Higgs exotic decays

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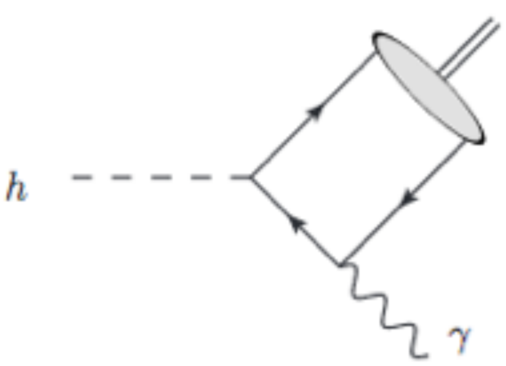
Higgs to mesons

- Rare decays of the Higgs boson to a meson and a photon give a direct window to the Yukawa couplings.

Decay mode	Branching ratio $[10^{-6}]$	Decay constant [MeV]
$h \to \pi^+ W^-$	$4.30 \pm 0.01_f \pm 0.00_{\rm CKM} \pm 0.17_{\Gamma_h}$	130.4 ± 0.2
$h \to \rho^+ W^-$	$10.92 \pm 0.15_f \pm 0.00_{\rm CKM} \pm 0.43_{\Gamma_h}$	207.8 ± 1.4
$h \to K^+ W^-$	$0.33 \pm 0.00_f \pm 0.00_{\rm CKM} \pm 0.01_{\Gamma_h}$	156.2 ± 0.7
$h \to K^{*+} W^-$	$0.56 \pm 0.03_f \pm 0.00_{\rm CKM} \pm 0.02_{\Gamma_h}$	203.2 ± 5.9
$h \to D^+ W^-$	$0.56 \pm 0.03_f \pm 0.04_{\rm CKM} \pm 0.02_{\Gamma_h}$	204.6 ± 5.0
$h \to D^{*+} W^-$	$1.04 \pm 0.12_f \pm 0.07_{\rm CKM} \pm 0.04_{\Gamma_h}$	278 ± 16
$h \to D_s^+ W^-$	$17.12 \pm 0.61_f \pm 0.56_{\rm CKM} \pm 0.67_{\Gamma_h}$	257.5 ± 4.6
$h \to D_s^{*+} W^-$	$25.10 \pm 1.45_f \pm 0.81_{\rm CKM} \pm 0.98_{\Gamma_h}$	311 ± 9
$h \to B^+ W$		
$h \to B^{*+} W$		
$h \to B_c^+ W$		

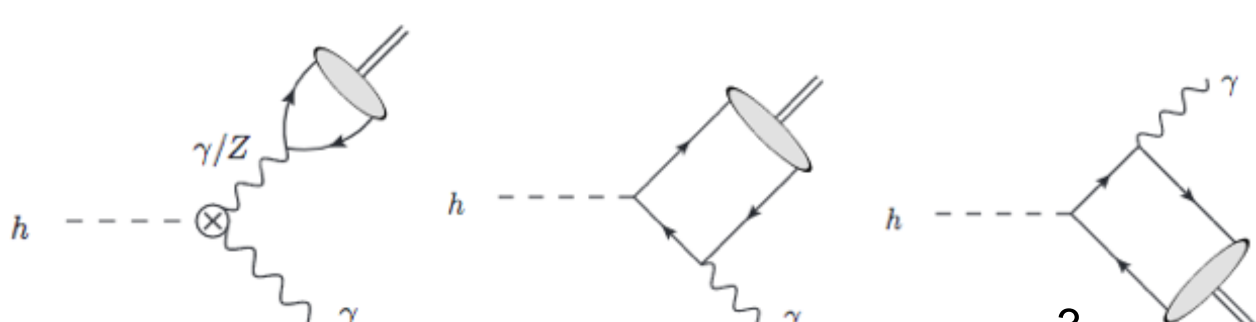
Decay mode	Branching ratio $[10^{-6}]$	Decay constant [MeV]
$h \to \pi^0 Z$	$2.30 \pm 0.01_f \pm 0.09_{\Gamma_h}$	130.4 ± 0.2
$h \to \eta Z$	$0.83 \pm 0.08_f \pm 0.03_{\Gamma_h}$	$f_\eta^s = -110.7 \pm 5.5$
$h \to \eta' Z$	$1.24 \pm 0.12_f \pm 0.05_{\Gamma_h}$	$f_{\eta'}^s = 135.2 \pm 6.4$
$h \to \rho^0 Z$	$7.19 \pm 0.09_f \pm 0.28_{\Gamma_h}$	216.3 ± 1.3
$h \to \omega Z$	$0.56 \pm 0.01_f \pm 0.02_{\Gamma_h}$	$f_\omega = 194.2 \pm 2.1, \quad f_\omega^s = -13.8 \pm 4.8$
$h \to \phi Z$	$2.42 \pm 0.05_f \pm 0.09_{\Gamma_h}$	$f_\phi = 223.0 \pm 1.4, \quad f_\phi^s = 230.4 \pm 2.6$
$h \to J/\psi\, Z$	$2.30 \pm 0.06_f \pm 0.09_{\Gamma_h}$	403.3 ± 5.1
		684.4 ± 4.6
		475.8 ± 4.3
		411.3 ± 3.7

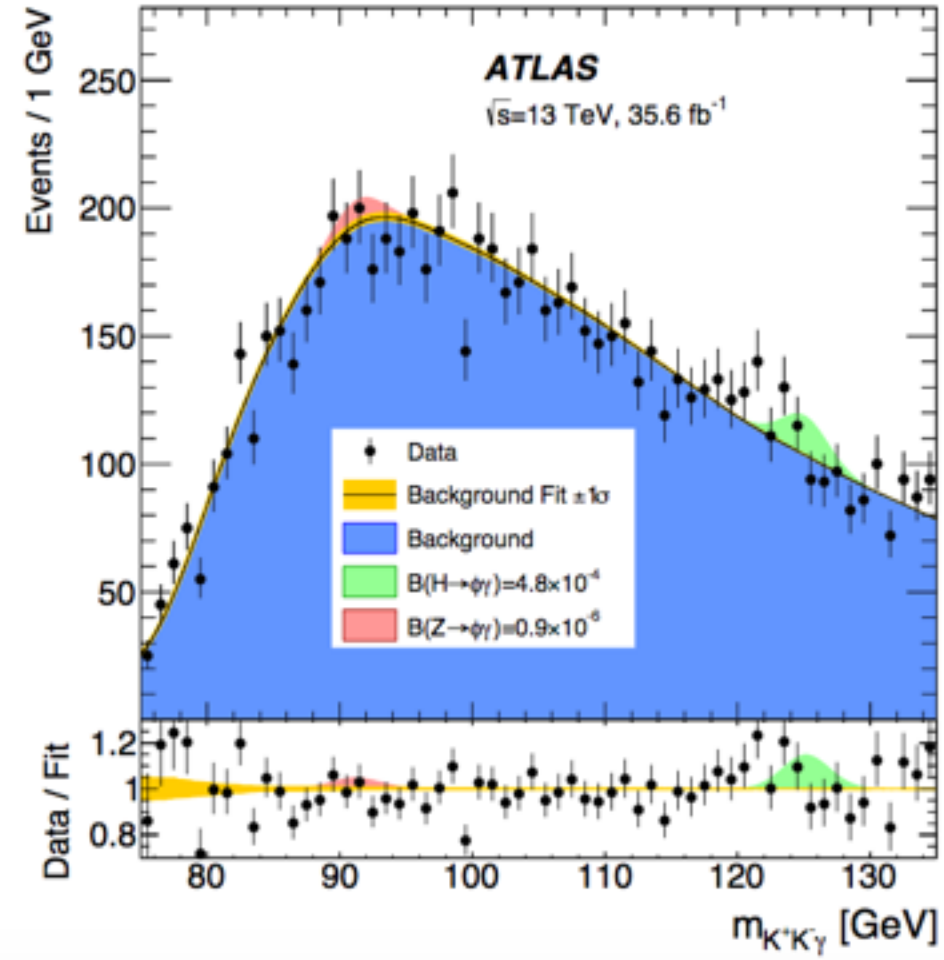
Mode / Method	Branching Fraction $[10^{-6}]$ NRQCD [1486]	LCDA LO [1485]	LCDA NLO [1488]
$\mathrm{Br}(h \to \rho\gamma)$	–	19.0 ± 1.5	16.8 ± 0.8
$\mathrm{Br}(h \to \omega\gamma)$	–	1.60 ± 0.17	1.48 ± 0.08
$\mathrm{Br}(h \to \phi\gamma)$	–	3.00 ± 0.13	2.31 ± 0.11
$\mathrm{Br}(h \to J/\psi\,\gamma)$	–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

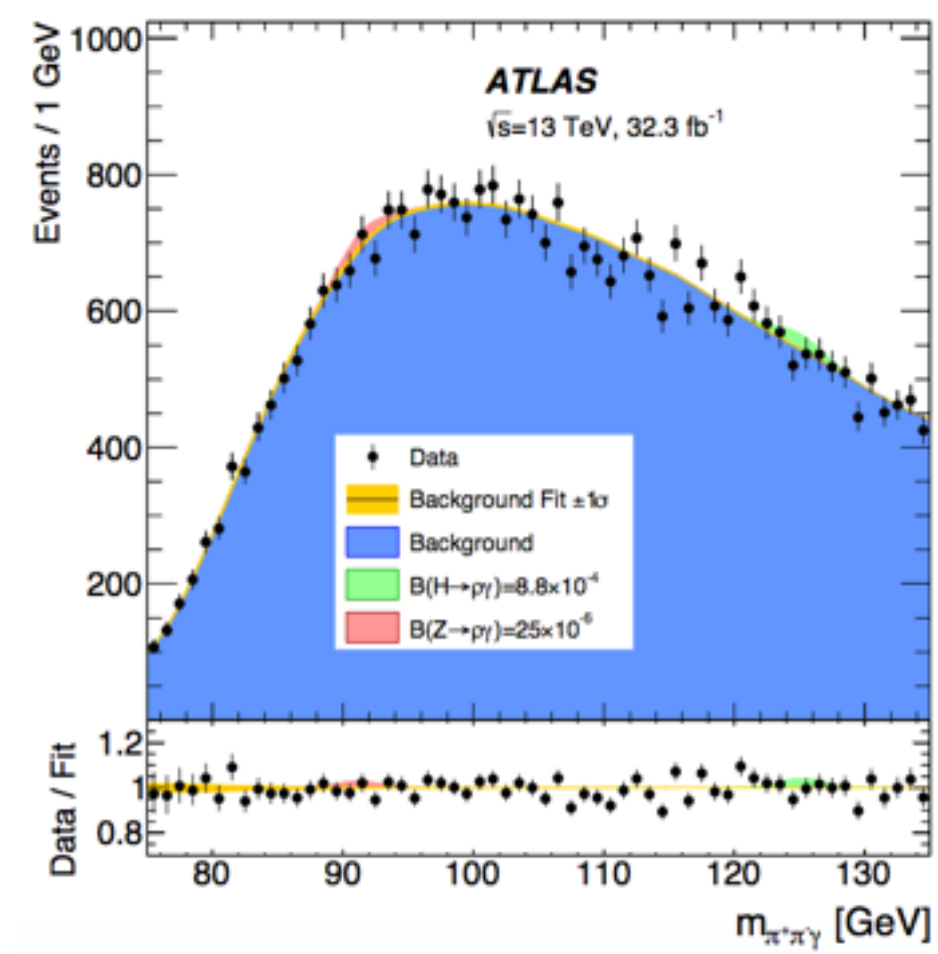


Higgs to mesons

- Several results published:
  - h→$\phi\gamma$ [1607.03400, 1507.03031].
  - h→J/$\psi\gamma$, Υγ [1501.03276].
  - h→$\phi\gamma$, ργ [1712.02758]. NEW
- New ideas:
  - h→ $K^{*0}(K^+\pi^-)\gamma$, $D^{*0}(D^+\pi^-)\gamma$, $\omega(\pi^+\pi^-\pi^0)\gamma$
- In general far away from being sensitive due to very small branching ratios.
- In terms of needs, analyzers think they are covered as the relevant SM BRs are calculated and there is some guidance for the relevant BSM models







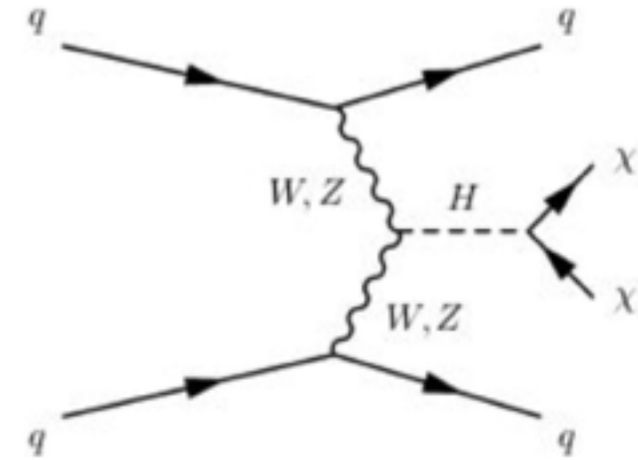
Higgs LFV

- Lepton Flavor Violating decays of the Higgs boson would be a clear indication of physics BSM.
- Existing results for H→μτ/eτ both lep-lep and lep-had channels [1604.07730, 1508.03372]
  - Most simplistic model for the LFV Higgs decays: a simple off-diagonal Yukawa coupling for h(125)→ℓℓ'.
  - Analyzers argue that the H→eμ cross-section values accessible at LHC are already excluded by MEG results (or some level of fine-tuning is needed).
    - Benchmark models available where a 10^{-4} BR for H→eμ is compatible with MEG limits?

- Current best limits from direct searches:

	With 8 TeV data	With 13 TeV data
BR(H→τμ)	< 1.43% (ATLAS)	< 0.25% (CMS)
BR(H→τe)	< 1.04% (ATLAS)	< 0.61% (CMS)
BR(H→eμ)	< 0.036% (CMS)	

Higgs to (semi) invisible



- Several final states studied by ATLAS:
  - h(→$\gamma\gamma$)+E_T^{miss} [1506.01081, 1306.03948] NEW
  - h(→bb)+E_T^{miss} [1707.01302] NEW
  - Mono-jet analysis [1502.01518].
  - Zh(→invisible) [1402.3244, 1711.00431, 1708.09624] NEW
  - VBF h(→invisible) [1508.07869].
  - V(→had)h(→invisible) [1504.04324].

- A handful of interpretations for many BSM models [1312.4992] covered, and more to come!

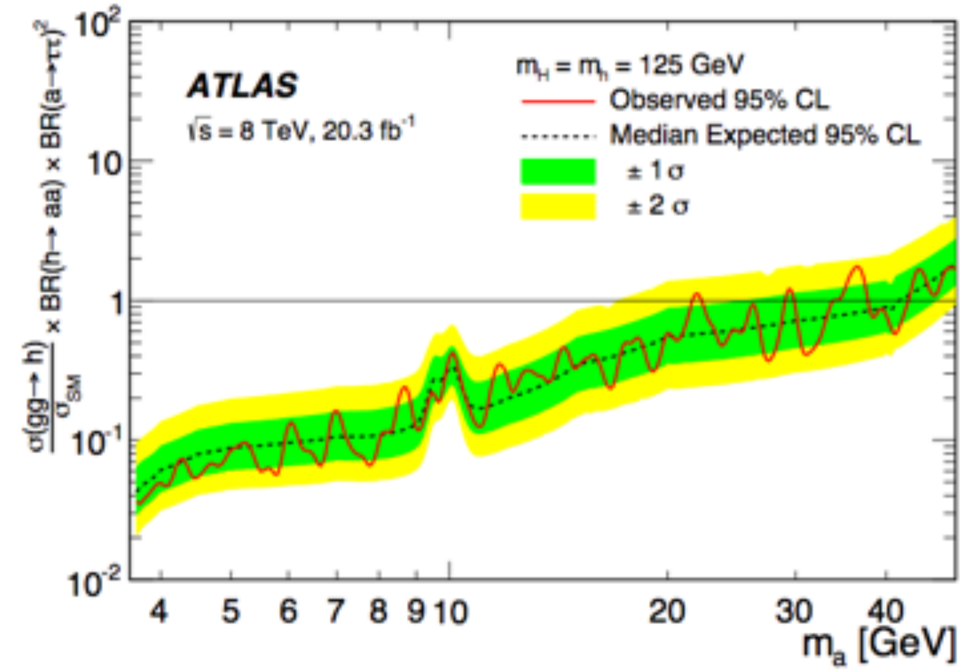
Higgs to SM particles via light bosons

- Higgs boson decays to a pair of new spin-zero particles, decaying each to a pair of SM particles.

- Predicted by many theories of physics BSM:
  - NMSSM
  - Several models of DM
  - Neutral Naturalness
  - …

- Several 2HSM+S benchmark models already provided in the WG3 Higgs Exotic Decay twiki.

Higgs to SM particles via light bosons



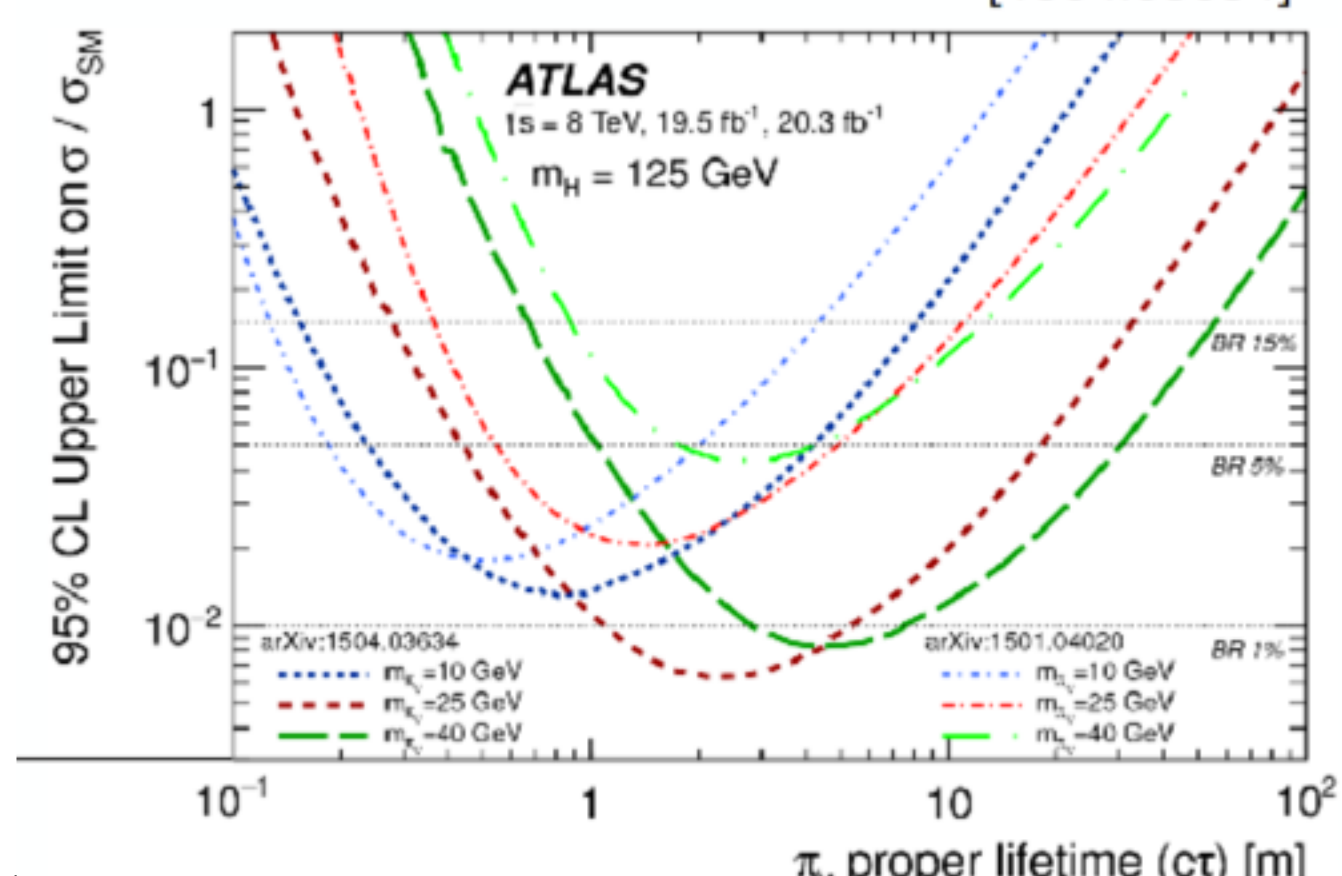
- Boost in the activity of this group in ATLAS.
  - Searches to cover (almost) every sensitive final state.
- Setting limits on several 2HDM+S and SM +V benchmark models.
- Summary plot in preparation.
- Several final states studied by ATLAS:
  - $h \to 2a \to 4b$ [1606.08391]
  - $h \to 2a \to 2\mu 2\tau$ [1505.01609]
  - $h \to 2Zd$ / ZZd / $2a \to 4\ell$ [1505.07645, 1802.03388] NEW
  - $h \to 2a \to 4\gamma$ [1509.05051]
- Other final states currently being studied.

Higgs to long-lived

- Many public results from Run 1 and 2 involving LLPs coming from the Higgs boson, specially exotic signatures looking for:
  - Displaced jets [1504.03634, ATLAS-CONF-2016-103]
  - Displaced lepton-jets [ATLAS-CONF-2016-042]

- New ideas and possible analysis re-interpretations currently being considered.

[1504.03634]



Comments from the experimentalists

- Different needs from the other Higgs working groups
  - We are not so dependent on how well the cross sections and branching ratios are calculated.
  - We are currently using very precise calculations for $pp \rightarrow h(125)$, but very simplistic $h \rightarrow X$ models.
- The needs for the ATLAS analyses on the Exotic Higgs Decays domain include:
  - A list of the models that are currently best motivated based on the experimental results up to now.
    - Very reduced person power spread in many different analyses.
  - Provide recommendations on how to generate MC for such models (or even generate them ourselves) so that feasibility studies can be made.

Things to do

- We have been asked to fill up the following table:
  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG3#Higgs_Exotic_Decays

Task	Involved persons	Status	Timescale
Provide final recommendations for h->W/Z+meson		Planned	
Add feasibility studies for Higgs rare decays beyond gamma+J/Psi, gamma+phi, gamma+Upsilon		Planned	
Add feasibility studies for h->2f+MET and develop benchmark scenarios predicting this type of signatures		Planned	
Study feasiblity for searches for Higgs decays involving one or more displaced vertices.		Planned	
What is the best way to present Higgs searches with displaced vertices to allow a simple recast by theorists?		Planned	