BSM physics with photons at ATLAS and CMS: Resonances and BSM Higgs

Chiara Rovelli (INFN Roma)

on behalf of ATLAS and CMS Collaborations

BSM physics at LHC

The discovery of a SM-like Higgs Boson completed the Standard Model

Strong indications that SM is a low-energy expression of a more general theory
- Direct evidence from observation (dark matter, matter-antimatter…)
- Conceptual problems

Huge number of searches ongoing at LHC

- 2HDM, extra dimensions (resonance bump)
- Dark Matter
- SUSY
- Contact Interactions
- BSM Higgs sector
- …

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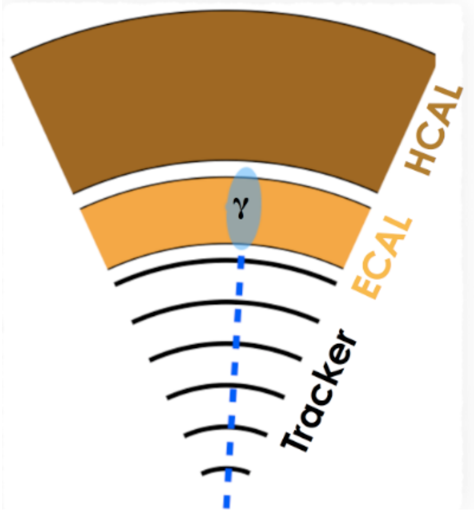
More on other topics in B.Schumm's talk

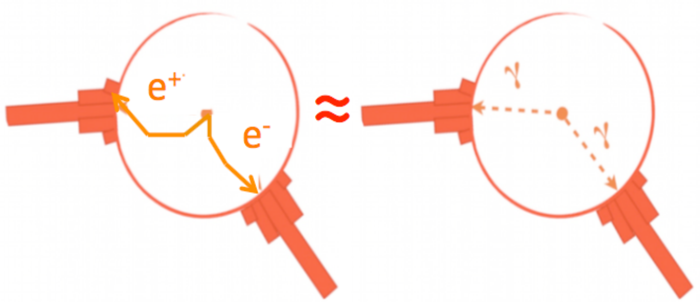
Probing new physics with photons

Photons give a clear experimental signature



Striking signature in the detectors:
- Isolated energy deposit in the electromagnetic calorimeter
- No track associated in the inner detector
- Distinctive shape of the energy deposits

Very good energy resolution
High purity and large reconstruction efficiency
- Can be controlled with data-driven techniques



Relatively low SM backgrounds
- Almost soft QCD production at LHC
- Fake photons from misidentified objects

Perfect "tool" to search for new physics

Details in F.Couderc's and K. Brendlinger's yesterday talks

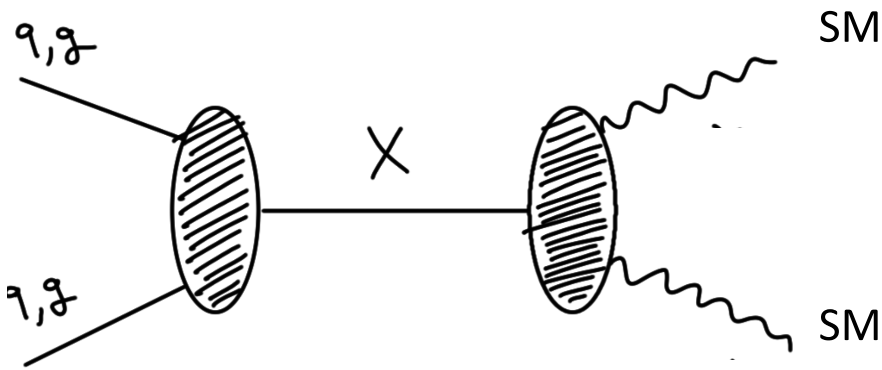
Searches for resonances

Many results available, only selected items here

Resonances at LHC

Generic prediction of several BSM theories

Production:
gluon fusion,
qq annihilation…



Decay to SM particles

Spin-2: extra-dimensions (e.g RS Gravitons)
Spin-1: W', Z' as in compositeness models
Spin-0: 2HDM (SM extensions with non-minimal Higgs sectors)

Where photons?

Bosonic decay channels

- X -> γγ, X-> Vγ, X->VV

Fermionic decay searches can profit from ISR photons

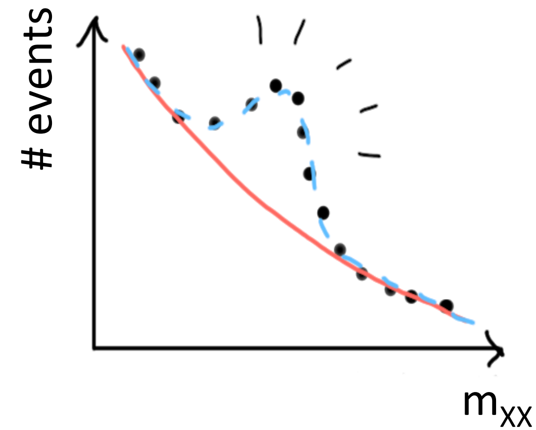
- E.g. X -> qq + γ

Bump searches

Reconstruct invariant mass of decay products and search for a "bump" on a smooth falling background

- experimentally robust, small systematics
- difficult for unknown backgrounds to mimic

$\Rightarrow$ *simple yet striking signature!*



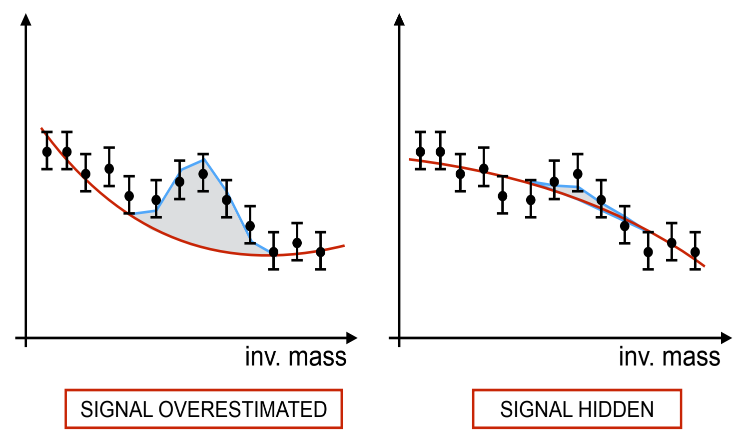
General strategy:

Signal: simulation with inputs from data

- efficiencies, energy scale, resolution..

Background: directly measured in data

- accounting from mis-modeling in the fit



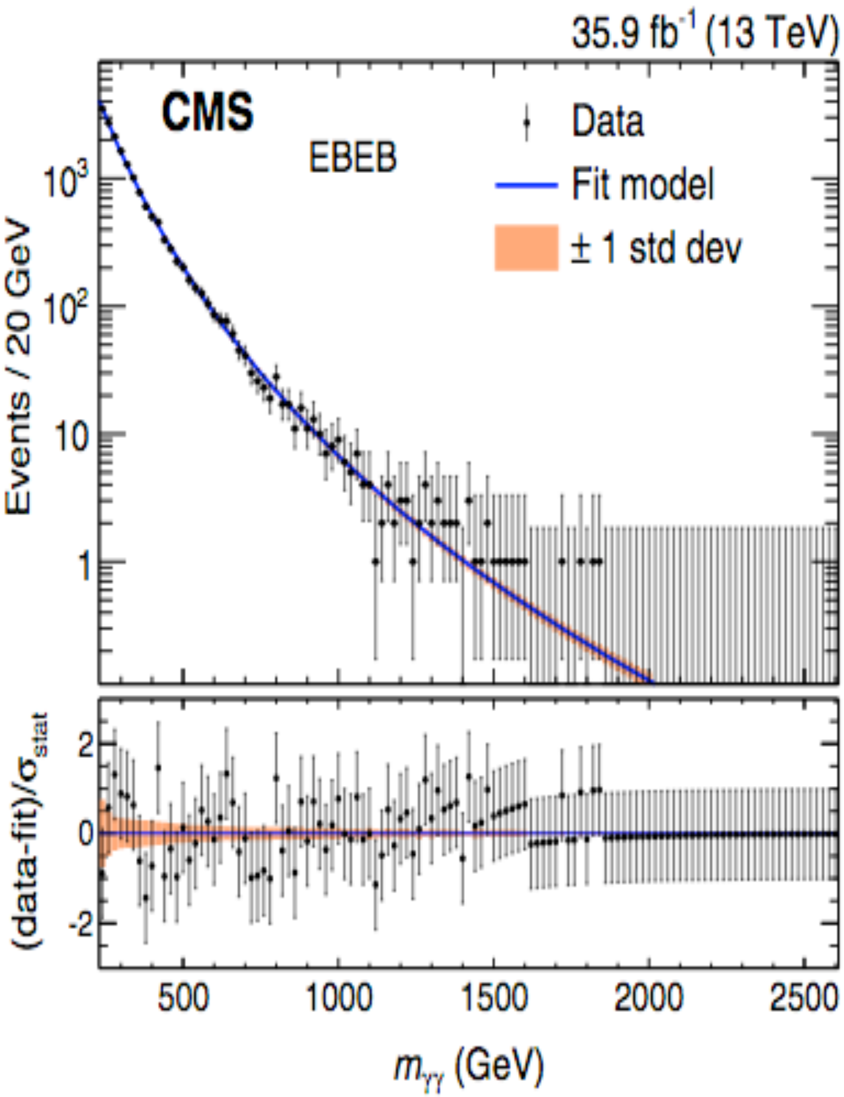
Among main challenges:

- Background understanding
- Objects reconstruction to maximize signal efficiency (e.g. pileup mitigation, isolation)
    - requiring a very good detector understanding

ATLAS and CMS approaches leading to similar sensitivities

High mass γγ resonances

Lots of interest in 2015-16 due to the (in)famous excess around 750 GeV



Phys. Rev. D 98 (2018) 092001

Events with 2 high p_T isolated photons, selected by di-photon triggers

Dedicated photon selection
- tuned to be flat vs di-photon mass

BDT-based vertex reconstruction
- ~90% efficient in selecting the good vertex

Events categorization to enhance analysis sensitivity

Main backgrounds directly fitted from data:
- non-resonant γγ
- mis-identified jets (γ+jet, jet+jet)

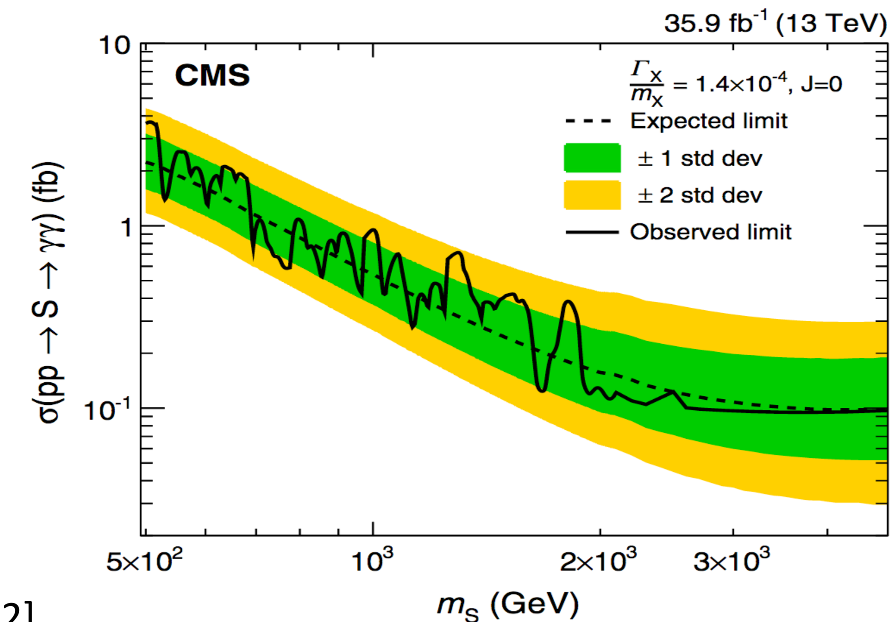
High mass X->γγ: Results

Phys. Rev. D 98 (2018) 092001
Phys. Lett. B 775 (2017) 105

Both ATLAS and CMS 2016 data not showing any excess

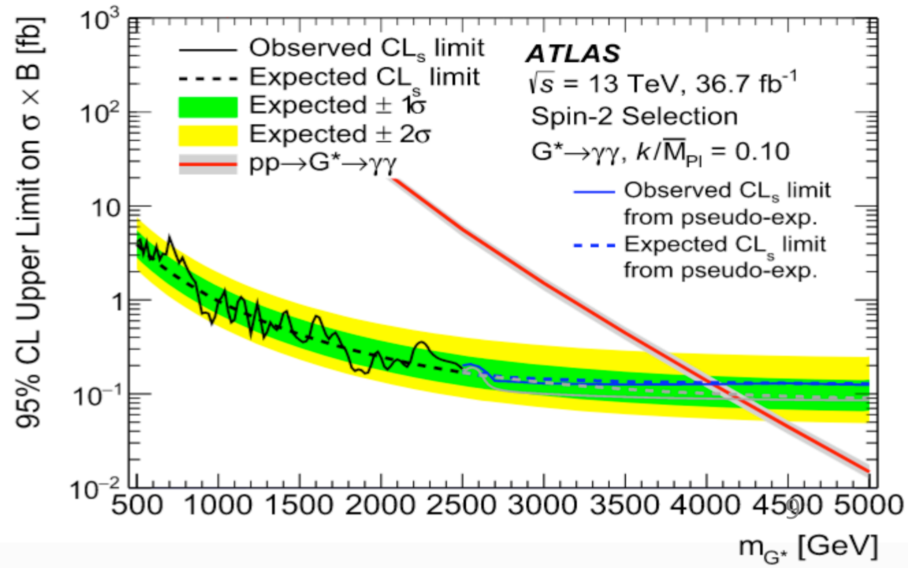
Interpretation:
Spin0 (extended Higgs sector)
and Spin2 resonances (RS Graviton)

Comparable sensitivities for the experiments



CMS (2016 data):

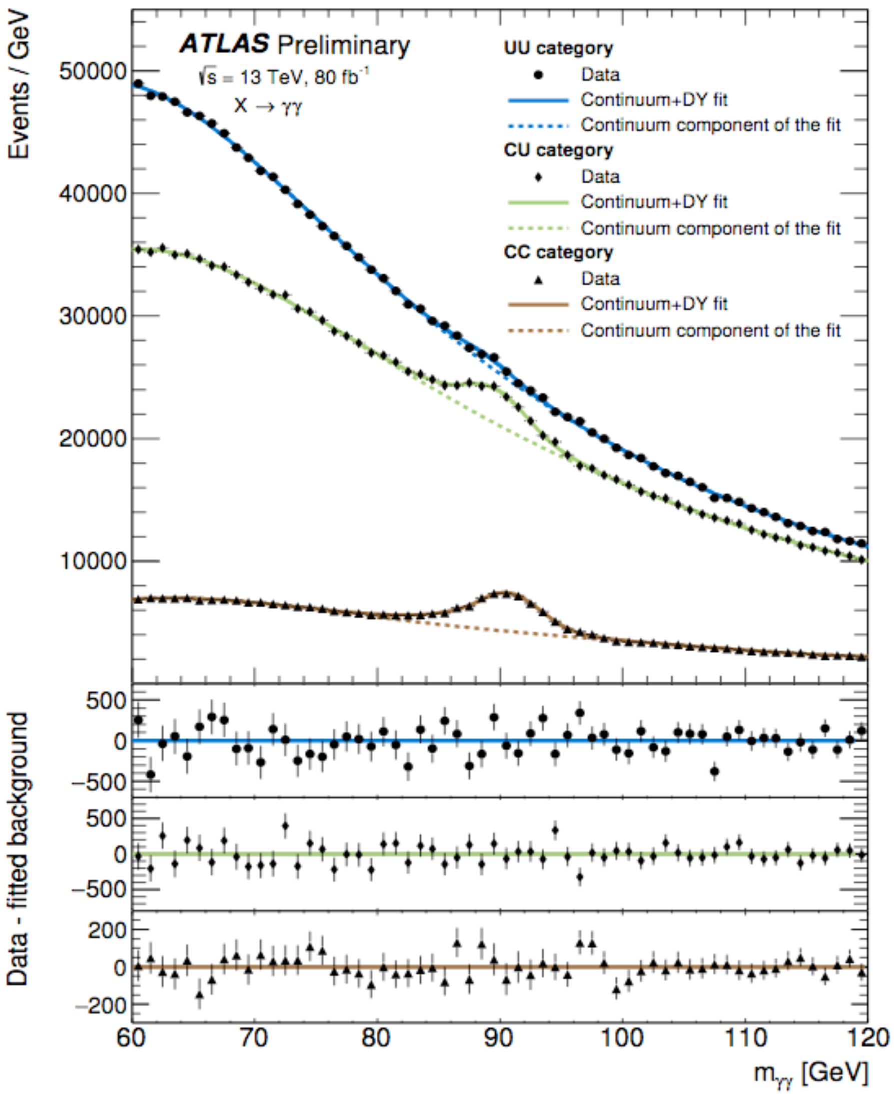
- m_G < 2.3-4.6 TeV excluded @95% CL for k = [0.01-0.2]
- Limits on spin0 resonances ($\Gamma/m = 1.4\times10^{-4}$, 1.4×10^{-2}, 5.6×10^{-2}) and fiducial pp->γγ cross-section also set



ATLAS (2015 + 2016 data):

- m_G < 4.1 TeV excluded @95% CL for k = 0.1
- Limits on σxBR @95%CL:
  Spin0: 11.4-0.1 fb for m_X = [200, 2700] GeV
  Spin2: 4.6-0.1 fb for m_G = [500, 5000] GeV

Low mass γγ resonances



ATLAS-CONF-2018-025

Focus on narrow X with m_X < 110 GeV

Similar strategy as for the high mass region

Main differences in background estimate:

- Z/γ* -> ee as additional background
    - electrons faking photons
    - shape and normalization constrained with data-driven e->γ measurement
- Impact of trigger thresholds at the low bound

Events categorization based on γ conversions

- Different DY contamination

Main uncertainties: statistical + background fit

Low mass X -> γγ: Results

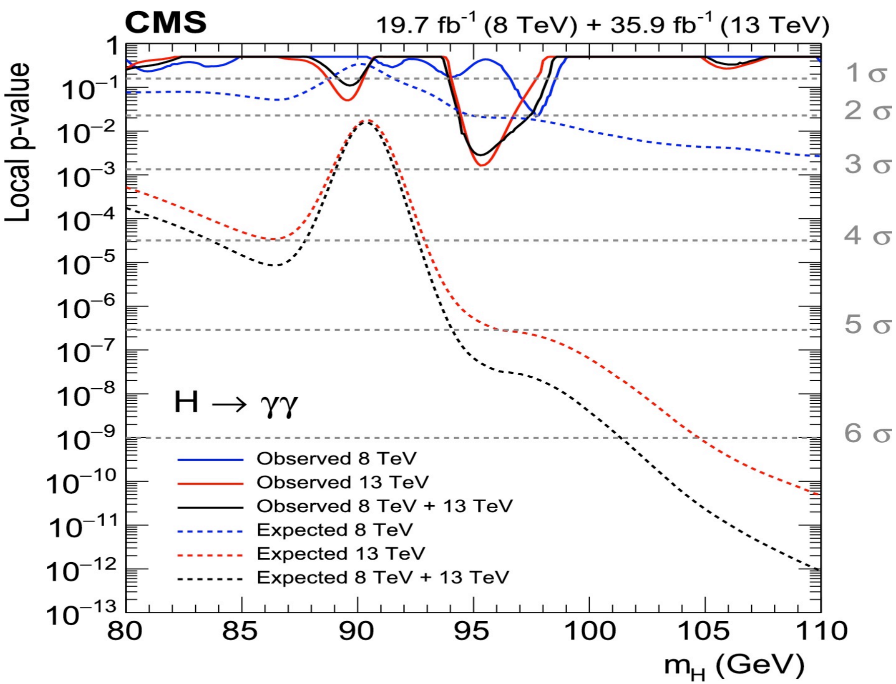
CMS: Phys. Lett. B 793 (2019) 320-347
ATLAS: ATLAS-CONF-2018-025

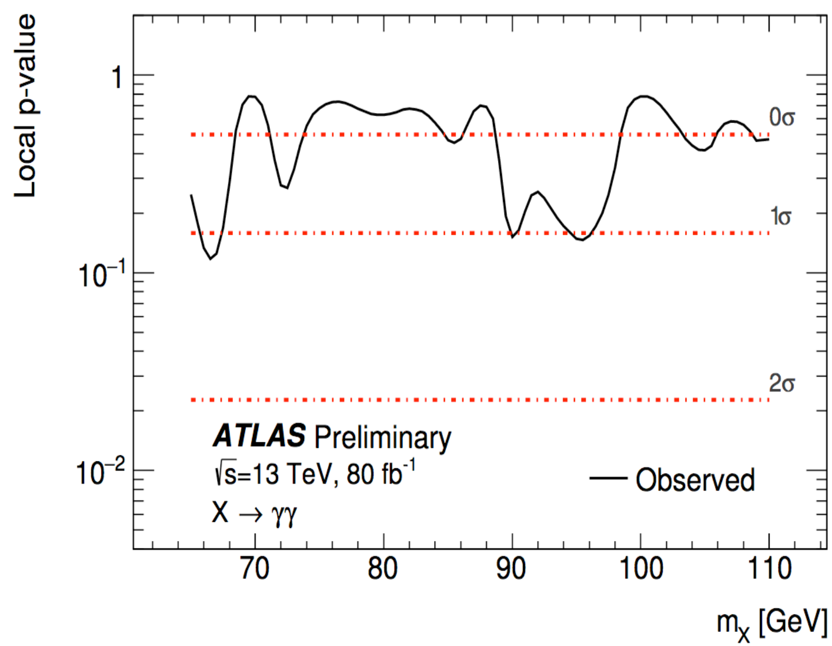
Both ATLAS and CMS focused on an additional SM-like Higgs boson

ATLAS (2015+2016+2017 data):
No significant excess observed

CMS (combined 2012 + 2016 data):
Maximum local (global) significance 2.8σ (1.3σ) at 95.3 GeV

	mX [GeV]	UL@95%CL σ x BR
ATLAS Run2	65-110	30-101 fb
CMS Run1	80-110	31-129 fb
CMS Run2	70-110	26-161 fb





X -> Vγ Resonances

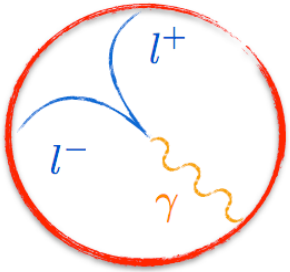
JHEP 09 (2018) 148
Phys. Rec. Lett. 122 (2019) 081804
JHEP 10 (2017) 112
Phys. Rev. D 98 (2018) 032015

Variety of X -> Z/W/H+γ searches performed by ATLAS and CMS on 2015 + 2016 datasets

Leptonic channels

Z-> ll, l = electron or μ

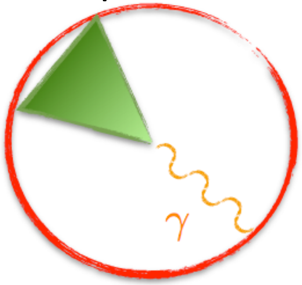
Good resolution, important at low m_X



Hadronic channels

Large-radius jet, light or b-quarks

Large BR, important at high m_X



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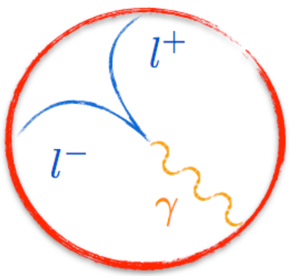

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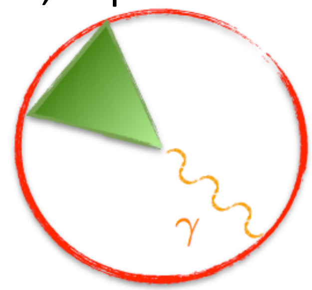
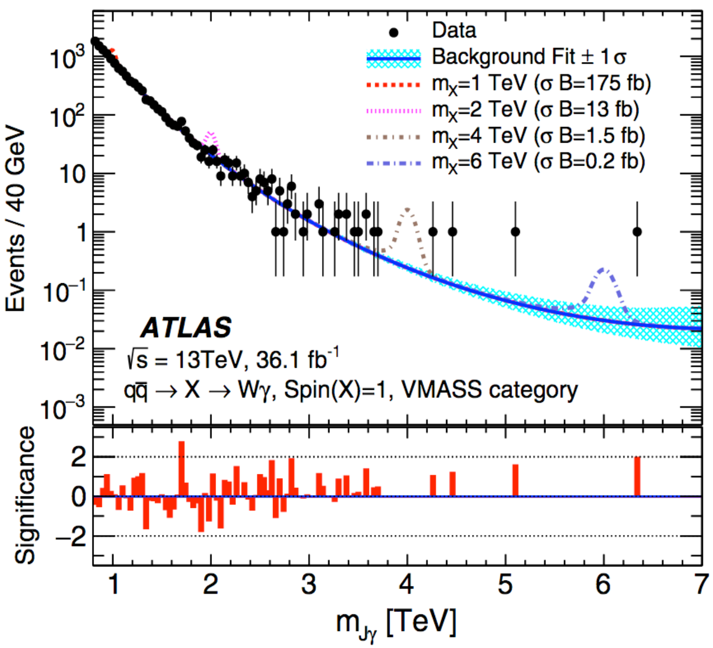




Phys. Rev. D 98 (2018) 032015

Hadron decays of Z, W, H

Main backgrounds: γ+jets, W/Z (W, Z -> jj) +γ, ttbar+γ

Selection on m_V, fit to $m_{j\gamma}$

Events classification to enhance sensitivity

No significant excess observed

Limits set on a variety of spin 0/1/2 models

Phys. Lett. B 788 (2019) 316
CMS-EXO-17-027

Low mass X -> qq + γ

Extensive searches for X->qq (dijets) performed at ATLAS and CMS

Large multi-jet background
Tight online requirements

Reduced sensitivity to low masses (m_X <~ 1TeV)

Effort to cover the whole mass range exploring new ideas

- *Exploit ISR jet / photon* → Lower trigger thresholds
  Lower background

CMS-EXO-17-027

Search for a light Z', 10 < $m_{Z'}$ < 125 GeV

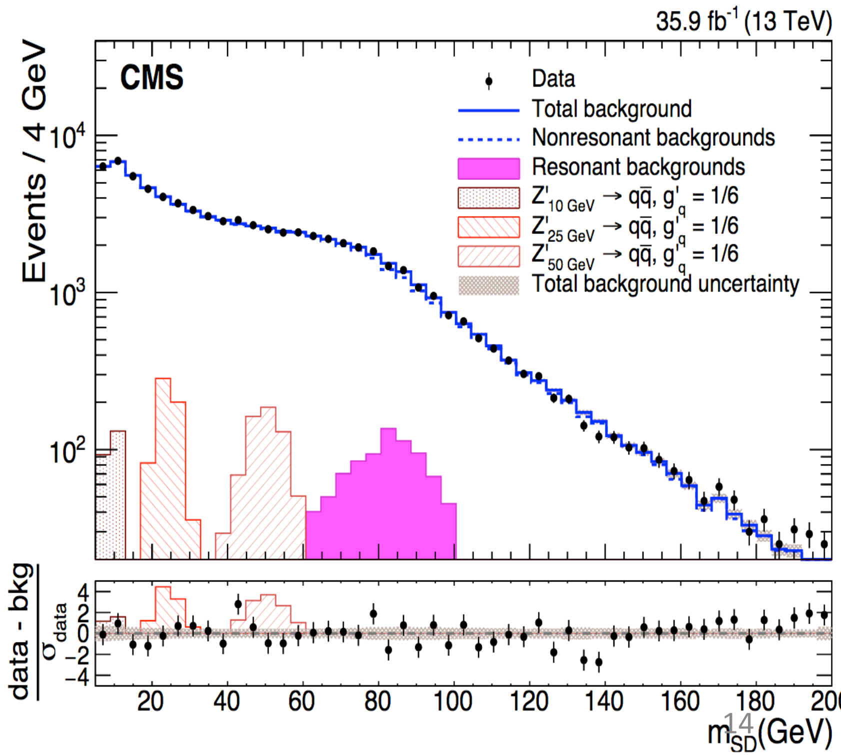
Boosted event topology, Z' recoiling against γ

- q/qbar merged in a single large radius jet
- jet sub-structure to reduce backgrounds

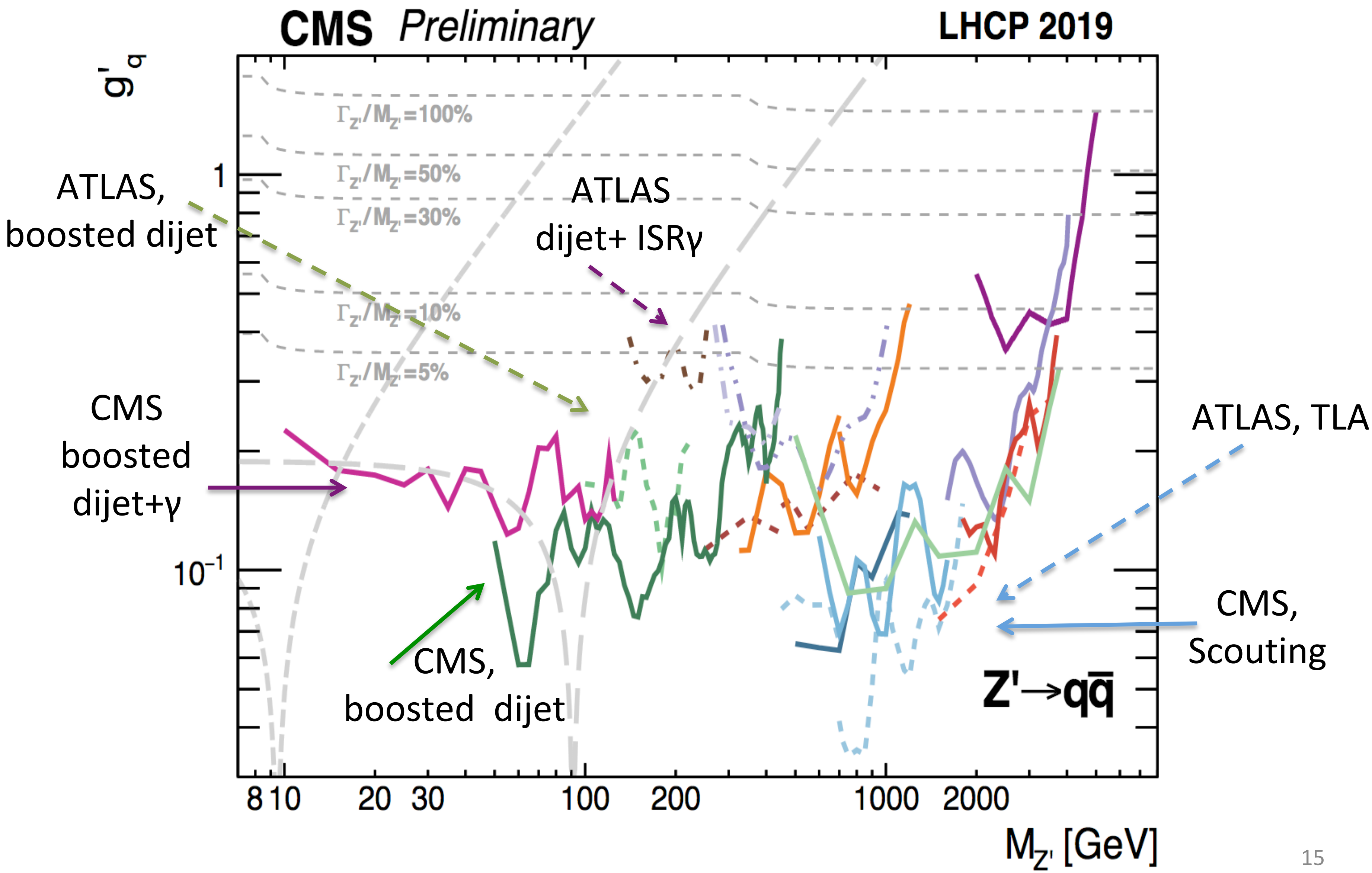
Events selected by single photon trigger

- Lower masses accessible

No excess found: limits set



Summary of X -> qq searches



JHEP 11 (2018) 040
Eur. Phys. J. C 78 (2018) 1007
Phys. Lett. B 788 (2018) 7

X -> HH Resonances

SM HH production cross section very small

- 34fb, ~1000 times smaller than for single Higgs

Several BSM models predict heavy resonances decaying to HH

	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0053%

Channels with H->γγ are powerful:
small branching ratio
BUT clean signal extraction

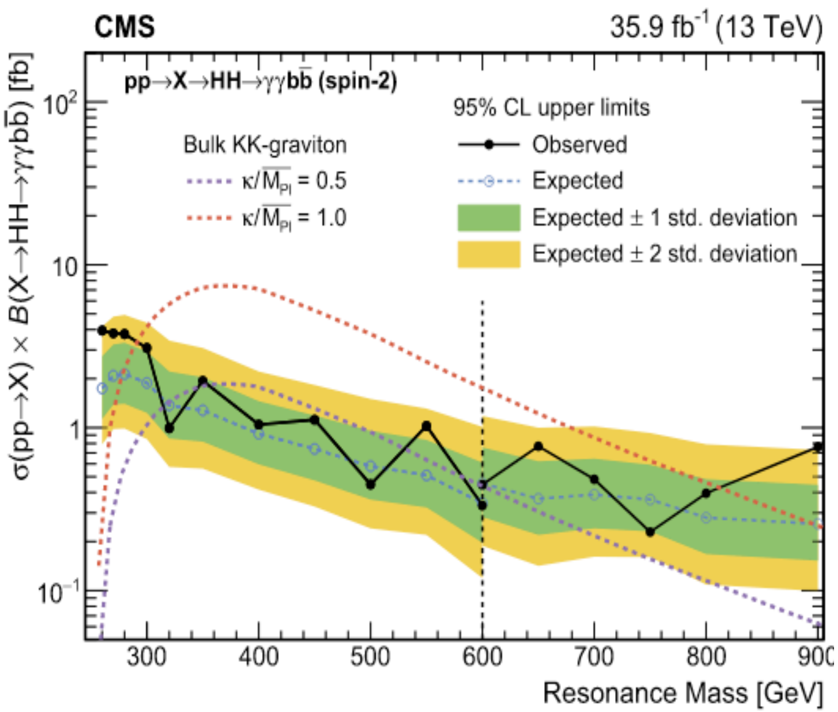
- Thanks to narrow H->γγ peak

H->γγbb (CMS/ATLAS)
2 photons and 2 jets in final state
Discriminating variables: mγγ, mjj, mγγjj

H->γγWW (ATLAS)
2 photons, 1e/μ, 2 jets (WW->lνqq)
Less sensitive

Main backgrounds: γγ continuum, single Higgs

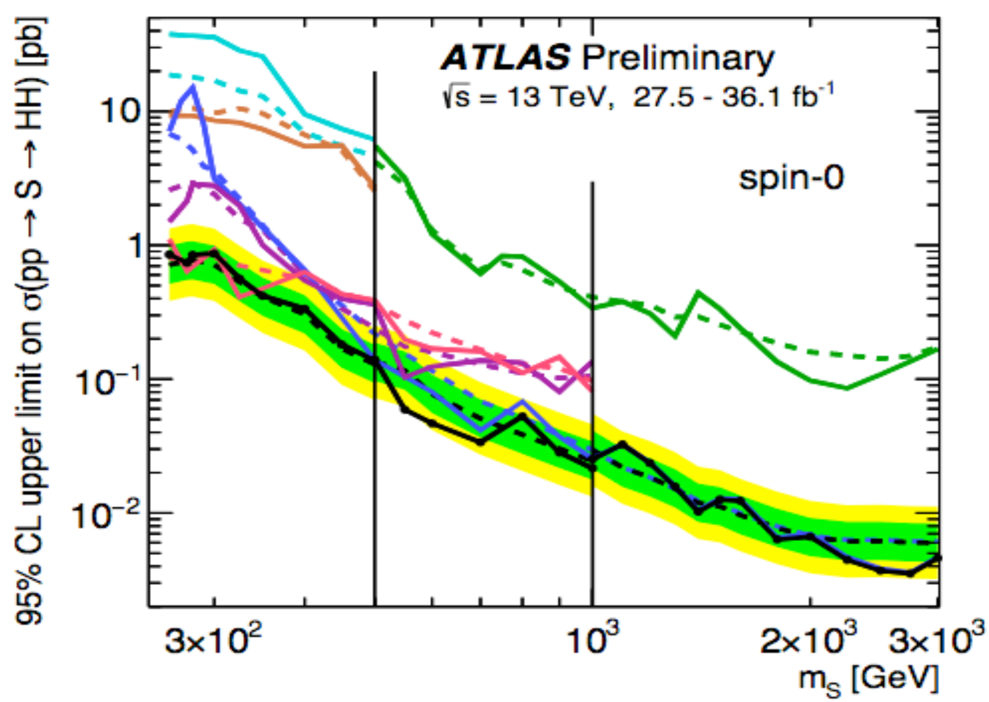
X->HH->bbγγ results



No significant excess observed

CMS UL @95%CL on σ x BR(pp->X->HH->γγbb):
0.23-4.2 fb (m_X=250-750 GeV)
depending on m_X and spin

ATLAS UL @95%CL on σ x BR(pp->X->HH):
0.12-1.14 pb (m_X=260-1000 GeV)
for narrow spin-0



bbγγ final state:
important role in the combination

BSM Higgs

Many results available, only selected items here

Higgs boson = key for BSM physics?

Higgs boson discovery opened the way to new searches for BSM

Exotic h(125) decays

SM Higgs has narrow width (~4 MeV): current limits allow for additional contributions

Indirect evidence for BSM: deviations from SM couplings

Direct evidence for BSM: observation of Higgs BSM decays

- Higgs -> invisible
- Higgs -> light (pseudo)scalars (H -> aa)
- Flavour violating decays

Exotic h(125) productions

- From new particles decay
- Originated in SUSY chains
- ....

More Higgses?

- Additional EW singlet mixing with SM-h
- Charged Higgs
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More on other topics in B.Schumm's talk (or final states with photons not relevant)

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Higgs decays to SM particles

channel	BR (SM)
H -> Zγ -> llγ	1.01×10^{-4}
H -> J/ψ γ	3.0×10^{-6}
H -> ϒγ	$\sim 5 \times 10^{-9}$

Important to look at all possible decay modes

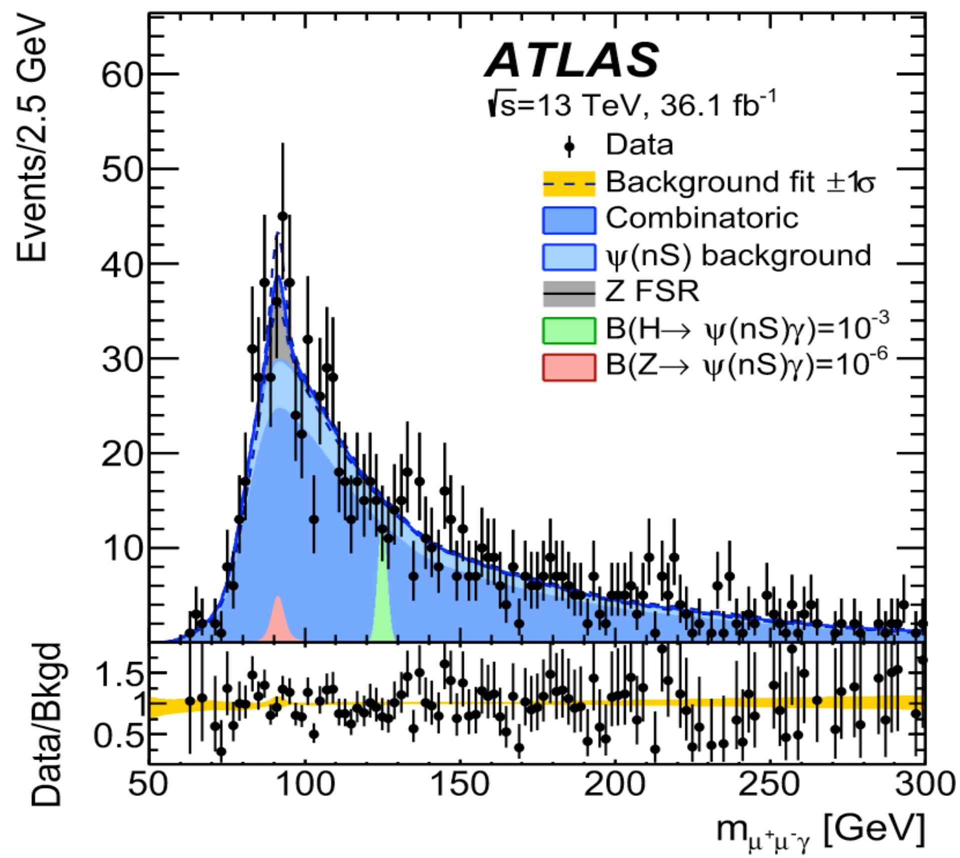
Very rare decays:

- Excess would indicate BSM physics
- Precision limited, slow increase with data

No surprise so far

ATLAS, *Phys. Lett. B 786 (2018) 134*
Study of H -> J/ψ γ decay
Probe of charm and bottom Yukava coupling
Focus on clean di-μ final state
95%CL UL on BR ~ 10^{-4}

CMS, *JHEP 11 (2018) 152*
Study of H -> ll γ
Focus on clean di-μ, di-ele final states
Observed (expected) 95%CL UL on
σ x BR = 3.9 (2.0) x SM



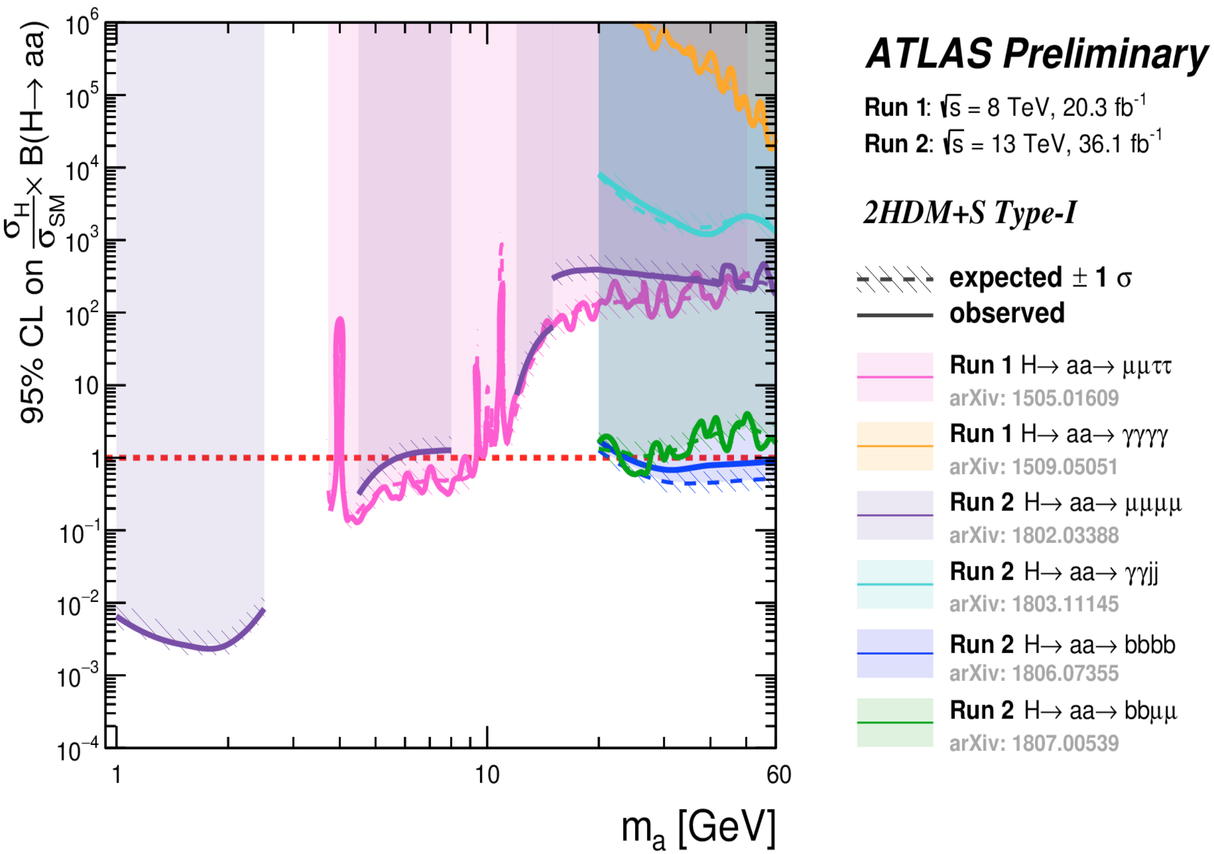
Higgs exotic decays: h->aa

ATLAS-PHYS-PUB-2018-045
Phys. Lett. B 782 (2018) 750

SM: single Higgs doublet Φ => 1 Higgs boson h
2HDM: two Φ1Φ2 => 5 Higgs bosons h, H0, A, H+, H-

Interesting scenarios with extra singlet (2HDM+S) a with $m_a < m_h$

- Significant h->aa possible



Final states with photons explored by ATLAS:
H->aa->4γ (Run1)
H->aa->2γ2b (Run2)

Complementary searches

Become relevant when fermionic decays suppressed

Summary

Photons are a primary ingredient in searches for BSM physics thanks to the clean signature in the detector

Many searches for resonances ongoing in final states with photons at ATLAS and CMS

The Higgs Boson discovery opened additional paths to search for new physics, in an extended Higgs sector

So far all observations are compatible with the SM expectations
Still O (100fb-1) of data to be analysed for many channels.
Many more results coming with full Run2 dataset. Stay tuned!