Looking for Dark Matter in Exotic Higgs decays

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on behalf of the ATLAS Collaboration

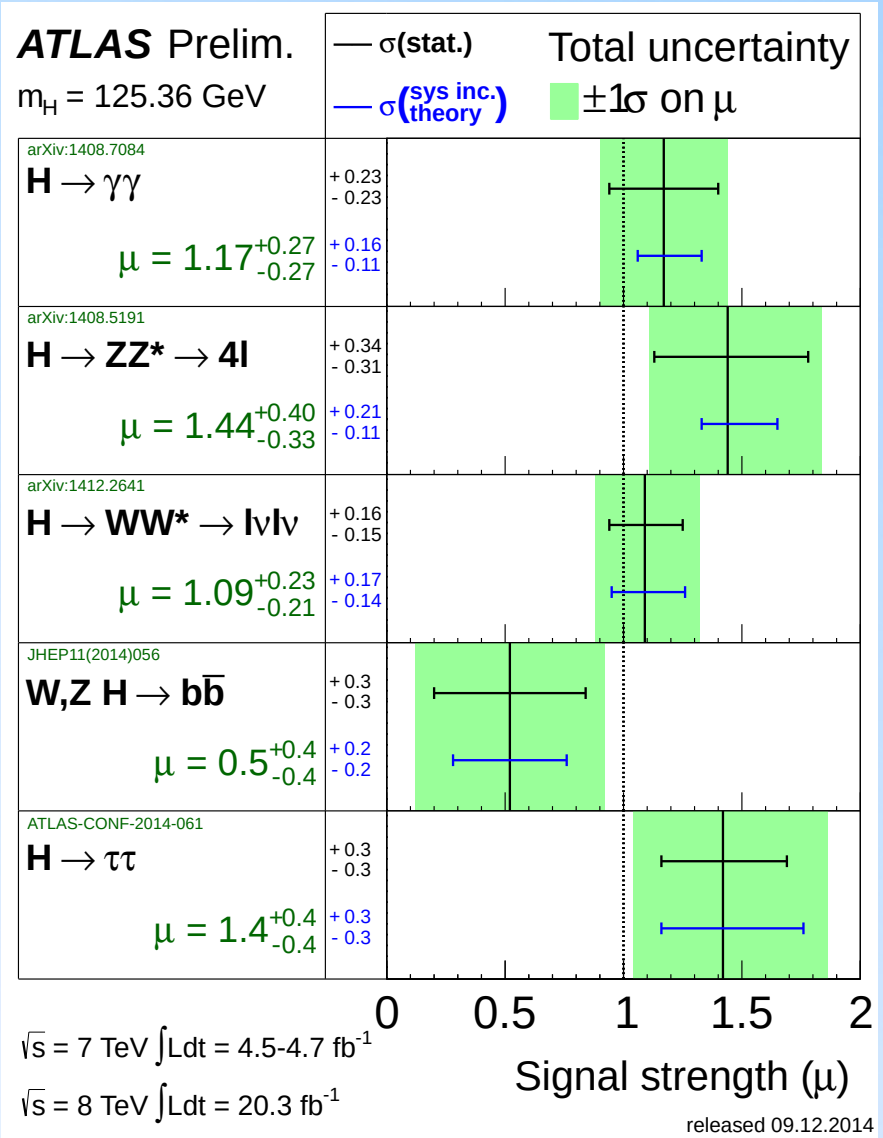
Outline:

1. Why exotics Higgs decays?
2. Lepton-jet searches
3. Displaced vertex searches
4. Invisible Higgs searches
5. Run-I legacy and Run-II outlook

Exotic Higgs decays

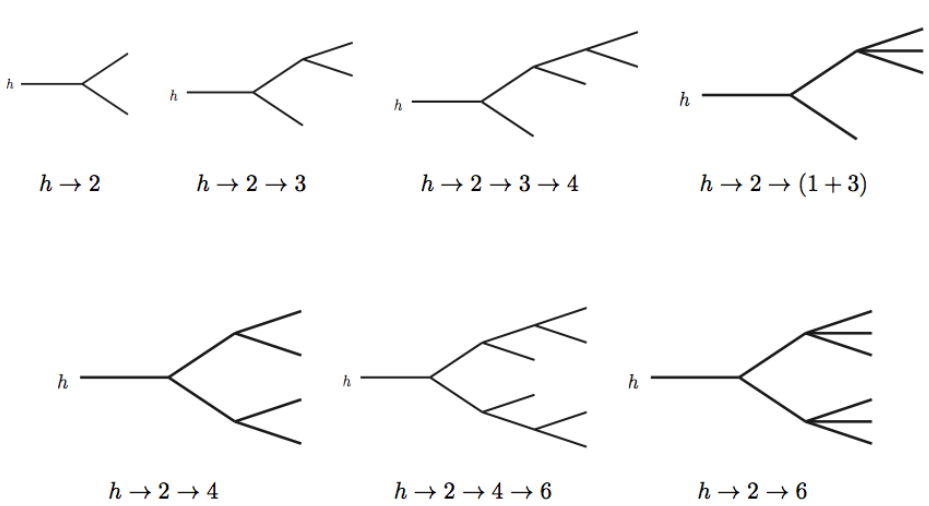
- new fundamental scalar consistent with SM Higgs boson
- constraints from observing the Higgs boson in the various SM channels allow non-SM BR of $\mathcal{O}$(20-50%)
- large experimental uncertainties on the Higgs boson couplings

The only way to know if the Higgs has a 10% non-SM branching ratio is to directly look at exotic signatures.



link to CombinedSummaryPlots twiki

Exotic Higgs decays

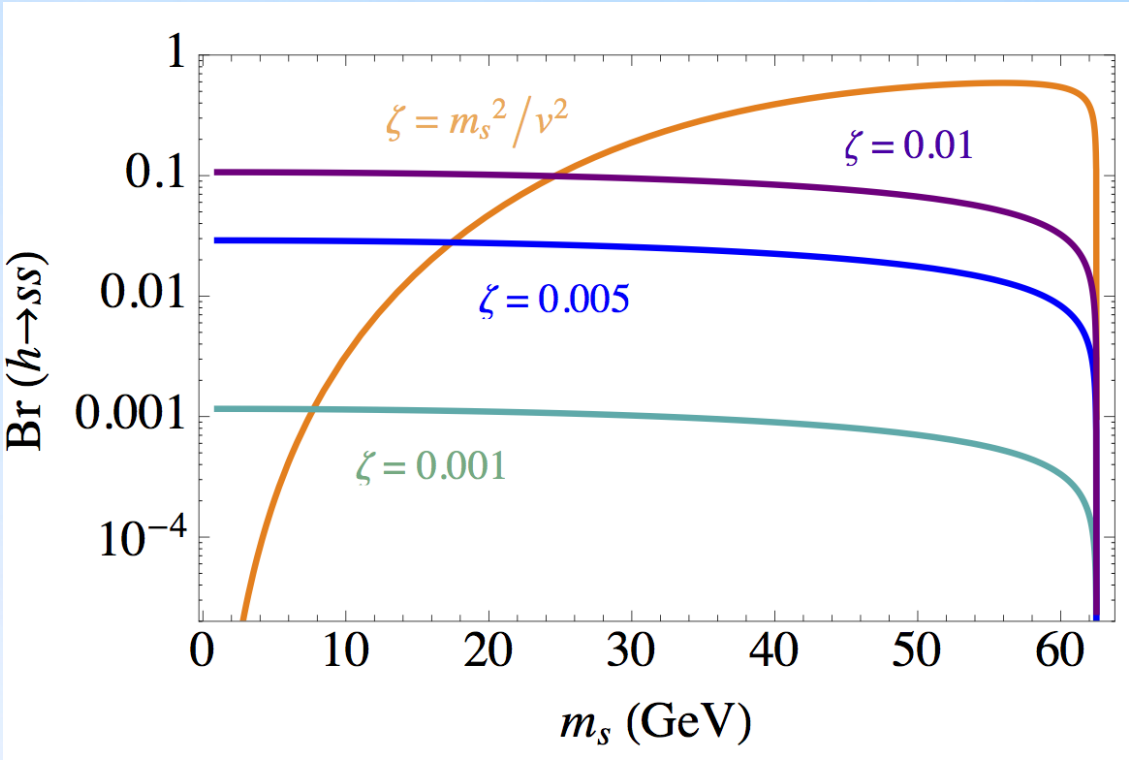


h→MET	h→Z_DZ_D→4l
h→4b	h→γ+MET
h→2b2τ	h→2γ+MET
h→2b2μ	h→4l+MET
h→4τ, 2τ2μ	h→2l+MET
h→4j	h→one lepton jet
h→2γ2j	h→two lepton jets
h→4γ	h→bb+MET
h→ZZ_D→4l	h→ττ+MET

Assuming an initial 2-body exotic Higgs decay:

- non-exhaustive list and clearly DM candidates and DM-driven signatures in many cases
- in addition to precise measurement of the properties, an aggressive search program by LHC experiments needs to be carried out
- Run-I for Higgs, Run-II for BSM Higgs
- some of these signatures not covered in Run-I , others still not public

Exotic Higgs decays

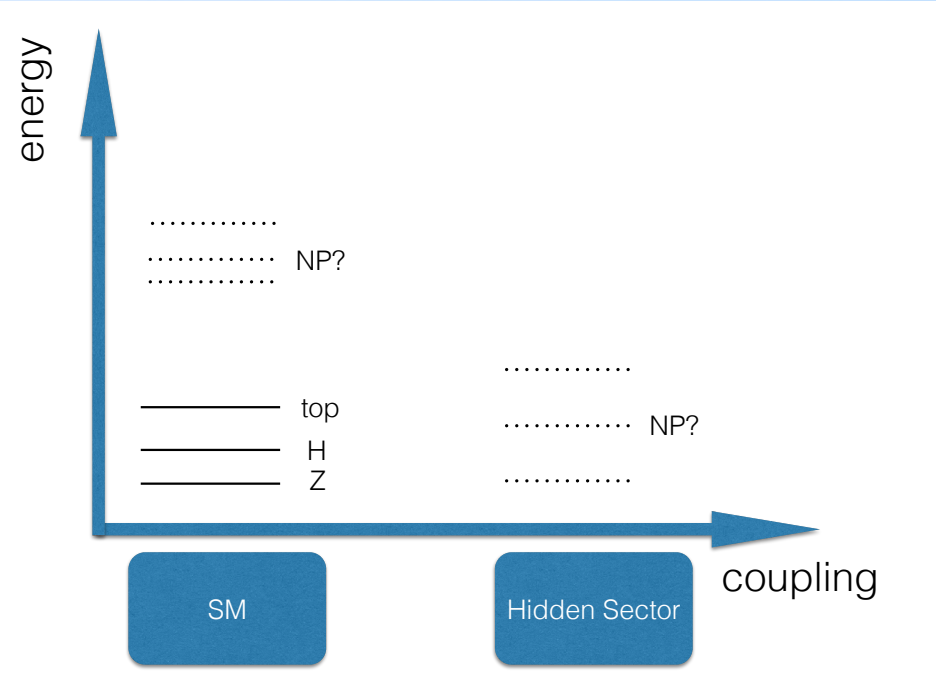


arXiv 1312.4992

Higgs can be the candle for looking for NP!

- Higgs width is only ~ 4 MeV and a tiny coupling can give rise to a large exotics BR
- $|H^2|$ is the only SM-singlet operator with $d < 4$ in the SM lagrangian and any BSM single operator can couple to the Higgs with no or mild coupling suppression

Hidden/Dark sectors



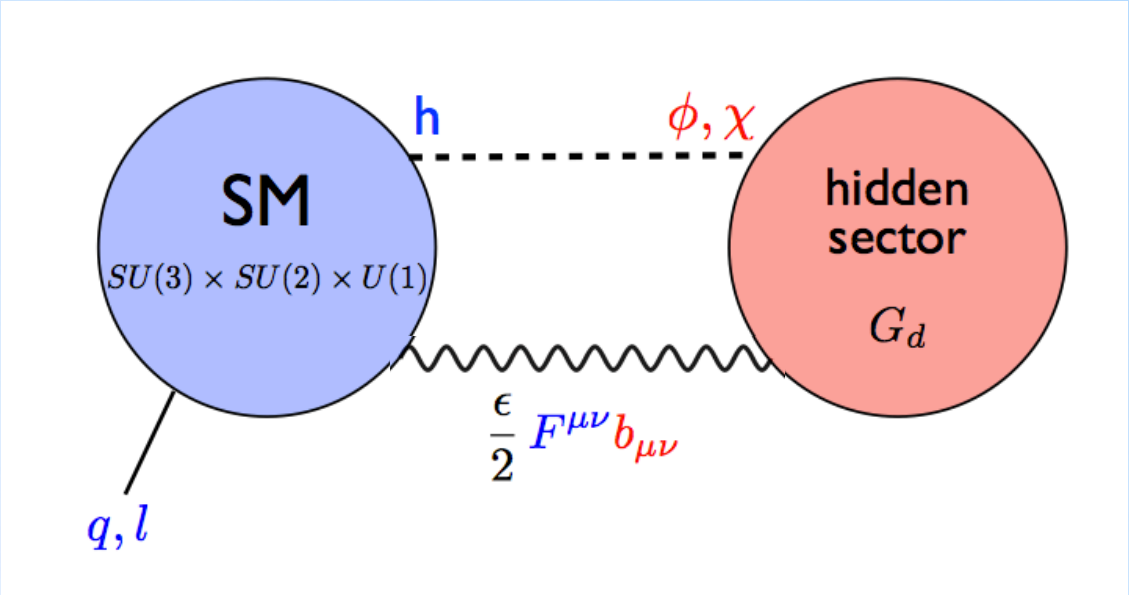
BSM not yet seen at the LHC because at higher energy scale or because hidden in a separate sector weakly coupled to the SM

- clear connection with Dark Matter beyond the WIMP paradigm
- intensity as important as energy
- framework that can accomodate various phenomenology scenarios

Focusing here on the signatures directly related to non-SM Higgs with DM interpretations

1. to dark photons
2. to long-lived meta-stable particles
3. to long-lived invisible particles

Vector portal models



Key feature of the vector portal model

- $U_d(1)$ gauge invariance resulting in a kinetic mixing between the SM photon and the dark photon
- the strength of the interaction is tuned by the ϵ parameter
- production of prompt/displaced collimated/nearly-collimated leptons

W + Prompt Electron-Jets

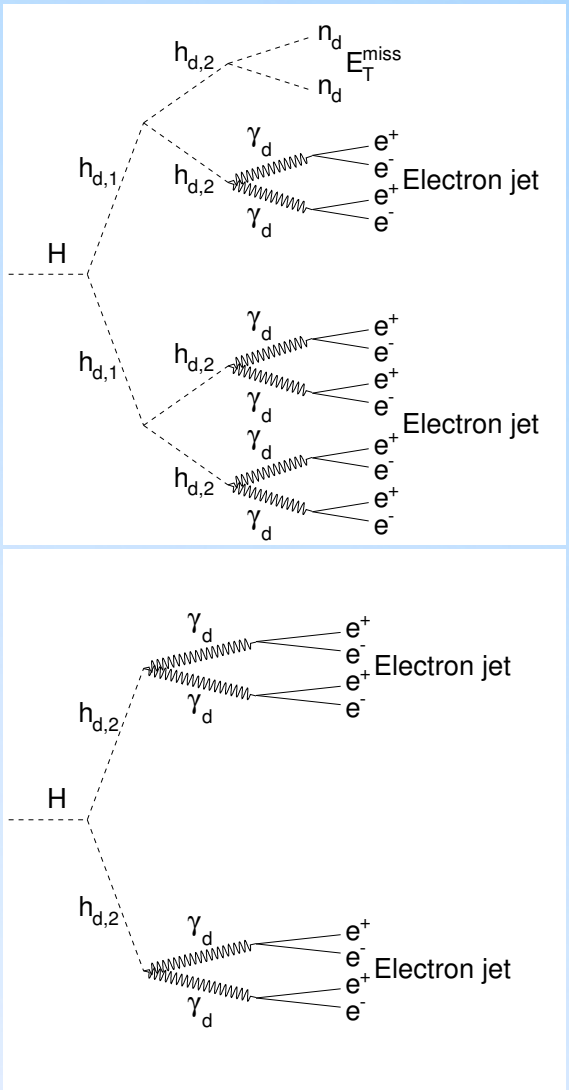
Associated Higgs boson production with:

- Higgs boson decay to electron-jets and weakly interacting neutral particles in a two- or three-step cascade;
- production of hidden sector particles: dark photon γ_d, neutral stable scalar n_d and hidden scalars h_d.

Final states considered:

- two distinct jets;
- at least 4 electrons per jet.

Reference
NJP 15, 043009 (2013)

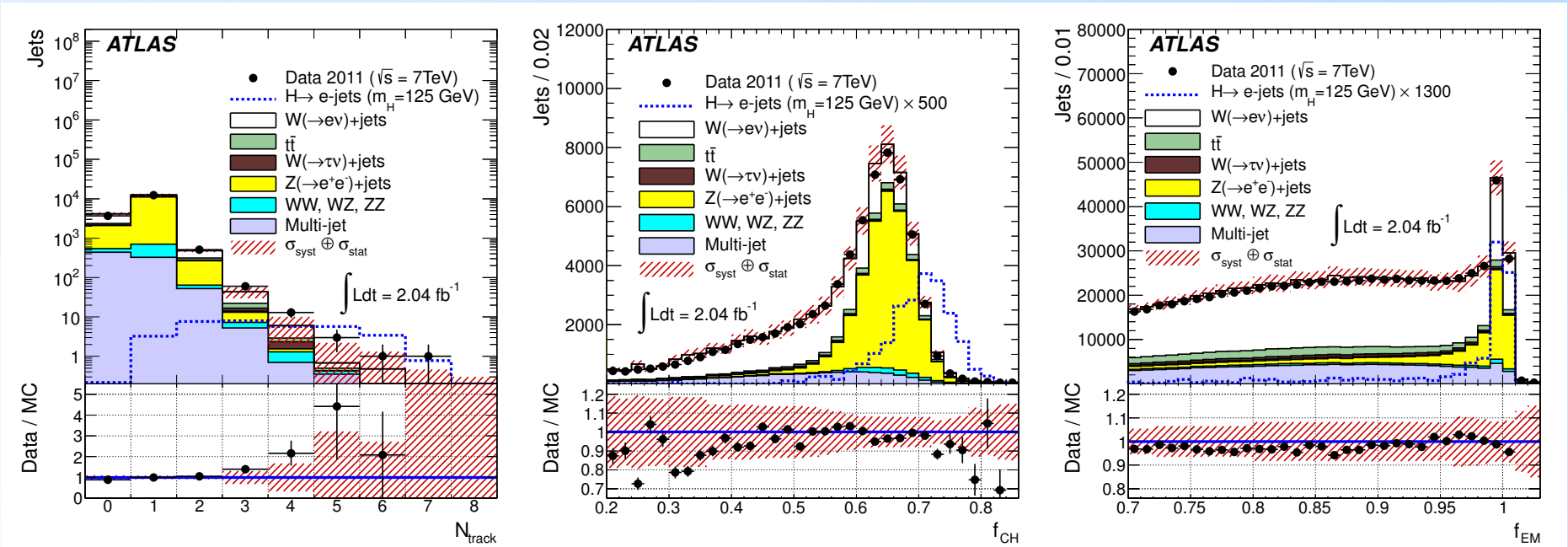


W + Prompt Electron-Jets

Both W decays to electron and muon considered:

- objects in the electron-jets are too collimated for standard reconstruction;
- 3 discriminating variables identified (jet EM fraction, fraction of hits with high energy deposition, jet charged particle fraction).

Background is dominated by W + jets.



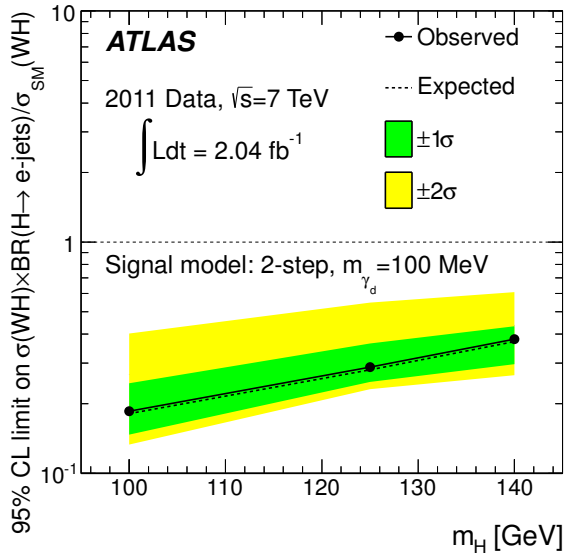
Results

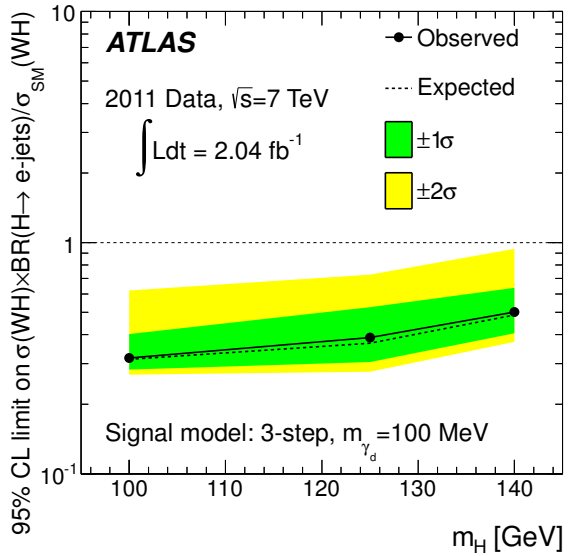
Higgs boson masses of 100, 125 and 140 considered with dark photon masses of 100 and 200 MeV.

Higgs boson branching ratios to electron-jets are excluded between 24% and 45% for $m_H = 125\,\text{GeV}$ at 95% C.L.

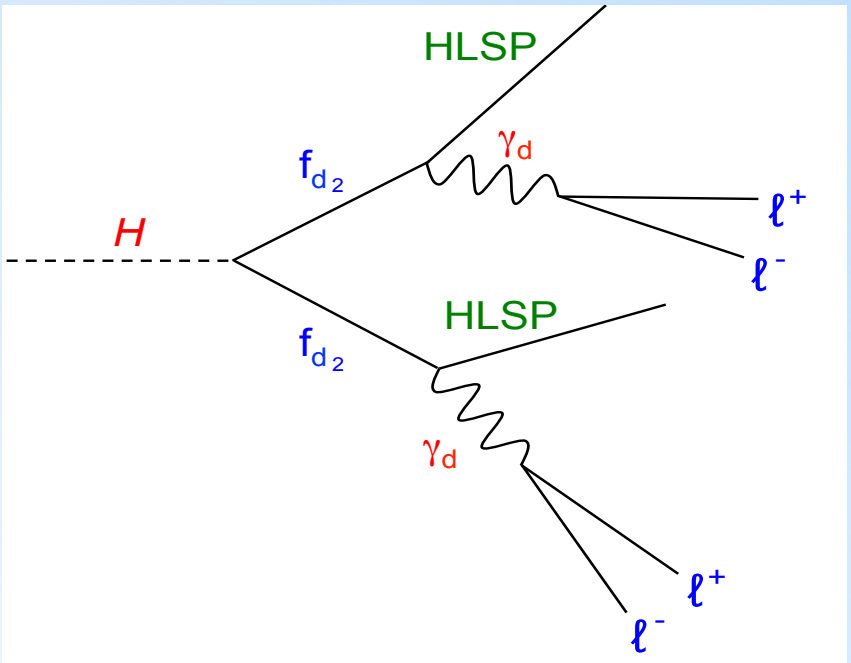
8 TeV prompt lepton-jet search being finalized.

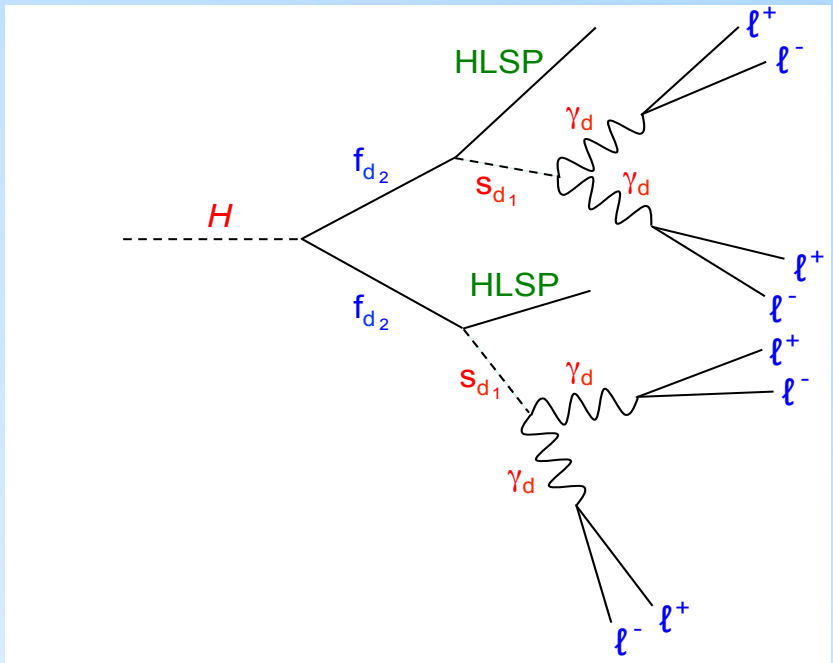
Signal	Three-step model		Two-step model	
m_H (GeV)	$m_{\gamma_d} = 100\,\text{MeV}$	$m_{\gamma_d} = 200\,\text{MeV}$	$m_{\gamma_d} = 100\,\text{MeV}$	$m_{\gamma_d} = 200\,\text{MeV}$
100	$14.3 \pm 1.7 \pm 0.8$	$12.4 \pm 1.6 \pm 0.7$	$22.6 \pm 2.1 \pm 1.2$	$23.5 \pm 2.1 \pm 1.2$
125	$11.3 \pm 1.0 \pm 0.6$	$10.7 \pm 1.1 \pm 0.6$	$16.2 \pm 1.2 \pm 0.9$	$18.1 \pm 1.4 \pm 1.0$
140	$9.6 \pm 0.8 \pm 0.5$	$9.0 \pm 0.8 \pm 0.4$	$13.7 \pm 0.9 \pm 0.8$	$13.9 \pm 0.9 \pm 0.8$
Background	$0.41 \pm 0.29 \pm 0.12$			
Data	1			





Displaced Lepton-Jets

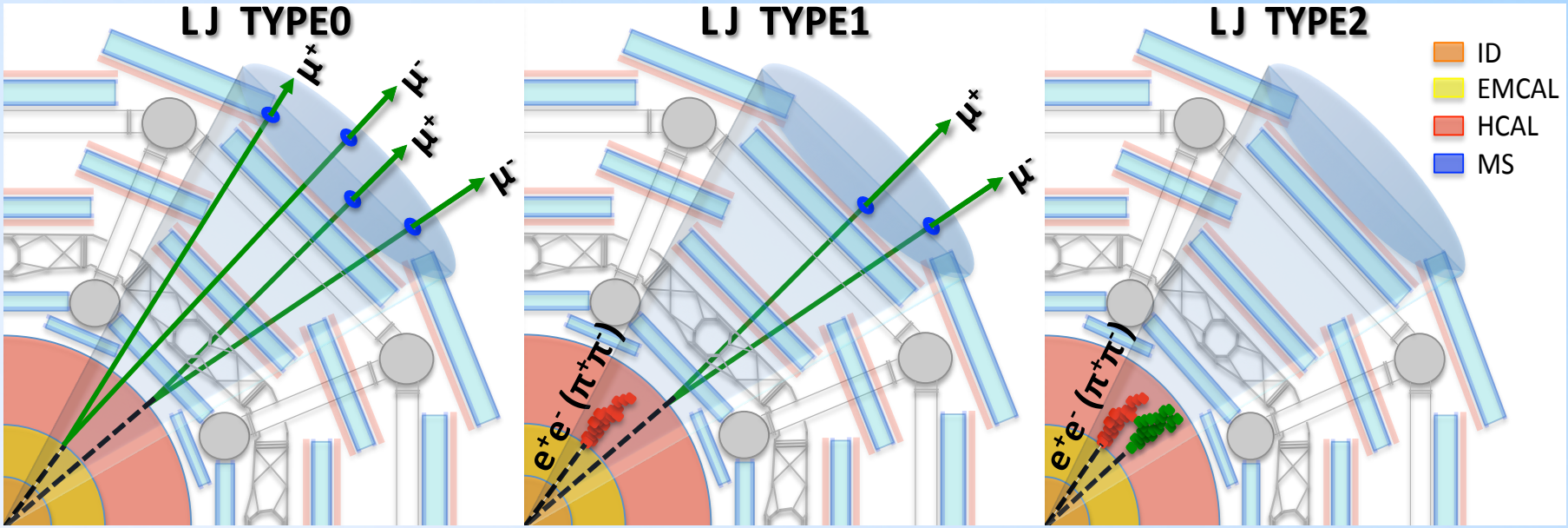




Entire analysis optimized generating lepton-jet events with different kinematics in a truly model-independent way

- benchmarks targeting dark photon production through exotic Higgs decay

Higgs to displaced lepton-jets

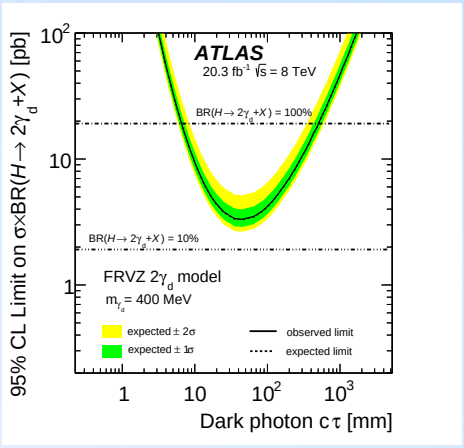


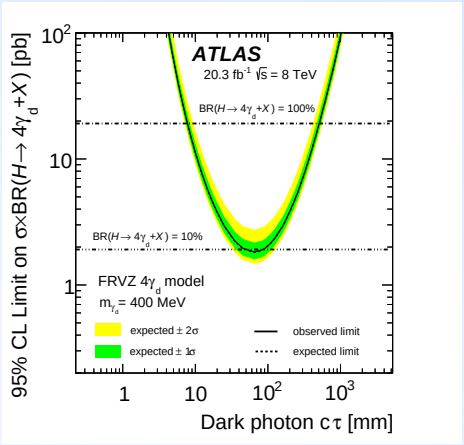
Main backgrounds:

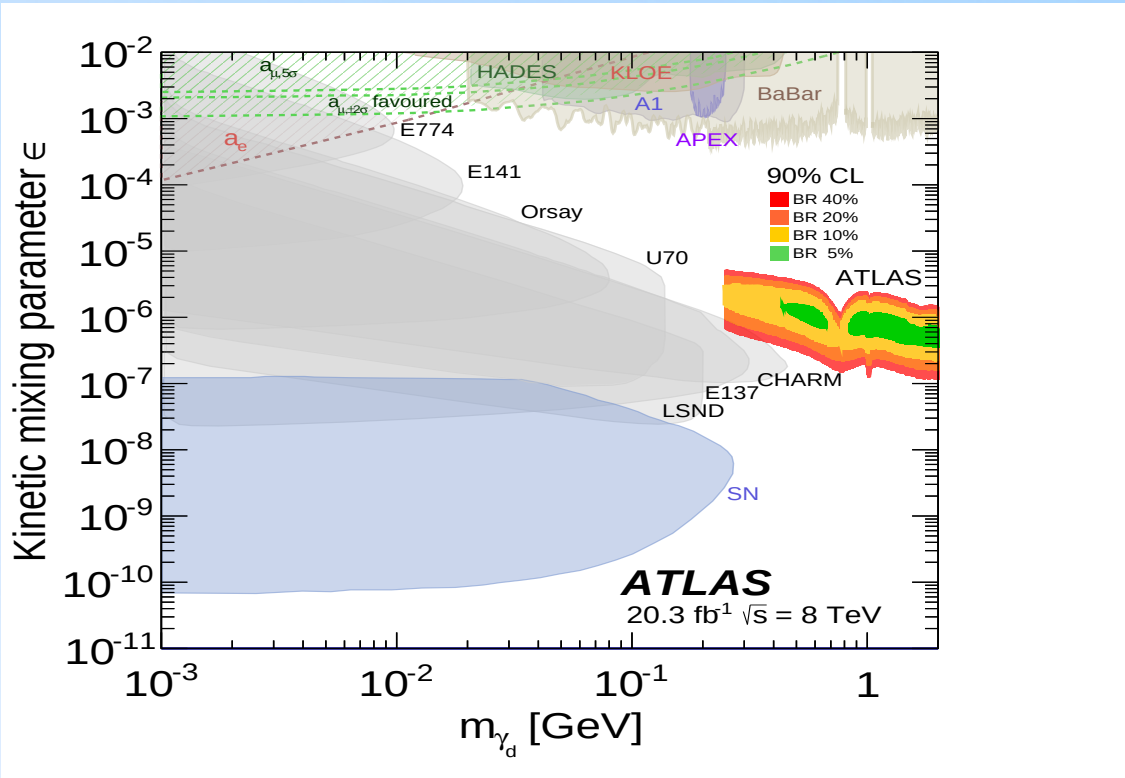
- QCD multi-jet background calculated with ABCD method
- cosmics background estimated analysis the empty bunches

Reference
JHEP 11 (2014) 088

Results







Hadron-collider experiment entering into the mass vs ϵ plot of the vector-portal interpretation.

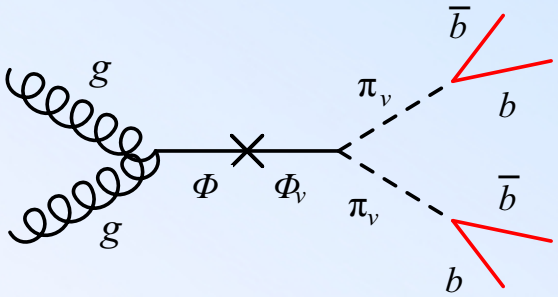
Consistent approach in presenting the limit from various experiments and various approaches within the same experiment. Previously unexplored region is now constrained by ATLAS.

Higgs to displaced jets in the HCal

Unique analysis, signature never explored before

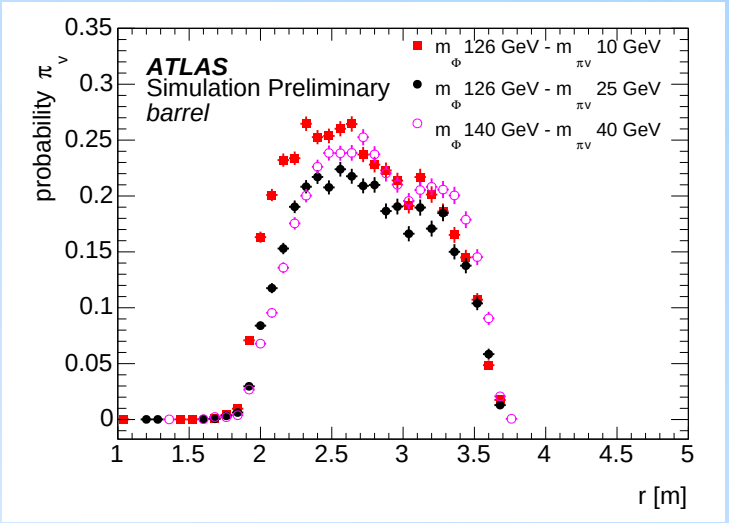
Main features

- two object strategy looking for displaced hadronic jets
- track isolation
- signature-driven trigger

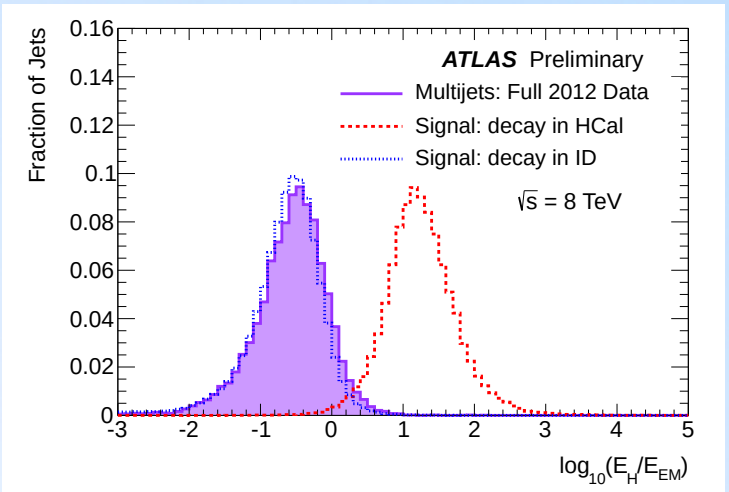


Reference
ATLAS-CONF-2014-041
JINST 8 P07015

trigger efficiency vs decay position



key discriminant variable against QCD background



Higgs to displaced jets in the HCal

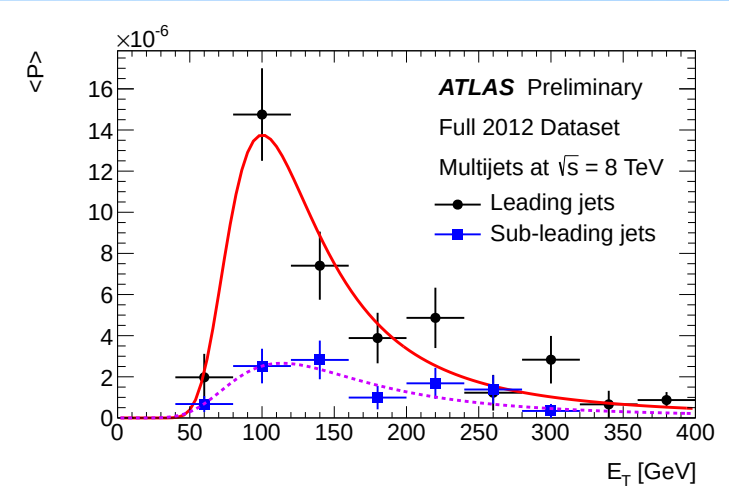
Background and systematics

- background dominated by QCD jets and estimated with a data-driven technique
- cosmic and beam halo background also considered
- derived JES systematics for low-EMF jets

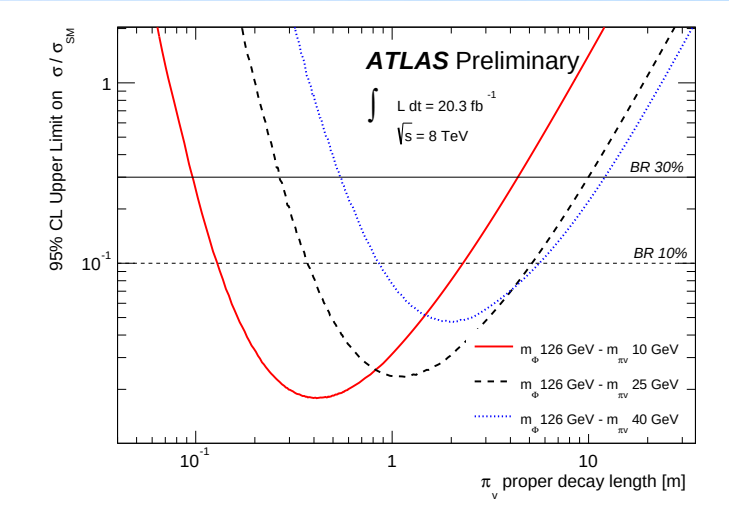
Exclusion limit considering a Higgs decay to a pair of long-lived pseudo-scalar π_v

MC sample m_H, m_{π_v} [GeV]	excluded range 30% BR [m]	excluded range 10% BR [m]
126,10	0.10 - 4.42	0.13 - 2.34
126,25	0.27 - 9.99	0.37 - 5.20
126,40	0.54 - 12.4	0.83 - 5.83

probability for a QCD jet to pass the cut flow



exclusion limit as a function of the lifetime



Higgs to displaced jets in the MS

Production of neutral LLP particle decaying in the MS.

- again two objects for suppressing the background
- signature-driven trigger asking for set of Muon RoIs isolated with respect to tracks and jets
- 8 TeV result public soon and will also include displaced vertices in the ID

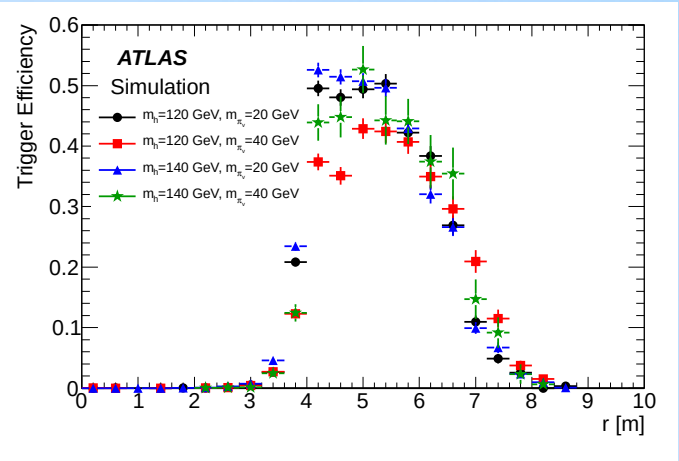
References

PRL 108.251801

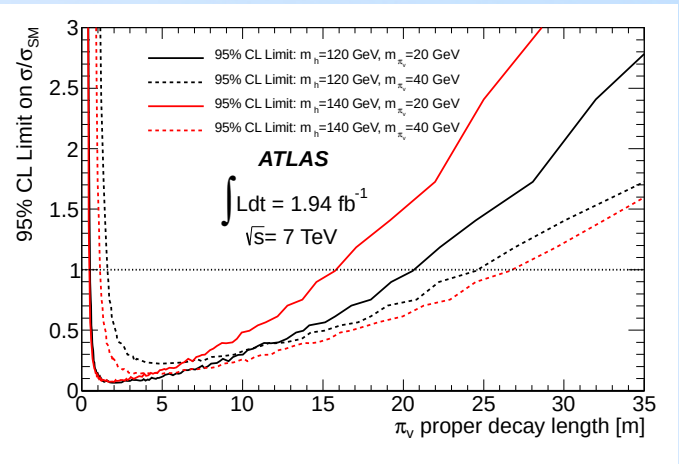
JINST 8 P07015

JINST 9 P02001

trigger efficiency vs decay position



exclusion limit as a function of the lifetime



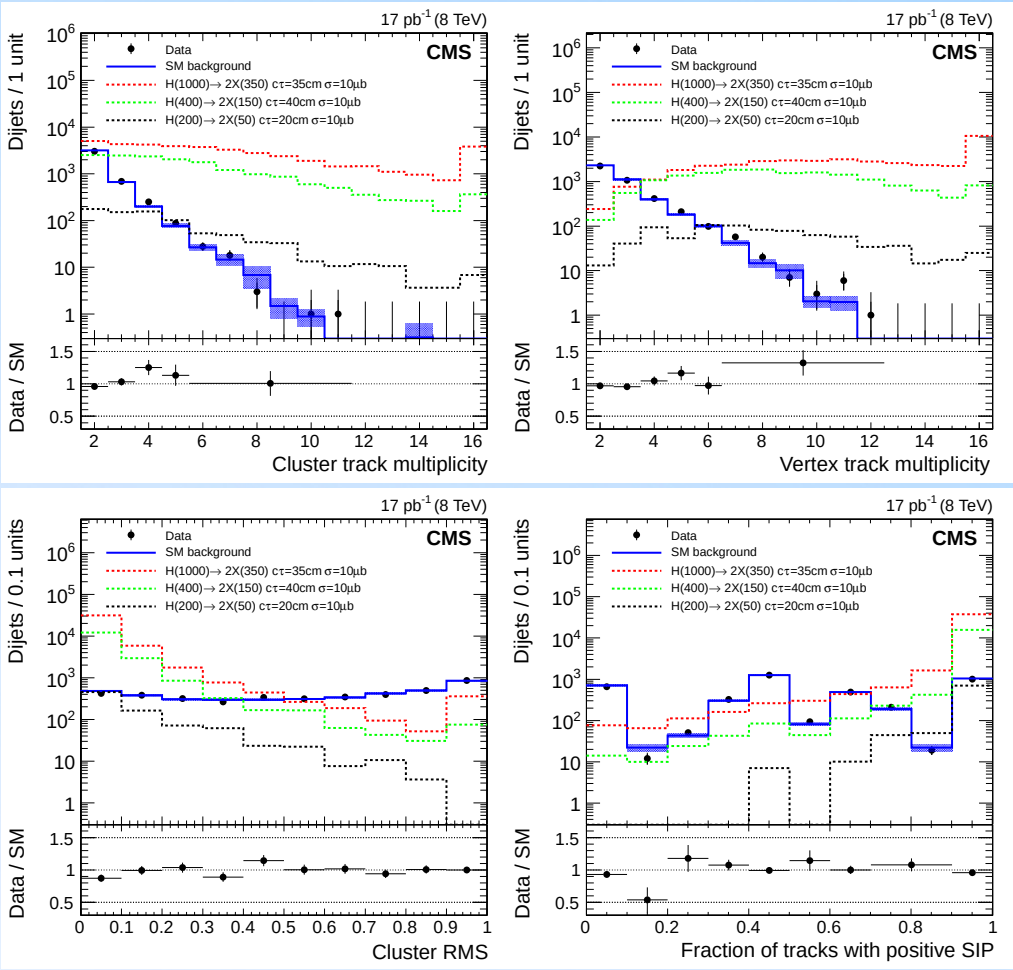
Higgs to displaced jets in the ID

Looking for displaced decays in the CMS tracker associated to jet pairs

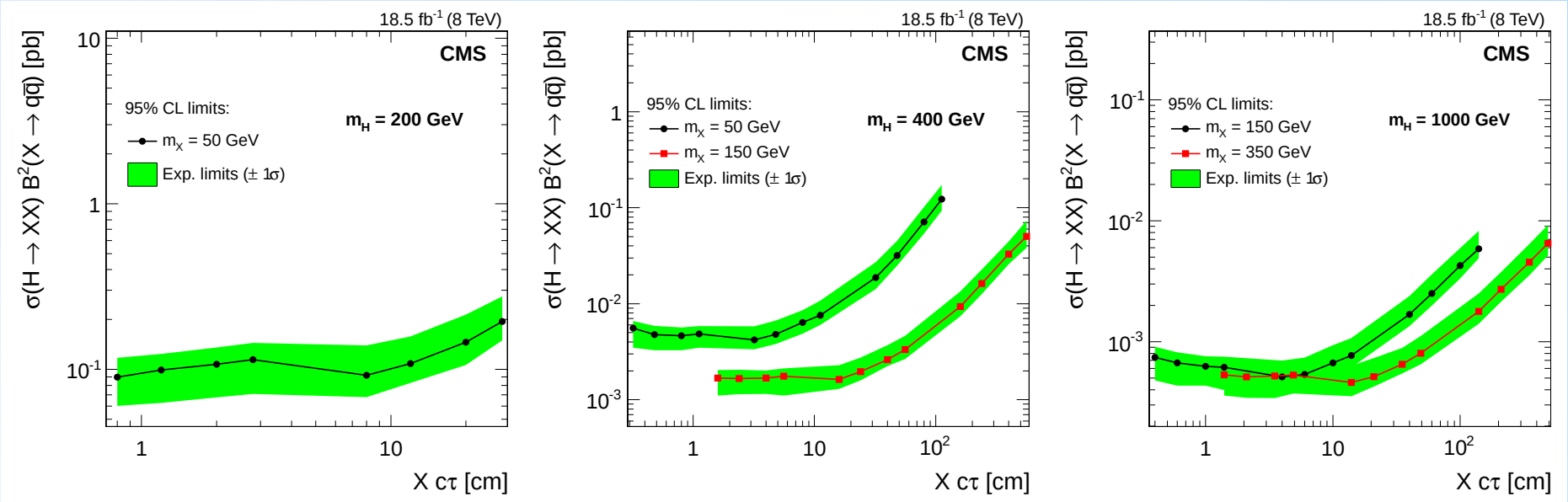
Main challenge is to gain sensitivity for displacements while keeping the potentially huge QCD background under control

- cuts on the 3D impact parameters and on the fraction of jet's total energy associated to tracks both online and offline
- two sets of displaced tracks are fitted for finding a common SV
- further likelihood discriminant with four ingredients

References
arXiv 1411.6530



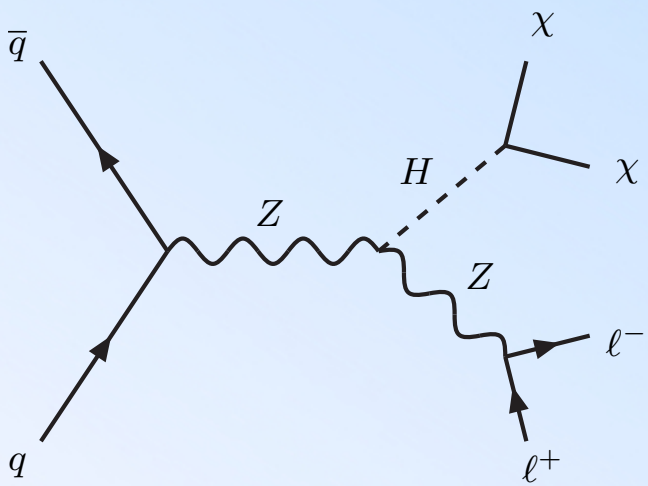
Higgs to displaced jets in the ID



Exclusion limits for various H and X masses as a function of the X proper lifetime when studying the process $H \to XX, X \to q\bar{q}$

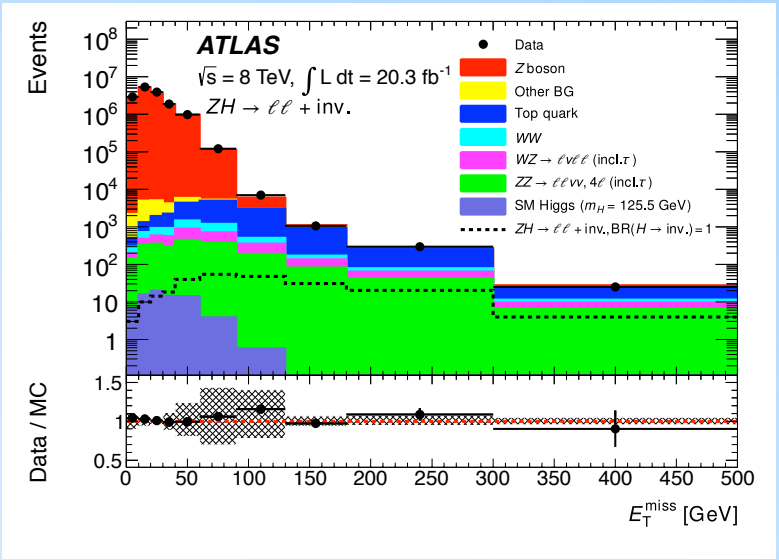
- for X with proper lifetimes between 0.4 and 200 cm, the upper limits are in the range 0.5-200 fb

$ZH \rightarrow$ invisible

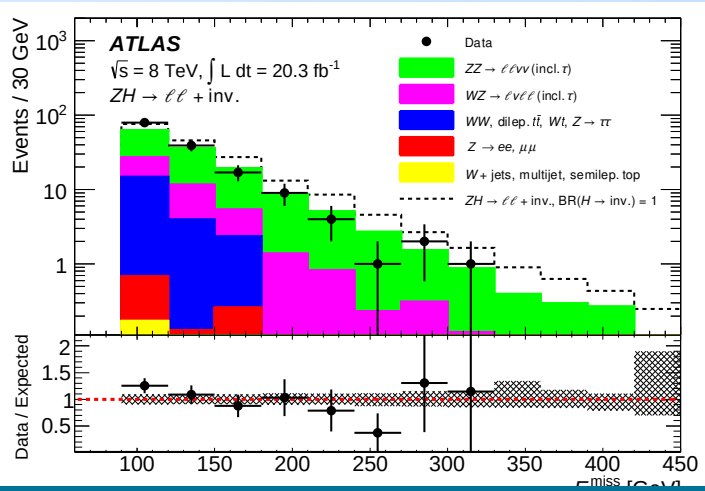


Reference
arXiv:1402.3244

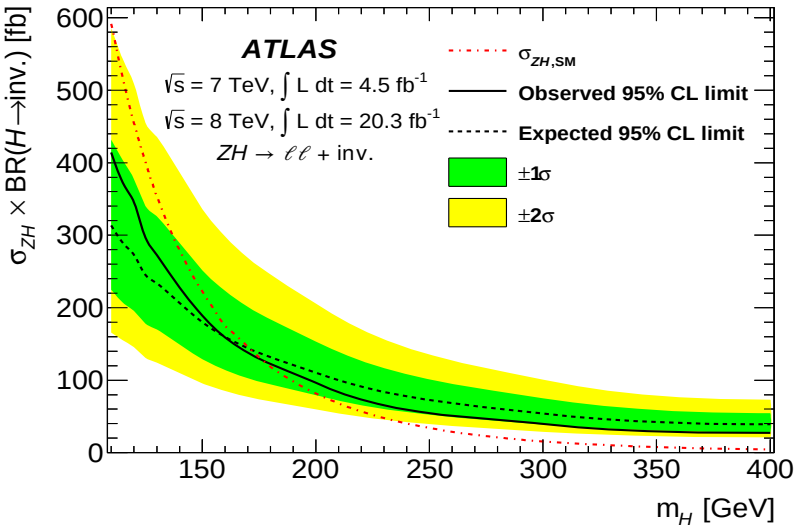
MET in the invariant mass of the two leptons

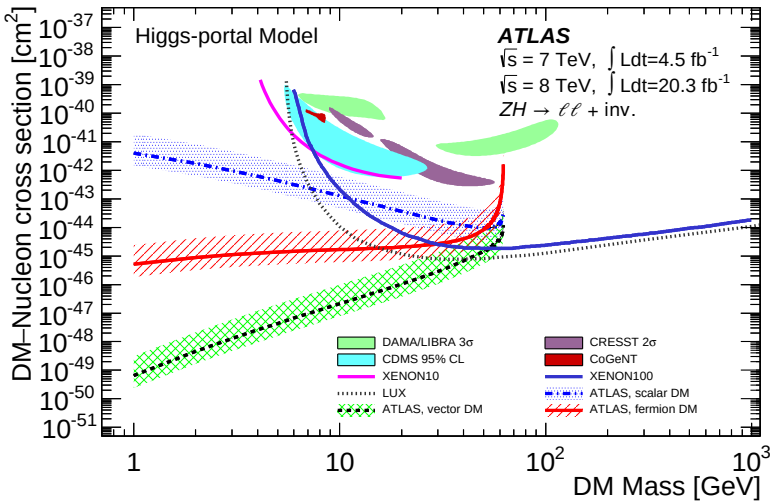


MET after the full analysis selection



$ZH \rightarrow$ invisible





Both direct and indirect searches setting limits on the DM-nucleon cross section

- the results from the direct-search experiments do not depend on the assumptions of the Higgs-portal scenario
- many more searches targeting invisible Higgs decays are planned or in the pipeline
  - recasting of CMS stop quark search to ttH production channel constrains the invisible decay to < 40 at 95% $C.L.$ - arXiv:1408.0011
- VBF production mode seems the most sensitive approach
- triggers targeting the VBF production mode planned for Run-II

Conclusions

Exotic Higgs searches provide an excellent opportunity for BSM physics including DM searches

- possibility to present results together with direct searches
- plethora of different signatures, each with its own challenges for reconstructing the objects and controlling the backgrounds
- ongoing efforts for optimizng non-standard reconstruction in Run-II

Much more is out should be coming out soon (not included here for timing constraints or for non including a non-SM Higgs decay imterpretation)

- dark Z searches mainly targeting the 4 lepton channel
- other techniques for reconstructing LLP decays (displaced di-leptons, displaced multi-track vertex plus a muon)
- delayed photons or multi nearly-collimated photons

Other searches targeting BSM Higgs physics are being planned for Run-II

- invisible Higgs searches considering various production mechanisms
- mono-Higgs searches (standard mono-X searches can't directly probe the effective SM-DM coupling) - arXiv:1312.2592