Gamma rays from the GC: DM Interpretations and Collider Signals

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A dark matter gamma-ray signal?

Daylan et al.
What can we learn from LHC data about models that can fit the GC excess?

We may not understand systematics enough to be convinced annihilation is to bb. However, LHC offers unique probe.

The next LHC run

- Starting early 2015
- Center of mass energy: from 8 TeV to 13-14 TeV
- Luminosity/statistics: from 20/fb to 100-300/fb
**bb̄ mediators**

SM mediators like Z are already very constrained. Higgs mediation is p-wave so $\langle \sigma v \rangle \to 0$ today.

**Assume fermion DM**

**Pseudoscalar**

**Sbottom-like**
LHC searches

Invisible particles

$\vec{p}_{T} = - \sum_{\text{visible}} \vec{p}_{T}$  \hspace{1cm} $E_{T} = \left| \vec{p}_{T} \right|$  

b-quark jets

b-tagging efficiency ~60%

Interaction point
b-flavored dark matter

\[- \mathcal{L} \supset \lambda \tilde{B}^* b_R \chi + \text{h.c.}\]

similar to sbottom: scalar, same charges as b

Preferred coupling to b-quarks could arise in MFV dark matter, where DM lives in a (quark) flavor multiplet

Batell, TL, Wang 2014
Agrawal, Batell, Hooper, TL 2014
Mediator pair production

2b+MET

Mediator mass already very constrained

CMS MSSM sbottom search
Because of large coupling, single production of mediator can also contribute:

Simulations of data with MadGraph+PYTHIA+Delphes, compared to ATLAS analysis

ATLAS, 1308.2631:
- $p_T(b$-jets) > 150, 30 GeV
- MET > 150 GeV
- Isolated lepton veto
- $mbb > 200$ GeV
- MCT > 350 GeV
Contransverse Mass

\[ M_{CT} < \frac{M^2_B - M^2_\chi}{M_\tilde{B}} \]

\[ M^2_{CT} = [E_T(j_1) + E_T(j_2)]^2 - [\vec{p}_T(j_1) - \vec{p}_T(j_2)]^2 \]

LHC 8 TeV, 20/fb

- Z+jets
- \( M_B = 700 \text{ GeV}, \) thermal relic
- \( M_B = 700 \text{ GeV}, \) sbottom

ATLAS cut

Tovey 2009
Events

$LHC \ 14 \ TeV, \ 100/fb$

- $Z+\text{jets}$
- $M_B = 600 \ GeV$
- $M_B = 750 \ GeV$
- $M_B = 900 \ GeV$
Single production of mediator:

\[ b \rightarrow \tilde{B} \rightarrow \chi \quad \text{Reach is weaker: suppressed by } b \text{ pdf.} \]

“mono-\( b \)” final state with plenty of MET + b-jet.

Simpler analysis, but also less info.

TL, Kolb & Wang 2013
**direct detection in bFDM**

**Charge-charge interaction:**

\[ \mathcal{M} = b_q \bar{u}_\chi \gamma^\mu u_\chi \langle N | Q \bar{q} \gamma_\mu q | N \rangle \]

\[ \mathcal{O} \sim \frac{1}{m^2_\phi} \bar{\chi} \gamma^\mu \chi \partial^\nu F_{\mu\nu} \]

\[ b_q = -\frac{3Q_b e \lambda_b^2}{64\pi^2 m^2_\phi} \left[ 1 + \frac{2}{3} \ln \left( \frac{m_b^2}{m^2_\phi} \right) \right] \]

\[ \sigma_n \approx 10^{-45} \text{cm}^2 \times \left( \frac{\lambda}{2.16} \right)^4 \left( \frac{725 \text{ GeV}}{m_{\tilde{B}}} \right)^4 \]

\[ \chi_b \quad \tilde{B} \quad p \]

\[ \bar{\chi}_b \quad b \quad \gamma \quad \gamma \quad p \]
Parameter space

large mediator mass, large coupling needed

mono-b, sbottom searches with LHC14,100/fb

definitely tested with increased LUX exposure
Pseudoscalar mediator

Collider channels with b-jets+MET:
Model-independent collider bounds on pseudoscalar couplings

Lighter shaded regions: LHC14, 300/fb

bbb search (7 TeV limits)

$b+\text{MET}, \ b\bar{b}+\text{MET}$

$m_A=100 \text{ GeV}$

GC excess
**UV-complete models?**

\[
H = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h \end{pmatrix}
\]

**Two-Higgs Doublet Model**

\[
H_d = \frac{1}{\sqrt{2}} \begin{pmatrix} -\sin \beta \ H^+ \\ v_d + \cos \beta \ h + \sin \beta \ H - i \sin \beta \ A \end{pmatrix}
\]

\[
H_u = \frac{1}{\sqrt{2}} \begin{pmatrix} \cos \beta \ H^+ \\ v_u + \sin \beta \ h - \cos \beta \ H + i \cos \beta \ A \end{pmatrix}
\]

\[
\tan \beta = \frac{v_u}{v_d}
\]

Many models introduce new pseudoscalar, where coupling to SM quarks arises from mixing with 2HDM.

(for example: “annihilon”, NMSSM…)}
More pseudoscalar searches

\[ g_{b,\tau} = y_{b,\tau} \tan \beta \]

CMS limits for MSSM A (assuming no coupling to DM)
Lighter shaded regions:
LHC14, 300/fb

bττ search
(8 TeV limits)

$m_A = 100$ GeV

b+MET, bb+MET

GC excess
# Channels

<table>
<thead>
<tr>
<th></th>
<th>b-flavored</th>
<th>pseudoscalar</th>
<th>current</th>
</tr>
</thead>
<tbody>
<tr>
<td>bb+MET</td>
<td>$\tilde{B}\tilde{B} \rightarrow bb+\chi\chi$</td>
<td>$bbA \rightarrow bb+\chi\chi$</td>
<td>[8 TeV, 20/fb]</td>
</tr>
<tr>
<td>b+MET</td>
<td>$\chi\tilde{B} \rightarrow b+\chi\chi$</td>
<td>$bA \rightarrow b+\chi\chi$</td>
<td>[8 TeV, 20/fb]*</td>
</tr>
<tr>
<td>bbb</td>
<td>n/a</td>
<td>$bA \rightarrow bbb$</td>
<td>7 TeV, 4/fb</td>
</tr>
<tr>
<td>b+ττ</td>
<td>n/a</td>
<td>$bA \rightarrow b+\tau\tau$</td>
<td>8 TeV, 20/fb</td>
</tr>
</tbody>
</table>

[ ] = Re-interpretation of constraints
* = LHC data analysis not yet public
Light mediators?

- Extremely weak LHC signals unless additional ingredients are added
- Aside: low-energy collider searches for light mediator could be effective, however.
Conclusions

- If the GC excess is interpreted as annihilation to $b$-quarks, then a new mediator particle is required.

- The mediator and/or DM can be produced at the LHC, giving rise to signals with $b$-jets and/or missing energy.

- Colored mediator scenario can be excluded. Parameter space of pseudoscalar mediators partially tested.
Another example:

\[ g_b = g_\chi \cdot (\chi \gamma^\mu \gamma^5 \chi)(\bar{b} \gamma^\mu \gamma^5 b) \]

From Izaguirre et al. 2014

Challenging to find UV-complete model?
Suppose we only introduce pseudoscalar of 2HDM.

Example: mixed singlet-doublet model

\[ -\mathcal{L} = \frac{1}{2} M_S S^2 + M_D D_1 D_2 \]
\[ + y \cos \theta S H_d D_1 \]
\[ + y \sin \theta S H_u D_2 \]

Higgs doublet couplings generates (sufficient) mass mixings, as well as coupling to \( A/h/H \)
Example: mixed singlet-doublet model

Lessons

• Coupling of DM to Higgs doublets constrained by direct detection
• Coupling of A to quarks constrained by collider searches
• Light pseudoscalar $m_A \sim 100$ GeV preferred

Near pseudoscalar resonance