

# Updates and Future Plans

LHC HXSWG Exotic Decay

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on behalf of the conveners:

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LHC HXSWG Annual Meeting  
July 13, 2017

# Tasks in progress

- Exploring opportunities at **LHCb**
- Recommended BRs for **SM exclusive mesonic modes**
  - Feasibility studies for additional rare mesonic decays
- Benchmark construction for  $h \rightarrow 2f + MET$ .
  - Feasibility studies needed
- Expanding and systematizing search coverage for  $h \rightarrow$   
**displaced**

# New possibilities at LHCb

- Complementary coverage and capabilities of LHCb:
  - unique opportunities for exotic decays
  - **related signatures** like low-mass Higgs portal production of exotic states
- We are very happy to welcome **Lorenzo Sestini** (Padua) as the LHCb convener
  - see his talk for more!

# Rare SM exclusive mesonic modes

- Update **recommended BRs** for SM exclusive mesonic modes with massive gauge bosons,  $h \rightarrow MZ, h \rightarrow MW$ :
- Updated results (post-YR4) [Alte, Konig, Neubert, 1609.06310] to be posted on twiki
- Contacts: **Stefan Alte, Matthias Konig**

# Rare SM exclusive mesonic modes

- Looking forward:

Mode Method	Branching Fraction [ $10^{-6}$ ]		
	NRQCD [1486]	LCDA LO [1485]	LCDA NLO [1488]
$\text{Br}(h \rightarrow \rho\gamma)$	–	$19.0 \pm 1.5$	$16.8 \pm 0.8$
$\text{Br}(h \rightarrow \omega\gamma)$	–	$1.60 \pm 0.17$	$1.48 \pm 0.08$
$\text{Br}(h \rightarrow \phi\gamma)$	–	$3.00 \pm 0.13$	$2.31 \pm 0.11$
$\text{Br}(h \rightarrow J/\psi\gamma)$	–	$2.79^{+0.16}_{-0.15}$	$2.95 \pm 0.17$
$\text{Br}(h \rightarrow \Upsilon(1S)\gamma)$	$(0.61^{+1.74}_{-0.61}) \cdot 10^{-3}$	–	$(4.61^{+1.76}_{-1.23}) \cdot 10^{-3}$
$\text{Br}(h \rightarrow \Upsilon(2S)\gamma)$	$(2.02^{+1.86}_{-1.28}) \cdot 10^{-3}$	–	$(2.34^{+0.76}_{-1.00}) \cdot 10^{-3}$
$\text{Br}(h \rightarrow \Upsilon(3S)\gamma)$	$(2.44^{+1.75}_{-1.30}) \cdot 10^{-3}$	–	$(2.13^{+0.76}_{-1.13}) \cdot 10^{-3}$

# Rare SM exclusive mesonic modes

- Looking forward:

Decay mode	Branching ratio [ $10^{-6}$ ]	Decay constant [MeV]
$h \rightarrow \pi^+ W^-$	$4.30 \pm 0.01_f \pm 0.00_{\text{CKM}} \pm 0.17_{\Gamma_h}$	$130.4 \pm 0.2$
$h \rightarrow \rho^+ W^-$	$10.92 \pm 0.15_f \pm 0.00_{\text{CKM}} \pm 0.43_{\Gamma_h}$	$207.8 \pm 1.4$
$h \rightarrow K^+ W^-$	$0.33 \pm 0.00_f \pm 0.00_{\text{CKM}} \pm 0.01_{\Gamma_h}$	$156.2 \pm 0.7$
$h \rightarrow K^{*+} W^-$	$0.56 \pm 0.03_f \pm 0.00_{\text{CKM}} \pm 0.02_{\Gamma_h}$	$203.2 \pm 5.9$
$h \rightarrow D^+ W^-$	$0.56 \pm 0.03_f \pm 0.04_{\text{CKM}} \pm 0.02_{\Gamma_h}$	$204.6 \pm 5.0$
$h \rightarrow D^{*+} W^-$	$1.04 \pm 0.12_f \pm 0.07_{\text{CKM}} \pm 0.04_{\Gamma_h}$	$278 \pm 16$
$h \rightarrow D_s^+ W^-$	$17.12 \pm 0.61_f \pm 0.56_{\text{CKM}} \pm 0.67_{\Gamma_h}$	$257.5 \pm 4.6$
$h \rightarrow D_s^{*+} W^-$	$25.10 \pm 1.45_f \pm 0.81_{\text{CKM}} \pm 0.98_{\Gamma_h}$	$311 \pm 9$
$h \rightarrow B^+ W^-$	$(1.54 \pm 0.15_f \pm 0.36_{\text{CKM}} \pm 0.06_{\Gamma_h}) \cdot 10^{-4}$	$186 \pm 9$
$h \rightarrow B^{*+} W^-$	$(1.41 \pm 0.10_f \pm 0.34_{\text{CKM}} \pm 0.06_{\Gamma_h}) \cdot 10^{-4}$	$175 \pm 6$
$h \rightarrow B_c^+ W^-$	$(8.21 \pm 0.57_f \pm 0.52_{\text{CKM}} \pm 0.32_{\Gamma_h}) \cdot 10^{-2}$	$434 \pm 15$

- Further studies needed!

# Rare SM exclusive mesonic modes

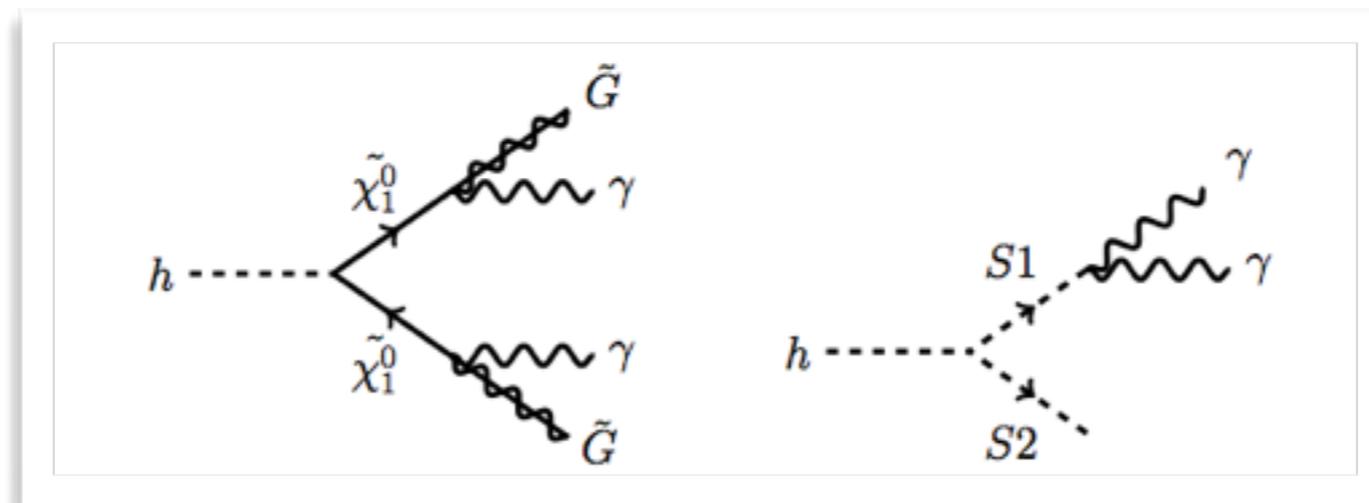
- Looking forward:

Decay mode	Branching ratio [ $10^{-6}$ ]	Decay constant [MeV]
$h \rightarrow \pi^0 Z$	$2.30 \pm 0.01_f \pm 0.09_{\Gamma_h}$	$130.4 \pm 0.2$
$h \rightarrow \eta Z$	$0.83 \pm 0.08_f \pm 0.03_{\Gamma_h}$	$f_\eta^s = -110.7 \pm 5.5$
$h \rightarrow \eta' Z$	$1.24 \pm 0.12_f \pm 0.05_{\Gamma_h}$	$f_{\eta'}^s = 135.2 \pm 6.4$
$h \rightarrow \rho^0 Z$	$7.19 \pm 0.09_f \pm 0.28_{\Gamma_h}$	$216.3 \pm 1.3$
$h \rightarrow \omega Z$	$0.56 \pm 0.01_f \pm 0.02_{\Gamma_h}$	$f_\omega = 194.2 \pm 2.1, f_\omega^s = -13.8 \pm 4.8$
$h \rightarrow \phi Z$	$2.42 \pm 0.05_f \pm 0.09_{\Gamma_h}$	$f_\phi = 223.0 \pm 1.4, f_\phi^s = 230.4 \pm 2.6$
$h \rightarrow J/\psi Z$	$2.30 \pm 0.06_f \pm 0.09_{\Gamma_h}$	$403.3 \pm 5.1$
$h \rightarrow \Upsilon(1S) Z$	$15.38 \pm 0.21_f \pm 0.60_{\Gamma_h}$	$684.4 \pm 4.6$
$h \rightarrow \Upsilon(2S) Z$	$7.50 \pm 0.14_f \pm 0.29_{\Gamma_h}$	$475.8 \pm 4.3$
$h \rightarrow \Upsilon(3S) Z$	$5.63 \pm 0.10_f \pm 0.22_{\Gamma_h}$	$411.3 \pm 3.7$

- Further feasibility studies needed!

# Semi-invisible decays

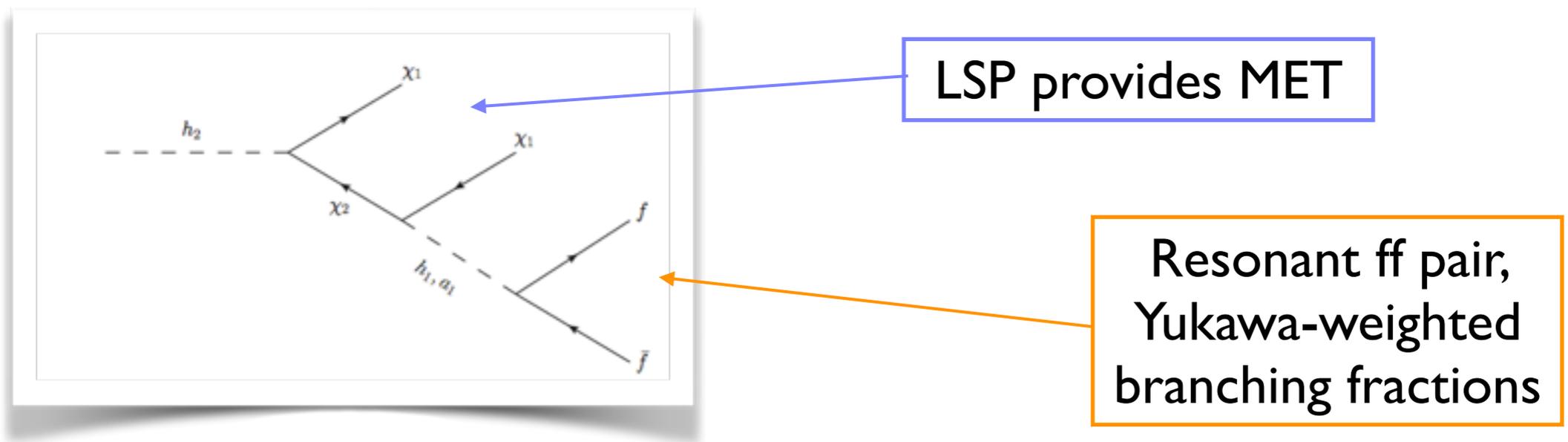
- Challenging signatures thanks to reduced kinematic information, several possible topologies
- However, large integrated luminosities mean LHC has historic discovery opportunities, particularly for leptonic or photonic modes



- initial feasibility studies for  $h \rightarrow 2\gamma + MET$  performed for YR4
- Also of high interest:  $h \rightarrow 2f + MET$

# Semi-invisible decays

- New benchmark models an important ingredient to help interpret and motivate searches
- Best-developed existing model: PQ-NMSSM



- Development of other benchmark models in progress
- assessing reach of  $h$  decays compared to other searches, particularly for models where the MET comes from dark matter

[Huang, Liu, Wang, Yu]

# Semi-invisible decays

- Need for **more feasibility studies** in additional channels
- Two key points (see e.g. YR4  $h \rightarrow 2\gamma + MET$ ):
  - trigger strategy may not be obvious: nontrivial interplay of production modes and trigger thresholds
  - maintain sensitivity to multiple possible topologies
- Possible synergy with electroweak SUSY: e.g. VBF jets + soft (tau) leptons + MET

# Displaced decays

- Higgs decays to long-lived particles are highly motivated by theories of neutral naturalness, dark matter
  - require new and dedicated strategies for reconstruction, triggering, background estimation
- in the past year, LLP searches at LHC have become an area of increasing community interest:
  - mailing list: [lhc-llp@cern.ch](mailto:lhc-llp@cern.ch)
  - effort to motivate, coordinate, systematize, and enhance searches for LLPs across LHC

# Displaced decays

- **Aim 1**: a **simplified model program** to help guide LLP searches
  - detailed proposal for **final states with 1, 2 LLPs**; high-multiplicity **dark showers** present different issues and are under consideration separately
  - in any given channel can approximately factorize **(production) x (decay)**
  - lifetime is a free parameter, and **all values from sub-mm to super-km are interesting**
  - each channel can thus give rise to several different signatures

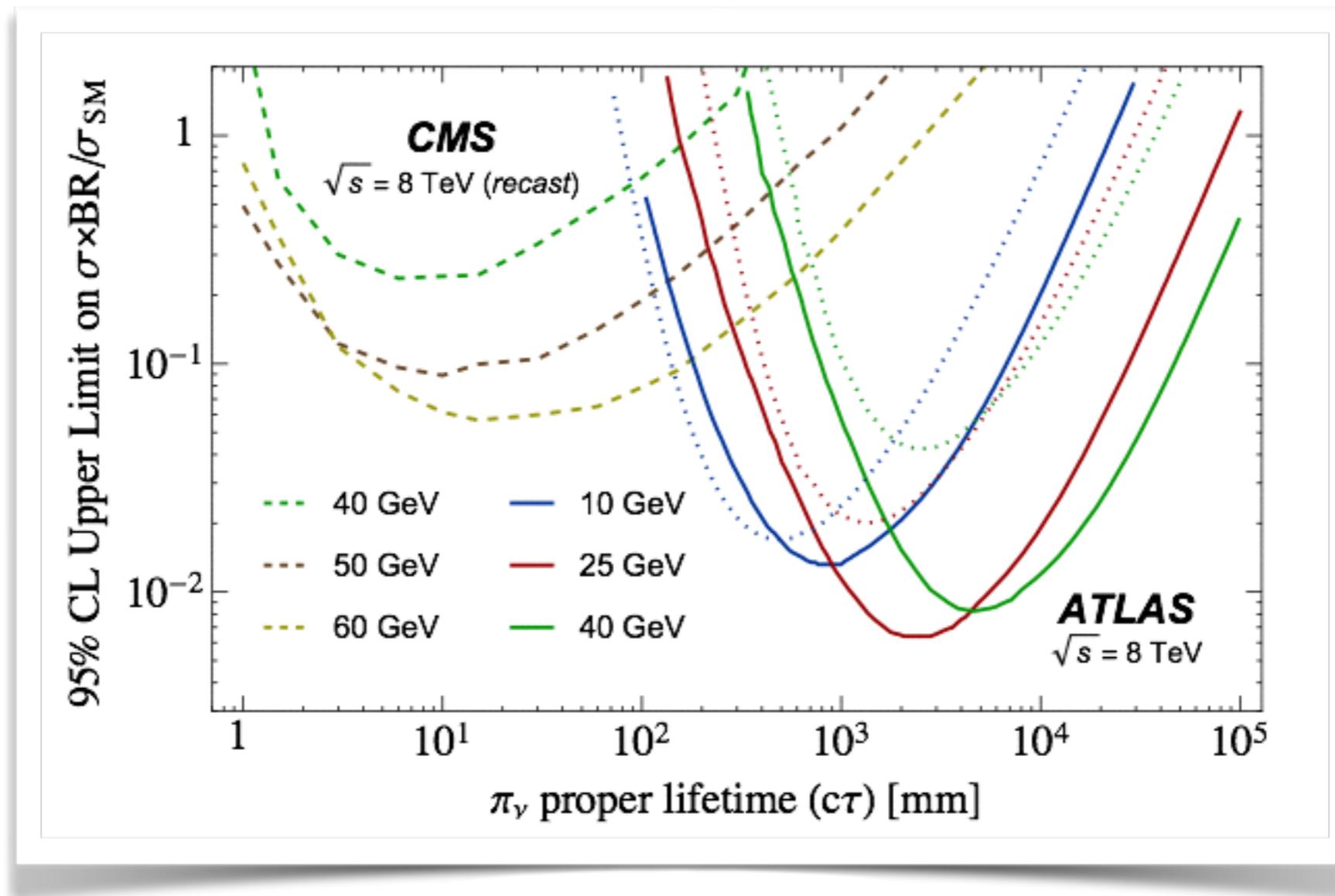
[key contact people: \*]. Beacham, G. Cottin, D. Curtin, J. Evans, Z. Liu, H. Russell, JS, \*B. Shuve]

# Displaced decays

- Proposing SM Higgs decay  $h \rightarrow XX$  as one of 8 benchmark LLP production modes
  - unique role of  $h$  in EWSB means **interplay of ggF, VBF, VH production modes** is vital for understanding best trigger strategies, depending on lifetime and decay mode of  $X$
- Proposed best-motivated decay modes:
  - $jj$  (Higgs portal mixing, ALPs),  $ll$  ( $Z_d$ ),  $\gamma\gamma$  (ALPs)
  - Future work: build on this to include separate consideration of **heavy flavor**

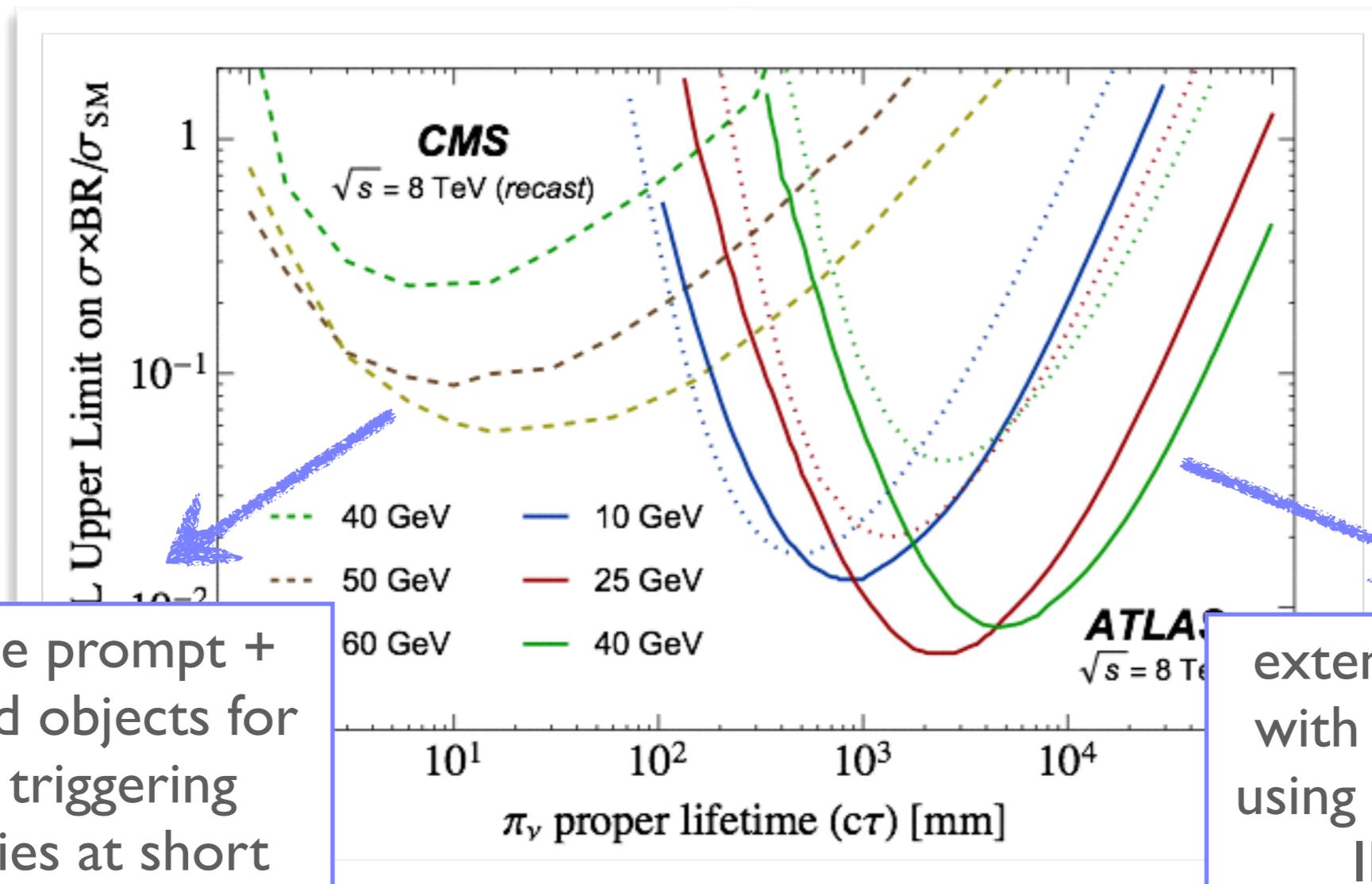
# Displaced decays

- Where we are and where we can go



# Displaced decays

- Where we are and where we can go



combine prompt + displaced objects for more triggering strategies at short lifetimes, low masses

extend acceptance with new searches using less restrictive ID criteria

# Displaced decays

- **Aim 2:** improve reusability of displaced searches
  - A common basis of simplified models will help provide standardized ways to communicate and compare efficiencies, etc.
  - Also discussing implementation of displaced searches in frameworks like **RECAST**
  - Includes but goes beyond a framework for reporting results (see YR4)

[key contact people: G. Cottin, O. Buchmuller, J. Evans, L. Heinrich]

# Displaced decays

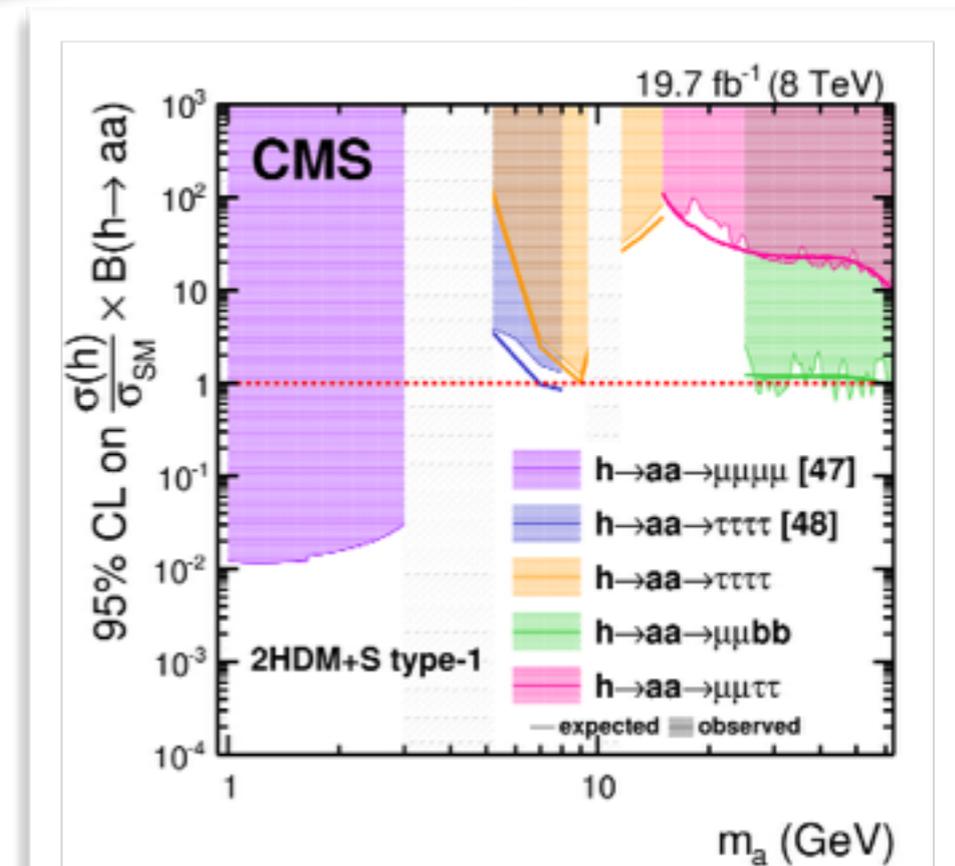
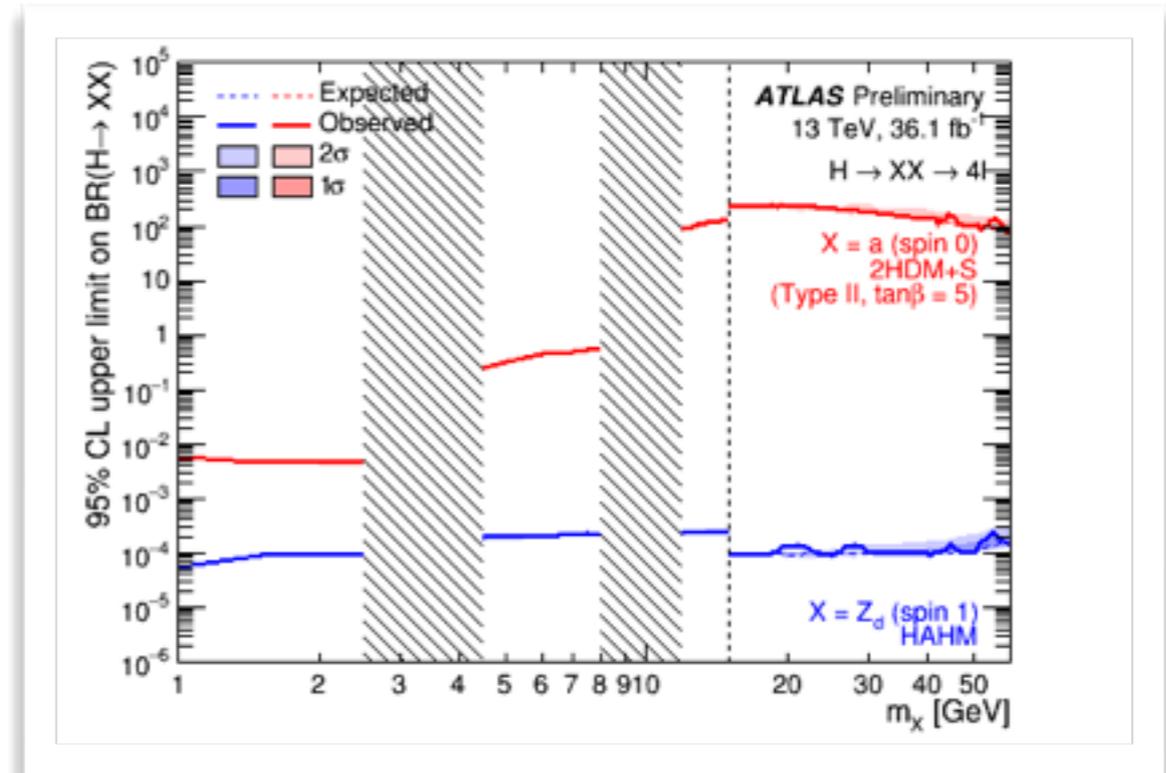
- **Aim 3:** improve coverage for models of **dark showers**
  - Highly motivated by e.g. **neutral naturalness**, but large theoretical uncertainties, event-by-event variations
  - map out effective parameter space for strongly coupled theories, understand basis of searches needed to cover
  - secondarily, (further) develop simulation strategies to cover both **QCD-like** and **large 't Hooft regimes**

# Displaced decays

- **Timeline** for LHC-LLP effort:
  - Draft of simplified models proposal planned to be released “soon”
  - White paper planned for late fall, with corresponding workshop in Trieste October 18-20
  - Some work in this program will likely be on longer timescales, particularly dark showers
- A starting point, not a capstone!
  - In particular **dedicated studies** will be needed to map out strategies for **covering as much Higgs territory as possible**

# New experimental results

- ATLAS  $h \rightarrow aa(Z_D Z_D) \rightarrow 4\ell$  extends search to lower masses
- ATLAS  $h \rightarrow \phi\gamma, h \rightarrow \rho\gamma$
- ATLAS 13 TeV  $Zh, h \rightarrow MET, h \rightarrow$  lepton jets
- CMS  $h \rightarrow aa(ss) \rightarrow 4f$  combines several different 8 TeV search channels



# Summary

- Lots of work in progress
- Many opportunities to explore new territory
  - **semi-invisible** decays
  - **displaced** decays, especially at short lifetime
  - **exclusive** decays with massive vector bosons
  - feasibility studies needed in many channels!