Searches for Exotic and Rare Higgs Decays (ATLAS+CMS)

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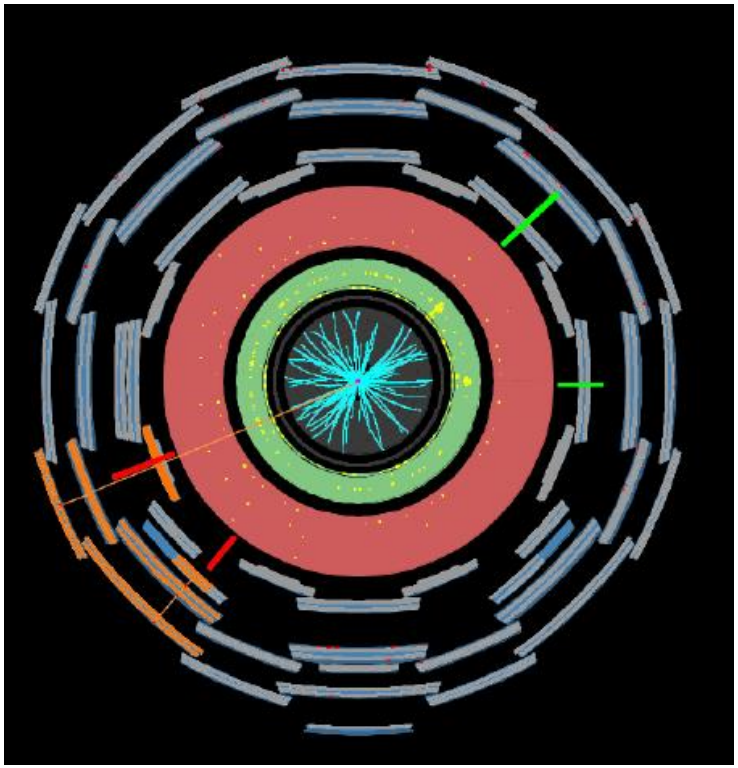
on behalf of the ATLAS and CMS collaborations

LHCP 2018 - Bologna

http://lhcp2018.bo.infn.it/

June 6, 2018



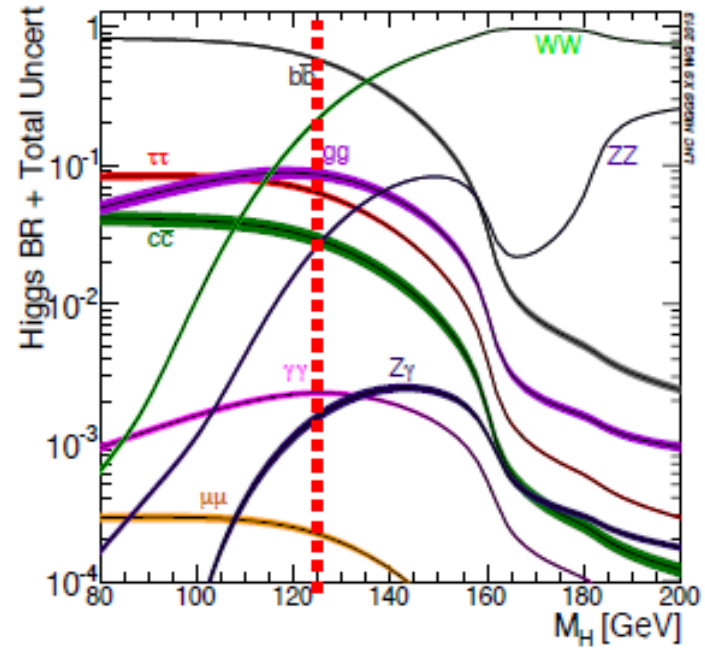
Introduction

Higgs discovery gives a new opportunity:
study it in detail and look for RARE or EXOTIC decays

Non-SM couplings?
- **H → Zγ, llγ**

1st and 2nd generation couplings?
- **H→mumu**
- **H→meson+γ**
- **Z+H→cc**
- **H→etau, mutau**

Decays to new particles?
- **h→invisible**
- **h→γ+MET**
- **h→other bosons (a, Z_D)**



$H \to a^0 a^0 \to \mu\mu\tau\tau$	BR<∼ (3.5 – 100)%	arXiv:1505.01609
$H \to a^0 a^0 \to \gamma\gamma\gamma\gamma$	BR<∼ (0.02 – 0.2)%	arXiv:1509.05051
$H \to a^0 a^0 \to 4\mu$	BR<∼ (0.02 – 100)%	arXiv:1802.03388
$H \to Z_D Z_D \to 4\ell$	BR<∼ $(5-30)\times 10^{-5}$	
$H \to Z Z_D \to 4\ell$	BR<∼ 0.1%	
$H \to a^0 a^0 \to \gamma\gamma jj$	BR<∼ 10%	arXiv:1803.11145
$WH \to \ell\nu a^0 a^0 \to \ell\nu 4b$	(1.5-6.2) pb	arXiv:1606.08391

Will not cover H →aa searches in this talk… see previous talk!

h→aa→2X2Y

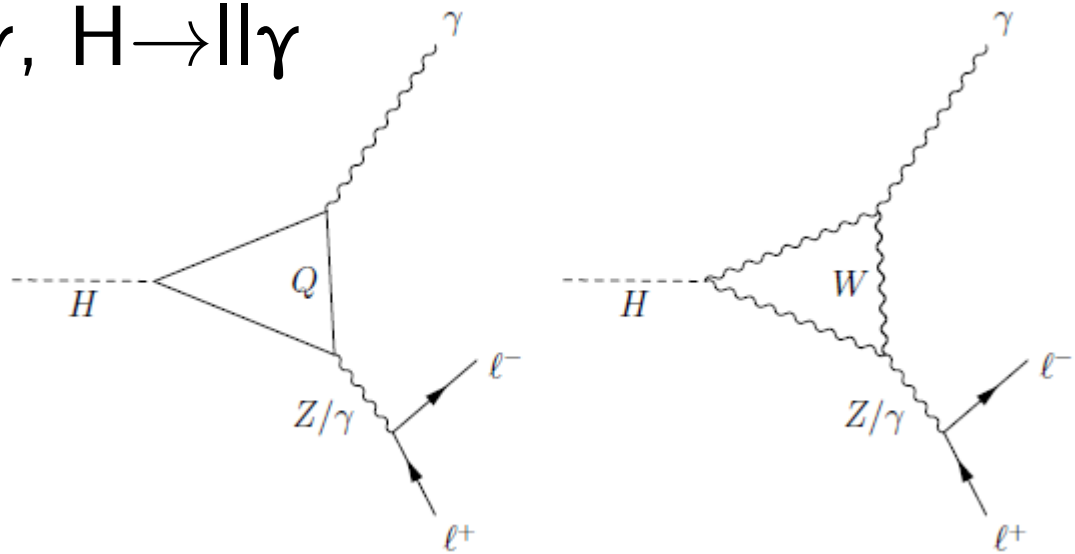
CMS HIG-17-029

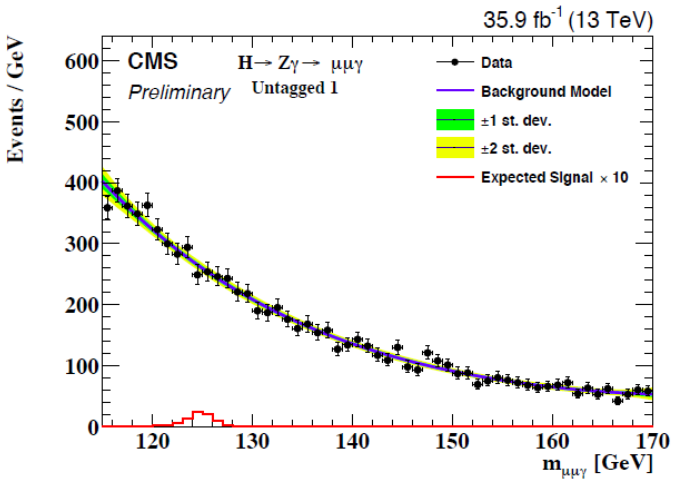
$H \to Z\gamma$, $H \to ll\gamma$

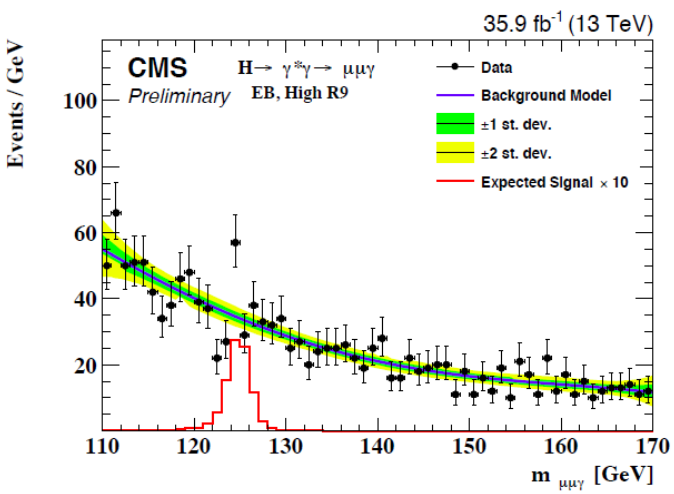
Present in the SM, but very small rate

Loop-induced decay, sensitive to new physics

Multiple event categories used to enhance signal sensitivity by 11-18%



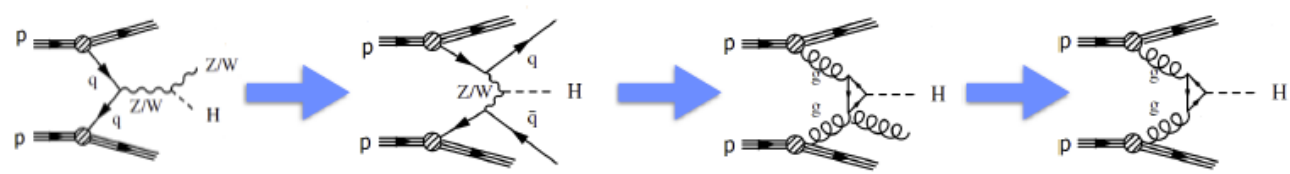




CMS HIG-17-007

$$\frac{\Gamma(H \to \gamma^*\gamma \to \mu\mu\gamma)}{\Gamma(H \to \gamma\gamma)} = (1.69 \pm 0.10)\%, \quad \frac{\Gamma(H \to Z\gamma \to \ell\ell\gamma)}{\Gamma(H \to \gamma\gamma)} = (2.27 \pm 0.14)\%$$

m_{ll} = 50 GeV, is used to separate $H \to Z\gamma$ and $H \to \gamma^*\gamma$



lepton tag

electron p_T > 7 GeV
muon p_T > 5 GeV

di-jet tag

$\Delta\eta_{jj}$ > 3.5, m_{jj} >500 GeV
Zeppenfeld < 2.5
$\Delta\Phi(ll\gamma, jj)$ > 2.4

boosted tag

$p_T^{ll\gamma}$ > 60 GeV

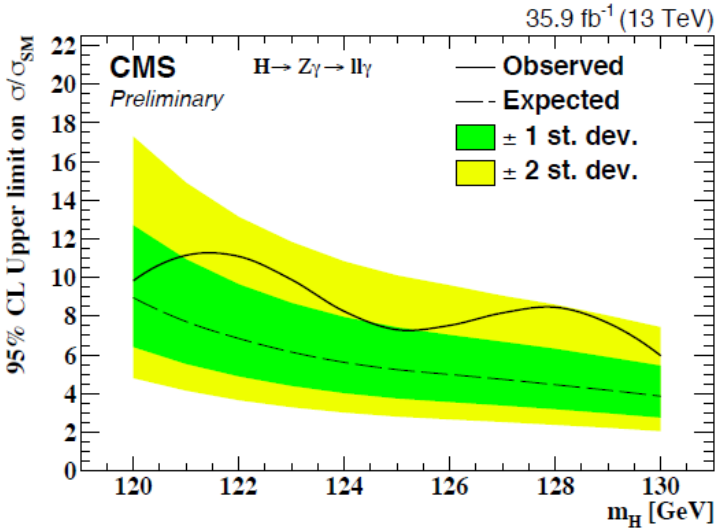
4 untagged categories

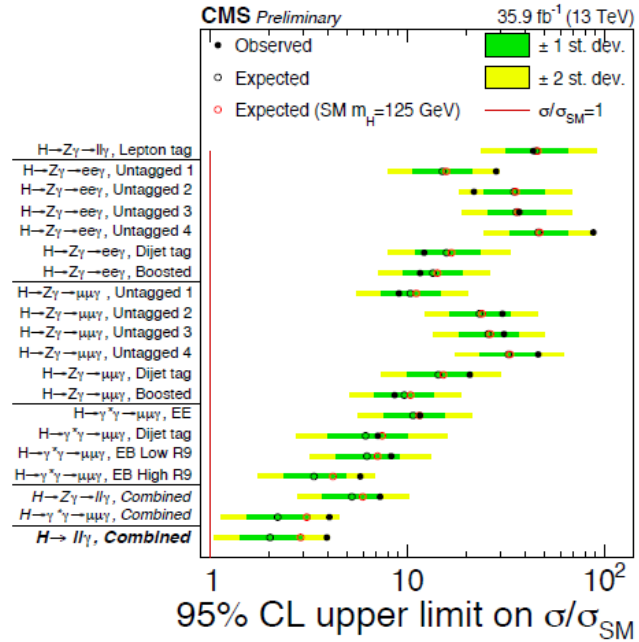
enhance $ll\gamma$ mass resolution and S/B

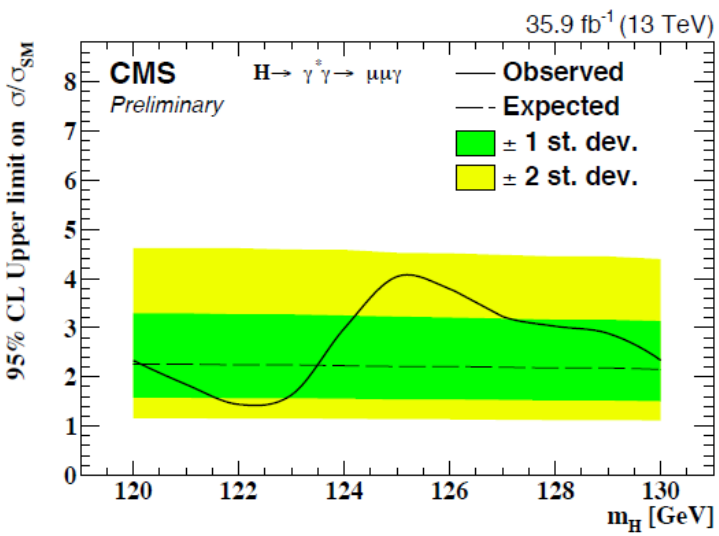
H→Zγ, H→llγ

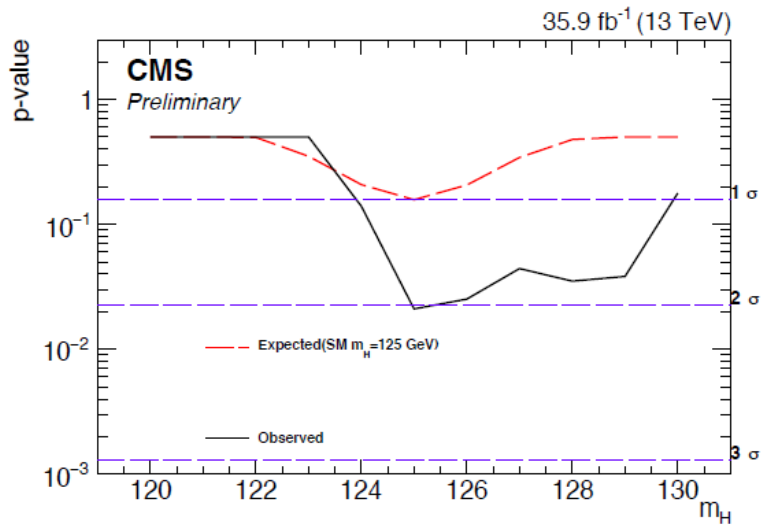
First hint of decay seen?

ATLAS limit: H→Zγ < 6.6 (5.2) xSM - arXiv:1708.00212









- **observed (expected) upper limit for σ/σ_{SM} is 3.9 (2.0)**
- **corresponding to an observed (expected) p-value of ~2σ (~1σ)**

H→mumu

CMS HIG-17-019

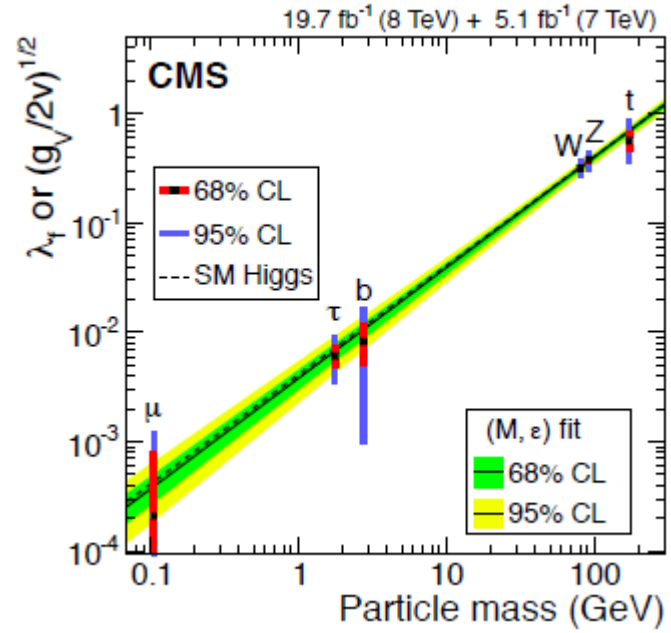
Very rare decay, BR=2.18E-4

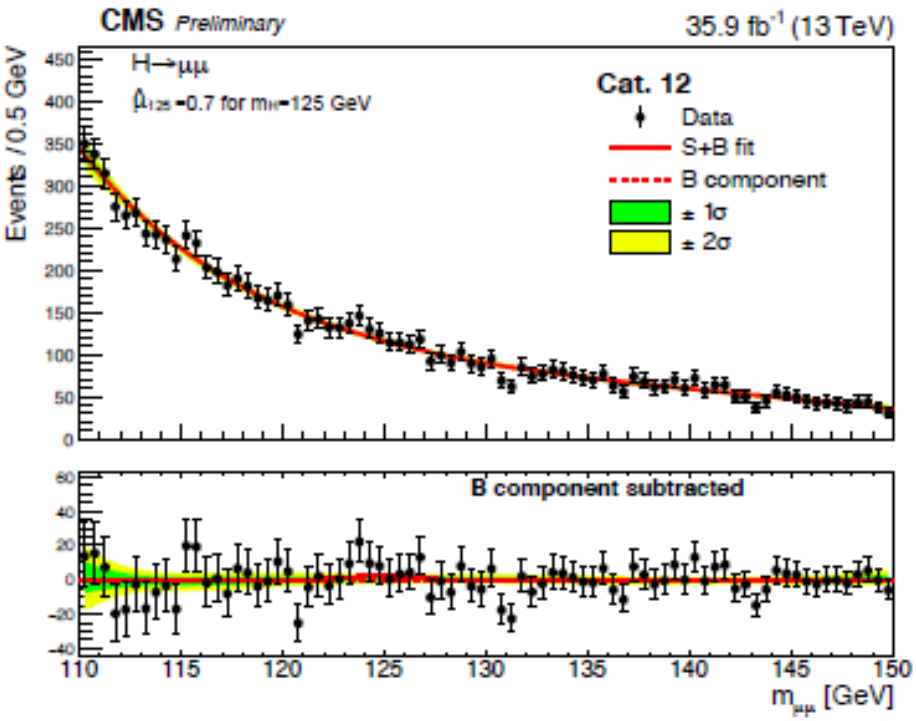
Clean and narrow peak, but huge background

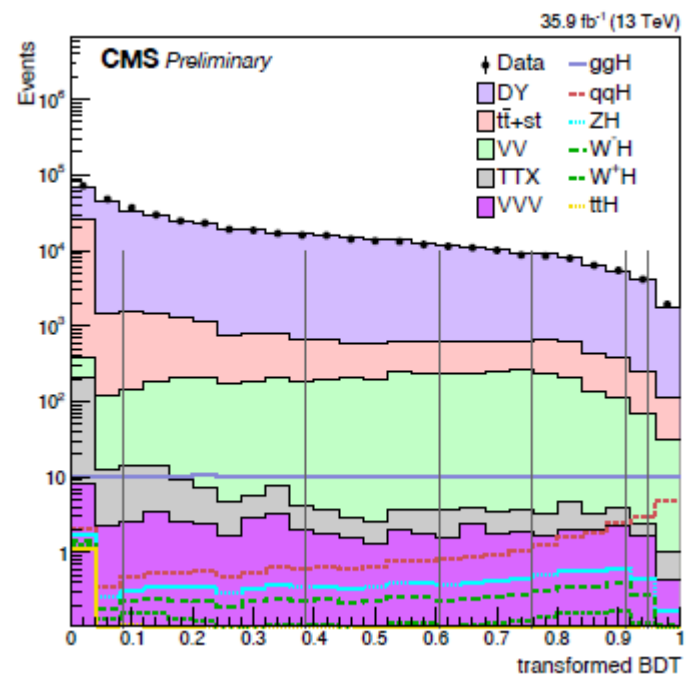
Only SM H decay to 2nd generation expected to be seen at LHC

Could be enhanced by new physics

BDT and 15 event categories (based on BDT and mass resolution) used to enhance sensitivity



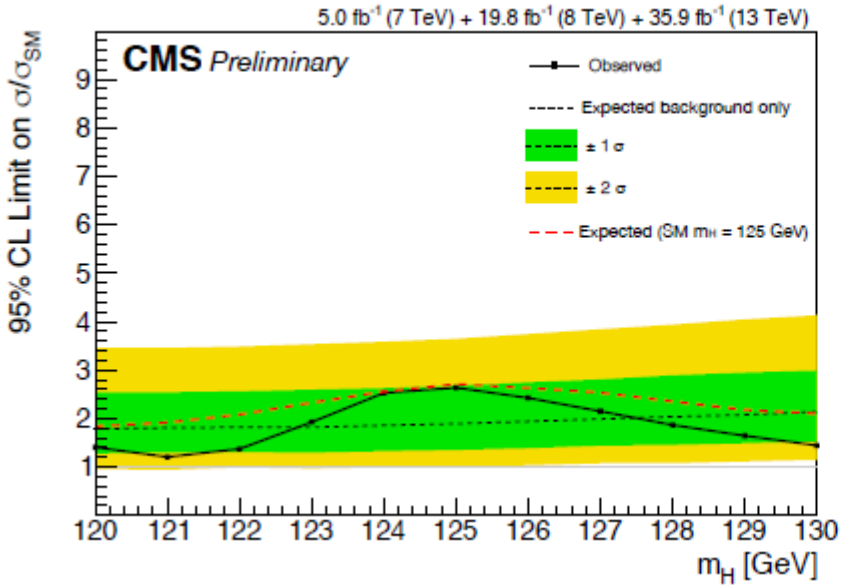


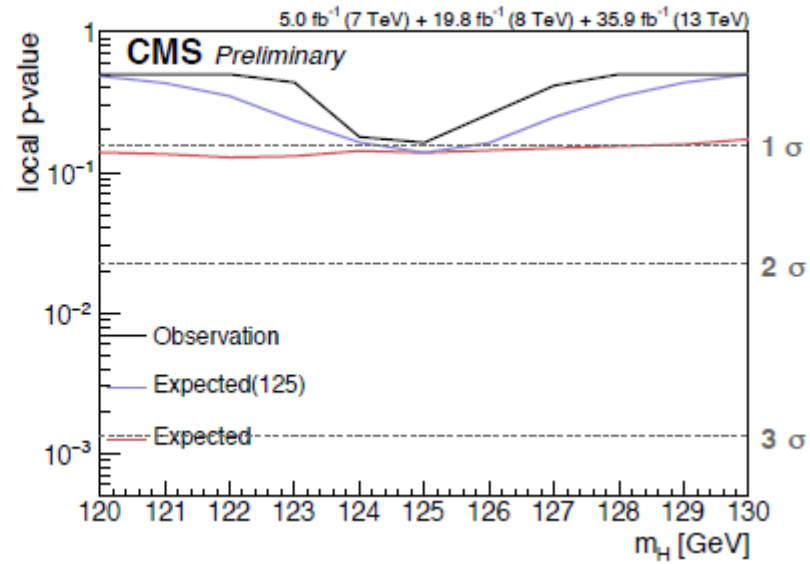


H→mumu

Combining Run1 and 2015/16 data, limit less than a factor of 3 away from SM rate!

First tiny hint of the decay being seen already?!



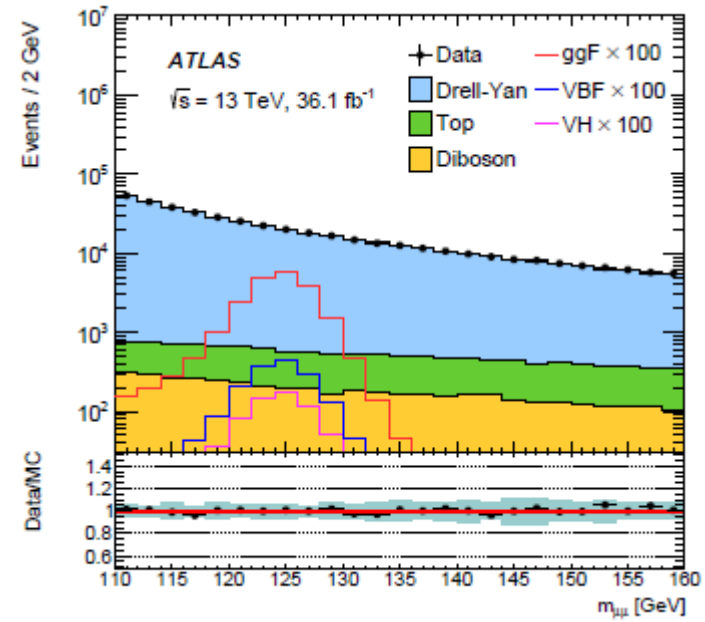


Dataset	95% CL limit on σ/σ_{SM} observed (expected)	Significance observed (expected)
13 TeV (35.9/fb)	2.64 (2.08)	0.74 (0.98)σ
7 TeV + 8 TeV+ 13 TeV	2.64 (1.89)	0.98 (1.09)σ

- **upper limit on BR(H→μμ) is 5.7×10^{-4}**

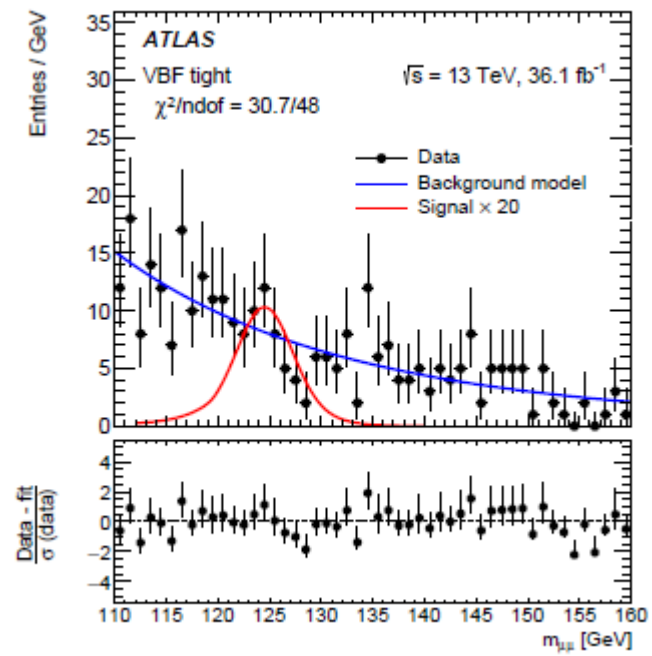
H→mumu

ATLAS also has an advanced analysis, with 8 event categories and a BDT for VBF for enhanced sensitivity



Combining Run1 + 2015/16 data: BR<2.8 (2.9) x SM rate

Mass resolution here is driven by the inner-tracker momentum resolution… higher B-field helps!



To improve sensitivity by x3, need ~9 times more data

9 x 40/fb = ~400 /fb

Good chance of seeing hints of this decay in Run3!

Phys. Rev. Lett. 119 (2017) 051802

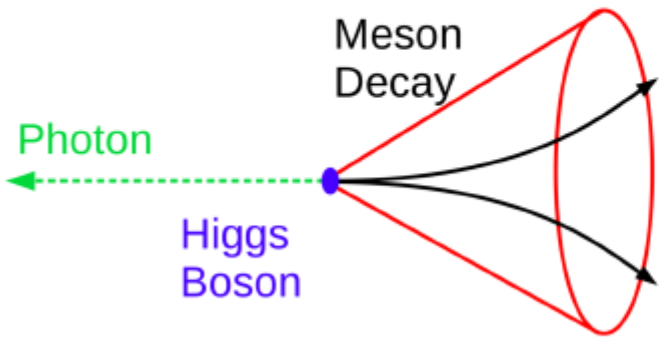
H→ meson + γ

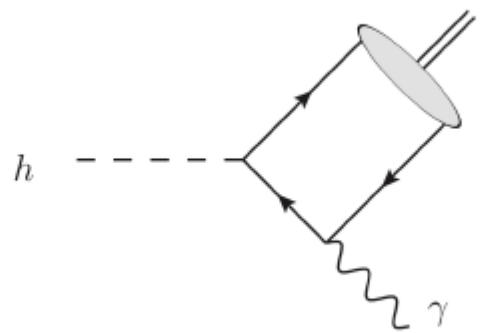
Innovative set of ATLAS searches using meson decays

Search for enhanced Higgs couplings to 1st and/or 2nd generation quarks

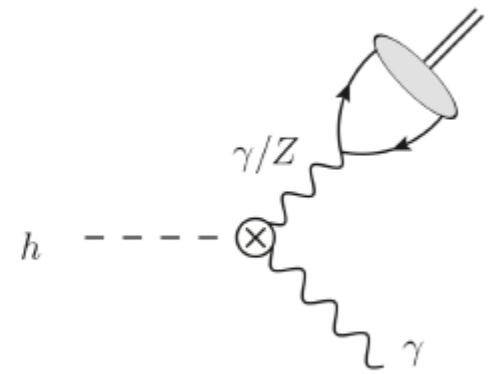
Uses triggers and background estimate techniques from B-physics group!

arXiv:1712.02758 and arXiv:1501.03276





Direct



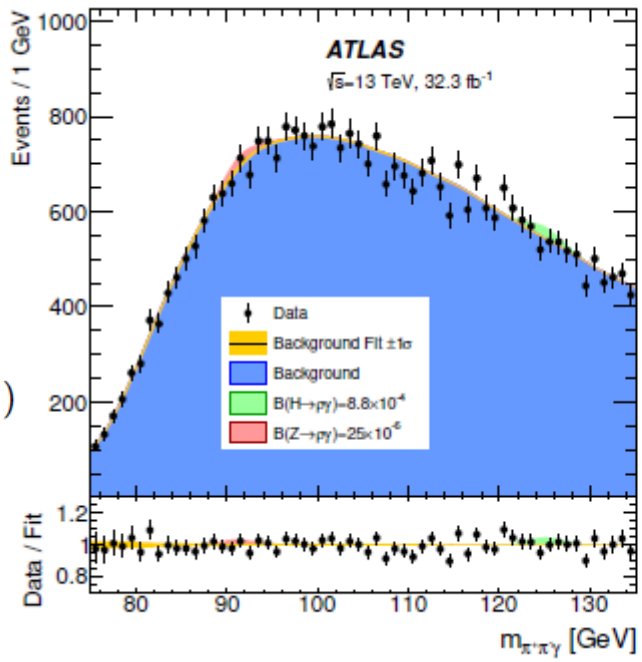
Indirect

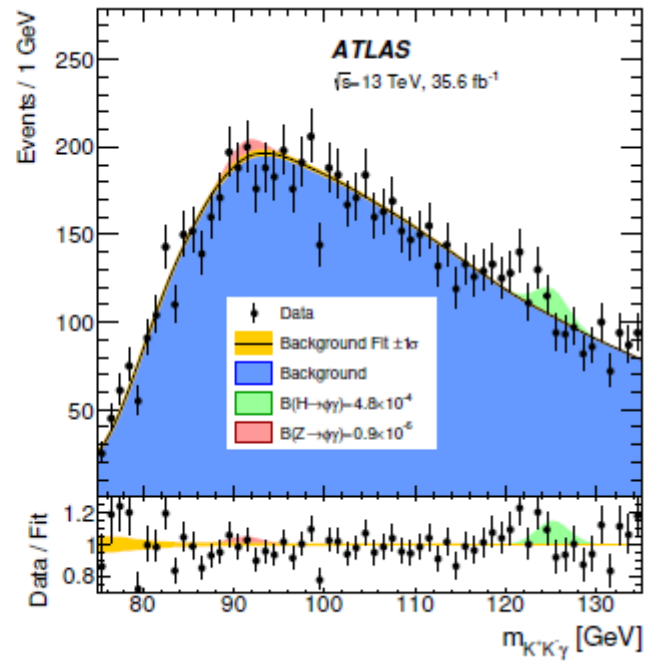
- Window to 1st and 2nd generation Yukawa couplings
- Distinctive topology to trigger and select events
- Target mesons:
  - ρ: $\mathrm{BR_{SM}}(H \to \rho\gamma) = 1.7 \times 10^{-5}$ †, $\rho \to \pi^+\pi^-$
  - ϕ: $\mathrm{BR_{SM}}(H \to \phi\gamma) = 2.3 \times 10^{-6}$ †, $\phi \to K^+K^-$
  - J/ψ: $\mathrm{BR_{SM}}(H \to J/\psi\gamma) = 2.8 \times 10^{-6}$ ‡, $J/\psi \to \mu^+\mu^-$
  - Υ: $\mathrm{BR_{SM}}(H \to \Upsilon(1S, 2S, 3S)\gamma) = (6.1, 2.0, 2.4) \times 10^{-10}$ ‡, $\Upsilon \to \mu^+\mu^-$

H→ meson + γ

Not close to SM, but would see enhanced decay

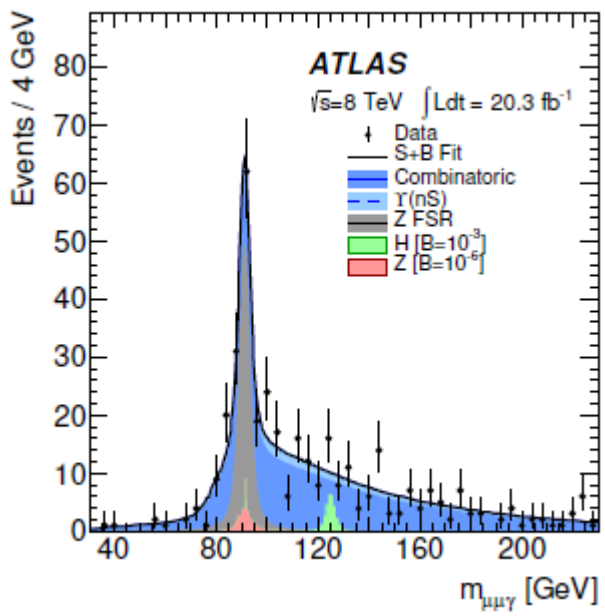
- $\mathrm{BR}(H \to \rho\gamma) < 8.8 \times 10^{-4}$ (**52**xSM)
- $\mathrm{BR}(H \to \phi\gamma) < 4.8 \times 10^{-4}$ (**208**xSM)

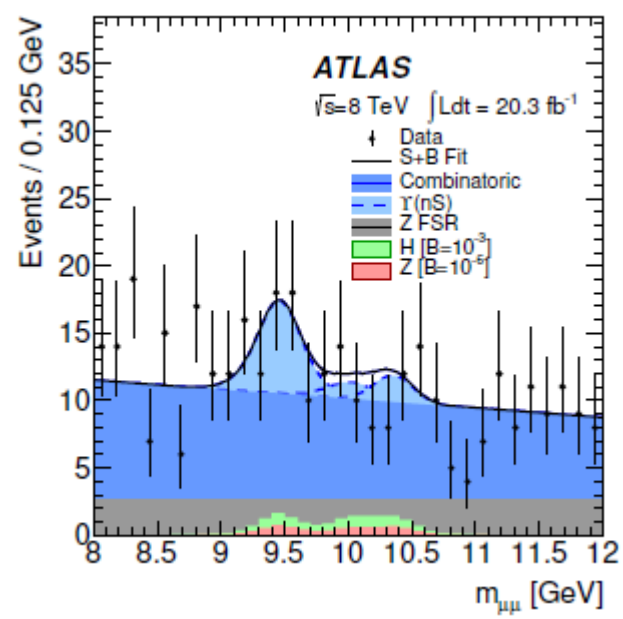




Unbinned maximum likelihood fits extract 95% CL limits of:

- $\mathrm{BR}(H \to J/\psi\gamma) < \mathbf{1.5 \times 10^{-3}}$
- $\mathrm{BR}(H \to \Upsilon(1S, 2S, 3S)\gamma) < (\mathbf{1.3, 1.9, 1.3}) \times \mathbf{10^{-6}}$





H→ ZH→ ll cc

arXiv:1802.04329

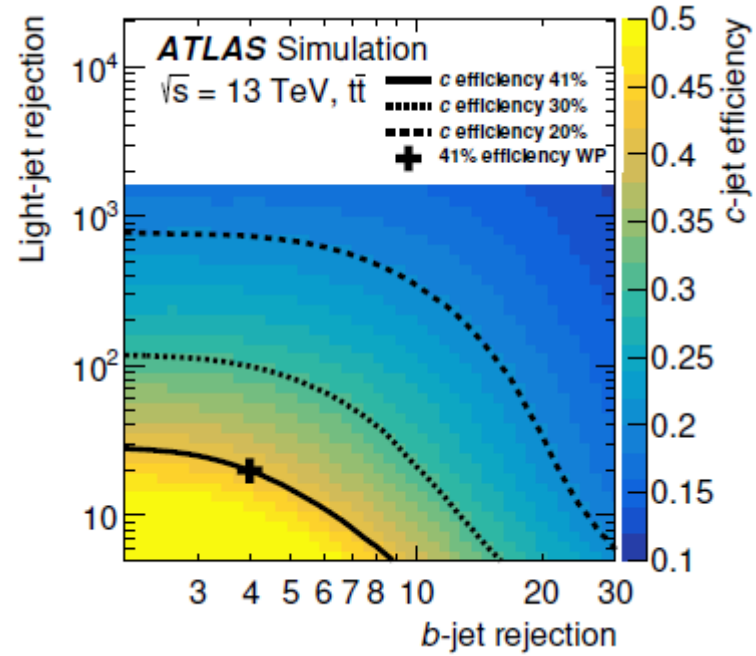
ATLAS also looks for direct H→cc decays

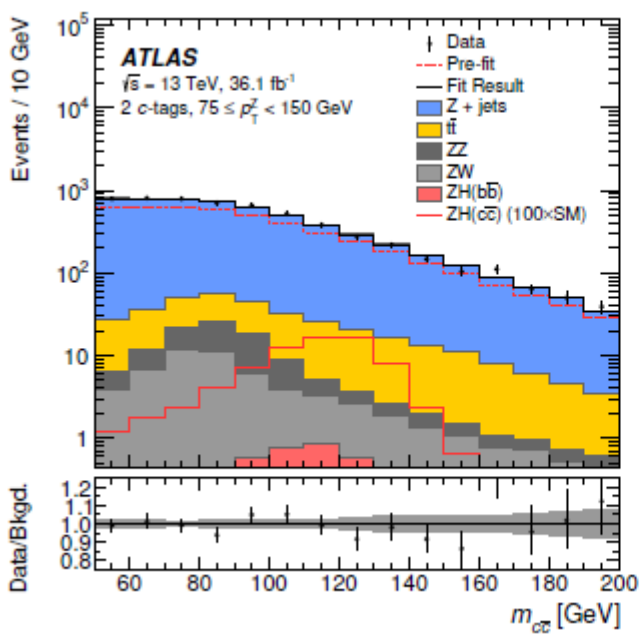
Use associated production with Z for triggering and to enhance S/sqrt(B)

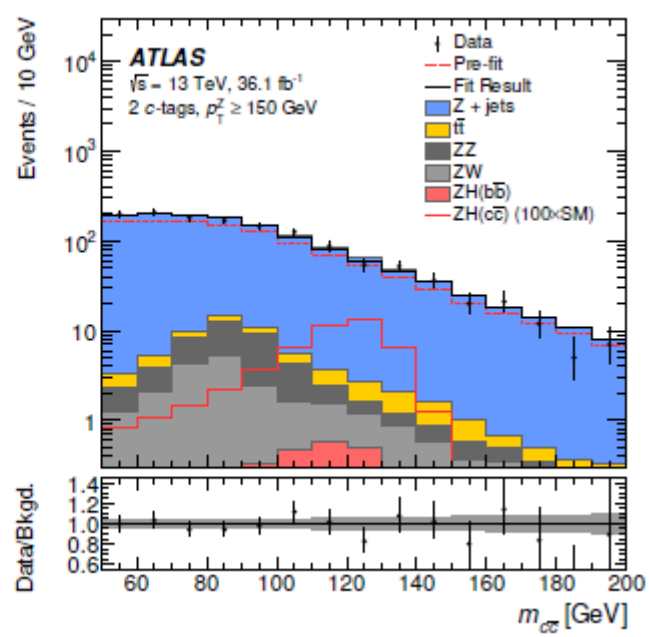
Use charm-jet tagging!

Split into low and high Z pT categories

BR H→cc < 110 (150 $^{+80}_{-40}$) times SM





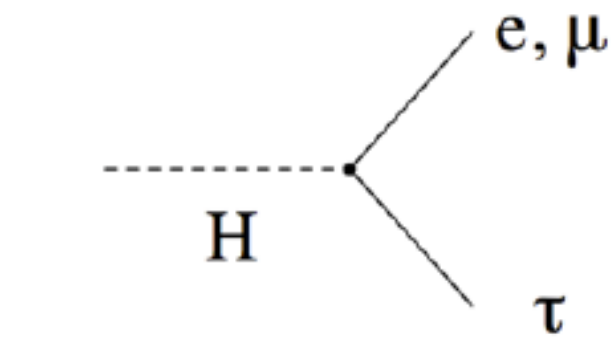


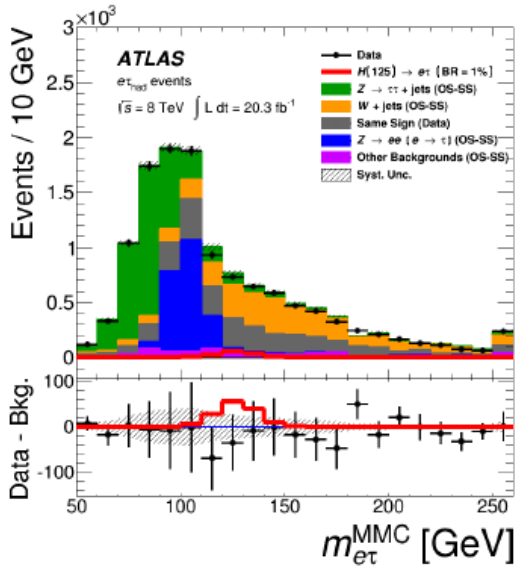
H→ e+tau / mu+tau

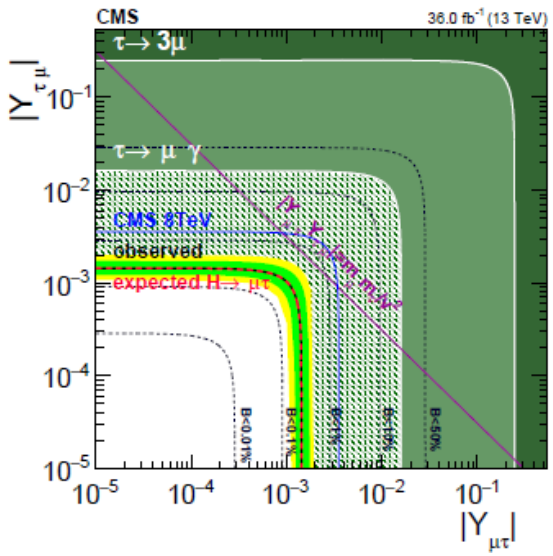
ATLAS: arXiv:1604.07730
CMS: arXiv:1712.07173

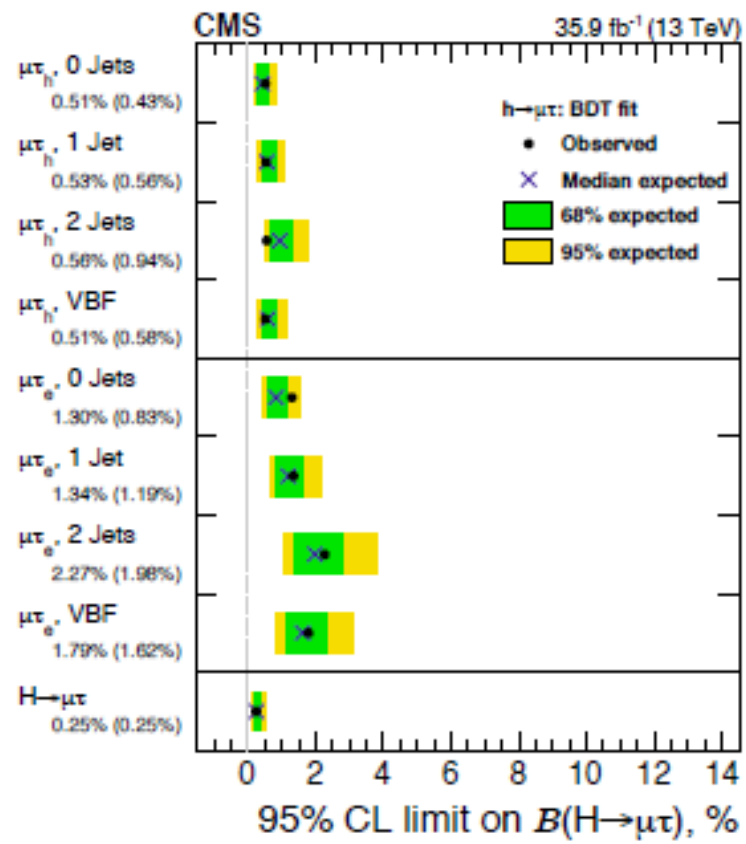
Lepton flavor violating – clearly would be new physics

Use multiple tau-decay channels, Higgs production categories, and BDT fits to improve sensitivity









	Observed (expected) limits (%)		Best fit branching fraction (%)	
	BDT fit	M_{col} fit	BDT fit	M_{col} fit
$H \to \mu\tau$	<0.25 (0.25)%	<0.51 (0.49) %	0.00 ± 0.12 %	0.02 ± 0.20 %
$H \to e\tau$	<0.61 (0.37) %	<0.72 (0.56) %	0.30 ± 0.18 %	0.23 ± 0.24 %

	BDT fit	M_{col} fit
$\sqrt{\lvert Y_{\mu\tau}\rvert^2 + \lvert Y_{\tau\mu}\rvert^2}$	$< 1.43 \times 10^{-3}$	$< 2.05 \times 10^{-3}$
$\sqrt{\lvert Y_{e\tau}\rvert^2 + \lvert Y_{\tau e}\rvert^2}$	$< 2.26 \times 10^{-3}$	$< 2.45 \times 10^{-3}$

H→ invisible

CMS HIG-17-023

arXiv:1711.00431
arVix:1712.02345

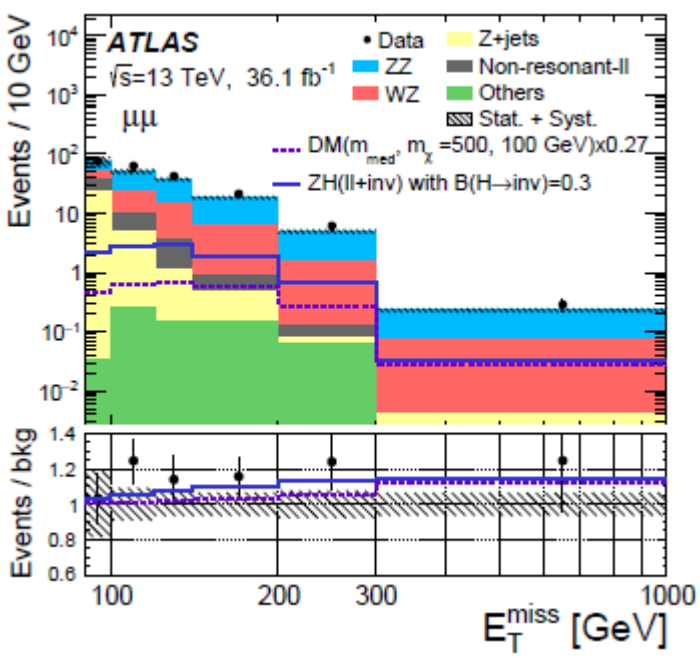
BR(H→ZZ→4ν) = 0.1% in SM

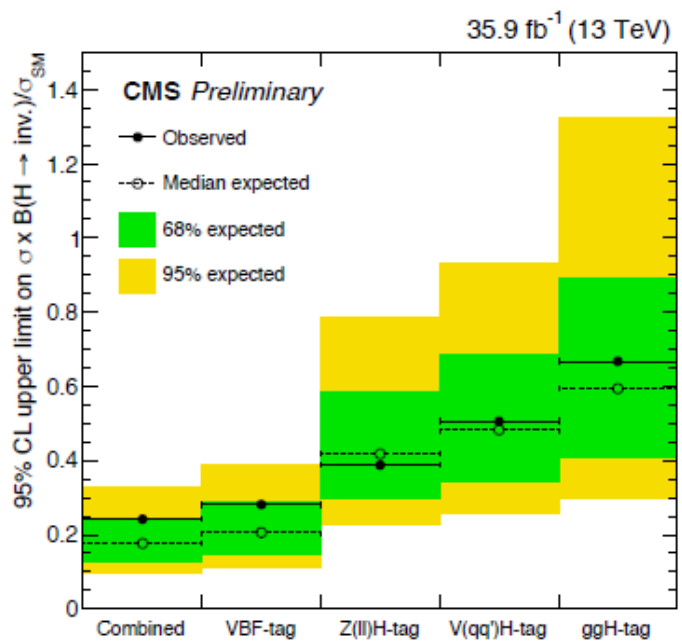
Many possible extensions of the SM would allow enhance the rate: decays to dark matter, hidden valleys / portals, …

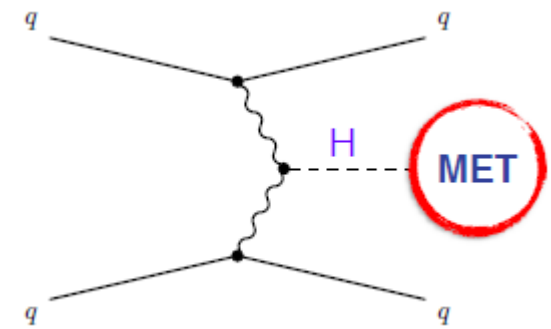
CMS use combination of VBF-tagged, associated W/Z (including boosted W/Z → quarks!), and ISR/mono-jet

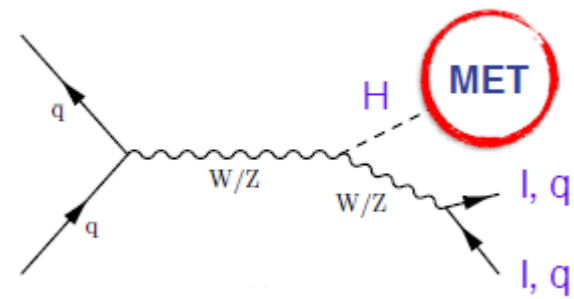
BR(H→invisible)<24 (18) % (at 95% CL)

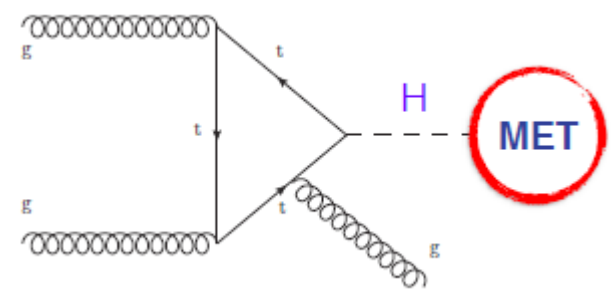
ATLAS ZH search: BR(H→invisible)<67 (39) % (at 95% CL)











$H \rightarrow ZZ_D$ or $Z_D Z_D$

arXiv:1802.03388

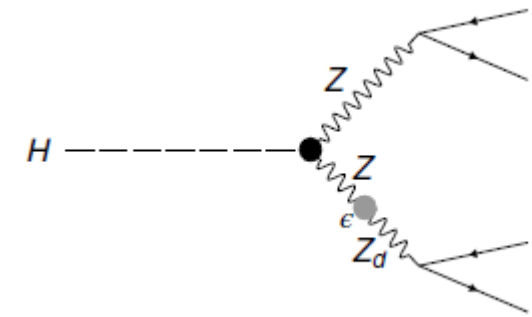
Reuse technology of H→4l measurement to search for new "hidden sector" decays

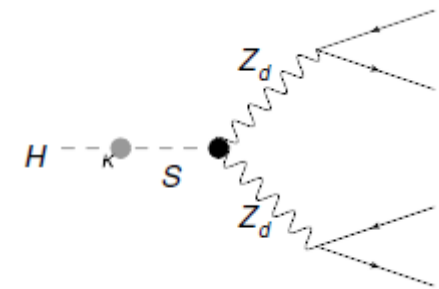
Dual range analysis:

- Low mass: $1 < m_{a^0\ \&\ Z_D} < 15$ GeV, 4μ only
- High mass: $15 < m_{a^0\ \&\ Z_D} < 60$ GeV, $4\mu + 2\mu 2e + 4e$

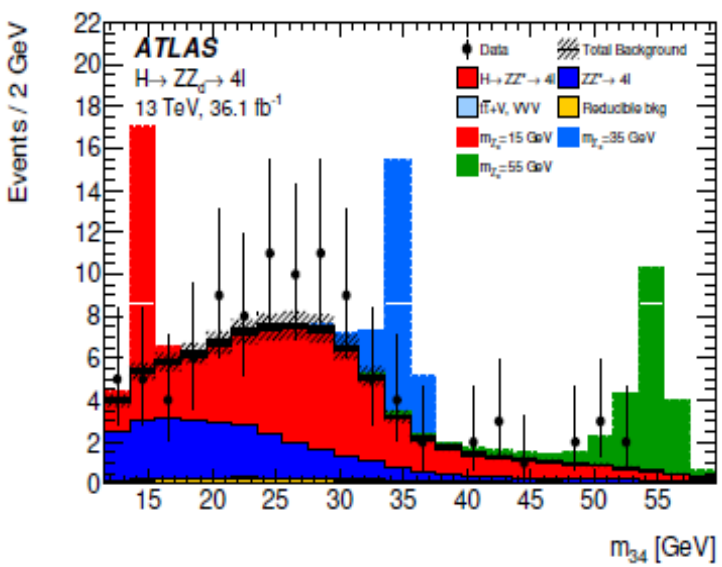
Select quadruplet with min: $\Delta m = |m_{12} - m_{34}|$

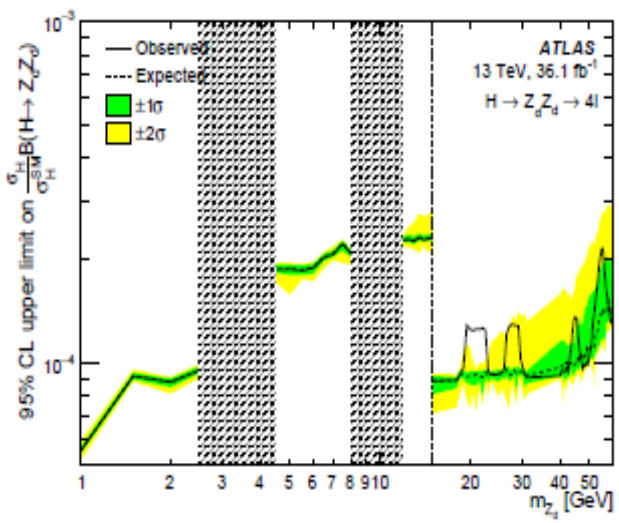
Observable: $\langle m \rangle = (m_{12} + m_{34})/2$

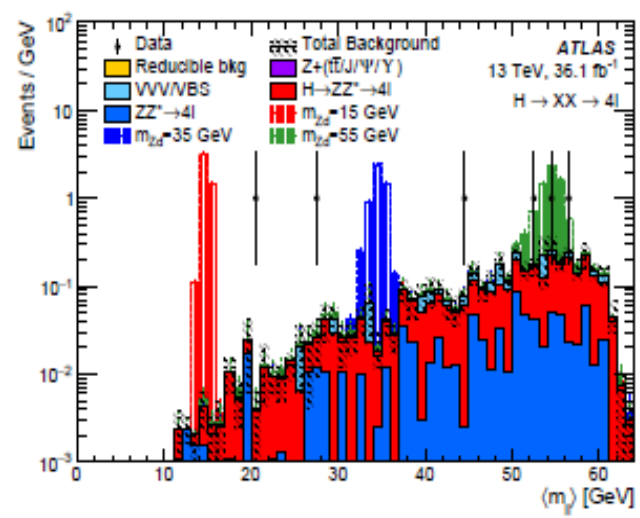




Set limits in the range of BR($H \rightarrow Z_D Z_D$) < ~10E-4 – E-3 and BR($H \rightarrow ZZ_D$) < ~E-3







Summary

Large range of rare and exotic Higgs decays considered by ATLAS/CMS!

- **H→ Zγ, llγ**
- **H→mumu**
- **H→meson+γ**
- **Z+H→cc**
- **H→etau, mutau**
- **h→invisible**
- **h→γ+MET**
- **h→other bosons (a, Z_D)**

Sensitive to many new-physics scenarios

Closing in on some rare SM Higgs decays

Run3 (and HL-LHC) will be critical for these statistics-limited searches… stay tuned!