Gamma rays from the GC: DM Interpretations and Collider Signals

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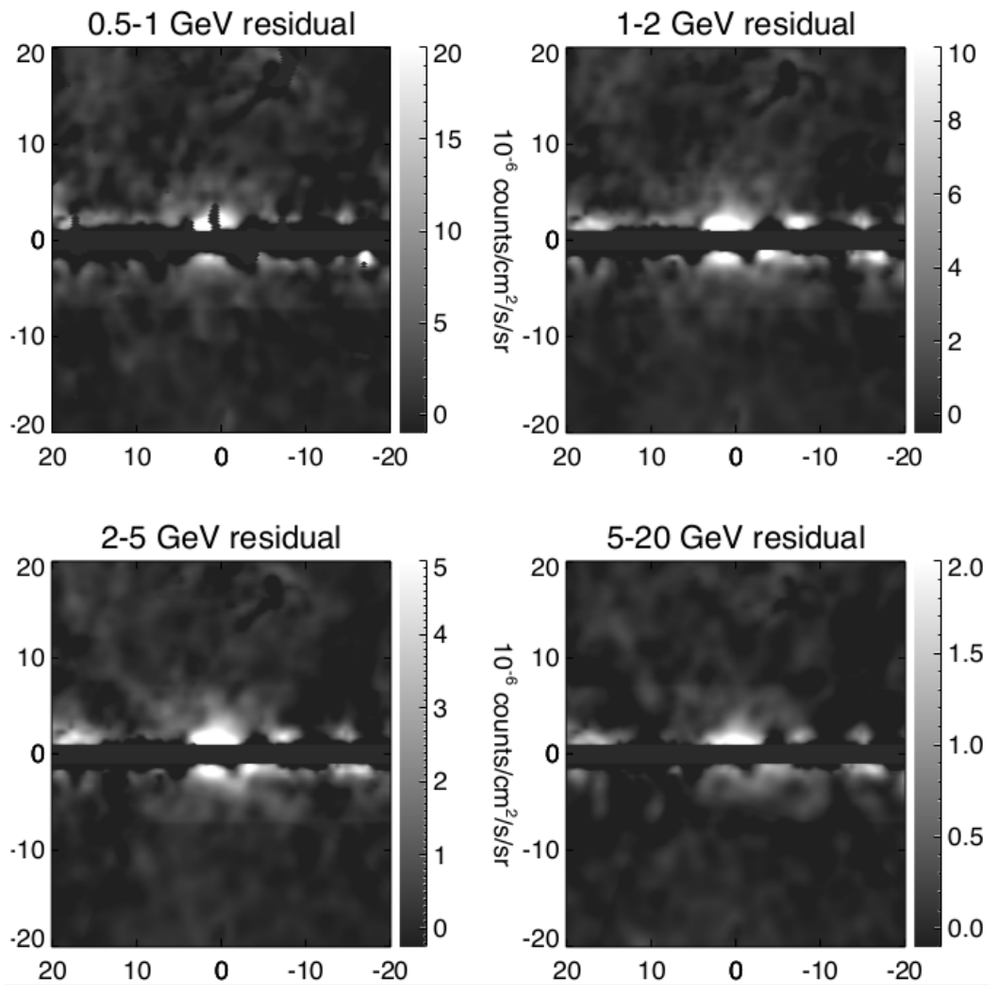
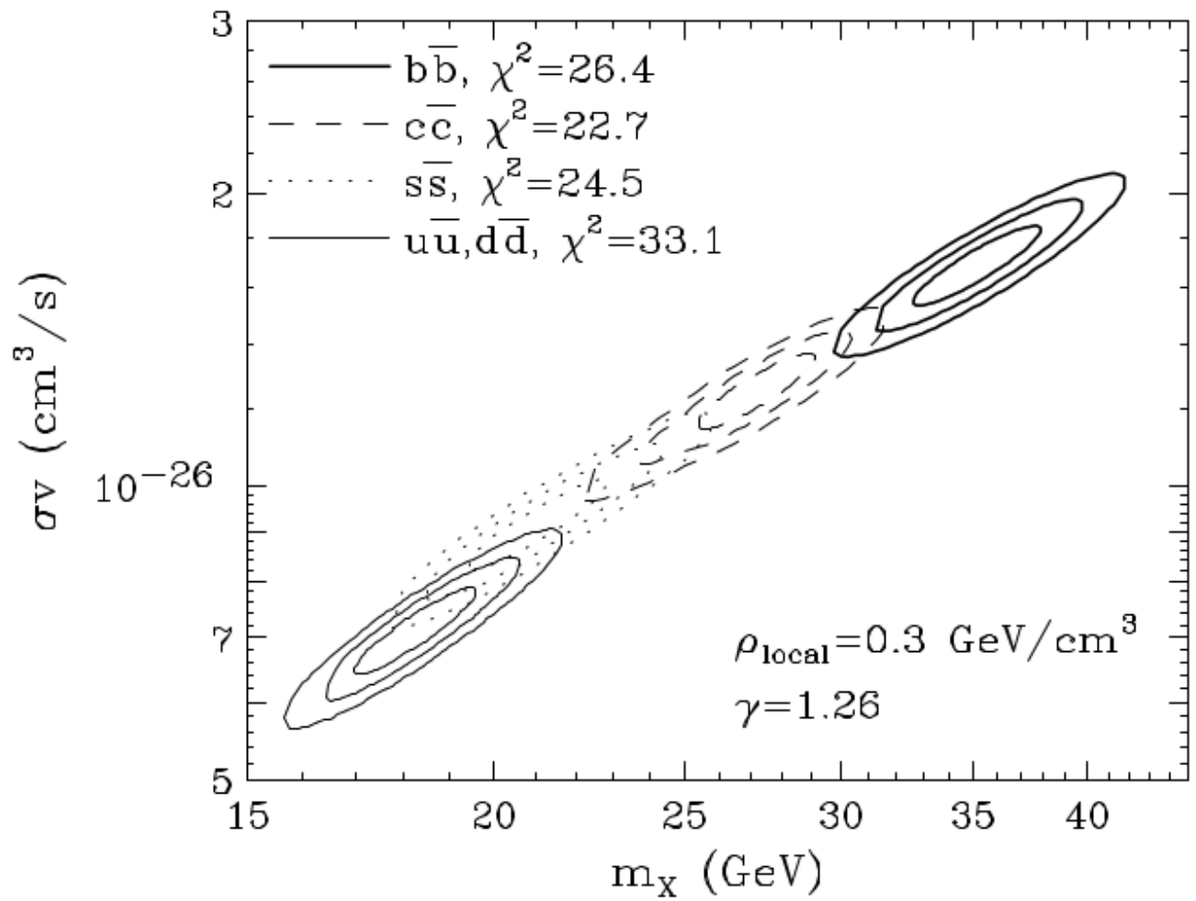
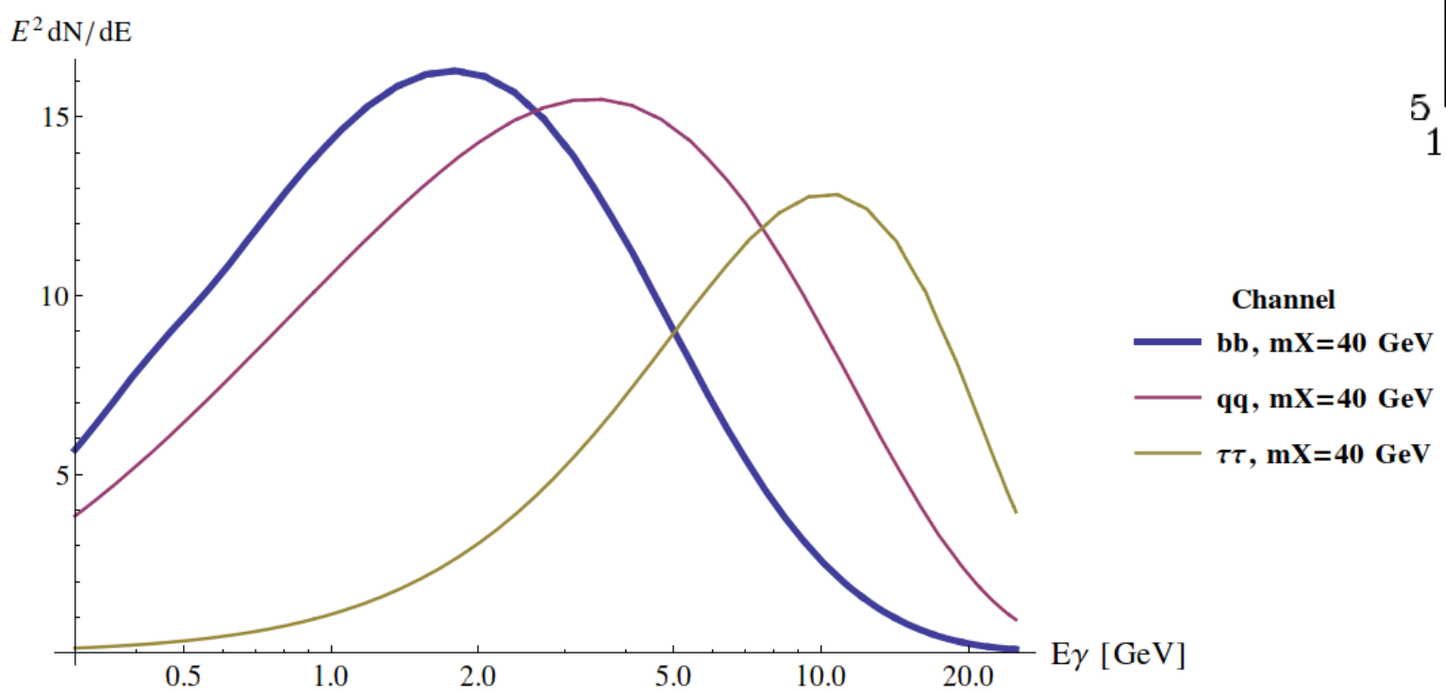
A dark matter gamma-ray signal?



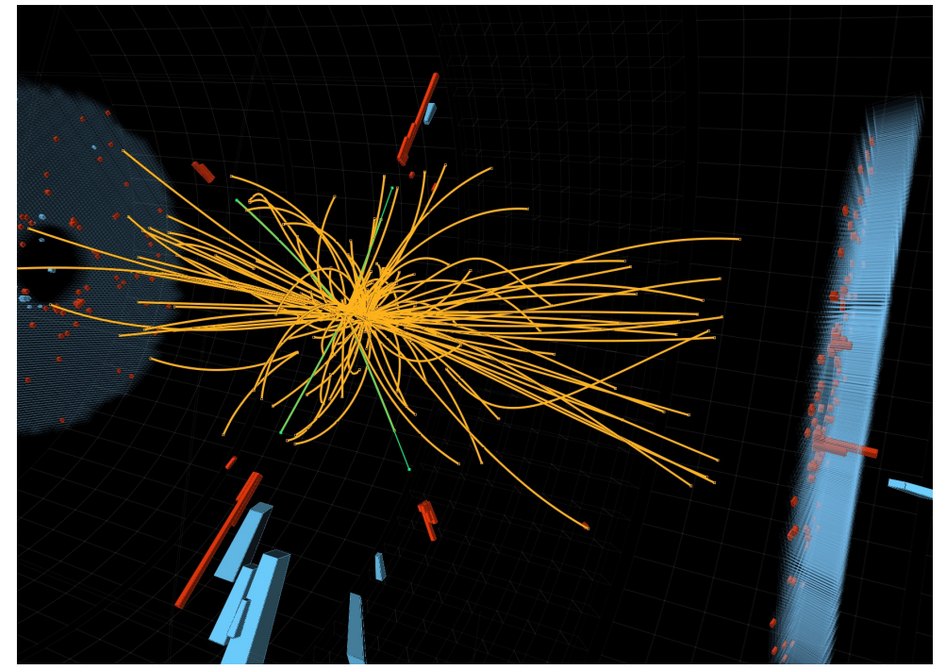




Daylan et al.

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.

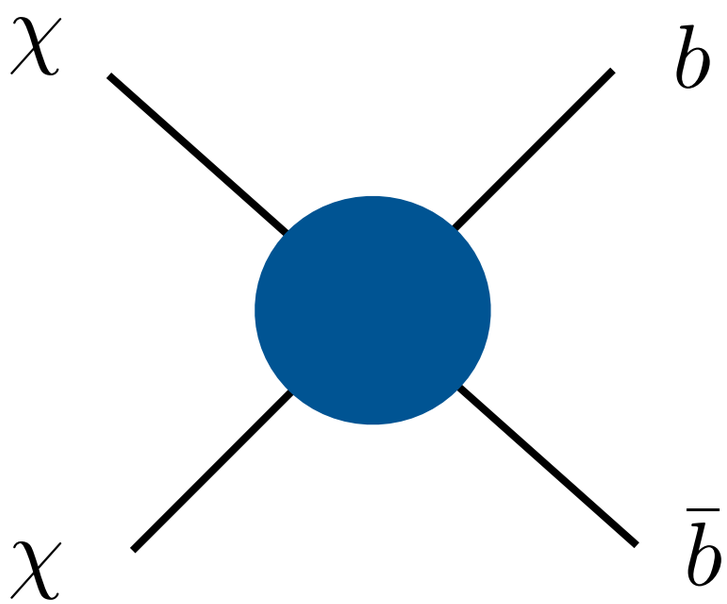


The next LHC run

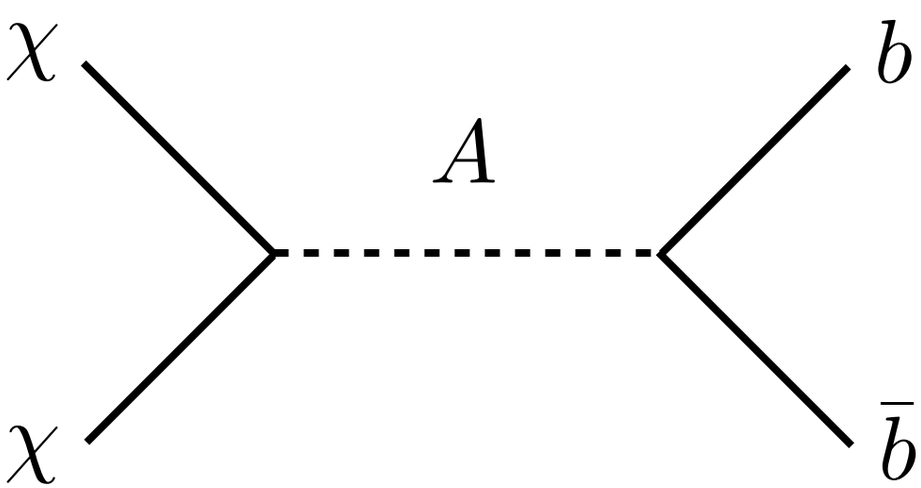
- Starting early 2015
- <u>Center of mass energy</u>: from 8 TeV to 13-14 TeV
- <u>Luminosity/statistics</u>: from 20/fb to 100-300/fb

$b\bar{b}$ mediators

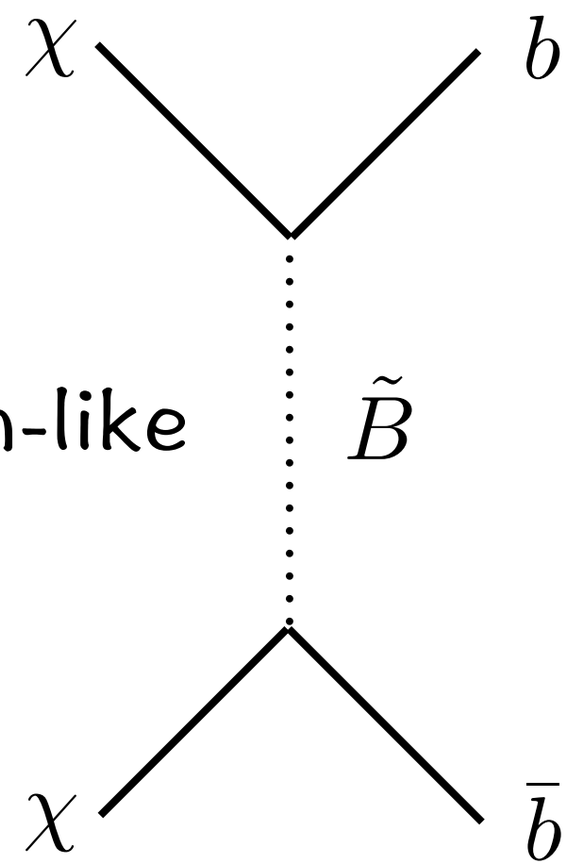
assume fermion DM



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

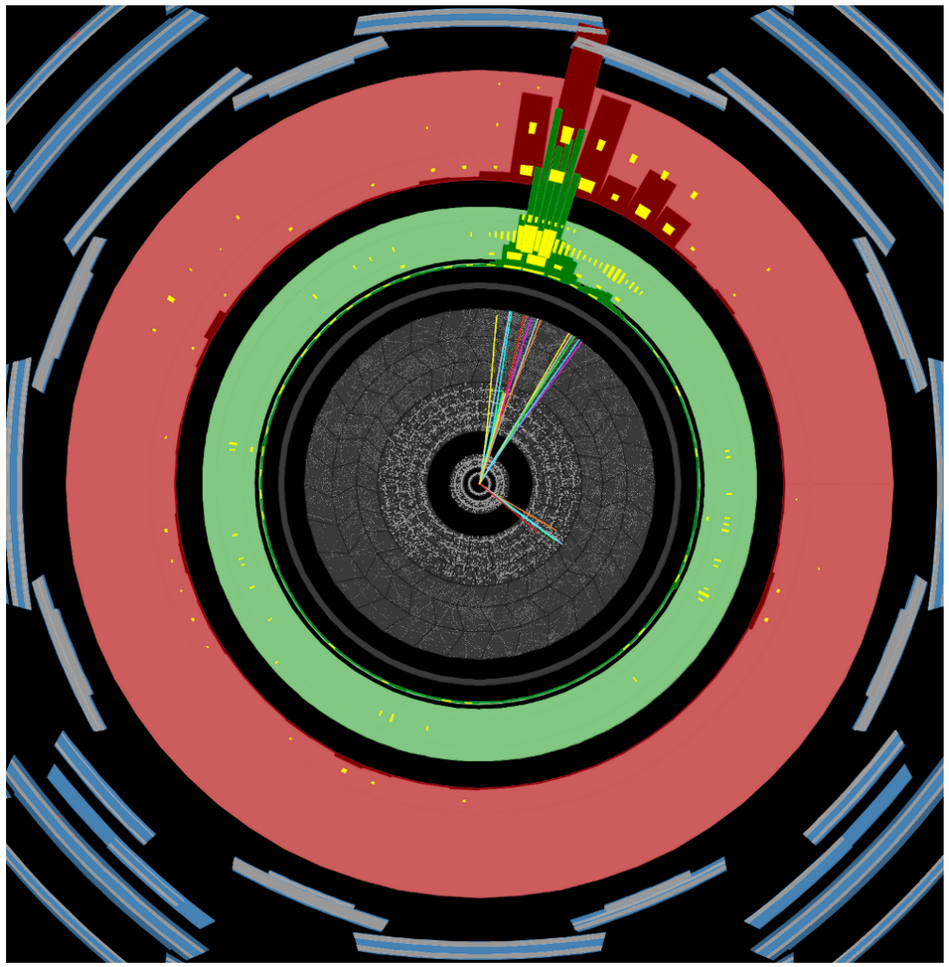


pseudoscalar



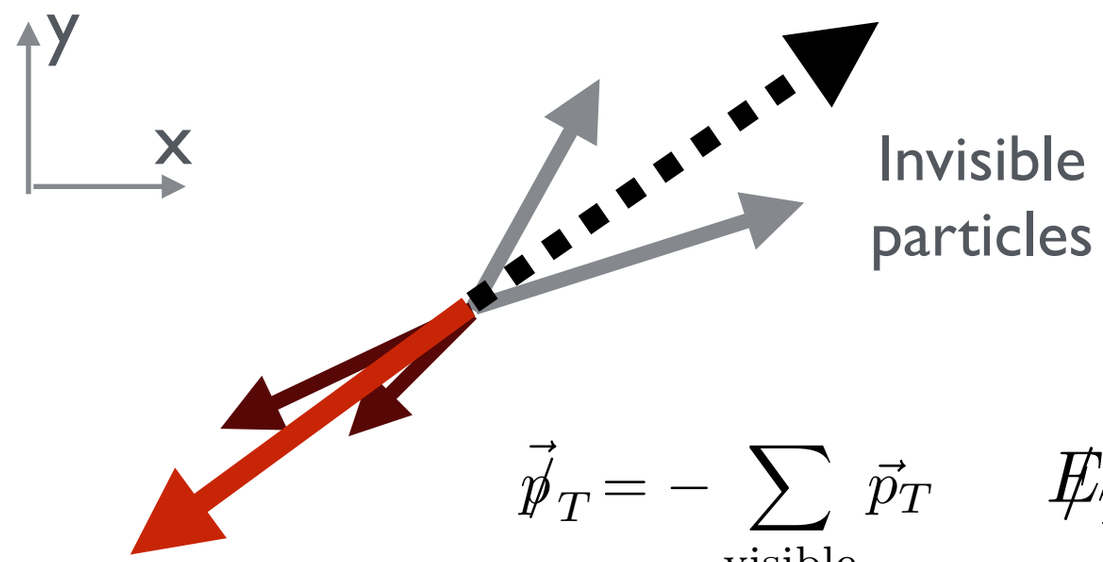
sbottom-like

LHC searches



ATLAS monojet event

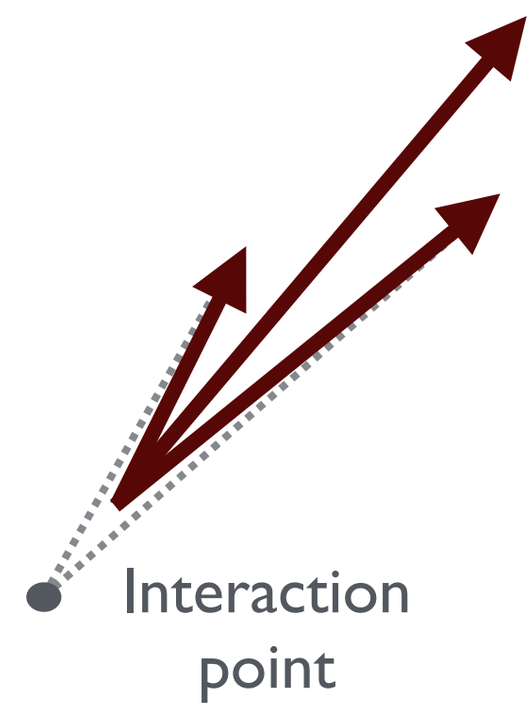
Missing transverse energy (MET)



$$\vec{\not{p}}_T = -\sum_{\text{visible}} \vec{p}_T \qquad \not{E}_T = \left|\vec{\not{p}}_T\right|$$

b-quark jets

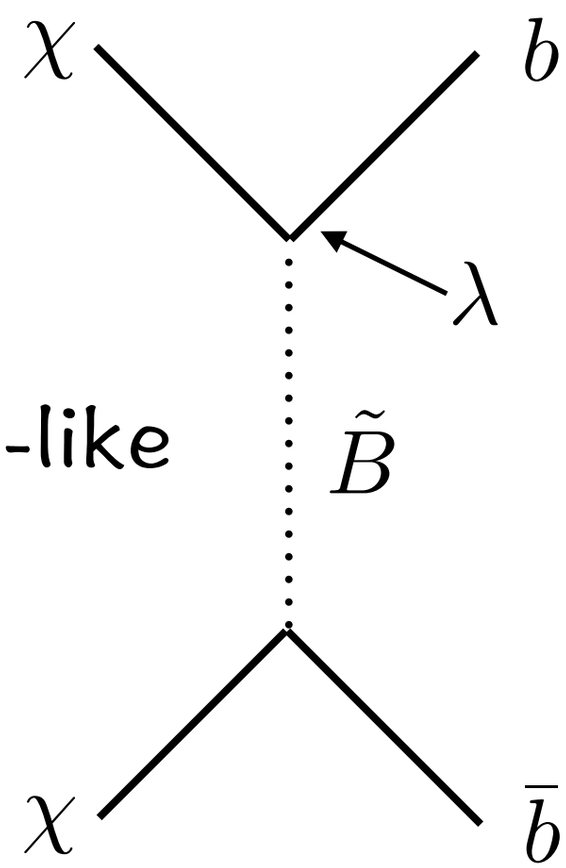
b-tagging
efficiency ~60%



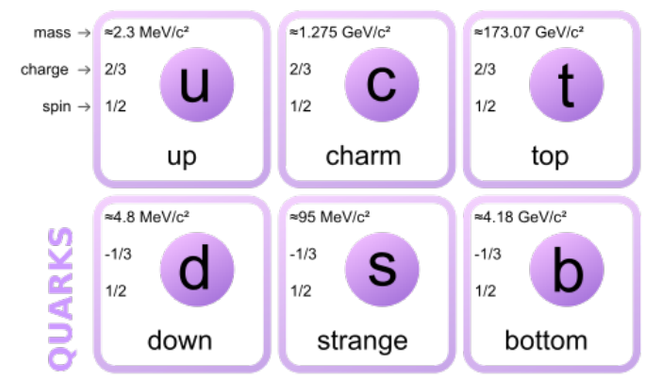
b-flavored dark matter

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

similar to sbottom: scalar, same charges as b



sbottom-like



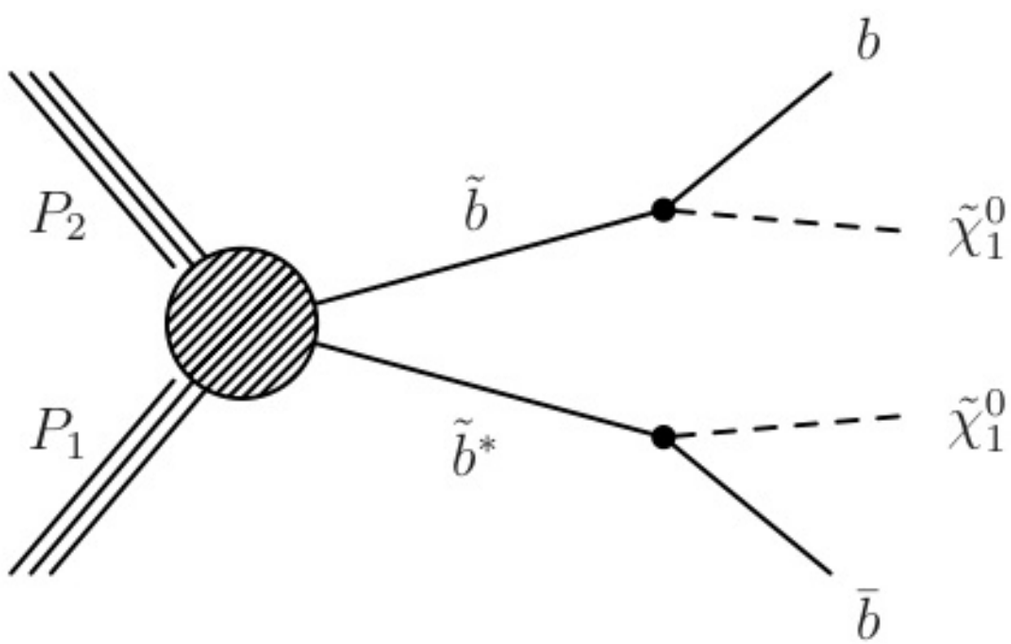
Preferred coupling to b-quarks could arise in MFV dark matter, where DM lives in a (quark) flavor multiplet

Batell, TL, Wang 2014

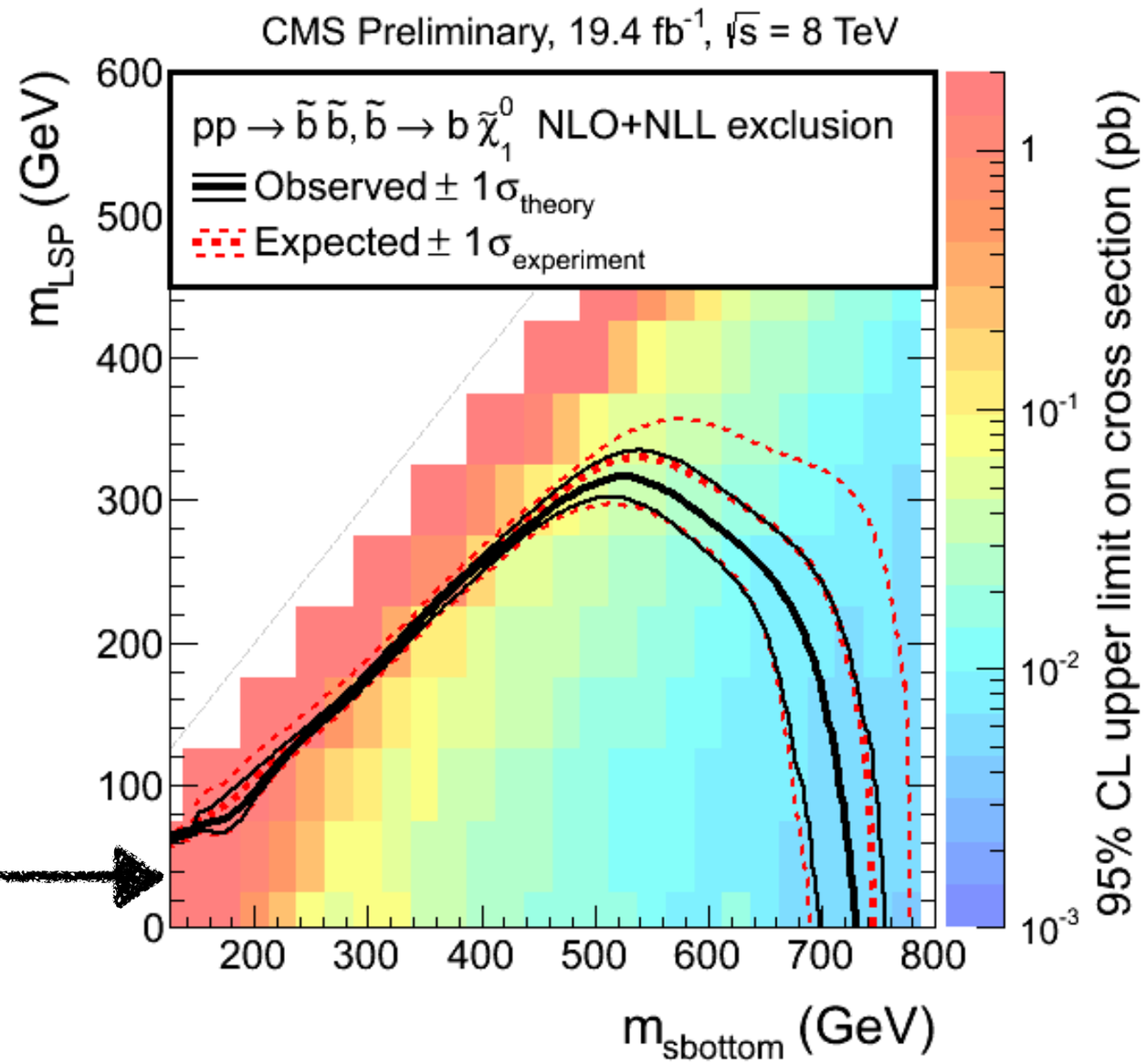
Agrawal, Batell, Hooper, TL 2014

Mediator pair production

2b+MET

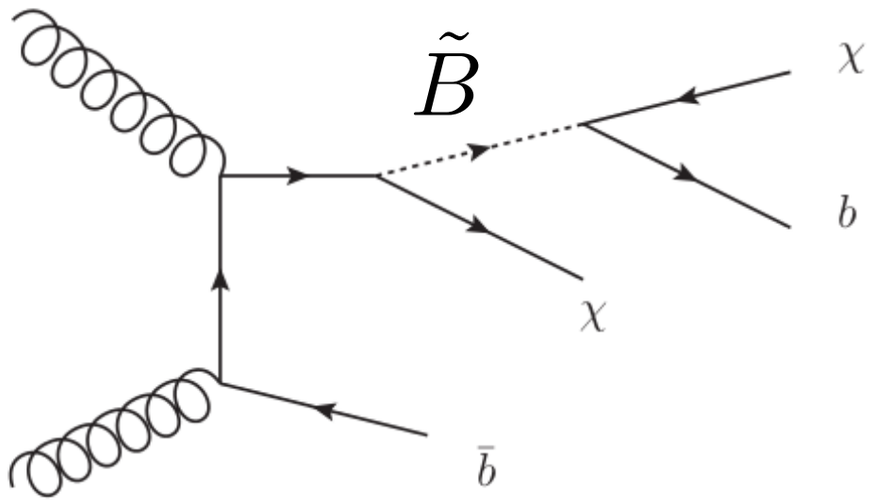


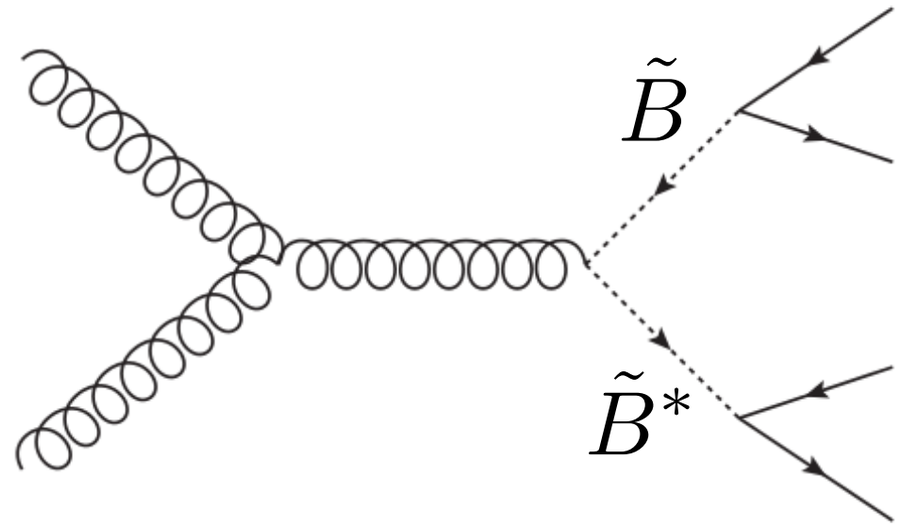
Mediator mass already very constrained



CMS MSSM sbottom search

Because of large coupling, single production of mediator can also contribute:

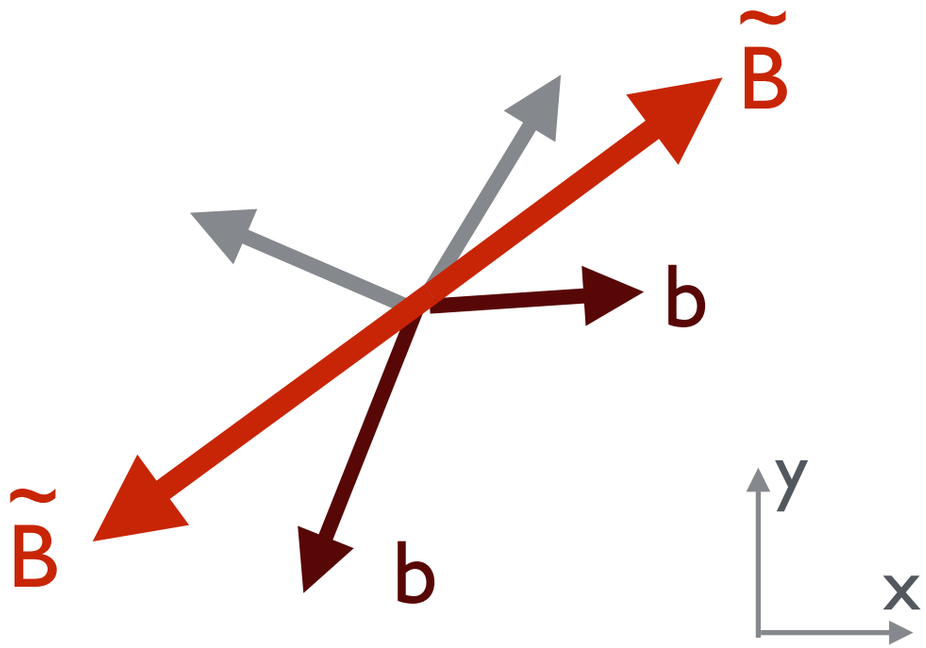


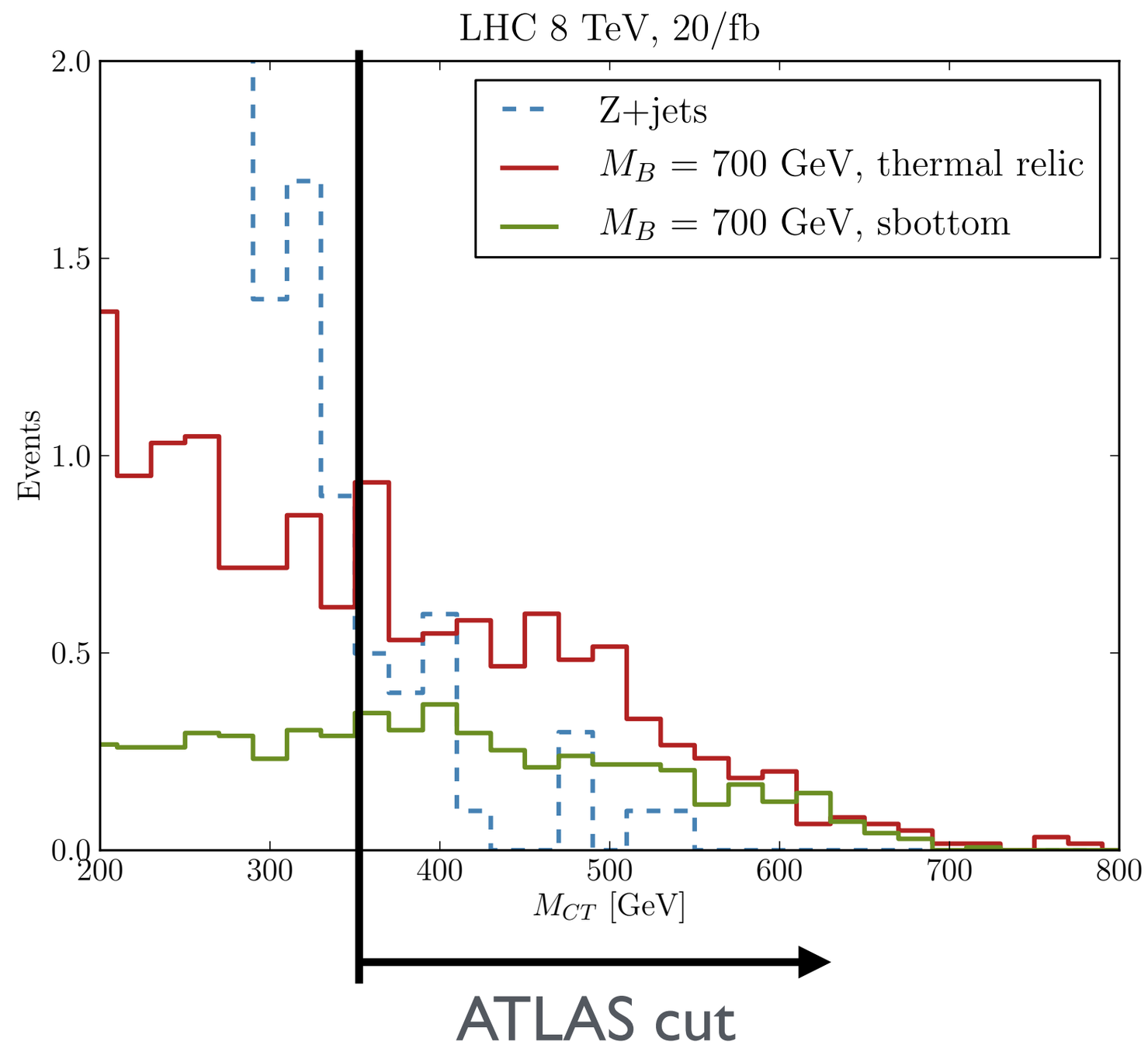


Simulations of data with MadGraph+PYTHIA+Delphes, compared to ATLAS analysis

ATLAS, 1308.2631:

- pT(b-jets) > 150, 30 GeV
- MET > 150 GeV
- Isolated lepton veto
- mbb > 200 GeV
- MCT > 350 GeV



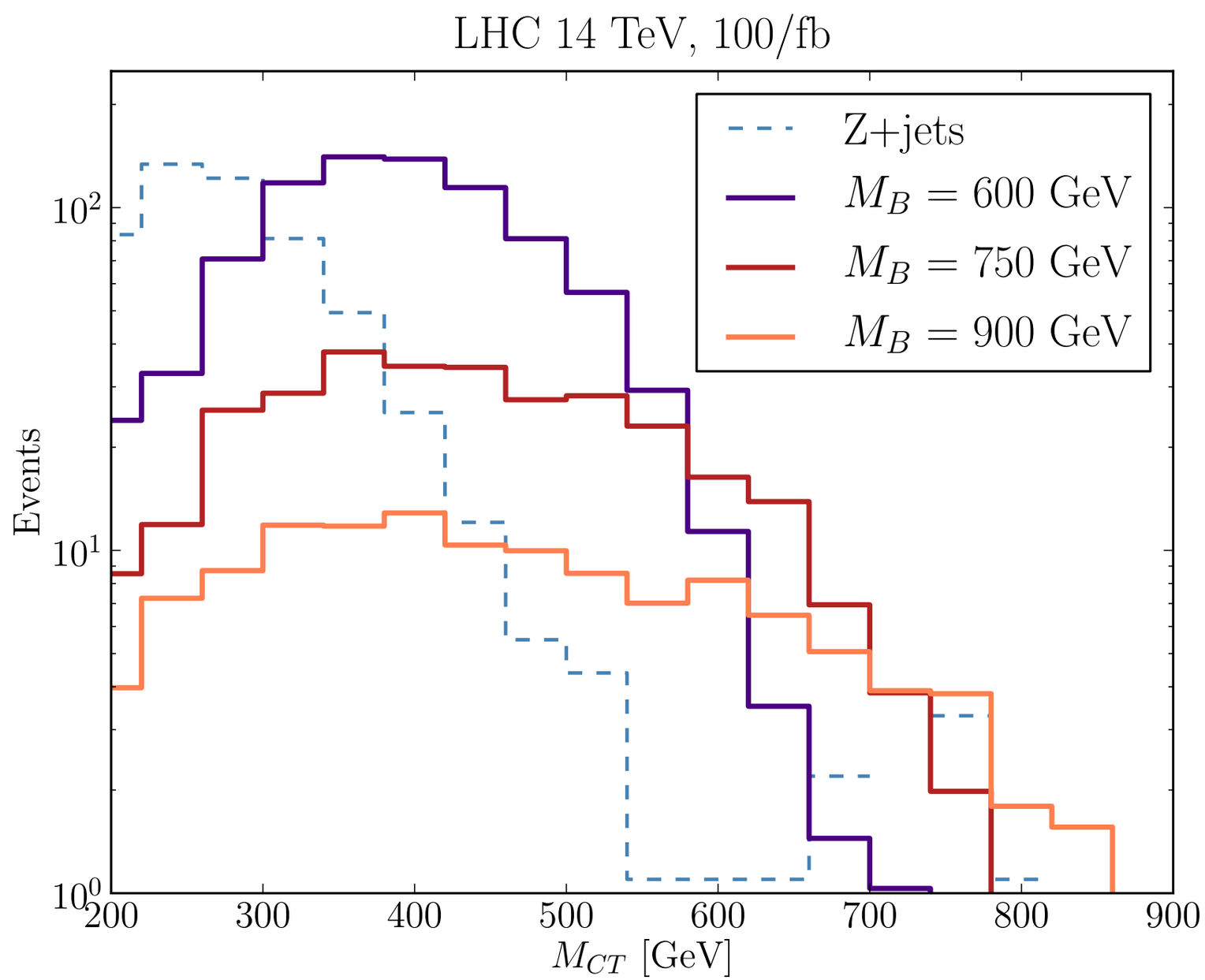


Contransverse Mass

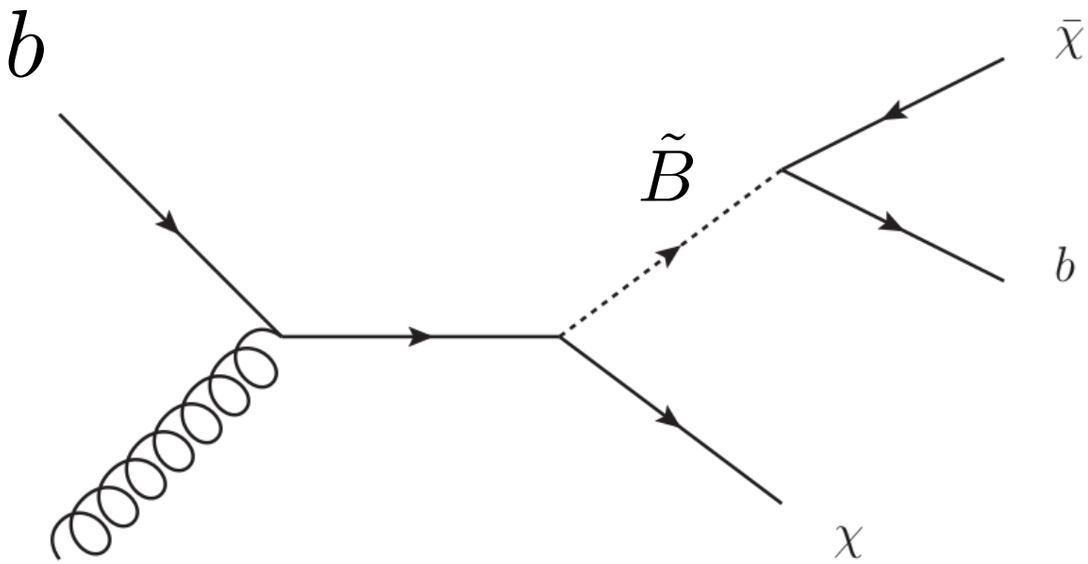
$$M_{CT} < \frac{M_{\tilde{B}}^2 - M_\chi^2}{M_{\tilde{B}}}$$

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

Tovey 2009


LHC 14 TeV, 100/fb
Z+jets
$M_B = 600$ GeV
$M_B = 750$ GeV
$M_B = 900$ GeV
Events
10^2
10^1
10^0
200
300
400
500
600
700
800
900
M_{CT} [GeV]

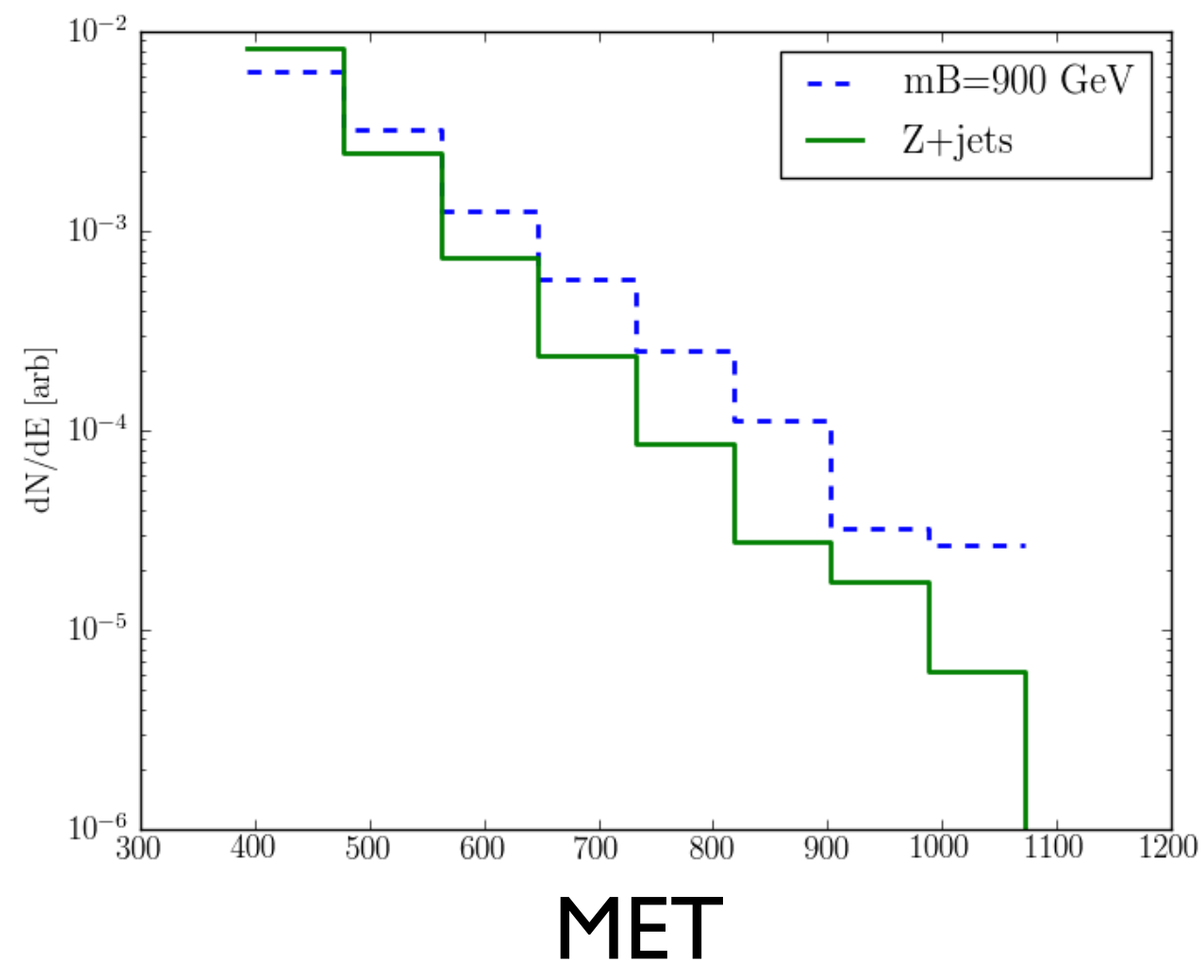
Single production of mediator:



Reach is weaker:
suppressed by b pdf.

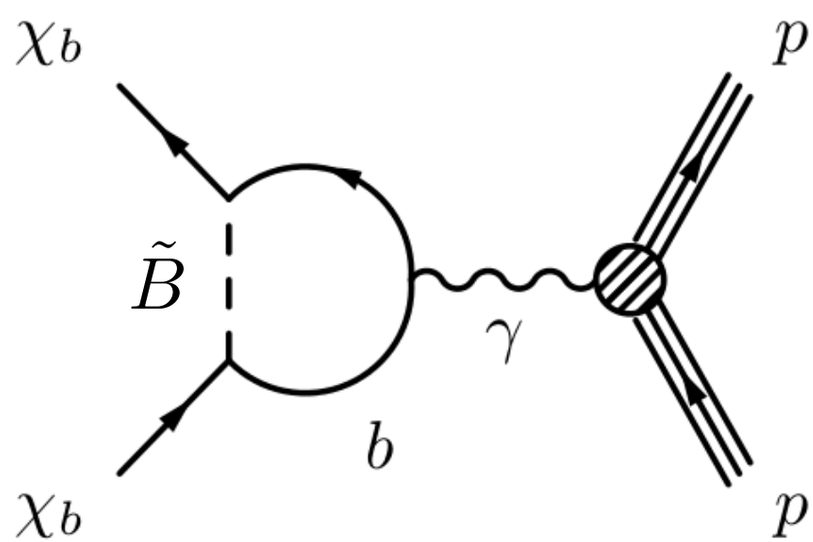
"mono-b" final state with
plenty of MET + b-jet.

Simpler analysis, but
also less info.



TL, Kolb & Wang 2013

direct detection in bFDM

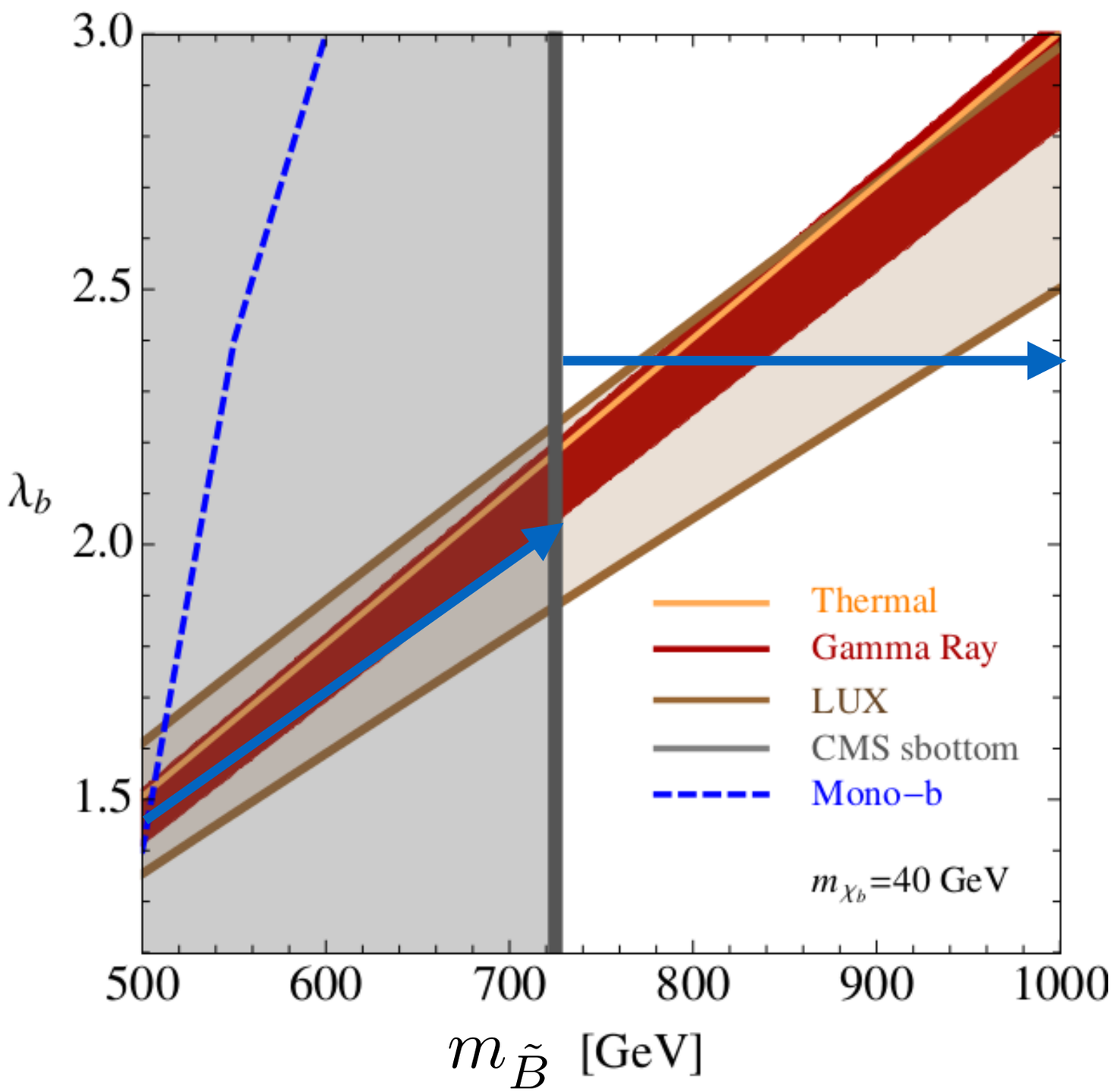


<u>Charge-charge interaction:</u> $$\mathcal{O} \sim \frac{1}{m_\phi^2}\bar{\chi}\gamma^\mu\chi\partial^\nu F_{\mu\nu}$$

$$\mathcal{M} = b_q \bar{u}_\chi \gamma^\mu u_\chi \langle N|Q\bar{q}\gamma_\mu q|N\rangle \qquad b_q = -\frac{3Q_b e\lambda_b^2}{64\pi^2 m_\phi^2}\left[1+\frac{2}{3}\ln\left(\frac{m_b^2}{m_\phi^2}\right)\right]$$

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

Parameter space

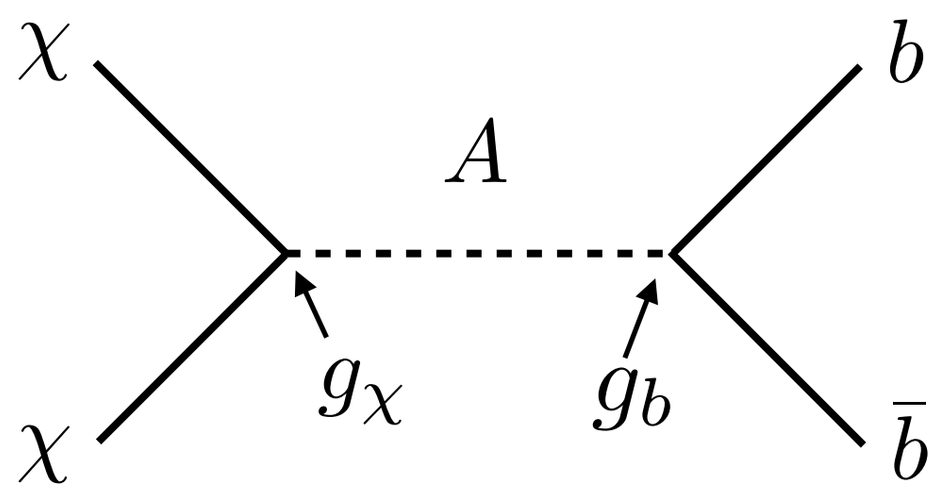


large mediator mass,
large coupling needed

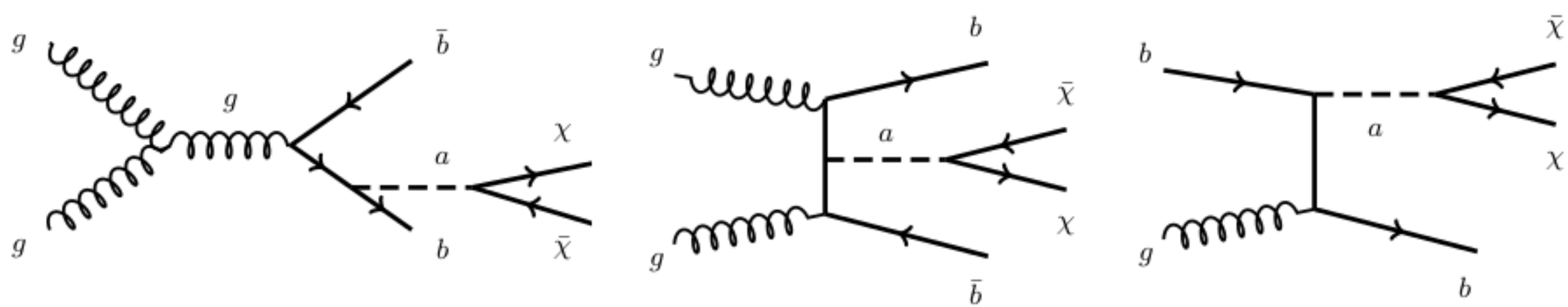
mono-b, sbottom
searches with
LHC14,100/fb

definitively tested
with increased
LUX exposure

Pseudoscalar mediator



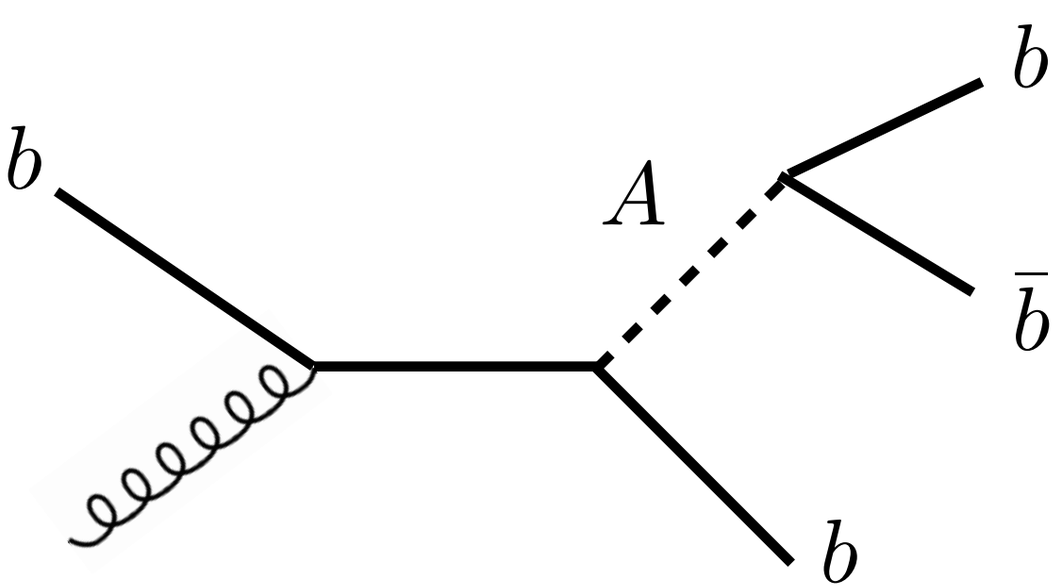
Collider channels with b-jets+MET:

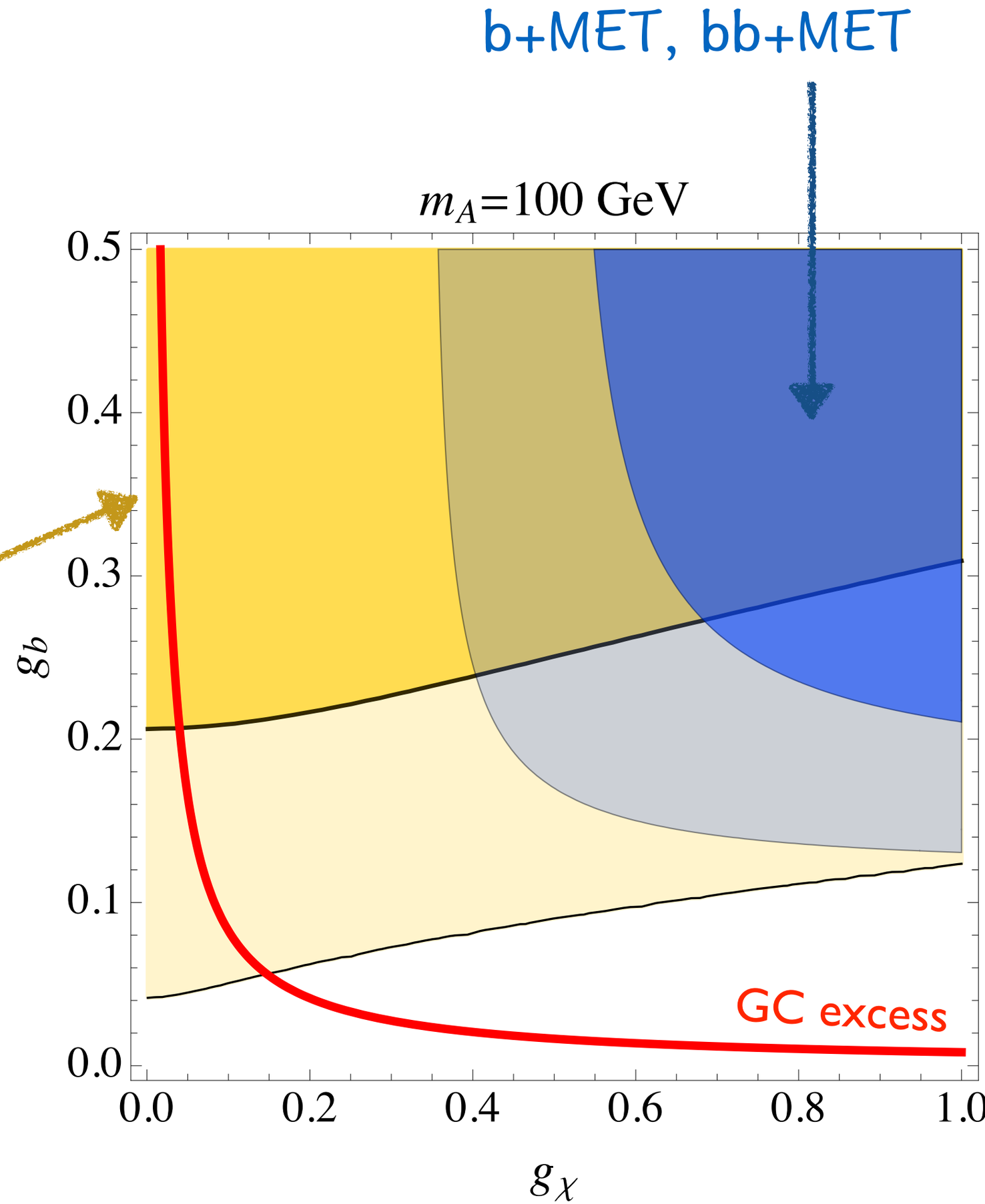


Model-independent collider bounds on pseudoscalar couplings

Lighter shaded regions: LHC14, 300/fb

bbb search (7 TeV limits)





UV-complete models?

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

<u>Two-Higgs Doublet Model</u>

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

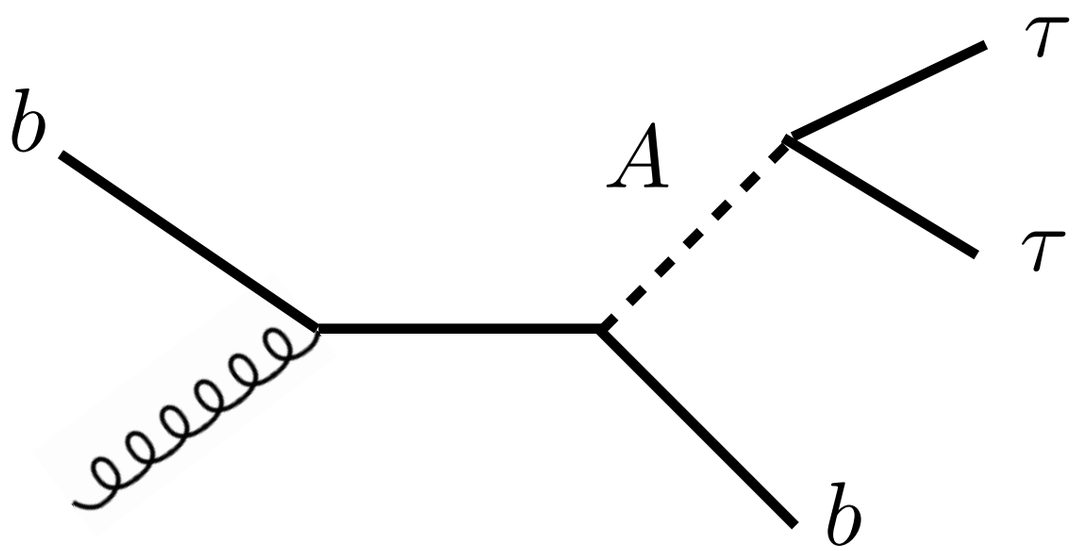
$$H_u = \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\beta \; H^+ \\ v_u + \sin\beta \; h - \cos\beta \; H + i \cos\beta \; A \end{pmatrix}$$

$$\tan\beta = \frac{v_u}{v_d}$$

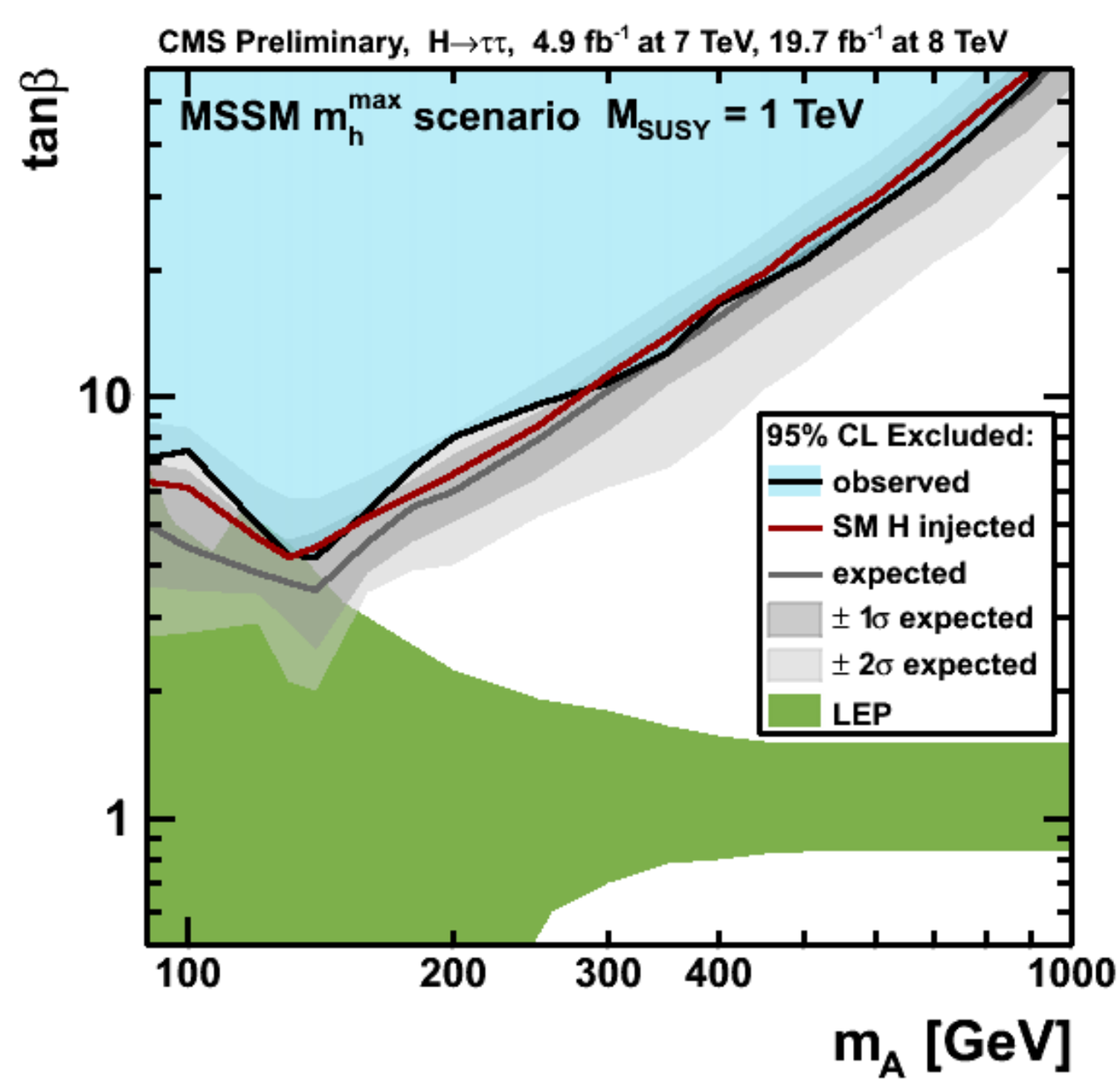
Many models introduce new pseudoscalar, where coupling to SM quarks arises from mixing with 2HDM.

(for example: “annihilon”, NMSSM⋯)

More pseudoscalar searches

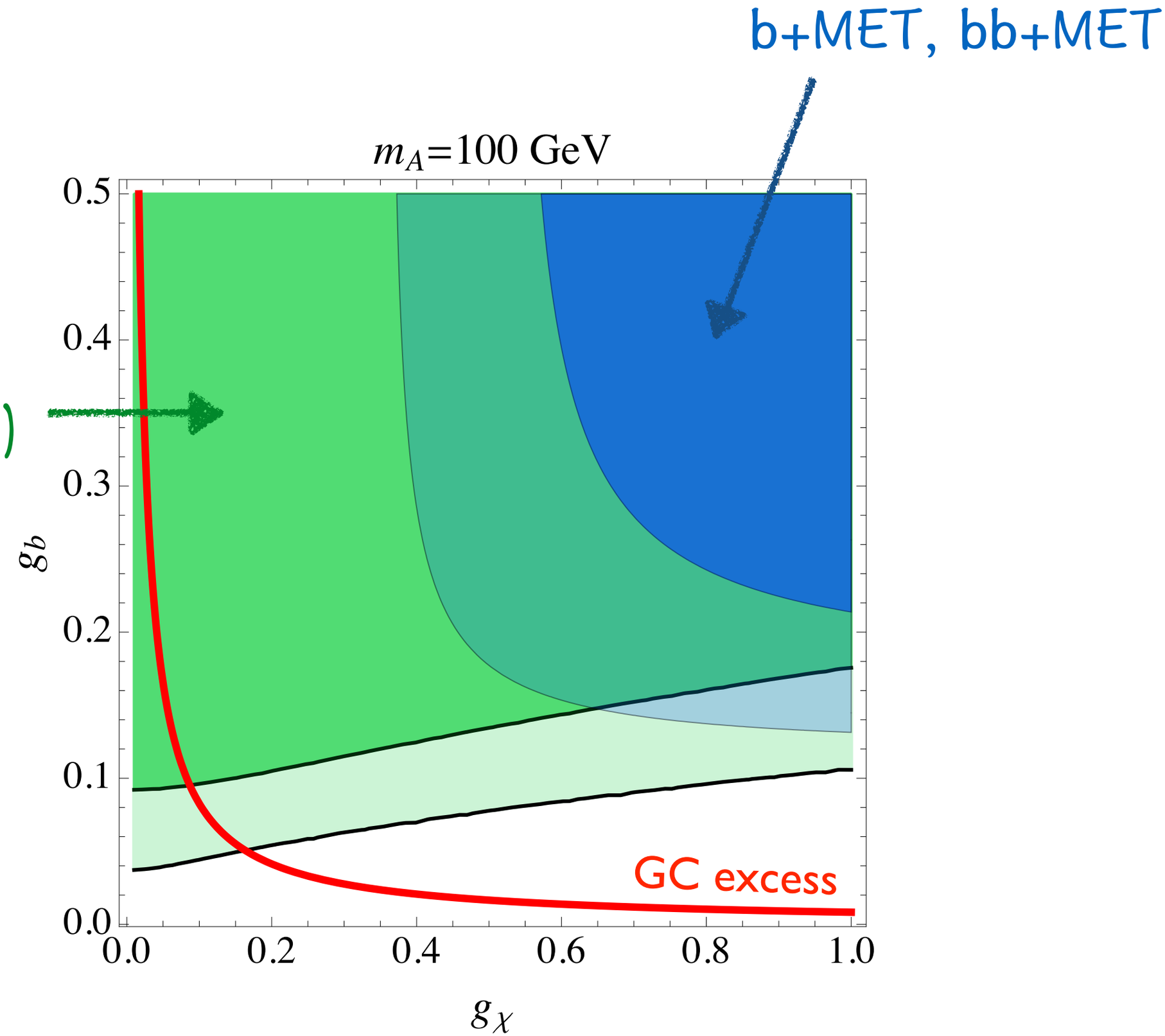


$$g_{b,\tau} = y_{b,\tau} \tan\beta$$



CMS limits for MSSM A (assuming no coupling to DM)

Lighter shaded regions: LHC14, 300/fb



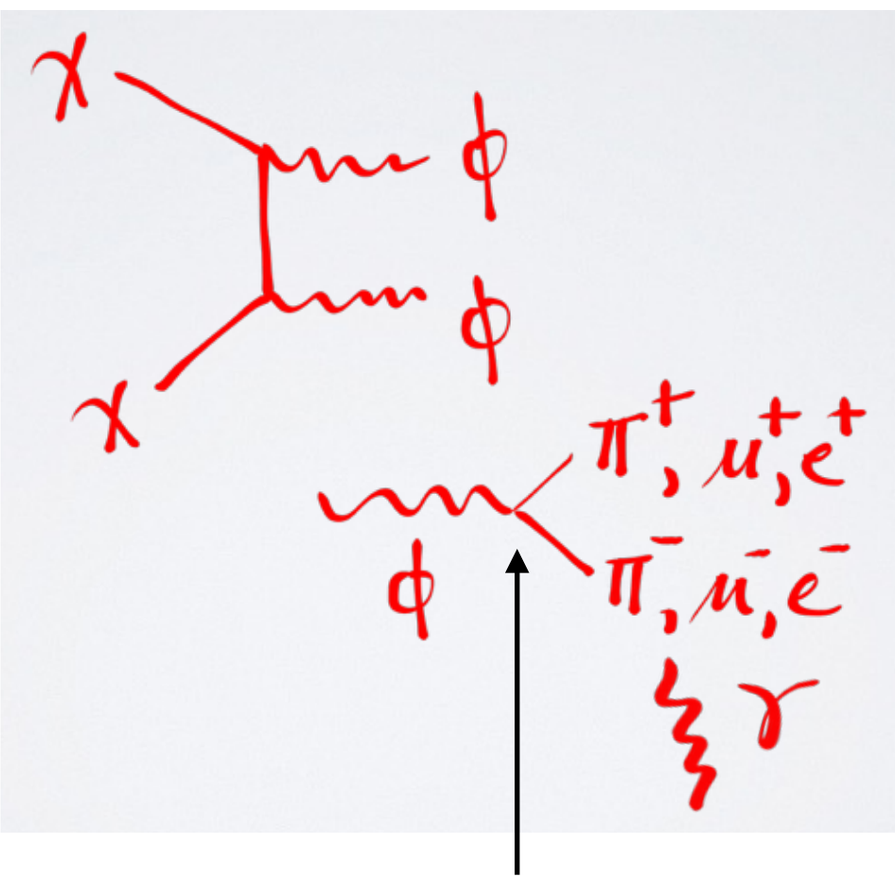
Channels

	b-flavored	pseudoscalar	current
• bb+MET	$\tilde{B}\tilde{B} \to bb+\chi\chi$	$bbA \to bb+\chi\chi$	[8 TeV, 20/fb]
• b+MET	$\chi\tilde{B} \to b+\chi\chi$	$bA \to b+\chi\chi$	[8 TeV, 20/fb]*
• bbb	n/a	$bA \to bbb$	7 TeV, 4/fb
• $b+\tau\tau$	n/a	$bA \to b+\tau\tau$	8 TeV, 20/fb

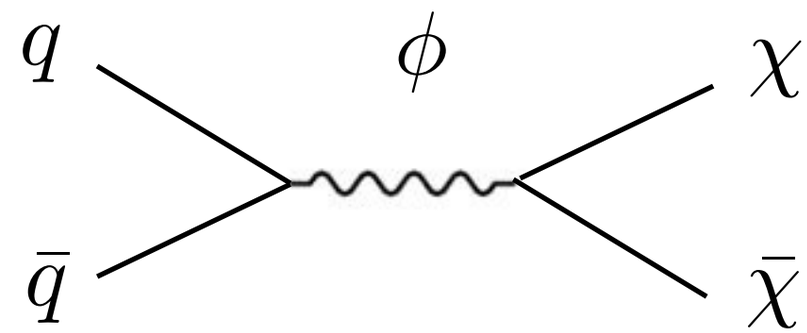
[ ] = Re-interpretation of constraints

* = LHC data analysis not yet public

Light mediators?



Small coupling

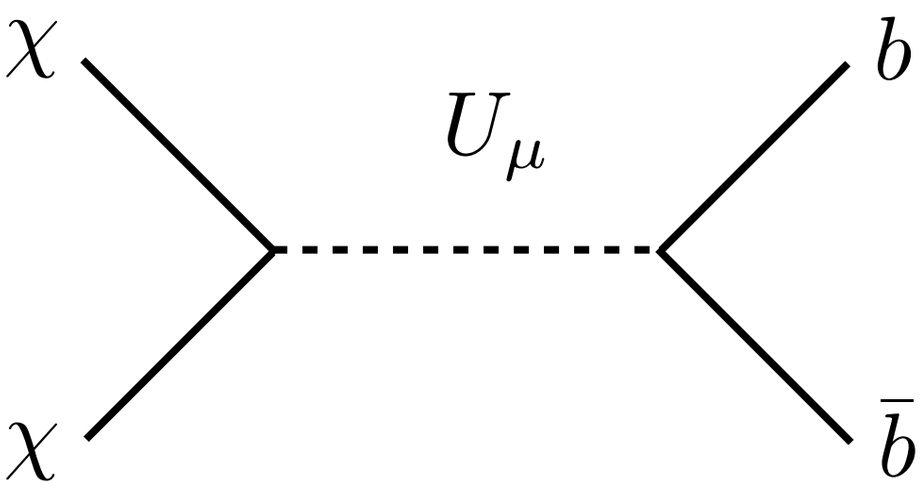


- Extremely weak LHC signals unless additional ingredients are added
- Aside: low-energy collider searches for light mediator could be effective, however.

Conclusions

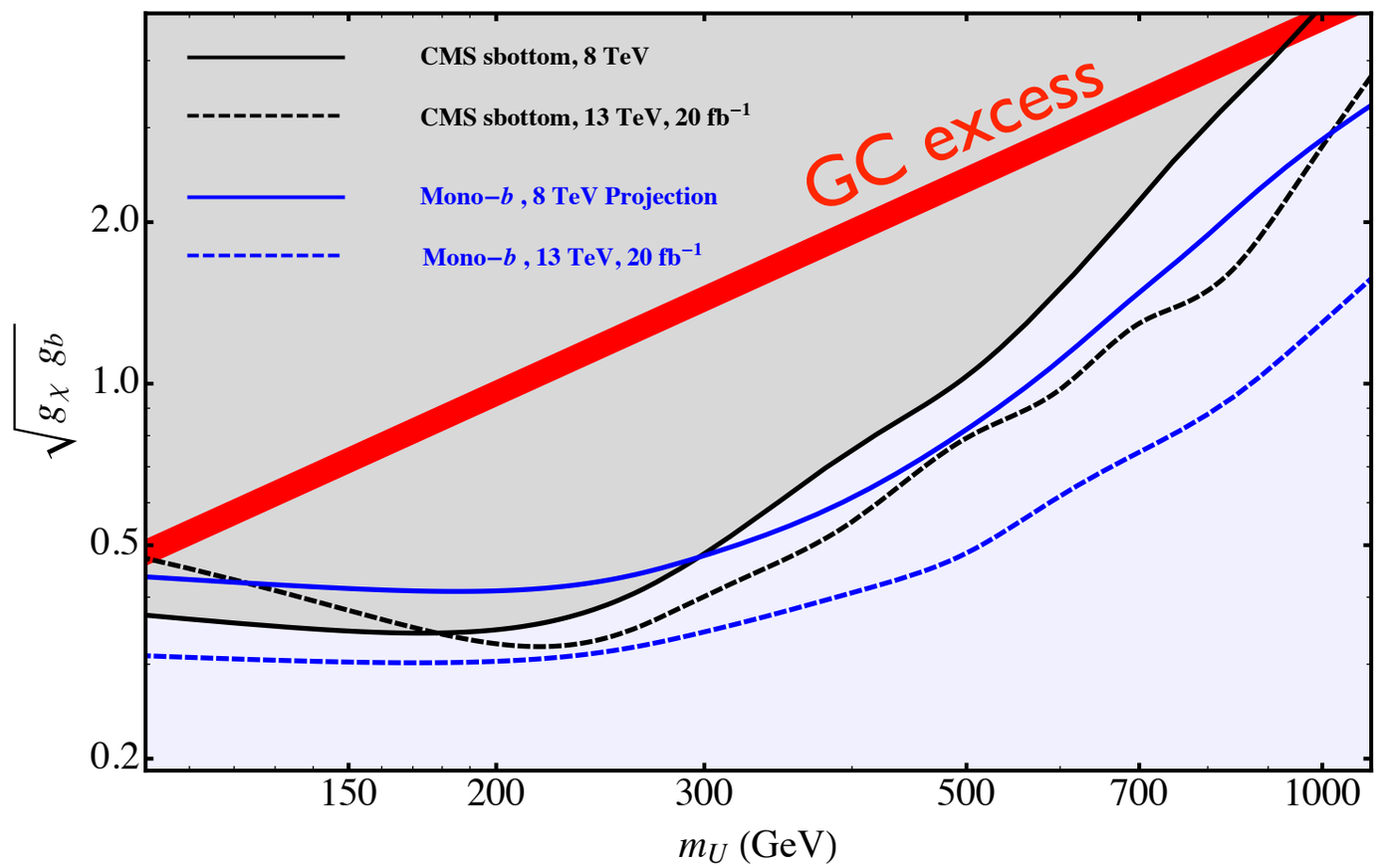
- If the GC excess is interpreted as annihilation to b-quarks, then a new mediator particle is required
- The mediator and/or DM can be produced at the LHC, giving rise to signals with b-jets and/or missing energy
- Colored mediator scenario can be excluded. Parameter space of pseudoscalar mediators partially tested.

Another example:



axial-vector mediator

$g_b = g_\chi$, $(\bar{\chi}\,\gamma^\mu\gamma^5\,\chi)(\,\bar{b}\,\gamma^\mu\gamma^5\,\mathrm{b})$



From Izaguirre et al. 2014

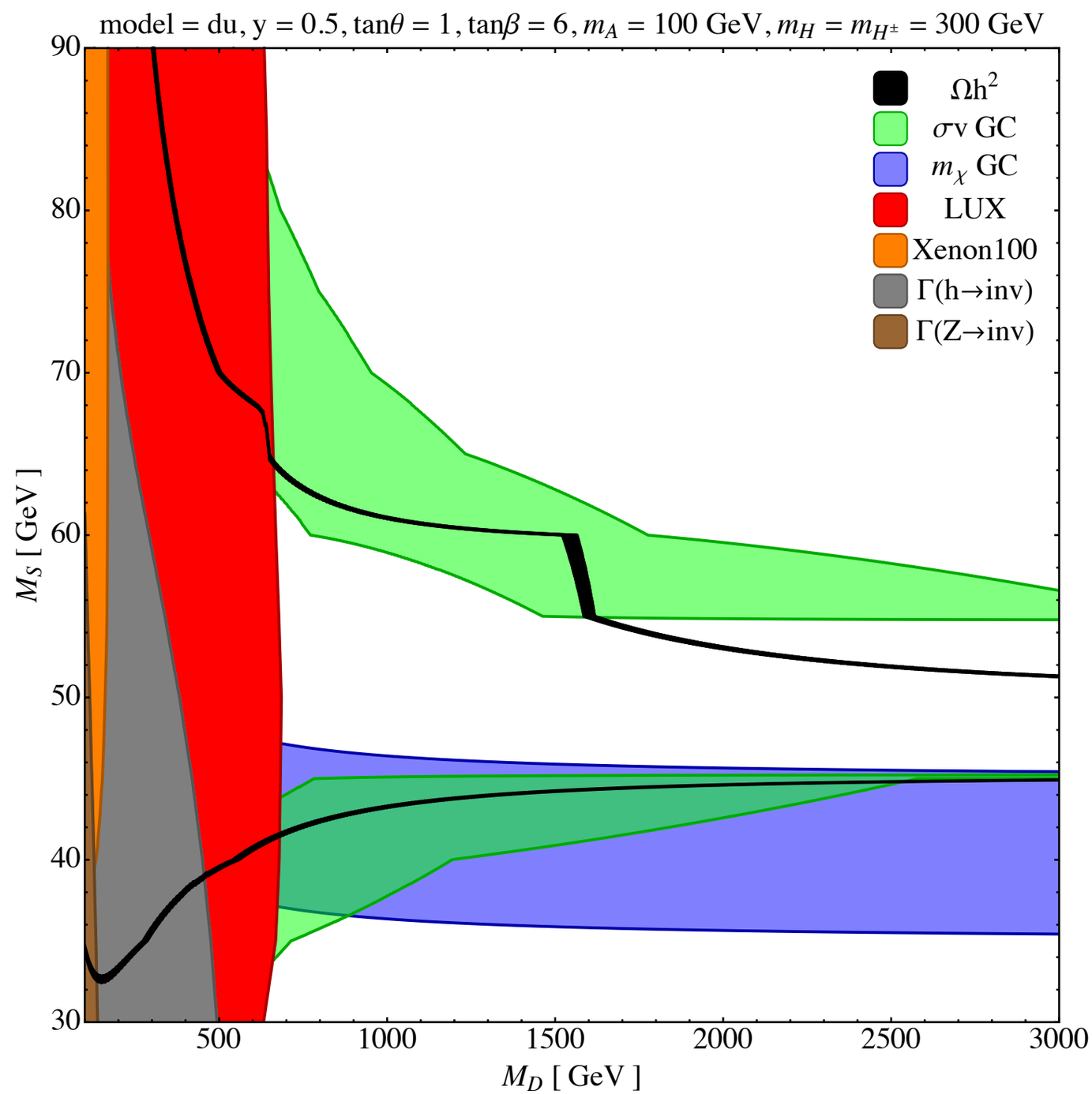
Challenging to find UV-complete model?

Berlin, Gori, TL, Wang, in prep.

Suppose we <u>only</u> introduce pseudoscalar of 2HDM.

Example: mixed singlet-doublet model

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



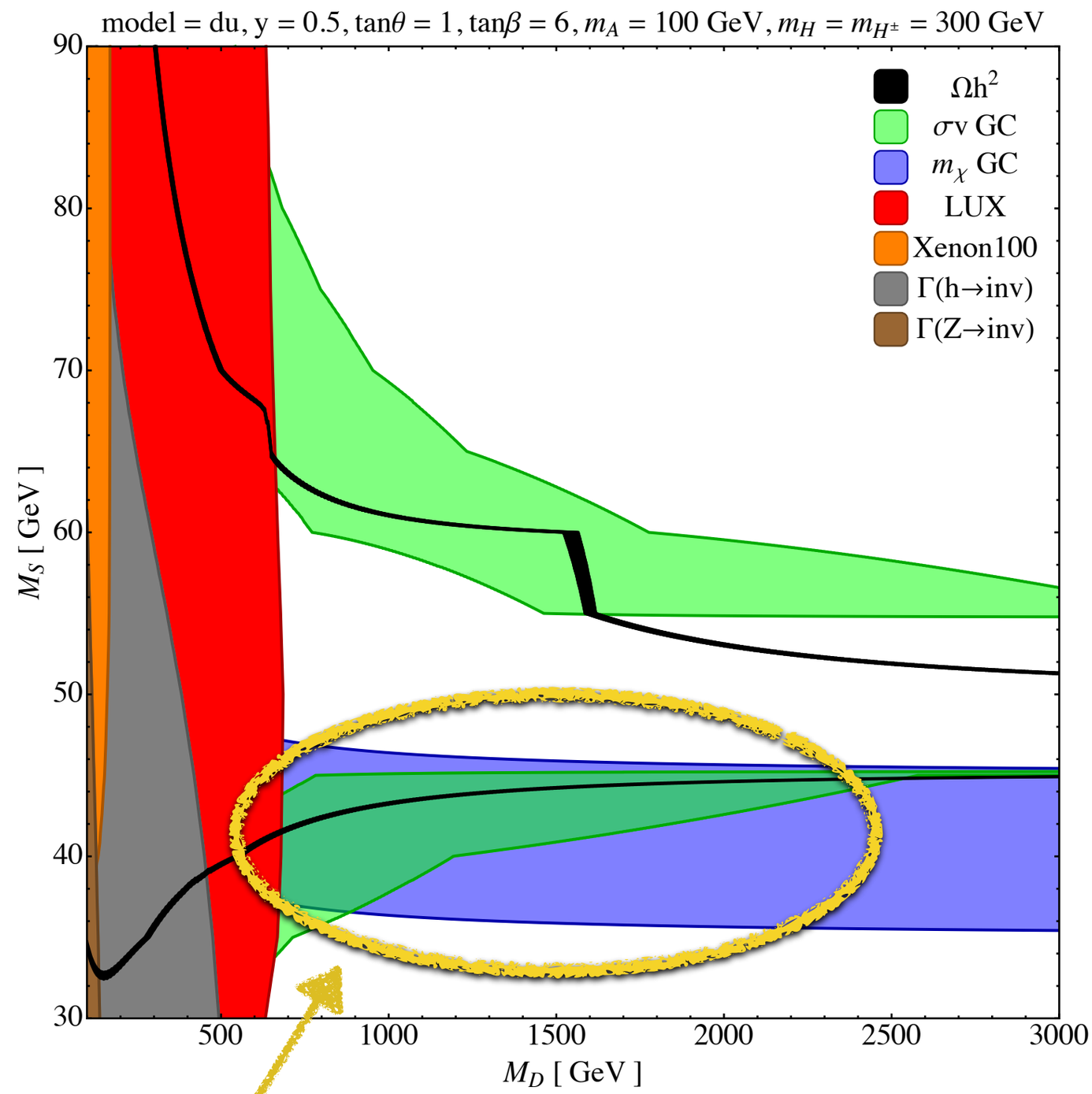
Higgs doublet couplings generates (sufficient) mass mixings, as well as coupling to A/h/H

Berlin, Gori, TL, Wang, in prep.

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 mA~100 GeV preferred



Near pseudoscalar resonance