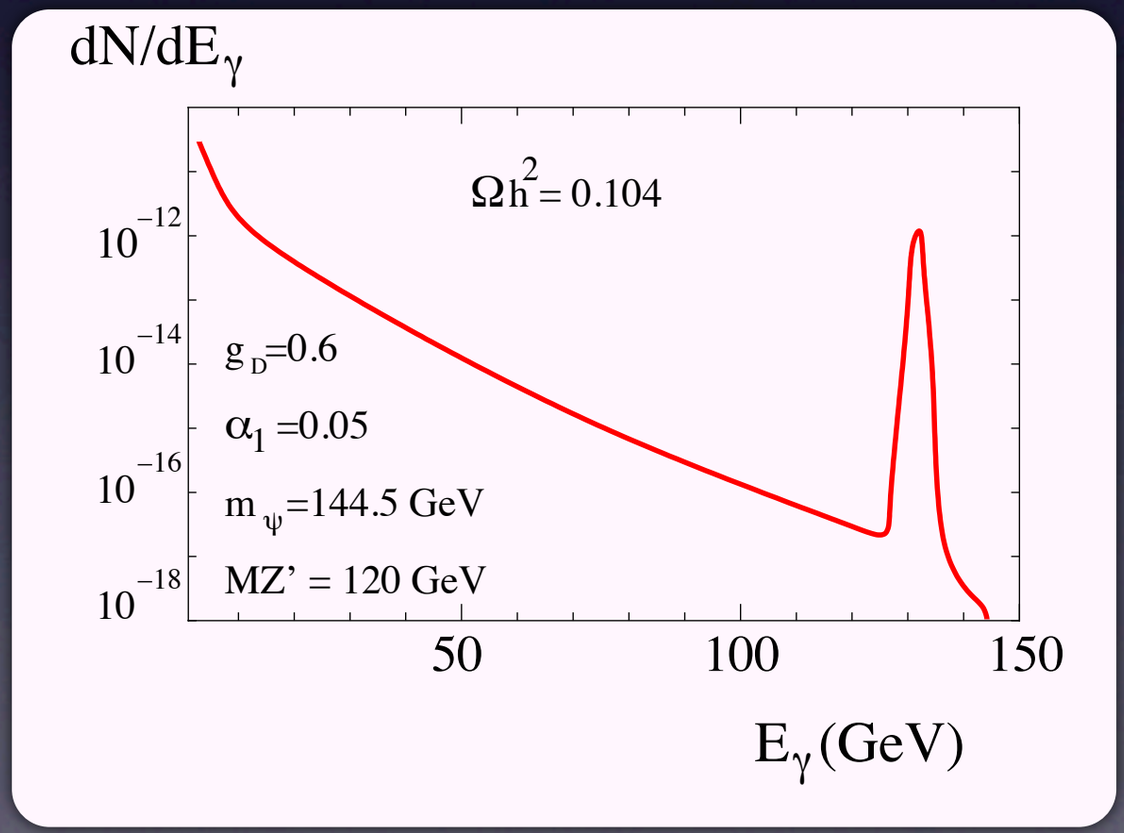
The two processes decouple:

$$\langle \sigma v \rangle \propto g_D$$

$$\langle \sigma v \rangle_{Z\gamma} \propto \alpha_1$$







Einasto profile

Comments & some theoretical insights

Origin of the Chern-Simons terms:

The broken SM symmetries and the U(1)` are realized in a Stueckelberg phase

$$\frac{i}{M^2}\epsilon^{\mu\nu\rho\sigma} D_\mu\theta(D_\nu H^\dagger H - H^\dagger D_\nu H)(c_1 F^Y_{\rho\sigma} + c_2 F'_{\rho\sigma}) \qquad \alpha_i \sim c_i v^2/M^2$$

M mass of heavy fermions — E.Dudas, Y.Mambrini, S.Pokorski, A.R.: JHEP 0908(2009)014

CS also present in generic in string constructions. — Anastasopoulos et al.: JHEP 0611(2006)057

If light fermions in the spectrum, computations change but we expect similar results

Coriano et al.:Nucl.Phys.B 746(2006)77
Dedes et al: arXiv:1202.4940 [hep-ph]
Mambrini: JCAP 0912(2009)005
Jackson et al.:JCAP 1004(2010)004

- In this model, direct detection is largely suppressed
- Kinetic mixing $10^{-11} \lesssim \delta \lesssim 10^{-2}$ is OK for a Z` decay safe for BBN and EW precision tests when $M_{Z'} < M_Z$
- Corrections $\delta M_Z^2 \sim (\alpha_i^2/16\pi^2)\Lambda^2 \longrightarrow \Lambda \lesssim 500\ \mathrm{GeV}$

Other possibilities

After the discussion of Weniger few other models have been proposed:

- Scalar DM and interactions through a virtual extra scalar electrically charged (and colored under extra symmetry group)
  Cline: arxiv:1205.2688[hep-ph]

- Right-handed sneutrino DM in MSSM + 2 extra neutrinophilic Higgs fields discrimineted with a Z_2 symmetry
  Choi et al.: arxiv:1205.3276[hep-ph]

- Scalar DM decaying in 2 photons by dim 6 operators suppressed at GUT scale
  Kyae et al.: arxiv:1205.4151[hep-ph]

- Extra complex scalar, PQ symmetry, vertices from anomalies (embedding in NMSSM)
  Lee et al.: arxiv:1205.4675[hep-ph]

- WIMP+Axions in String/M-theory compactifications
  Acharya et al.: arxiv:1205.5789[hep-ph]

Conclusions & Open Questions

- Discussed a tentative evidence for a narrow spectral feature at $E_\gamma \simeq 130\ \mathrm{GeV}$, in the FERMI-Lat data and its interpretation in terms of DM annihilation process
- Proposed one of the "few" DM models in the market with a signature compatible with it, where an extra U(1)` gauge symmetry provides the portal between visible and dark sectors and where the key is represented by trilinear vector bosons couplings
- Discussed the different scenarios allowed by the model

- Are we really seeing a monochromatic line?
- If yes, is it really related to DM?
- If yes, how many lines? (hints for model building)

Rajaraman et al.: arxiv:1205.4723[hep-ph]

- For us: combined analysis with collider bounds

Barbieri et al.: Phys.Lett.B688(2010)212-215

Formulas backup

$$\begin{aligned}\mathcal{L}_{mix} \;=\; \frac{1}{M^2}\Big\{ & b_1 \mathcal{T}r(F^X F^Y \widetilde{F}^Y) + 2b_2 \mathcal{T}r(F^X F^W \widetilde{F}^W) + b_3 \mathcal{T}r(F^Y F^X \widetilde{F}^X) \\ & + \mathcal{D}^\mu \theta_X \left[i(D^\nu H)^\dagger (c_1 \widetilde{F}^Y_{\mu\nu} + c_2 \widetilde{F}^W_{\mu\nu} + c_3 \widetilde{F}^X_{\mu\nu}) H + c.c. \right] \\ & + \partial^\mu \mathcal{D}_\mu \theta_X \left[d_1 (F^Y \widetilde{F}^Y) + 2d_2 (F^W \widetilde{F}^W) + d_3 (F^Y \widetilde{F}^X) \right] \\ & + \mathcal{D}_\mu \theta_X \mathcal{D}^\mu \theta_X \left[d_4 (F^Y F^Y) + 2d_5 (F^W F^W) \right] \Big\}\end{aligned}$$

$$\mathcal{D}_\mu \theta_X = (\partial \theta_X - Z')_\mu$$

$$\mathcal{S} = -\sum_i \int d^4x \frac{1}{4g_i^2} F_{i,\mu\nu} F_i^{\mu\nu} + \frac{1}{2} \int d^4x \sum_i (\partial_\mu a^i - g_i V_i A^i_\mu)^2$$

$$+ \frac{1}{96\pi^2} C^I_{ij} \; \epsilon^{\mu\nu\rho\sigma} \int a^I F^i_{\mu\nu} F^j_{\rho\sigma} + \frac{1}{48\pi^2} E_{ij,k} \; \epsilon^{\mu\nu\rho\sigma} \int A^i_\mu A^j_\nu F^k_{\rho\sigma} \; .$$