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

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on behalf of ATLAS and CMS Collaborations

Workshop on Photon Physics and Simulation at Hadron Colliders
Frascati, 6-7 June 2019

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
- From observation (dark matter, matter-antimatter…)
- Conceptual problems

Huge number of searches ongoing at LHC

New Resonances
Dark Matter
SUSY
Contact Interactions
BSM Higgs Sector
…

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- New Resonances
- Dark Matter
- SUSY
- Contact Interactions
- BSM Higgs Sector
- …

More on other topics in B.Schumm's talk

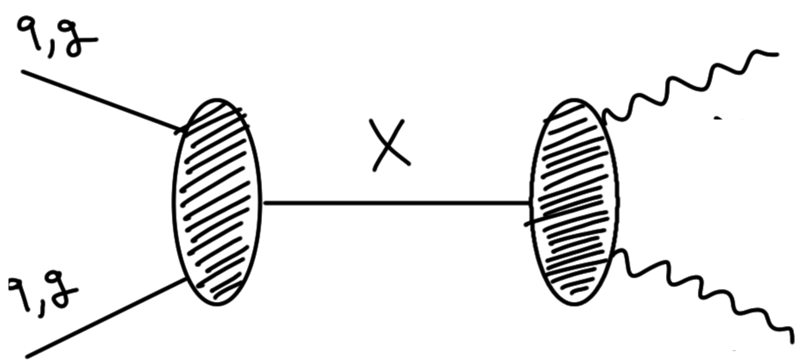
Searches for Resonances

Many results available, only selected items here

Resonances at LHC

Generic prediction of several BSM theories

Production:
gluon fusion,
qq annihilation…



SM

Decay to SM particles

SM

Spin-2: extra-dimensions, RS Gravitons
Spin-1: W’, Z’ as in compositeness models
Spin-0: 2HDM (SM extensions with non-minimal Higgs sector)

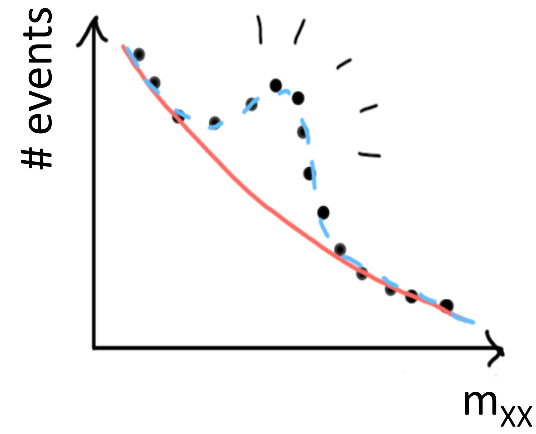
only ones relevant for γγ

Where photons?

- Decay channels like X -> γγ, X-> Vγ, ...
- Searches with fermions can also profit from ISR photons (e.g. X -> qq + γ)

Very close new states resulting in a broad excess in the mass spectrum are also predicted (e.g. ADD model). Results available, but not discussed in this talk

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 create resonances

⇒ *simple yet striking signature!*

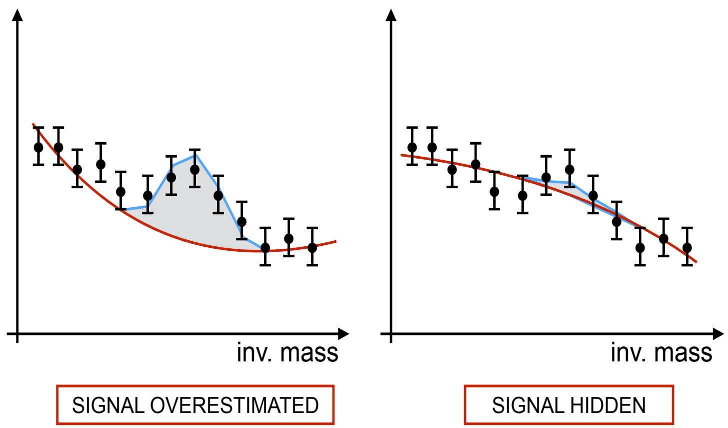
General strategy:

Signal: simulation with inputs from data

- efficiencies, energy scale, resolution..

Background: directly measured in data

- accounting for possible biases in the fit



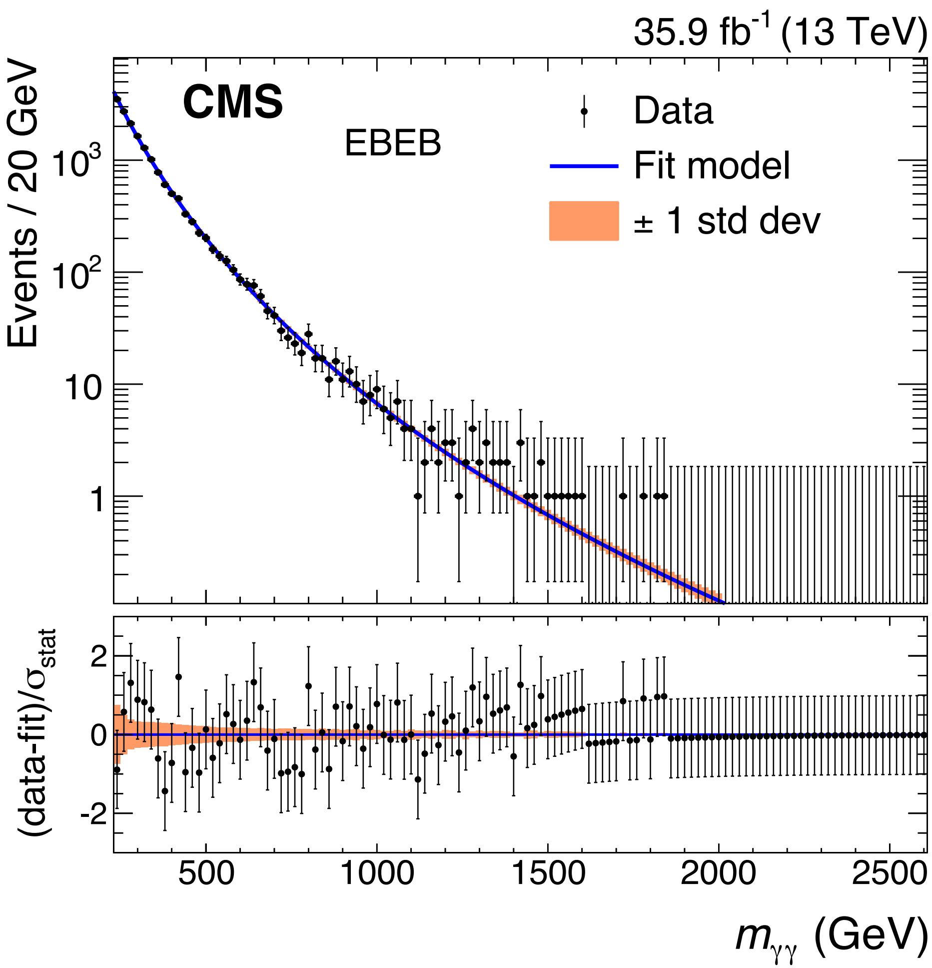
Among main challenges:

- 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
(2016 data)

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)

Similar strategy adopted by ATLAS in Phys. Lett. B 775 (2017) 105 (2015+2016 data)

High mass X->γγ: Results

Both ATLAS and CMS 2016 data not showing any excess. Comparable sensitivities

Interpretation:

- Spin0 (extended Higgs sector) and Spin2 resonances (RS Graviton)
- Limits on σ x BR (pp->γγ)
- [+ ADD]

CMS (2016 data only):

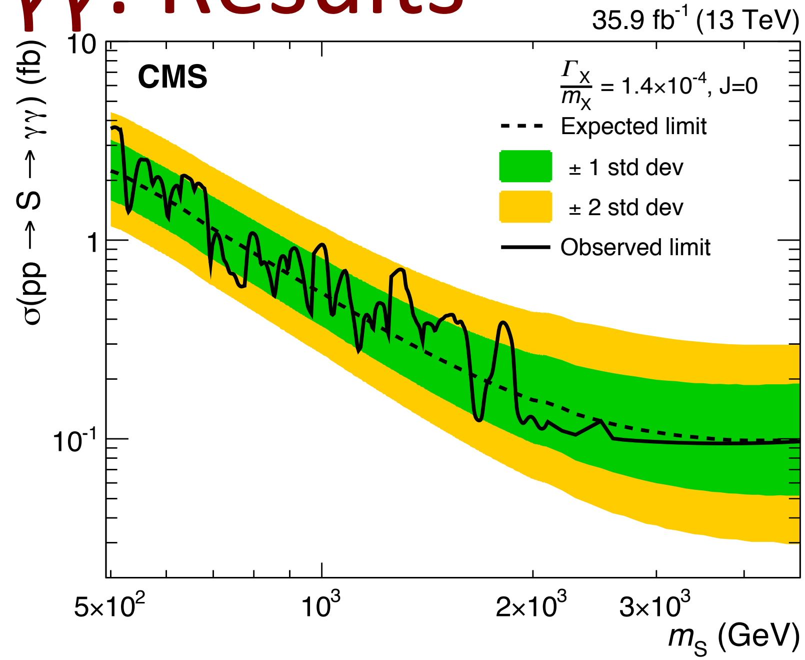
Phys. Rev. D 98 (2018) 092001

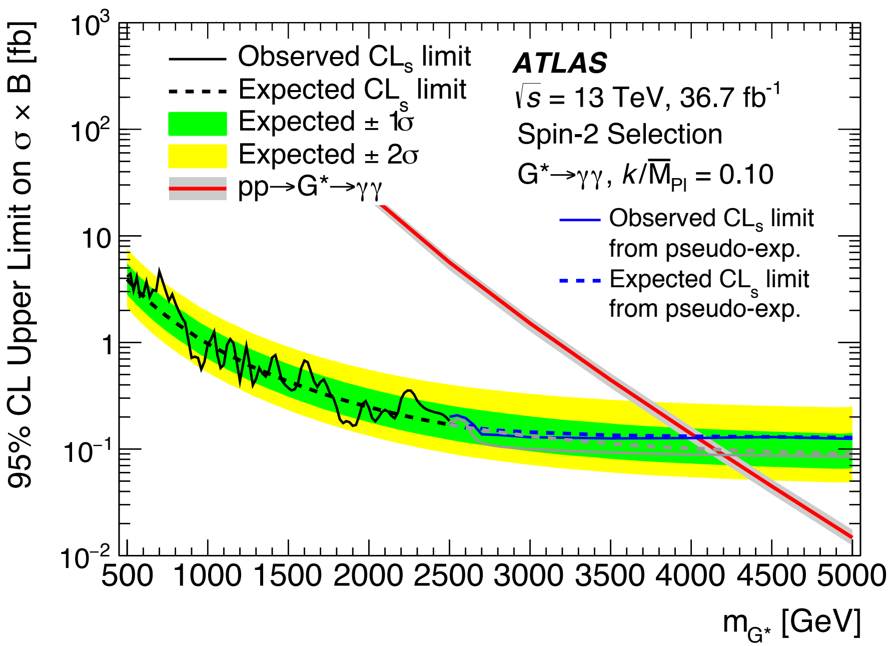
- m_G < 2.3-4.6 TeV excluded @95% CL for k = [0.01-0.2]

ATLAS (2015 + 2016 data):

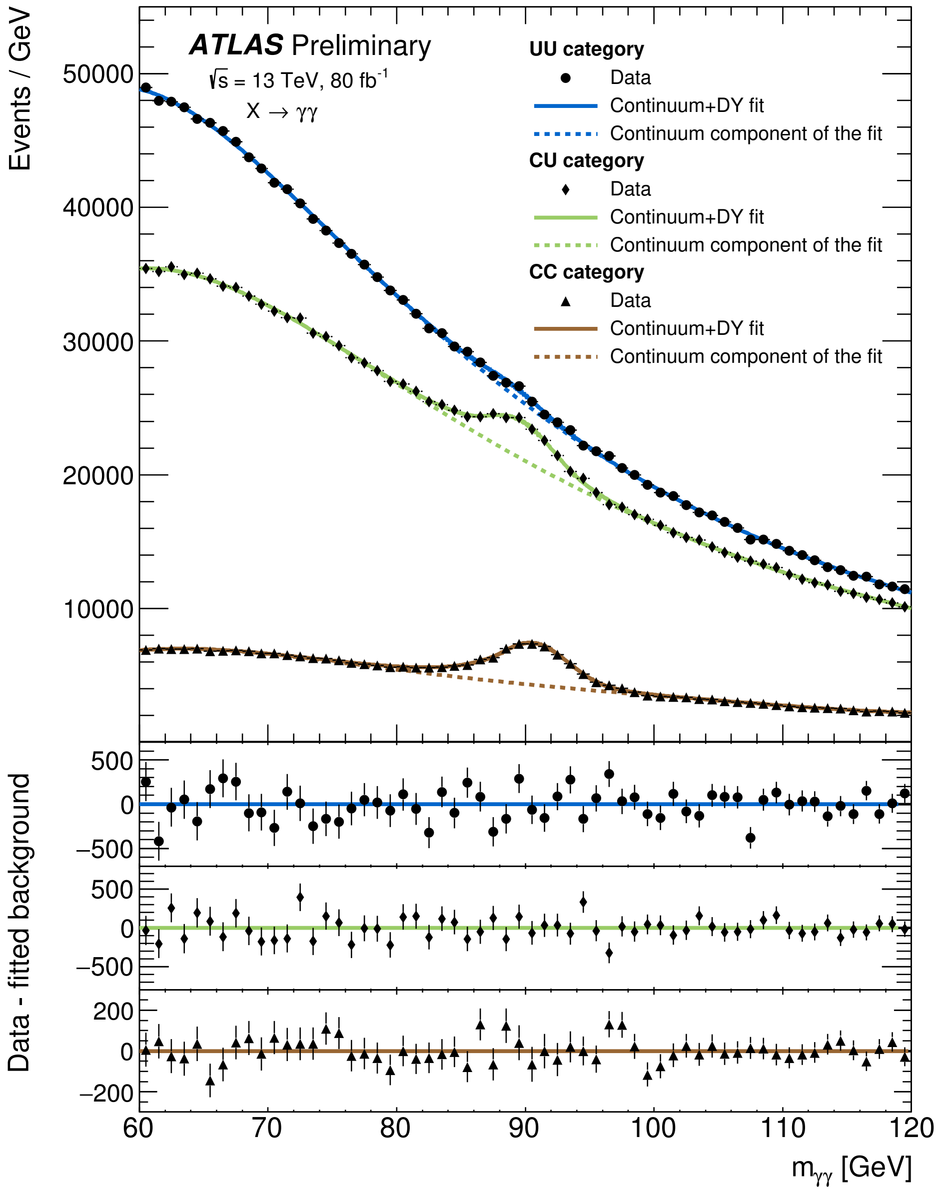
Phys. Lett. B 775 (2017) 105

- m_G < 4.1 TeV excluded @95% CL for k = 0.1





Low mass γγ resonances



ATLAS-CONF-2018-025
(2015, 2016, 2017 data)

Focus on narrow X with $m_X < 110$ GeV

Similar strategy as for the high mass region

Main difference = background estimate

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

Events categorization based on γ conversions

- Different DY contamination

Main uncertainties: statistical + background fit

Similar analysis presented by CMS in Phys. Lett. B 793 (2019) 320-347 (2012+2016 data)

Low mass X -> γγ: Results

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

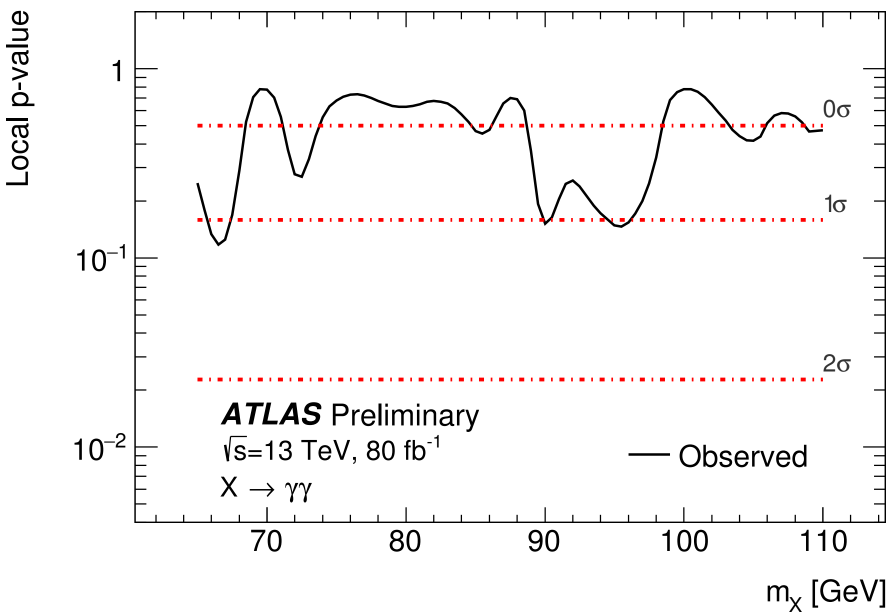
ATLAS (2015+2016+2017 data)

ATLAS-CONF-2018-025

$65 < m_X < 110$ GeV

UL@95%CL σxBR: 30-101 fb

No significant excess observed



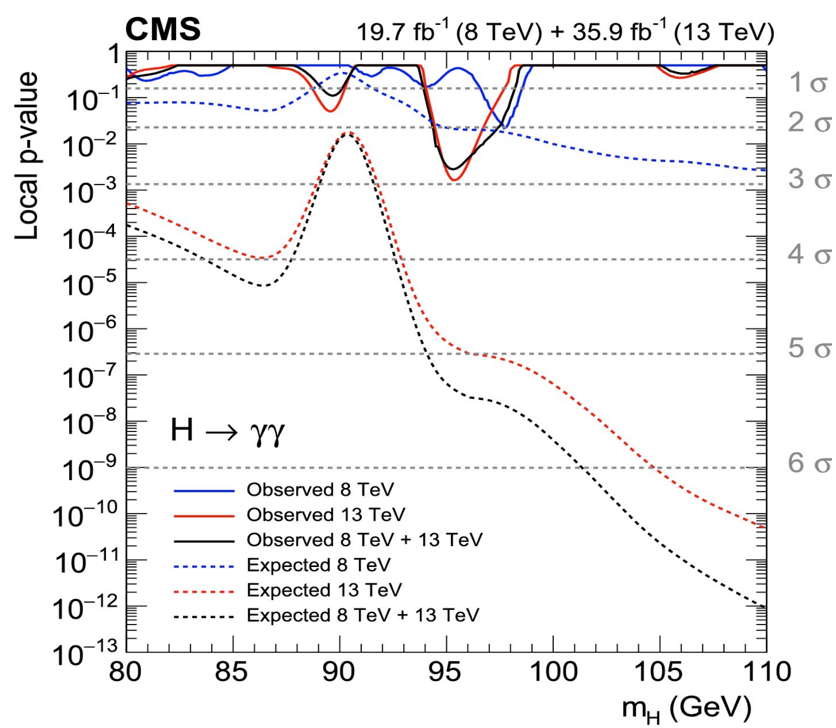
CMS (2012 + 2016 combination)

Phys. Lett. B 793 (2019) 320-347

$80 < m_X < 110$ GeV

UL@95%CL σxBR/SM: 0.2-0.7

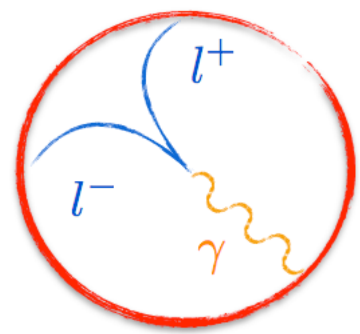
Maximum local (global) significance: 2.8σ (1.3σ) at 95.3 GeV



X -> Z/W/H+γ Resonances

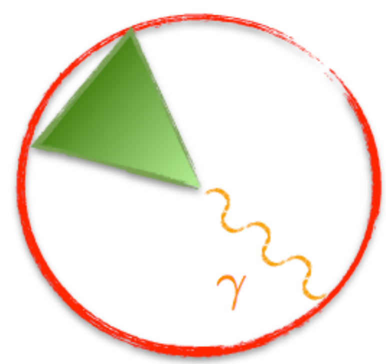
Many X -> Z/W/H+γ searches performed by ATLAS and CMS on 2016 (+2015) data

Final states with leptons: Z -> ll, l = electron or μ
Good mass resolution
PRO: clean channel
CON: low BR
More relevant for m_X <~1TeV (large background)



Final states with hadrons: V -> jj
PRO: large BR
CON: large QCD background
More relevant for m_X >~1TeV
Either 2 well separated jets or single large-radius jet

- Jets merging due to large V boost
- Jet substructure techniques useful against backgrounds



No significant excess observed. Limits set on a variety of spin 0/1/2 models

JHEP 09 (2018) 148
Phys. Rev. Lett. 122 (2019) 081804

JHEP 10 (2017) 112
Phys. Rev. D 98 (2018) 032015

Low mass X -> qq + γ

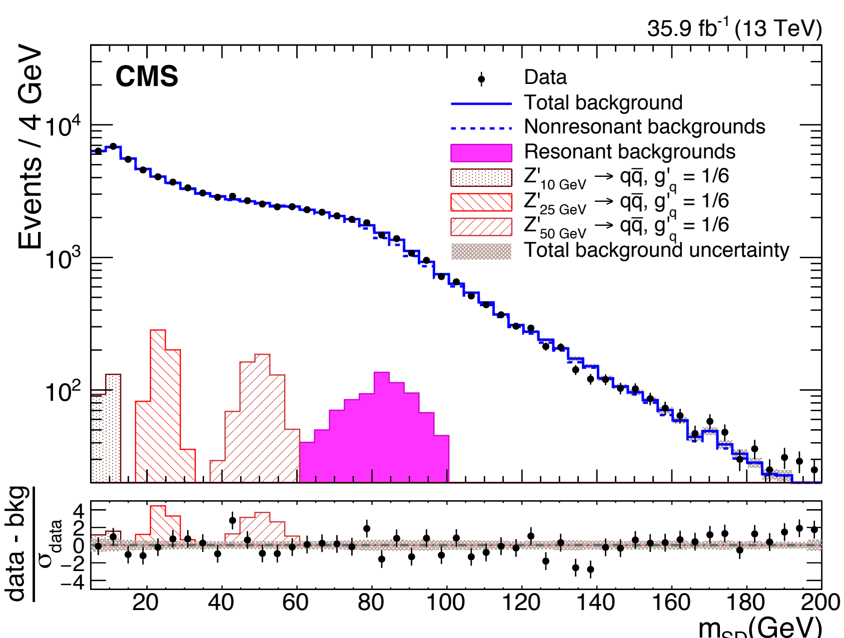
Extensive searches for X->qq (dijets) performed at ATLAS and CMS

Large multi-jet background
Tight online requirements

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

New ideas to cover an extended resonance mass range

- Record of partial event information only
- *ISR jet / photon* → CON: Reduced phase-space
  → PRO: Lower background wrt dijet only
  → Efficient triggering at low masses



CMS-EXO-17-027
(2016 data)

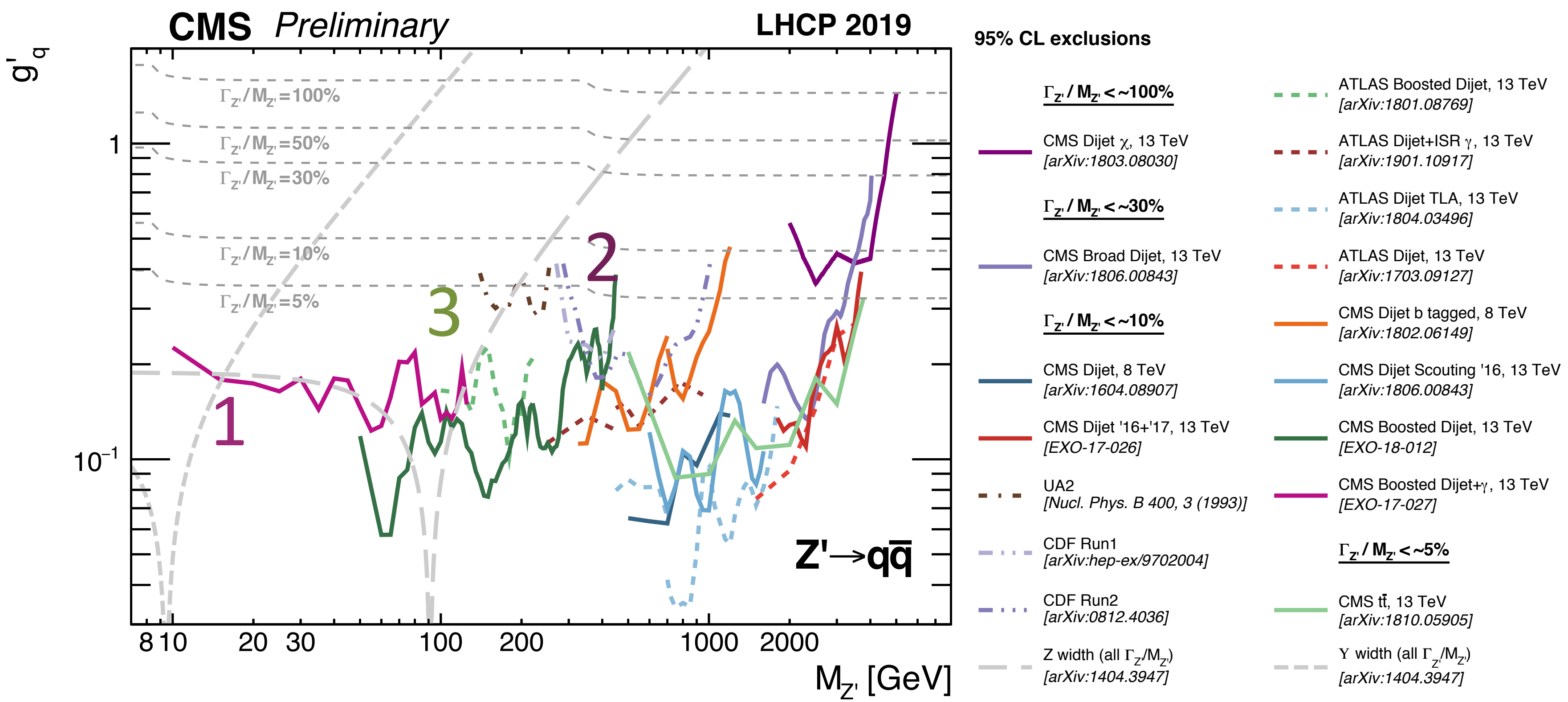
Search for a light Z', 10 < $m_{Z'}$ < 125 GeV

Events selected by single photon triggers

- Lower masses accessible

Boosted event topology
and jet sub-structure exploited

Summary of X -> qq searches



1. CMS-EXO-17-027 (2016 data)
   Boosted dijet + γ
2. ATLAS arXiv:1901.10917 (2015/16/17 data)
   Dijet + ISR γ
3. ATLAS *Phys. Lett. B 788 (2019) 316* (2015/16 data)
   Boosted dijet + γ/j

Big sensitivity gain asking for photons in the final state

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:
small branching ratio
BUT clean signal extraction
Thanks to the narrow H->γγ peak

H->γγbb:
2 photons and 2 jets in final state
Discriminating variables: mγγ, mjj, mγγjj

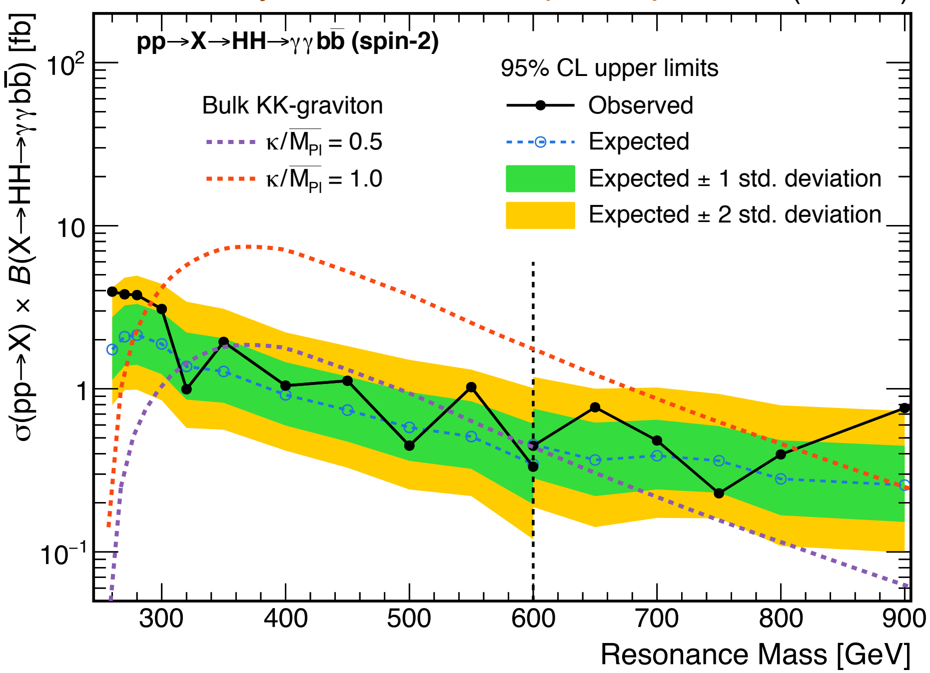
ATLAS: JHEP 11 (2018) 040
CMS: Phys. Lett. B 788 (2018) 7

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

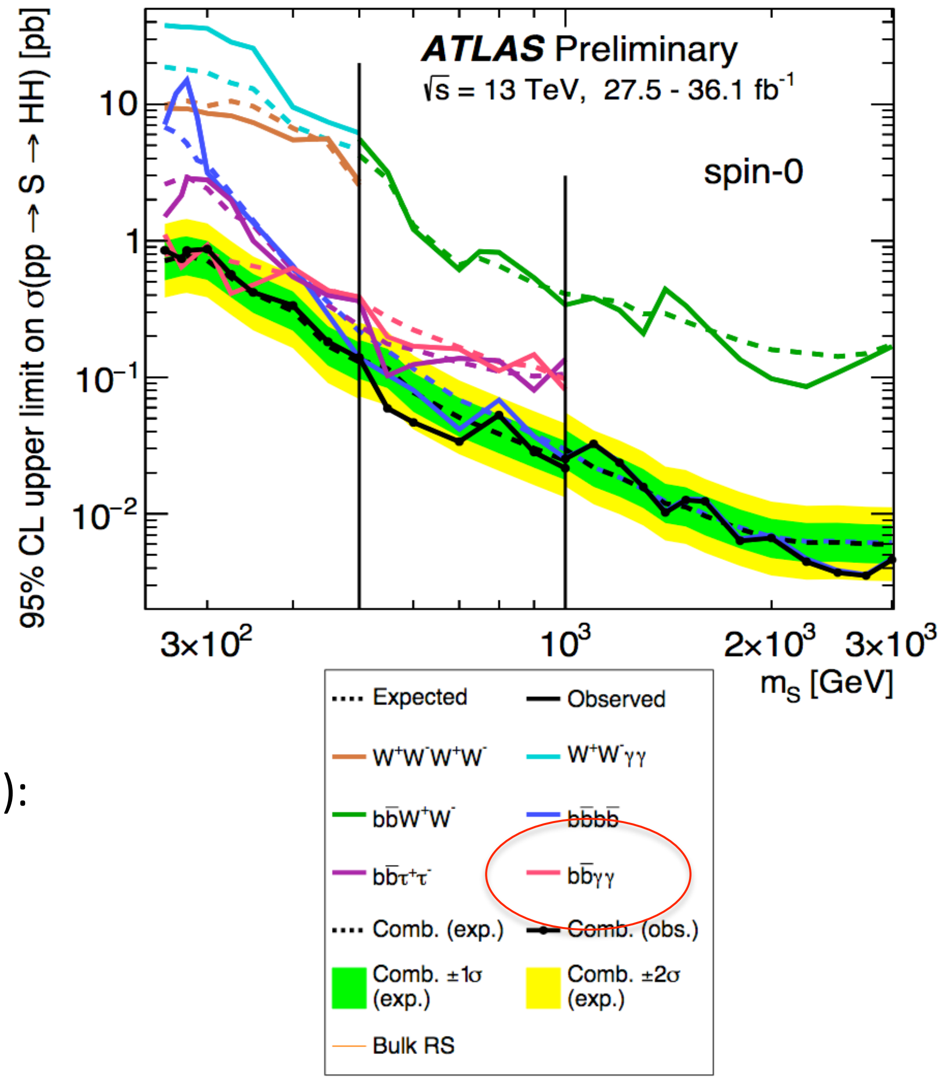
ATLAS: Eur. Phys. J. C 78 (2018) 1007

X->HH->bbγγ results

Phys. Lett. B 788 (2018) 7



arxiv:1906.02025



No significant excess in 2016 data

CMS UL @95%CL on σ x BR(pp->X->HH->γγbb):
0.23-4.2 fb (m_X=250-900 GeV)
depending on m_X and spin

ATLAS UL @95%CL on σ x BR(pp->X->HH):
0.12-1.1 pb (m_X=260-1000 GeV)
for narrow spin-0

bbγγ important role in the combination

Other extensions to the Higgs sector

Many results available, only selected items here

Higgs boson = key for BSM physics?

Higgs boson discovery opened the way to new searches for BSM physics

Exotic h(125) decays

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)
- Flavor 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

Important to look at all possible decay modes

Very rare decays:

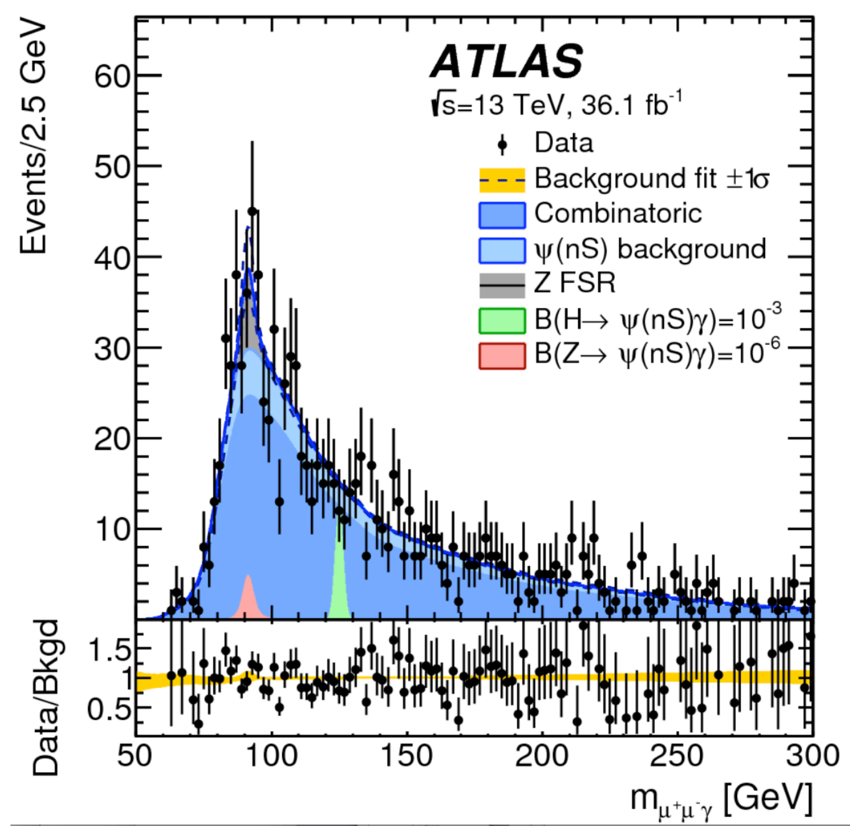
- Excess would indicate BSM physics
- Precision limited, slow increase with data

No surprise so far

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

Phys. Lett. B 786 (2018) 134
(2016 data)

H -> J/ψ γ decay
Probe of charm Yukawa coupling
Focus on clean di-μ final state
95%CL UL on BR ~ 10^{-4}



JHEP 11 (2018) 152
(2016 data)

H -> ll γ decay
Focus on clean di-μ, di-ele final states
Obs. (exp.) 95%CL UL on
σ x BR = 3.9 (2.0) x SM

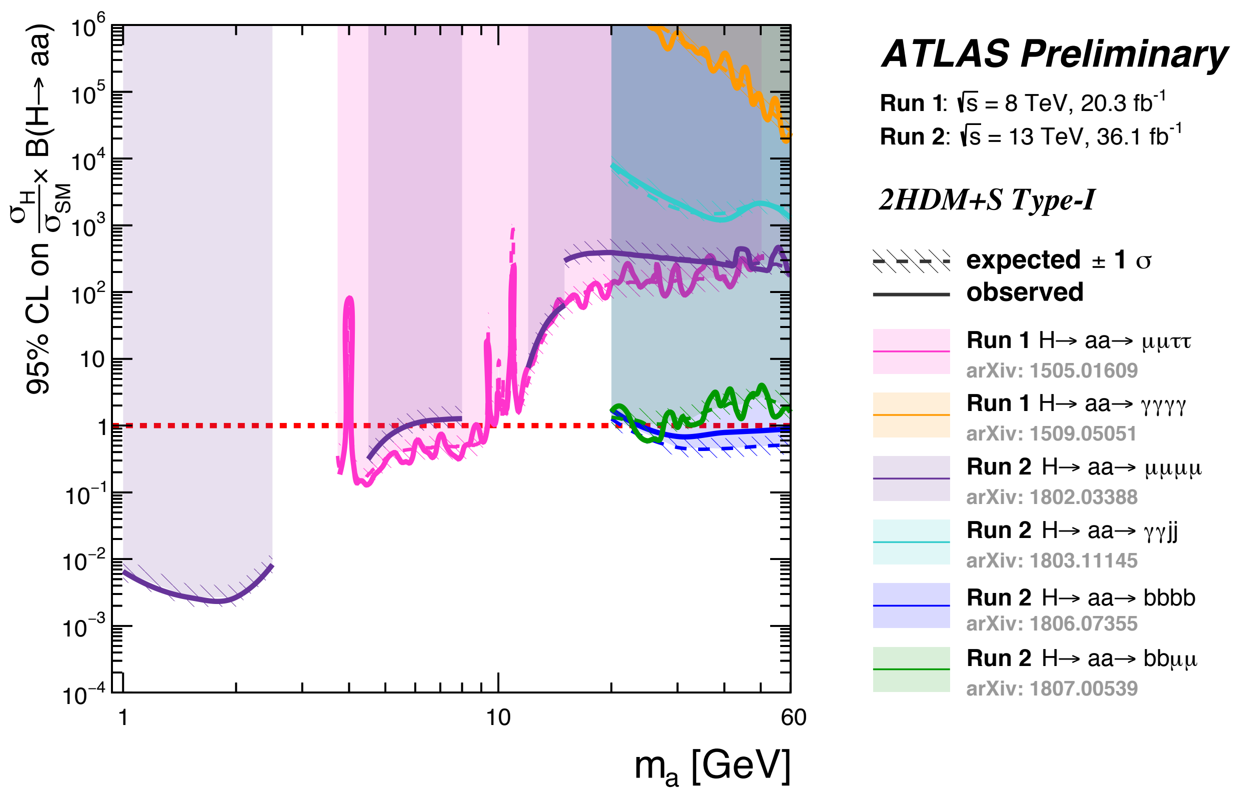
Higgs exotic decays: h->aa

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 at ATLAS:
H->aa->4γ (Run1)
H->aa->2γ2j (Run2)

Complementary searches

Become relevant with suppressed fermionic decays

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 analyzed for many channels.
Many more results coming with full Run2 dataset.

These and more results

ATLAS EXPERIMENT

Phys. Lett. B 775 (2017) 105
ATLAS-CONF-2018-025
JHEP 10 (2017) 112
Phys. Rev. D 98 (2018) 032015
arXiv:1901.10917
Phys. Lett. B 788 (2019) 316
JHEP 11 (2018) 040
Eur. Phys. J. C 78 (2018) 1007
Phys. Lett. B 786 (2018) 134
ATLAS-PHYS-PUB-2018-045
Phys. Lett. B 782 (2018) 750
ATLAS-CONF-2018-024

CMS

Phys. Rev. D 98 (2018) 092001
Phys. Lett. B 793 (2019) 320-347
JHEP 09 (2018) 148
Phys. Rev. Lett. 122 (2019) 081804
CMS-EXO-17-027
Phys. Lett. B 788 (2018) 7
Phys. Rev. Lett. 122, 121803 (2019)
JHEP 11 (2018) 152