Uncovering Light Scalars with Exotic Higgs Decays to $bb\mu\mu$

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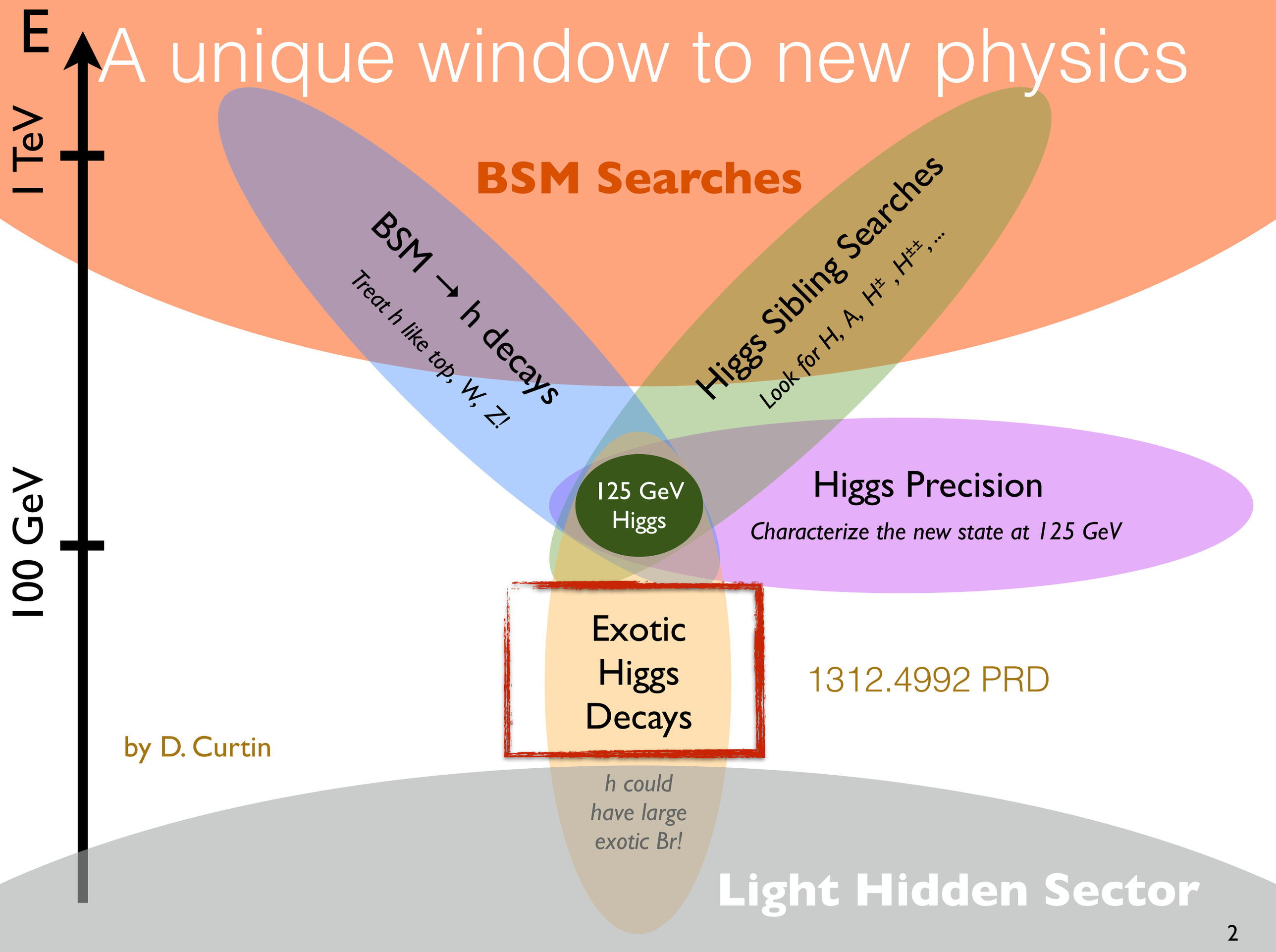
D. Curtin, R. Essig, S. Gori, P. Jaiswal, A. Katz, T. Liu, Z. Liu, D. McKeen, J. Shelton, M. Strassler, Z. Surujon, B. Tweedie, YMZ,
PRD 90, 075004 (2014), arXiv:1312.4992

D. Curtin, R. Essig, YMZ,
arXiv:1412.4779

Phenomenology Symposium, 05/04/2015

A unique window to new physics



1312.4992 PRD

by D. Curtin

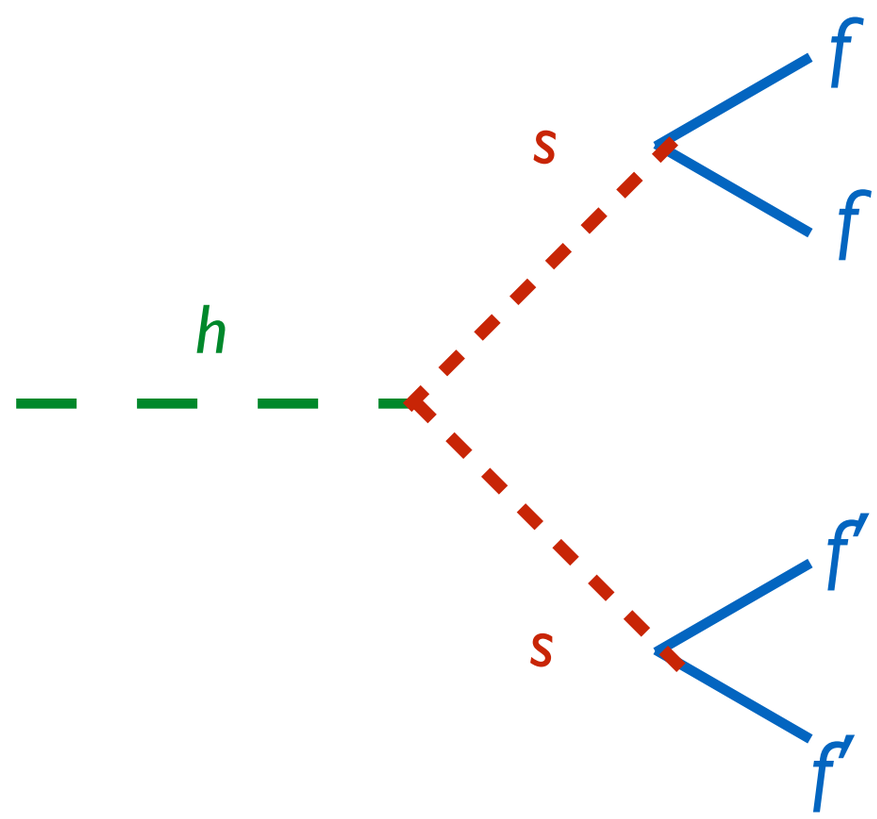
Light scalars in exotic Higgs decays

- SM+S

$$V(H,S) = -\mu^2|H|^2 + \lambda|H|^4 - \frac{1}{2}\mu_S^2 S^2 + \frac{1}{4}\lambda_S S^4 + \frac{1}{2}\kappa S^2|H|^2$$

- Gives two neutral CP-even scalars
  h = the SM Higgs
  s: a **light** scalar ($m_s < m_h/2$)
- s inherits couplings of H to fermions

An interesting decay topology



$h \rightarrow 2s \rightarrow 4f$

$4f = 4b,\ 2b2\tau,\ 4\tau,\ 2b2\mu,\ 2\tau2\mu\ \ldots$

Why $h \rightarrow 2s \rightarrow 2b2\mu$?

Trade-off

- Small BR compared to $4b$, $2b2\tau$, 4τ (SM+S)

+ Large production: can use ggF & VBF Higgs productions and trigger on muons

Can BR be even larger in more general models?

Two-Higgs-doublet model (2HDM)

		MSSM-like	lepton-specific	flipped
	I	II	III	IV
u	H_1	H_1	H_1	H_1
d	H_1	H_2	H_1	H_2
e	H_1	H_2	H_2	H_1

Viable in the "decoupling limit", where one Higgs is SM-like

see e.g. recent reviews by Craig et al, Branco et al

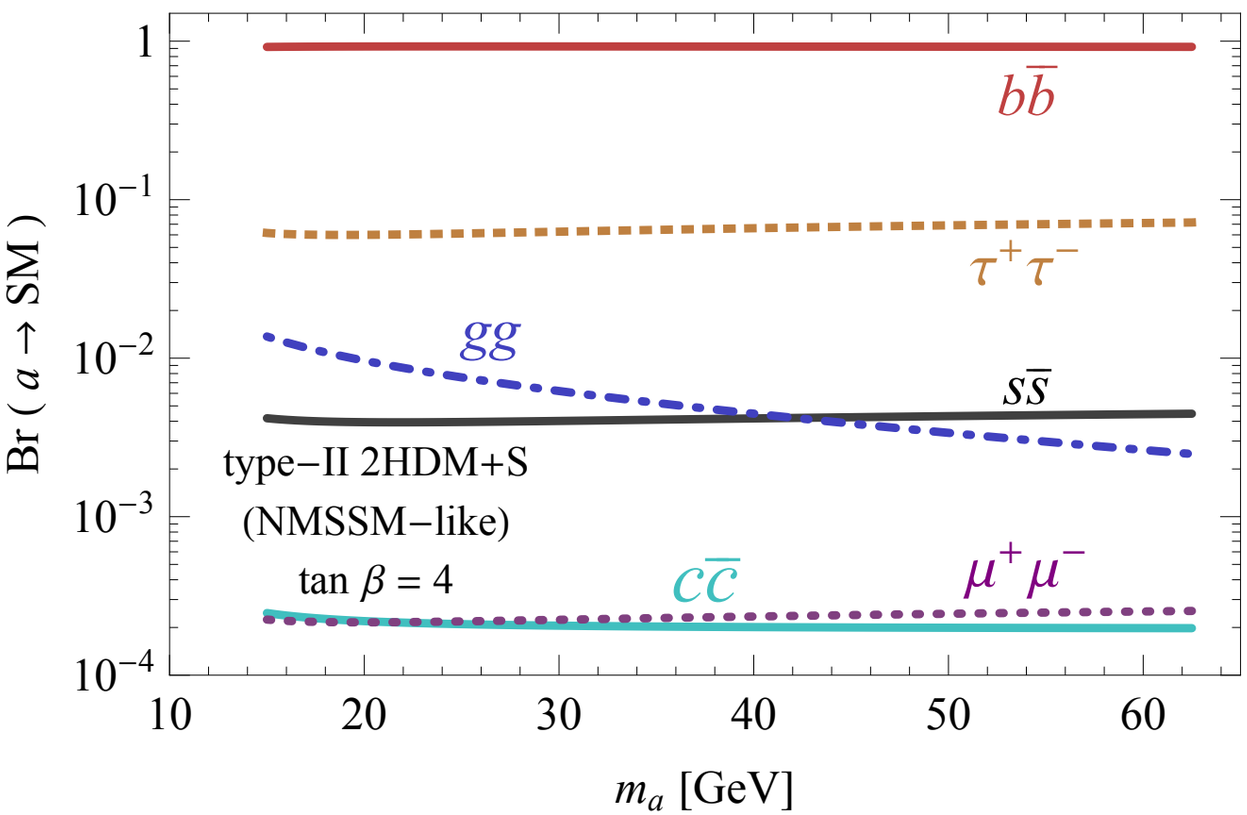
SM+S ⇒ 2HDM+S

- S yields light CP-odd Higgs (*a*) & CP-even Higgs (*s*)
- S has a small mixing with $H_{1,2}$ ⇒ **singlet-like** *a*/*s*
- *a*/*s* inherits a mixture of 2HDM couplings to fermions (inherit four Yukawa types)

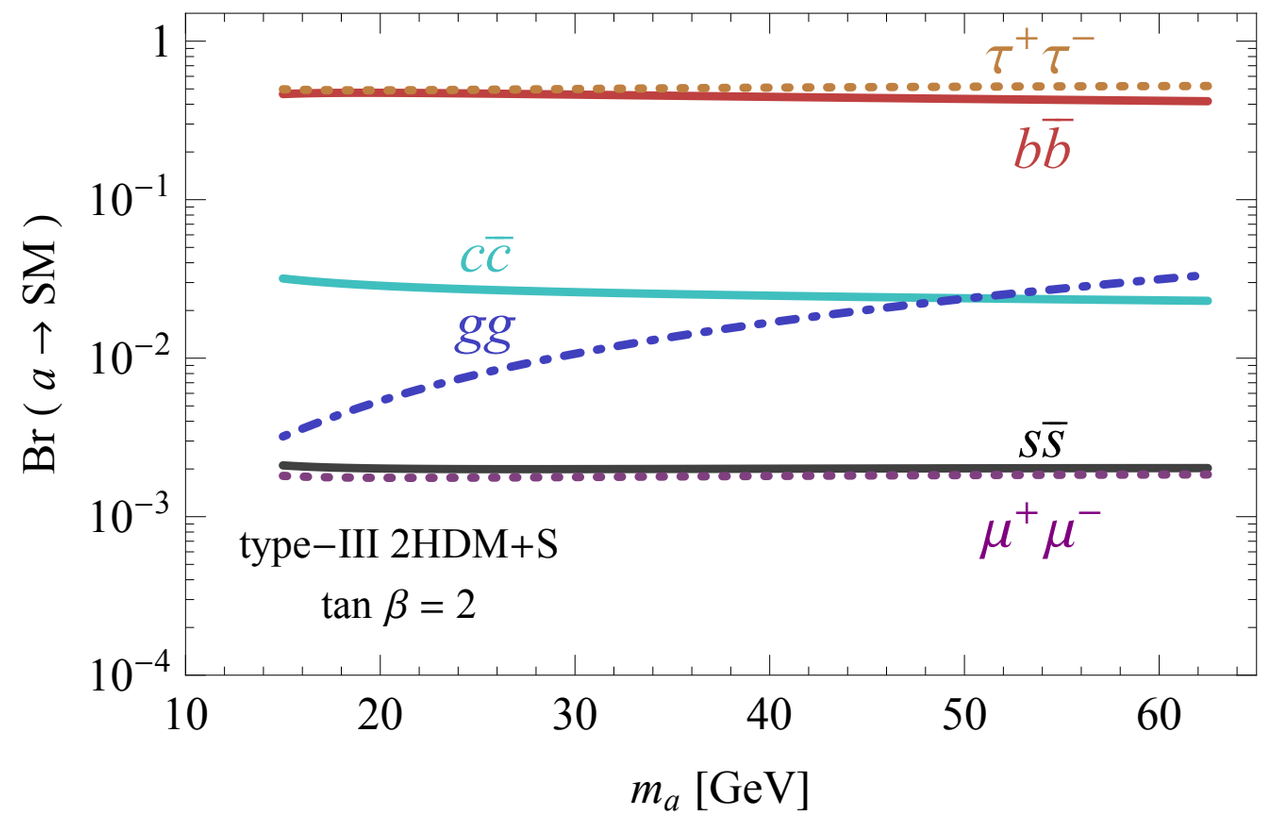
1312.4992 PRD;
see also Chen et al, 1312.3949

A rich set of exotic decays

NMSSM-like 2HDM+S



Lepton-specific 2HDM+S



$$\frac{\mathrm{Br}(h \to 2a \to 2b2\mu)}{\mathrm{Br}(h \to 2a)} = 4 \times 10^{-4} \quad \Rightarrow \quad 1.6 \times 10^{-3}$$

(four times of that of SM+S)

Reach Estimate

Signal and backgrounds

- **Signal**: CP-odd scalar, *a* (m_a = 15 - 60 GeV)

  $h \rightarrow 2a \rightarrow 2b2\mu$ (w/ ggF Higgs production)

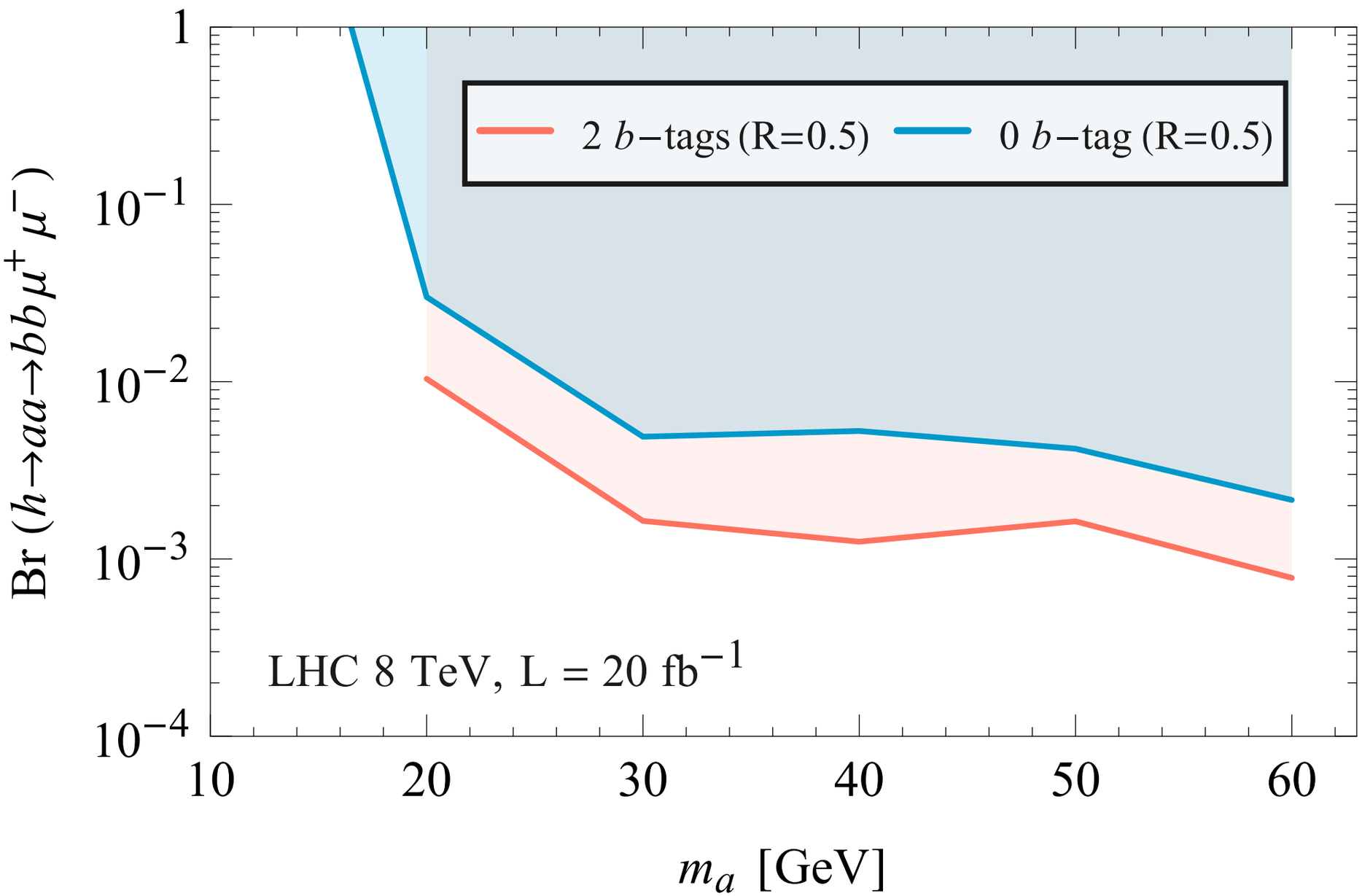
- **Backgrounds**:

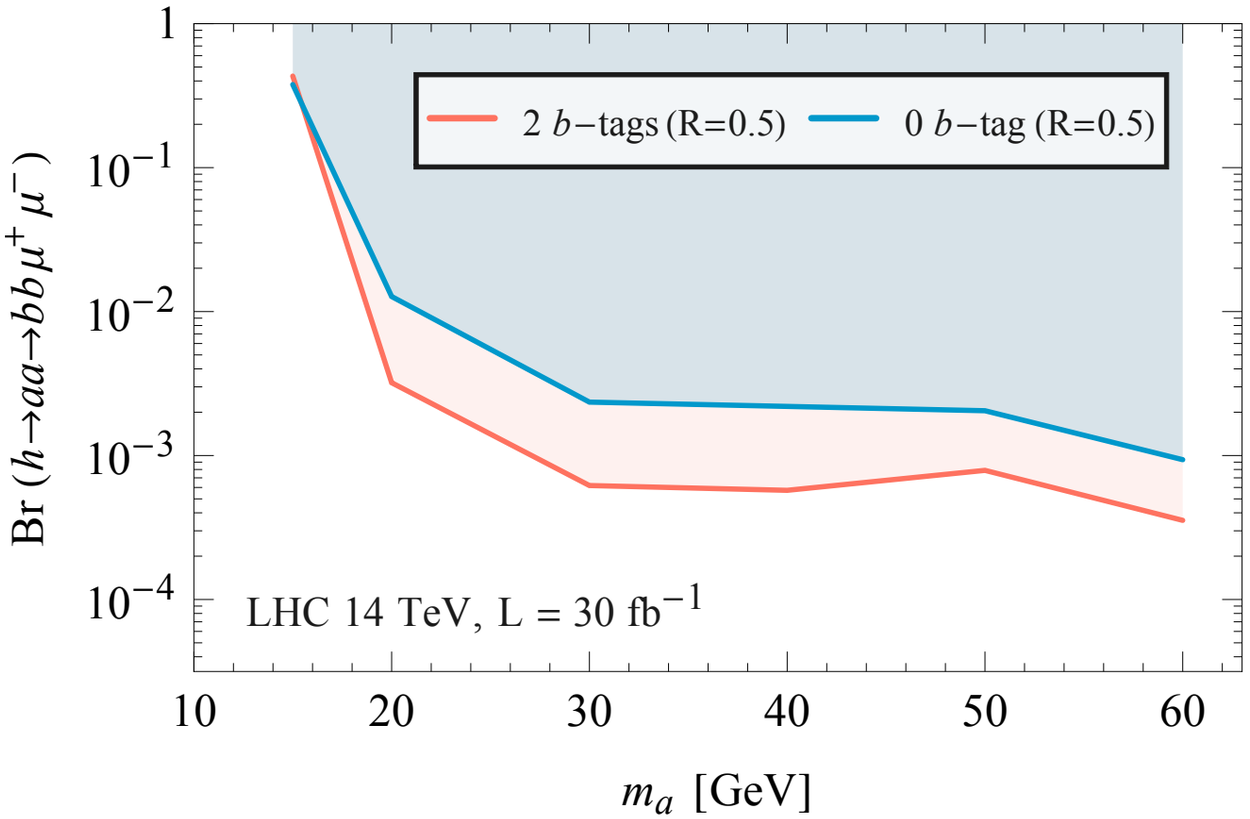
  Drell-Yan, tt-bar, ~~VV, environmental~~

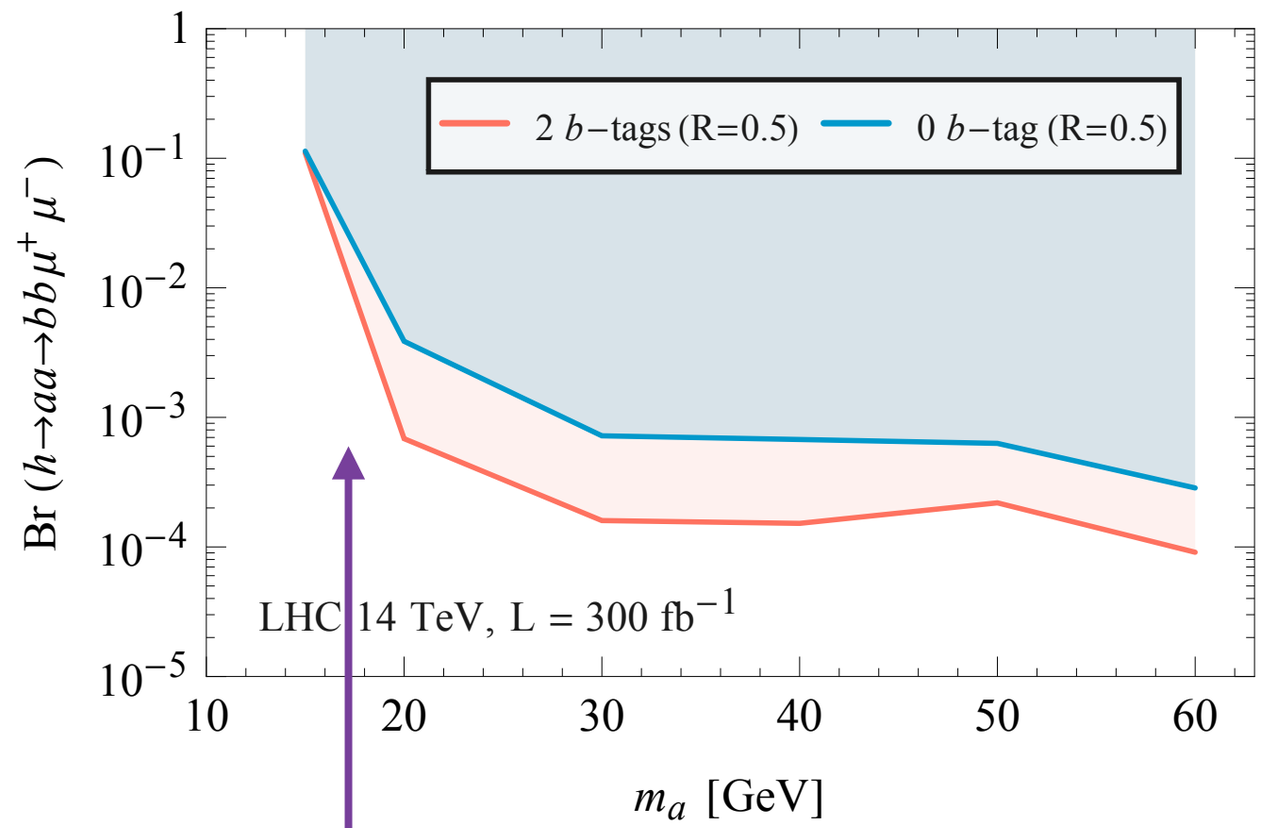
- Signal & backgrounds are generated in SHERPA for LHC at 8 TeV & 14 TeV.

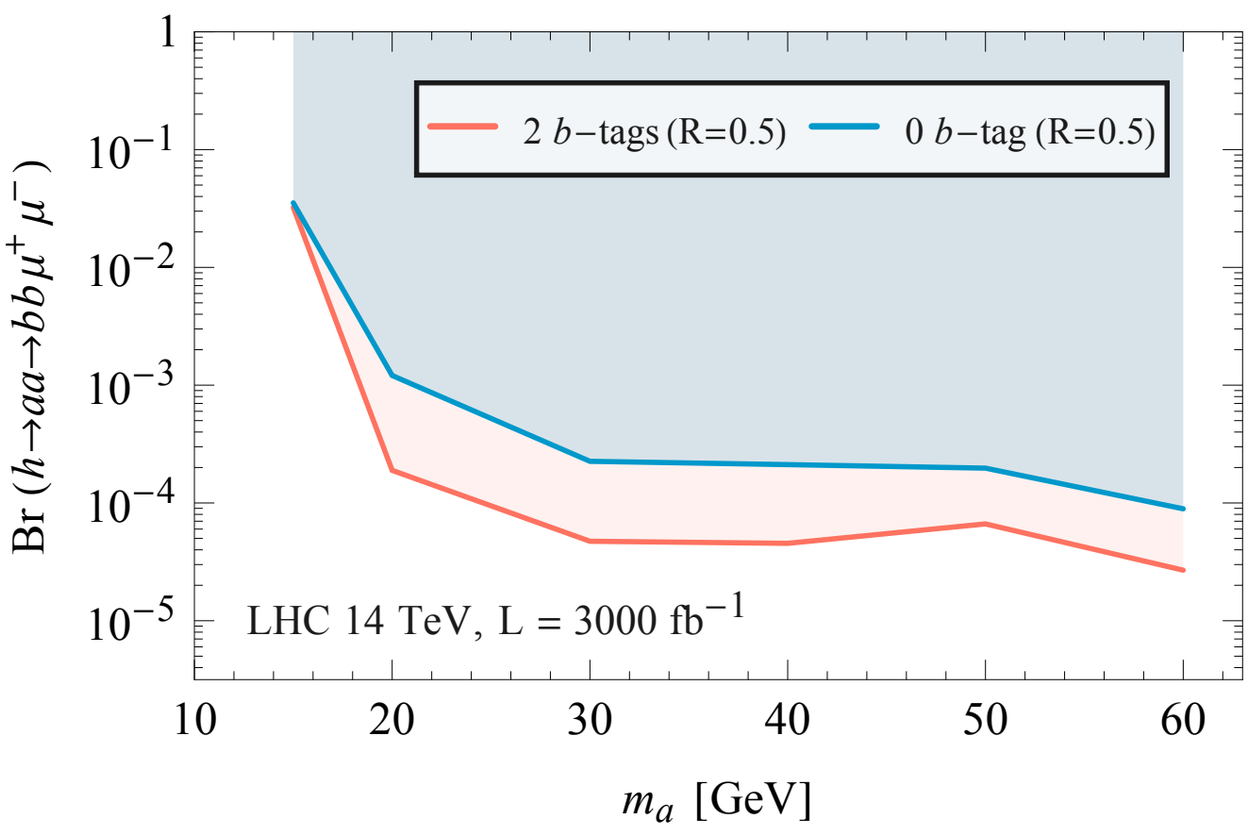
“Conventional” analysis

Cluster jet w/ radius R = 0.4/0.5 for ATLAS/CMS









Loss of sensitivity due to collimated jets

Better analysis for light scalars

Solution 1: analysis with smaller jet radius

Clustering jets w/ a smaller radius R = 0.2

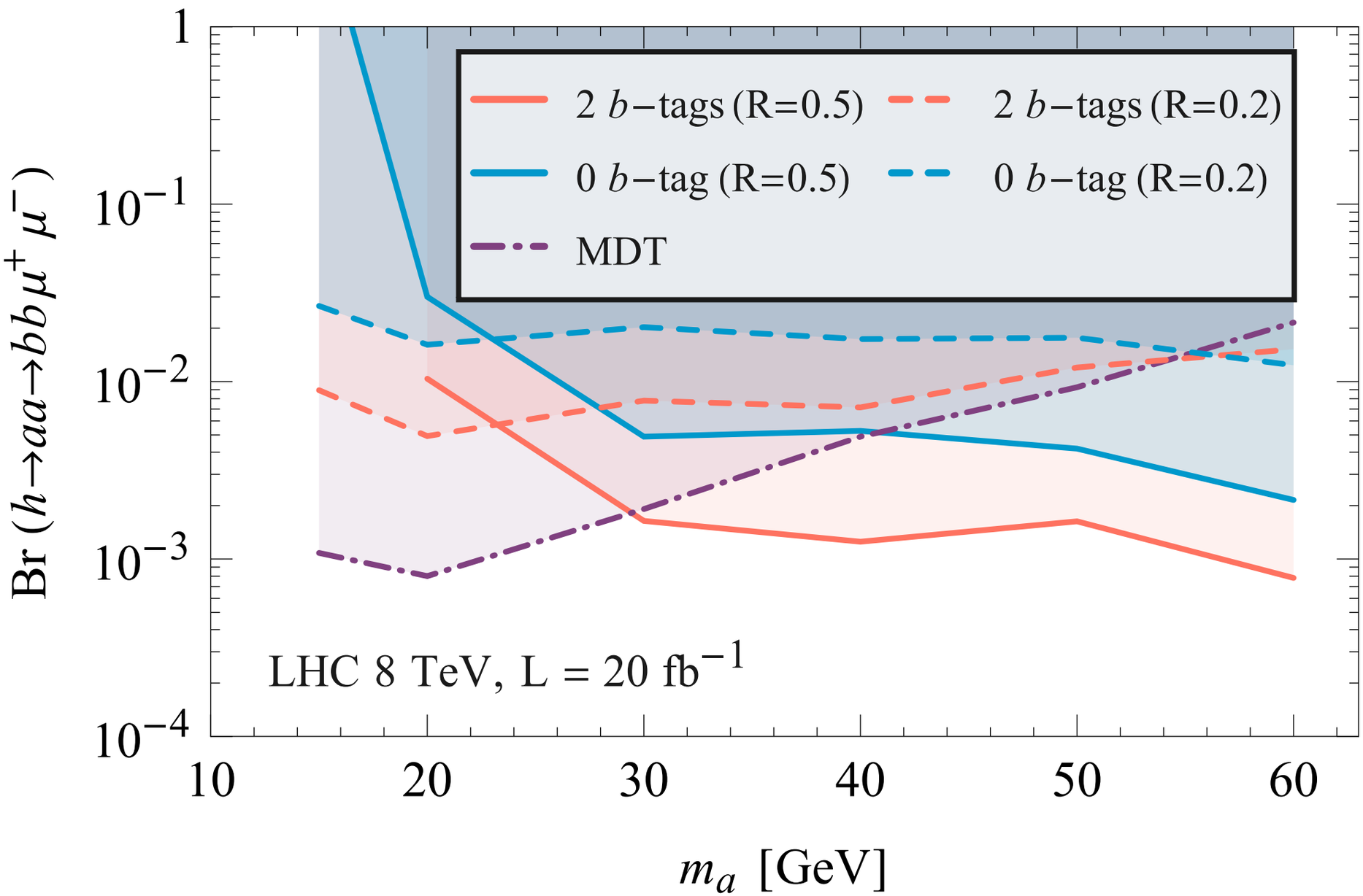
discussion with J. Hobbs

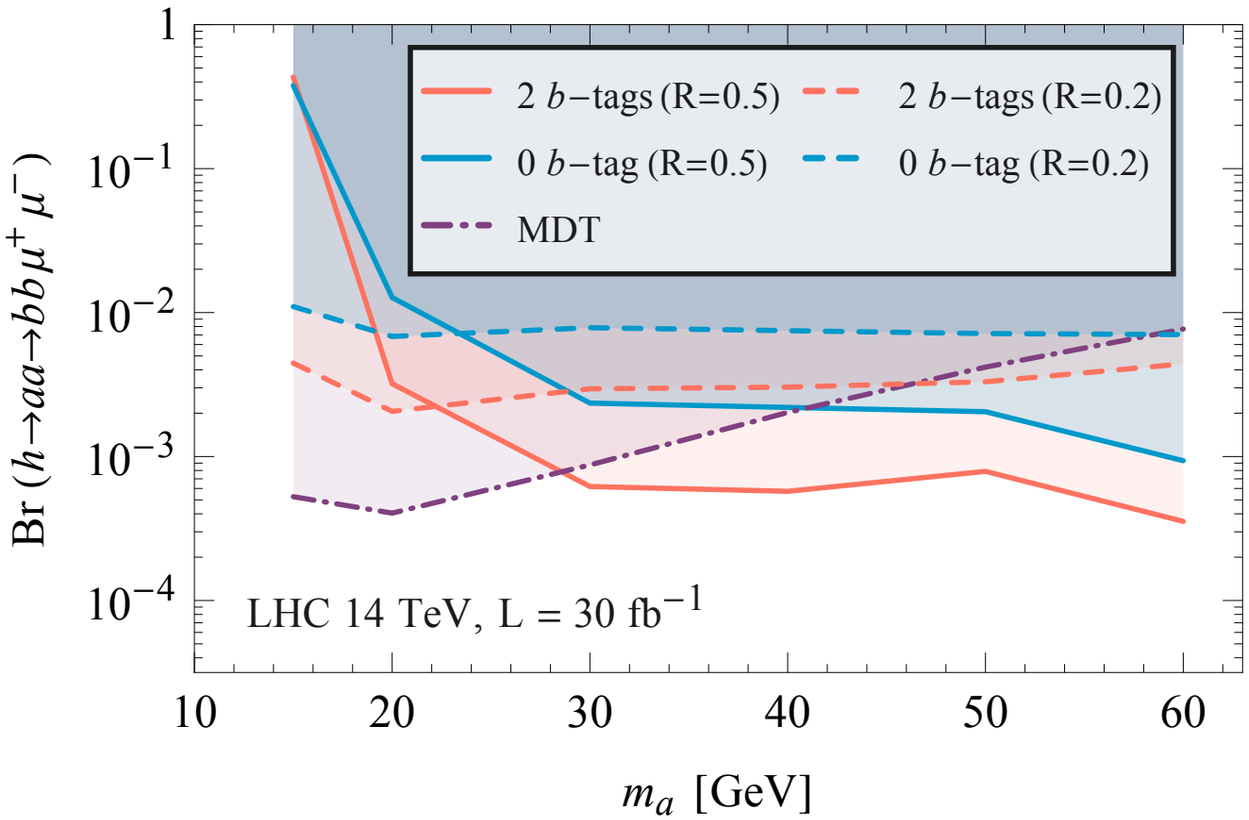
Solution 2: **jet substructure**
(tried many methods)

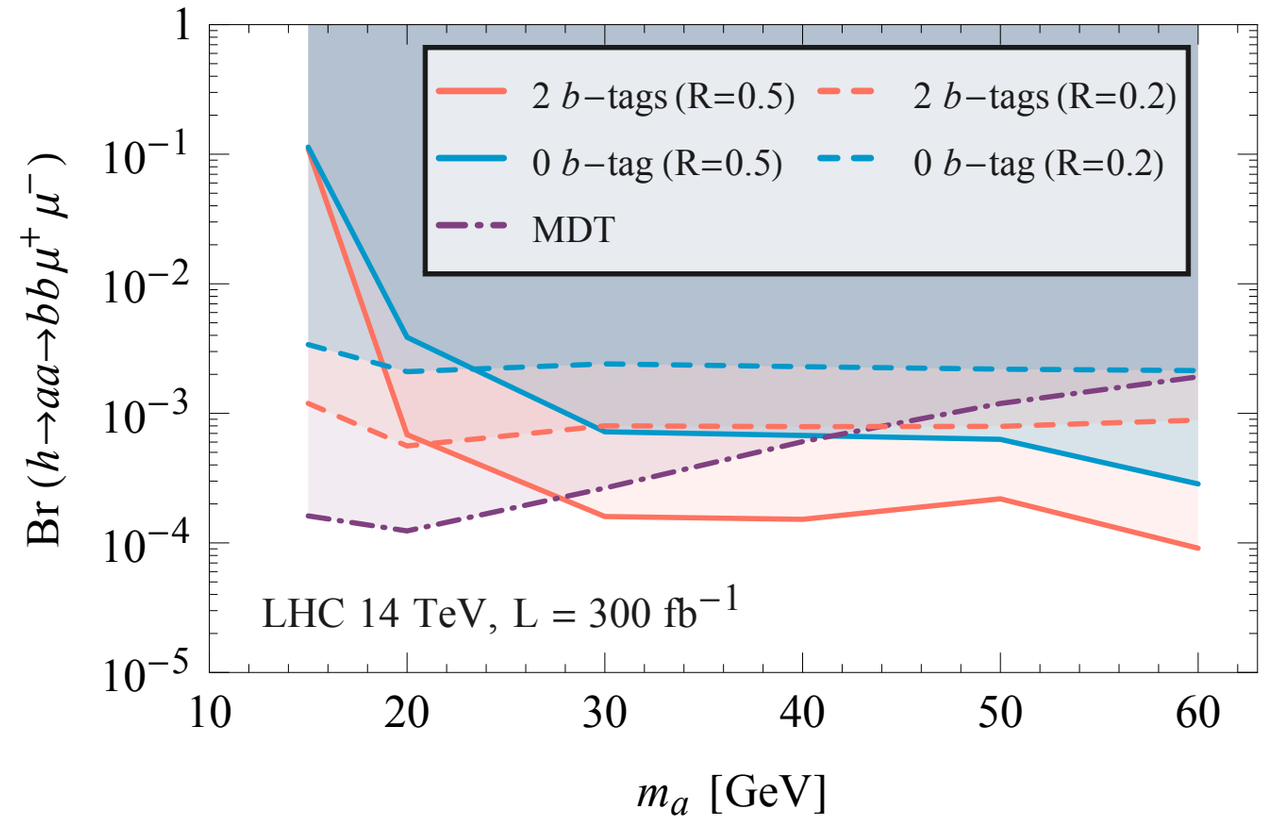
Two sub-jets should be symmetric
⇒ **mass drop tagger** (MDT)

Butterworth, 0809.2530

Small jet radius & jet substructure analysis




2 b−tags (R=0.5)
2 b−tags (R=0.2)
0 b−tag (R=0.5)
0 b−tag (R=0.2)
MDT
LHC 14 TeV, L = 30 fb^{-1}
Br ($h \to aa \to bb\mu^+\mu^-$)
m_a [GeV]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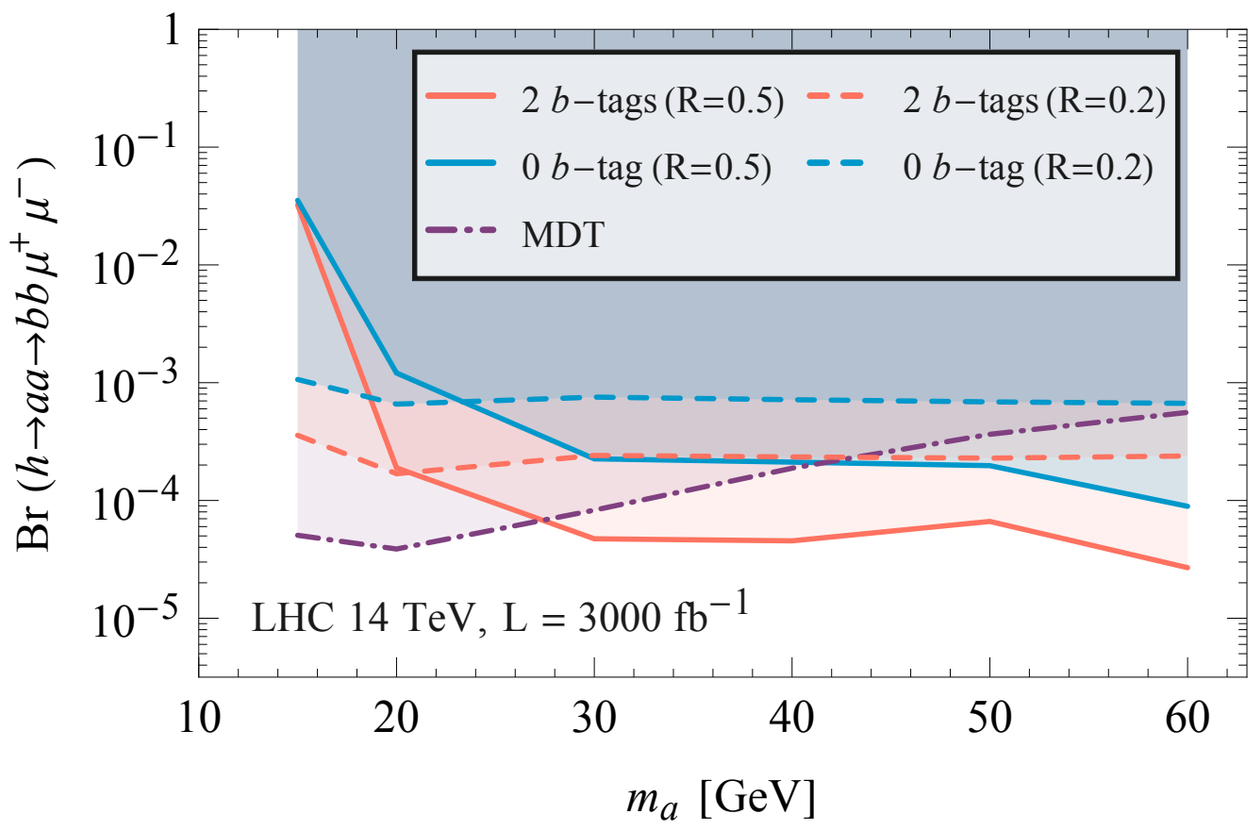
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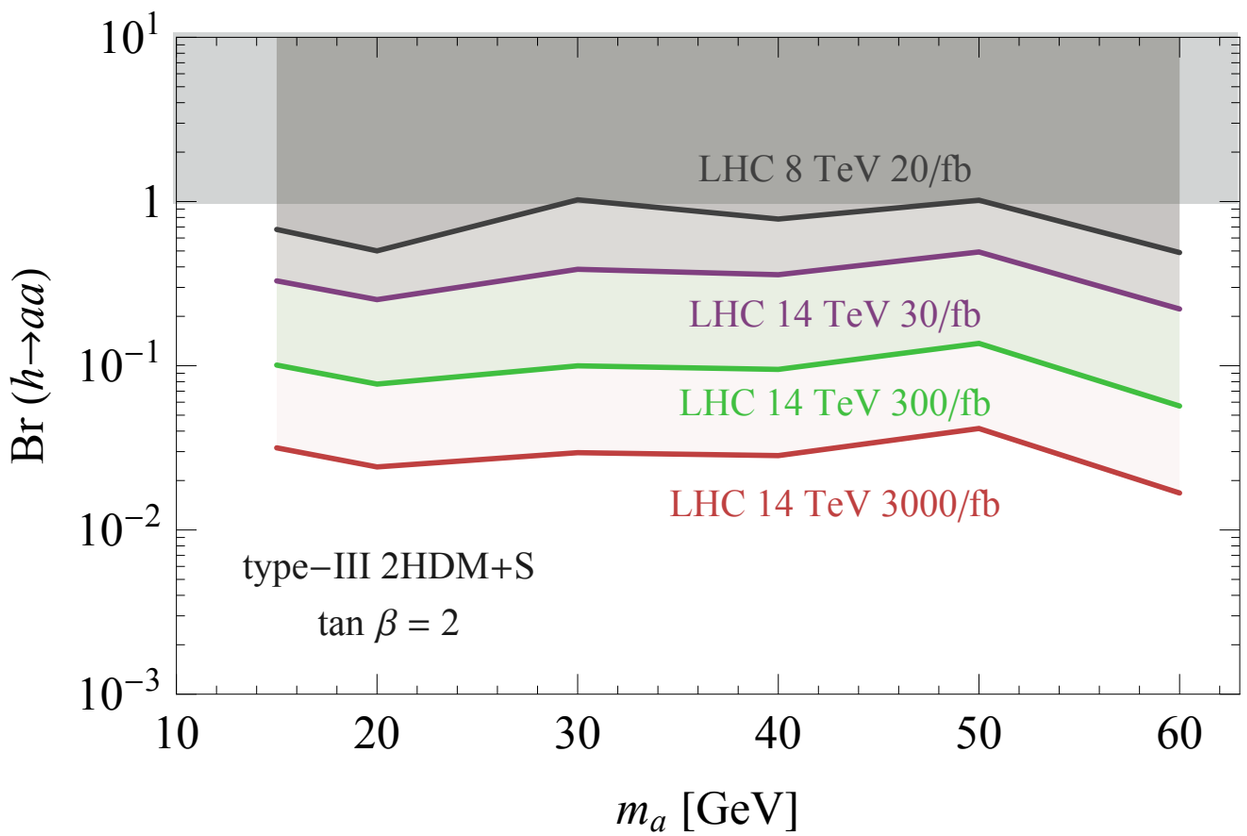
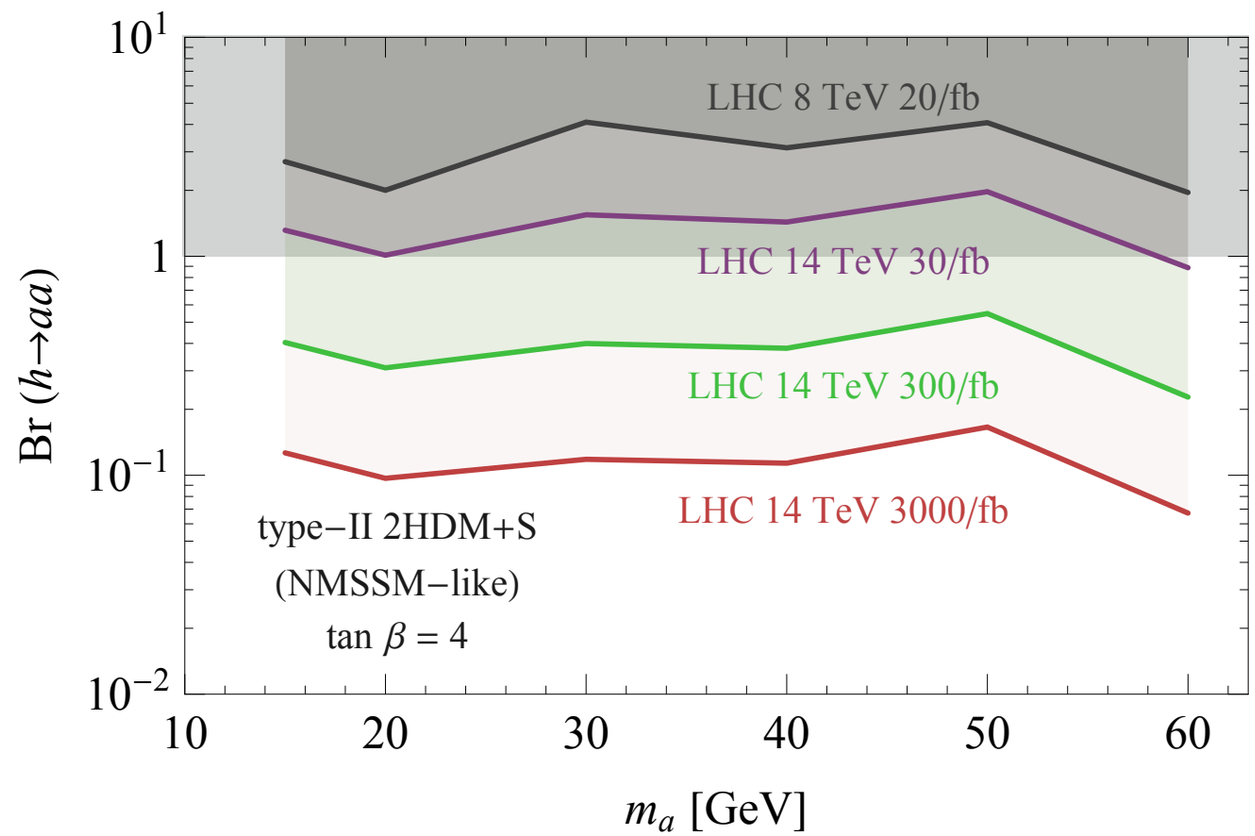
95% CL sensitivity to Br($h \to 2a$)

Yukawa dependent

$$\mathrm{Br}(h \to 2a) = \mathrm{Br}(h \to 2a \to 2b2\mu)/(2\mathrm{Br}(a \to 2b)\mathrm{Br}(a \to 2\mu))$$



Lepton-specific 2HDM+S



NMSSM-like 2HDM+S

Sensitivity to Br($h \to 2a$) from other modes

1. Lepton-specific 2HDM+S
   2b2μ is better than *4b* & comparable to *2τ2μ*
   (no reliable study on *2b2τ*) 1312.4992 PRD

2. SM+S, NMSSM-like 2HDM+S
   4b seems better than *2b2μ* by a factor of a few

Kaplan & McEvoy, 1102.0704; Cao et al, 1309.4939

2b2μ is generally less reliant on low-p_T *b*/*τ*-reconstruction

Important to **probe multiple channels**

Summary

Exotic Higgs decays have unique sensitivity to light scalars.

$h \to 2s\,(a) \to 2b2\mu$ can arise naturally in scenarios like 2HDM+S.

8 TeV LHC can probe BR < 1 for some 2HDM+S.
HL-LHC can probe BR at 0.01 ~ 0.1 level.

Sensitivity to $h \to 2a$ can be competitive or better than other decay modes (depending on models).