Exotic Decays: report and plans

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on behalf of the conveners

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Jessie Shelton (UIUC, Theory)

The 12th Workshop of the LHC Higgs Cross Section Working Group
CERN, October 13th 2015

Our working group for the YR4

Exotic Higgs Decays

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Thanks to all!

also many thanks to Andrea Coccaro, Csaba Csaki, Eric Kuf lk, Salvator Lombardo, Henry Lubatti, and Oren Slone

Goals of the working group

Searches for new decay modes of the 125 GeV Higgs boson

Four main broad topics:

1. Flavor changing decays. Example: $h \to \tau\mu$
   Rare decays to mesons + gauge boson. Example: $h \to J/\Psi + \gamma$ } to SM particles
2. Prompt decays without MET. Example: $h \to aa \to (b\bar{b})(\mu\bar{\mu})$
3. Prompt decays with MET. Example $h \to \chi\chi \to 2\gamma + \mathrm{MET}$
4. Decays with displaced vertices. Example: $h \to g_B g_B \to 4f$

} to NP particles

Outline of this presentation:

- What we have done for the YR4 for the four sets of signatures
- Plans for the future

1. Higgs rare decays. YR4

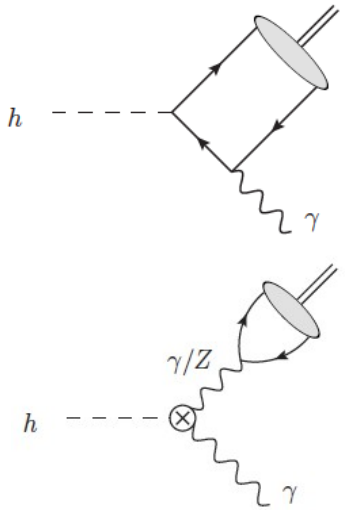
- Precise calculation of the SM predictions for the branching ratios

Example:

Mode / Method	Branching Fraction $[10^{-6}]$ NRQCD [1483]	LCDA LO [1482]	LCDA NLO [1485]
$\mathrm{Br}(h \to \rho^0\gamma)$	–	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
$\mathrm{Br}(h \to \Upsilon(1S)\,\gamma)$	$(0.61\,^{+1.74}_{-0.61}) \cdot 10^{-3}$	–	$(4.61\,^{+1.76}_{-1.23}) \cdot 10^{-3}$
$\mathrm{Br}(h \to \Upsilon(2S)\,\gamma)$	$(2.02\,^{+1.86}_{-1.28}) \cdot 10^{-3}$	–	$(2.34\,^{+0.76}_{-1.00}) \cdot 10^{-3}$
$\mathrm{Br}(h \to \Upsilon(3S)\,\gamma)$	$(2.44\,^{+1.75}_{-1.30}) \cdot 10^{-3}$	–	$(2.13\,^{+0.76}_{-1.13}) \cdot 10^{-3}$

+ the additional decay modes with a massive gauge boson (W, Z)

These BRs depend on the Higgs couplings to light quarks



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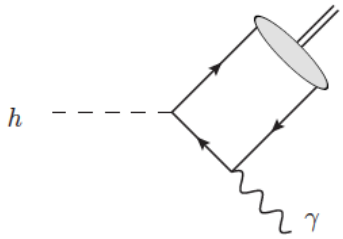
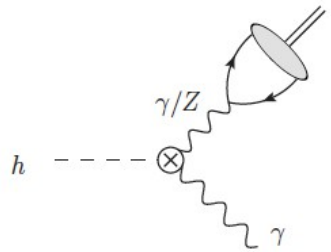


- Discussion of a large set of models predicting enhanced couplings of the Higgs with light fermions, consistent with (low energy) constraints.



- Discussion of new possible decay modes that can be searched for, beyond J/ψ + γ, φ + γ, and Υ(nS) + γ.

1. Higgs rare decays. Future

We plan to:

- Write a CERN note comparing the BRs for $h \to M W$, $M Z$ computed using QCD factorization approach and those discussed in the YR4

Latest paper by Alte, Konig, Neubert, 1609.06310

- Perform additional feasibility studies for new mesonic rare decay modes.

So far ATLAS and CMS searched for $J/\psi + \gamma$, $\varphi + \gamma$, and $\Upsilon(nS) + \gamma$.
What about the others?

- More studies of signal modeling. Pythia?

- Investigate complementary ways to probe light Yukawas

  - Question for experimentalists:
    some additional info you would need from theorists?

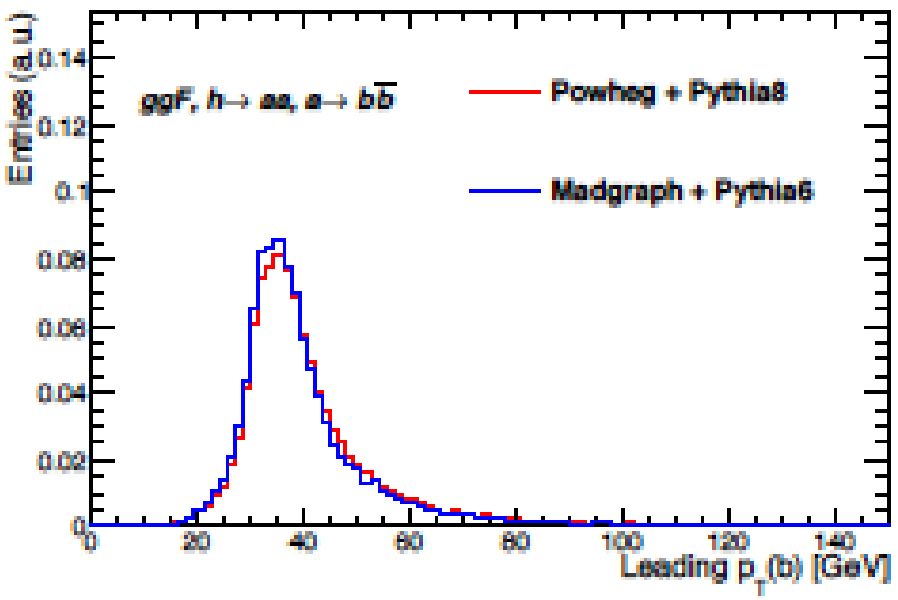
2. Decays to resonances without MET. YR4

- Comparative study of the partonic distributions for the prompt decay topology for several production modes of the Higgs boson

$$h \rightarrow \underbrace{XX}_{\text{NP particles}} \rightarrow \underbrace{2Y\,2Y'}_{\text{SM particles}}$$

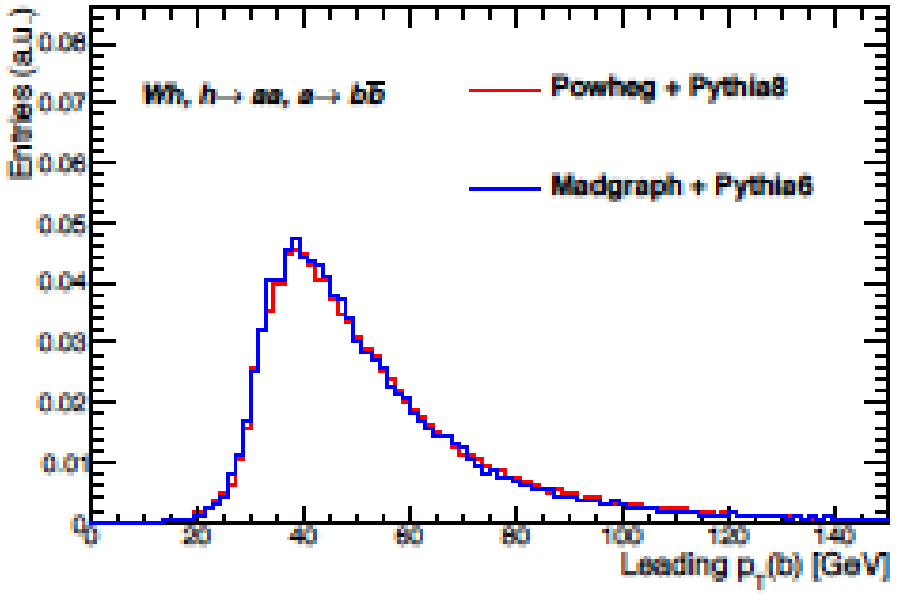
Example: h → aa → 4b
(It applies also to the other decay modes of a)

Gluon fusion



m_a = 60 GeV

Wh associated production



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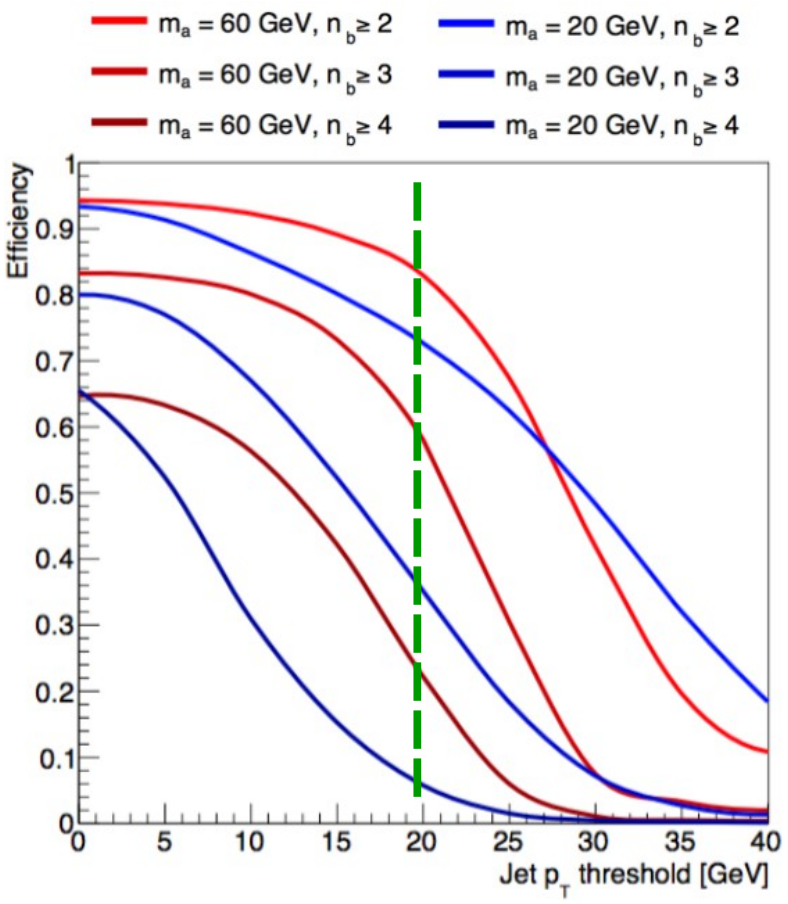
- Warning about trigger choices

Gluon fusion



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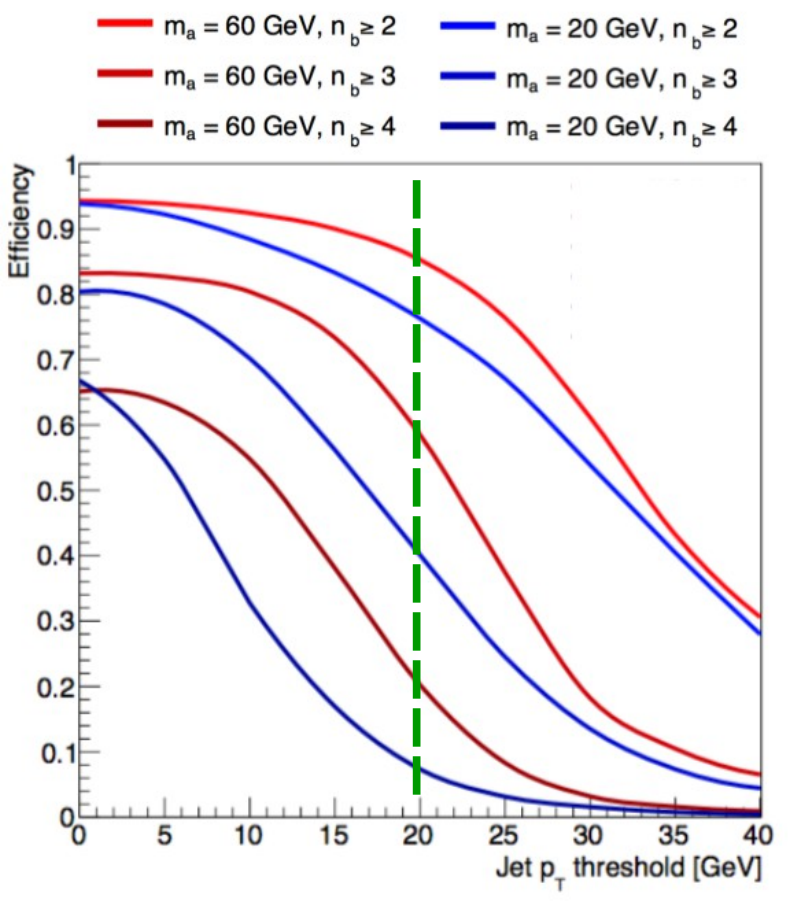
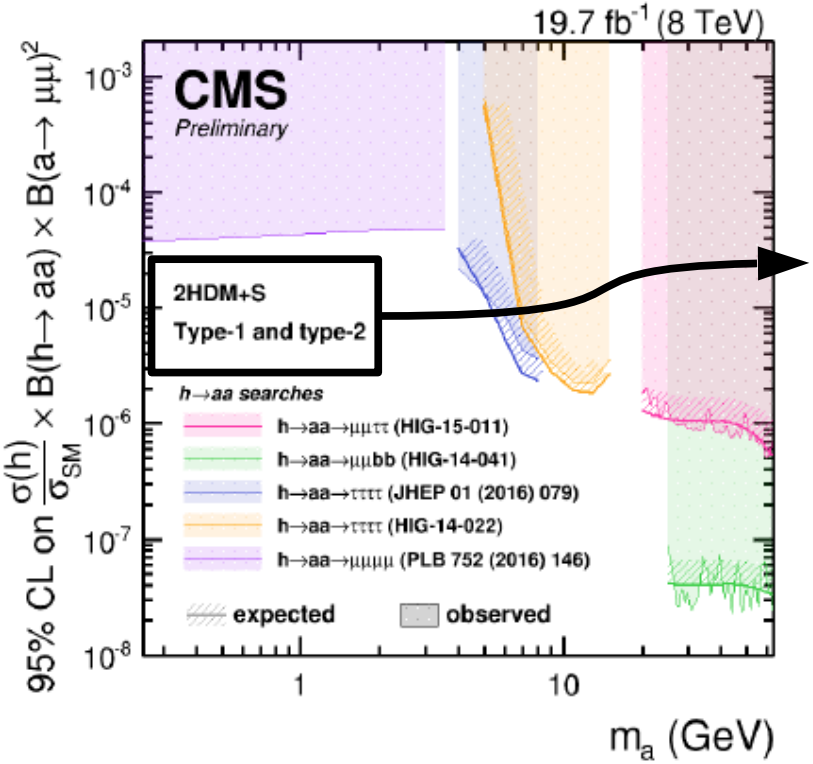


2. Decays to resonances without MET. Future

- Several experimental searches have been performed after we started our work

Nice summary plot from the CMS collaboration:



Benchmark scenario presented in our survey paper 1312.4992

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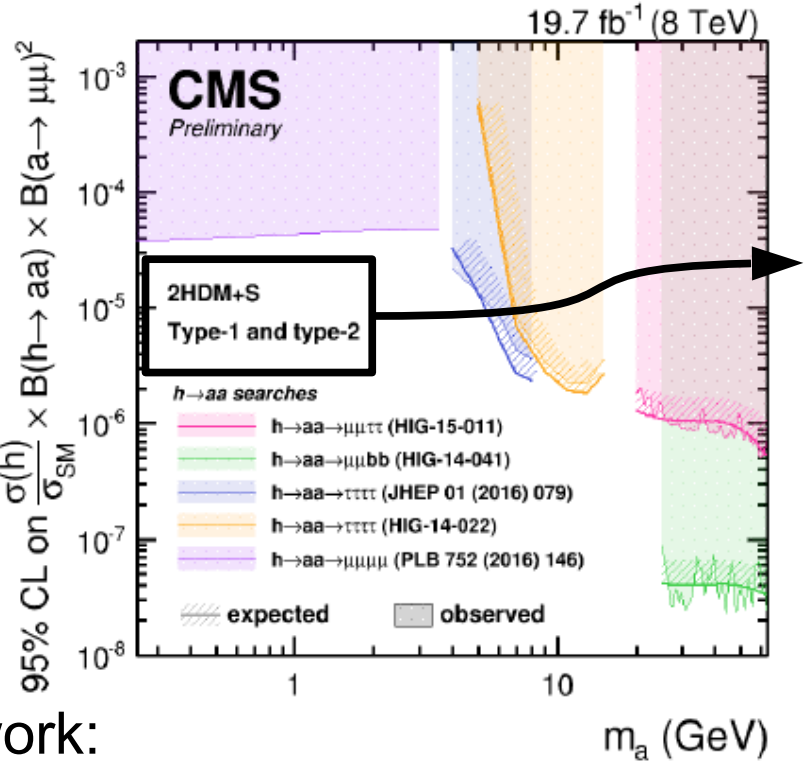


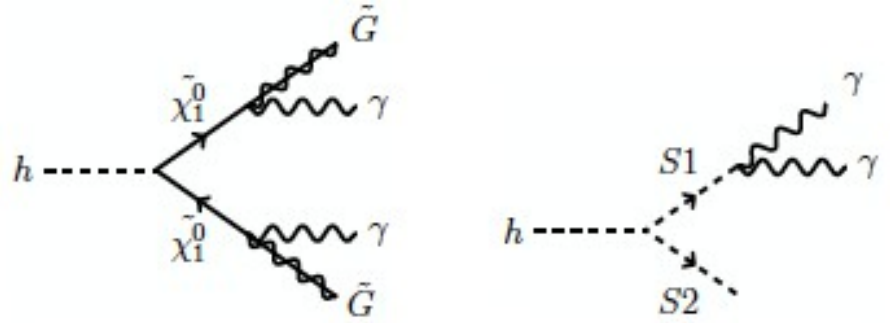
Benchmark scenario presented in our survey paper 1312.4992

- Open questions for future work:
  - Study of new benchmark model points
  - Support development of analyses searching for additional final states. Examples: 2b2τ, collimated objects?
  - Framework for combination of channels
  - Modeling of hadronic backgrounds for the most difficult decays (4b)
  - More studies of the complementarity of the different Higgs production modes

3. Decays with MET. YR4

Di-photon + MET

Feasibility study for the decay topology,
2γ + MET, using 100 fb^{-1} data



- This final state has been already looked for at Run I

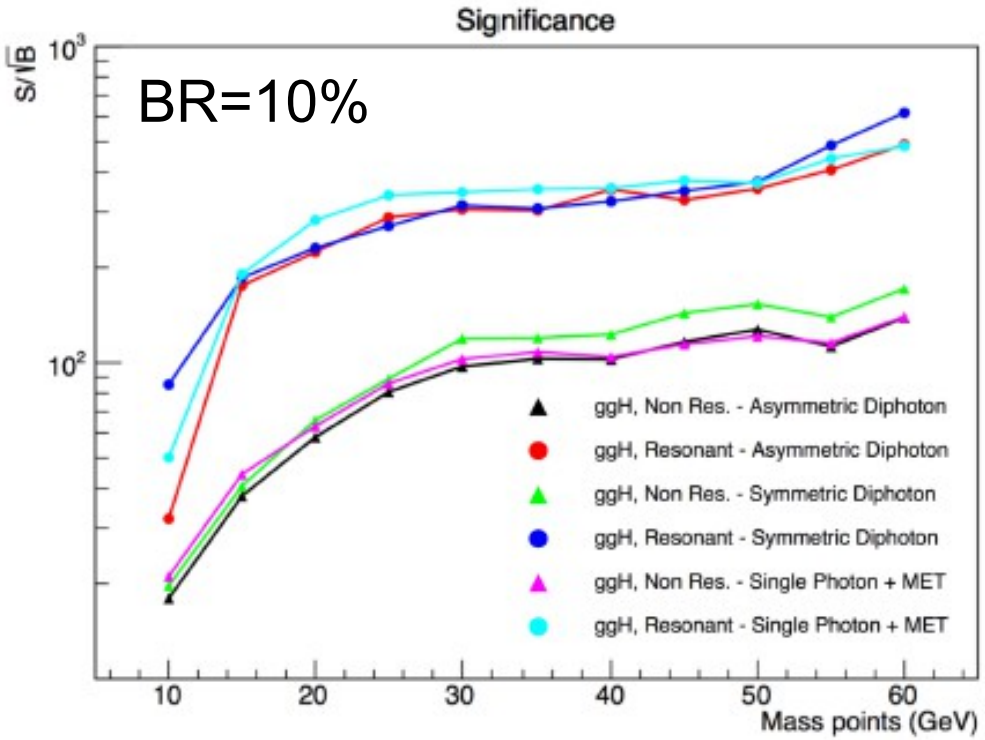
  ATLAS-CONF-2015-001, CMS, 1507.00359

  Bounds on the BRs are up to ~10%

- How do we extend these analyses?

  Comparison of the effectiveness
  of different triggers (for gg fusion):
  - symmetric di-photon trigger
  - asymmetric di-photon trigger
  - 1photon + MET trigger

- This is a channel that will improve quickly with luminosity



3. Decays with MET. Future

- Feasibility studies for additional decay modes (not yet looked for):
  h → 2leptons + MET, h → 2b + MET, h → 2τ + MET.
  Role of different Higgs production mechanisms. Relevance of VBF + X trigger?

- Development of additional benchmark models motivating this type of decay modes

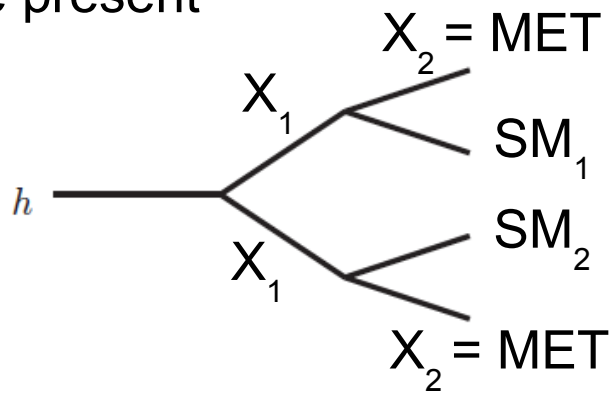
  - For the photons + MET, we have several models, e.g. Gauge Mediated SUSY models

  - What about models for h → 2leptons + MET, h → 2b + MET, h → 2τ + MET?

- Study of what is the best way to present experimental results.

More degrees of freedom, if compared to the decay without MET;
Several mass scales are present

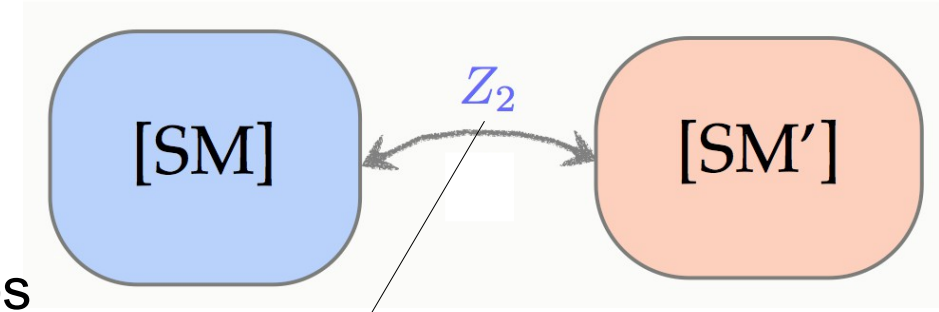
Example for
a 2 → 4 process



4. Displaced decays. YR4

$h \rightarrow G_0\ G_0 \rightarrow SM$
displaced

- Discussion of the motivations:
  - neutral naturalness theories (folded SUSY, fraternal twin Higgs models, …)
  - Gauge mediated SUSY theories



- Computation of Higgs branching ratios and life times predicted by these models

Not commuting with the SM color

Hidden QCD

with hidden glueballs: the lightest preferred in (10-60) GeV

- Discussion of the limiting factors of the present searches for displaced particles
  - requirement of 2 displaced vertices
  - large n.tracks, p_T thresholds, … (searches targeted on heavier particles)
  - sizable displacement (above the ~mm-cm)

- Proposal for new searches

4. Displaced decays. Future (1)

We want to ask the question:
what is needed to have a broad experimental program
for Higgs decaying to particles with displaced decays?

"Experimental questions":

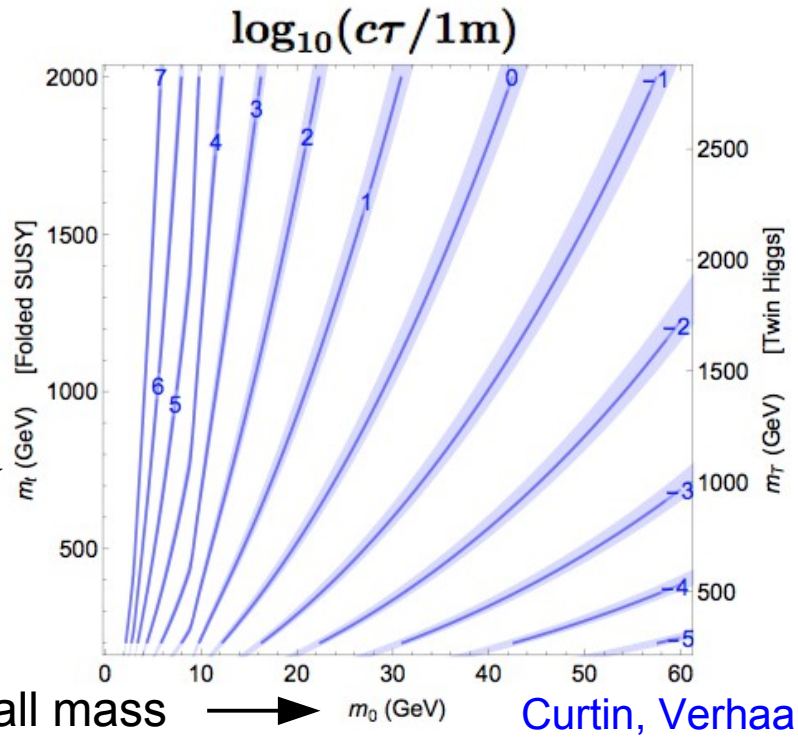
- what are the feasible searches?

Focus on 1 displaced vertex + associated object (lepton, forward jets, …)
coming from the Higgs production?

- How low can we go in the displacement?
  Combined prompt + displaced searches?

Large range of life times
are interesting!

Top partner
mass



Glueball mass

Curtin, Verhaaren,
1506.06141

4. Displaced decays. Future (2)

We want to ask the question:
what is needed to have a broad experimental program
for Higgs decaying to particles with displaced decays?

"Theoretical/Experimental questions":

- What is the best way to present experimental results?

- For the prompt decays it is simpler:
bound on σ X BR, as a function of m_X ($h \rightarrow X\,X \rightarrow SM$) or
as a function of the two mass scales m_{X1}, m_{X2} ($h \rightarrow X_2\,X_2 \rightarrow SM\,X_1\,X_1$)

Our recommendation for YR4

- How to extend this recommendation to displaced decays?

- Minimal set of free parameters allowing a simple recast by theorists.
- Publication of supplementary information to enhance usability of results
(Efficiency maps and fiducial observables)

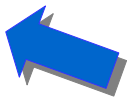
Expect to coordinate with efforts dedicated to displaced objects generally: e.g. LHC long-lived particle forum

More plans/wish list for the future

1. Our next target:

Facilitate and maximize the number of experimental analyses that will be performed with the first 100fb^{-1} LHC13 data

Development of trigger strategies for this scope



Urgency

2. We will also start to look at the opportunities the HL-LHC will offer for rare/exotic Higgs decays. O(10^8) Higgs bosons will be produced!

We would like to coordinate our work with the future physics performance CMS and ATLAS groups

Aim to be the reference for experimentalists working on Higgs rare/exotic decays

Summary of the future directions

More studies of Higgs rare and exotic decays aimed for 100fb^{-1} LHC13

Start the effort for the HL-LHC. What are the best channels?

Large luminosities ahead ⇒ many opportunities!

Continue to analyze good trigger pathways for signals, depending on the Higgs production mechanism we are aiming for

Theory-experiment dialogue extremely useful

Please send us feedback on future directions!

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Abdollah Mohamadi (abdollah.mohammadi@cern.ch), Jessie Shelton (jshelton137@gmail.com)

Next meeting: SLAC, November 7-8,
immediately followed by Higgs Couplings 2016 (Nov. 9-12)

http://indico.cern.ch/event/492240/

All are welcome!

Our assumptions

1312.4992

1. The observed 125 GeV is SM-like

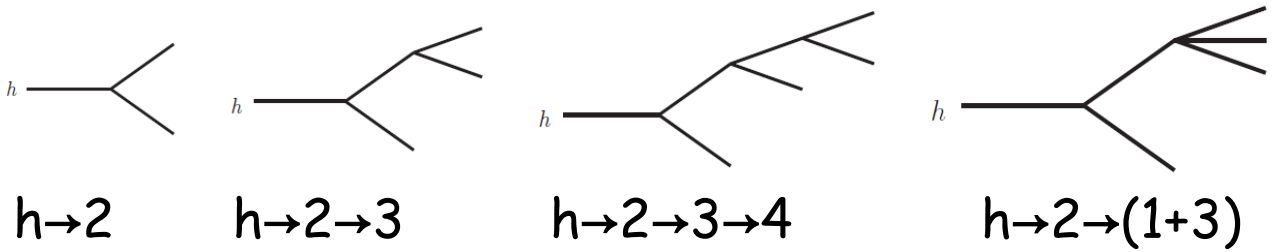
In particular its production cross section in the several channels is the one of the SM Higgs

2. The Higgs decays promptly to new BSM particles that are either stable or promptly decaying

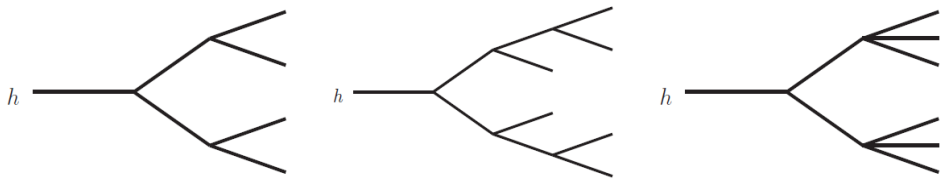
we do not consider rare or nonstandard decays to SM particles

3. The Higgs decay is a 2-body decay

3-body decays are possible, but require new light states with substantial coupling to h to overcome phase space suppression



h→2 h→2→3 h→2→3→4 h→2→(1+3)



h→2→4 h→2→4→6 h→2→6

h→MET	h→$Z_D Z_D$→4l
h→4b	h→γ+MET
h→2b2τ	h→2γ+MET
h→2b2μ	h→4l+MET
h→4τ, 2τ2μ	h→2l+MET
h→4j	h→one lepton jet
h→2γ2j	h→two lepton jets
h→4γ	h→bb+MET
h→ZZ_D→4l	h→ττ+MET