Rare decays of the Higgs boson in the llγ final state in pp collisions at √s=13 TeV

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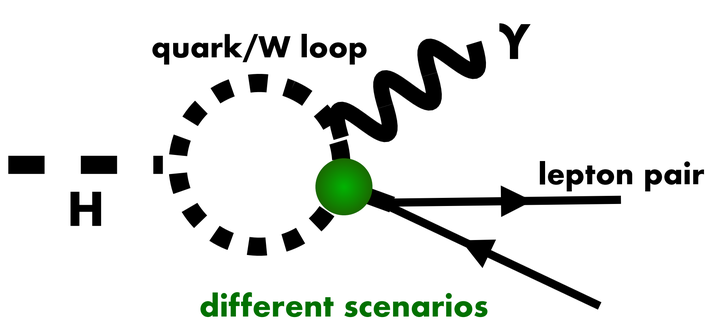
Abstract

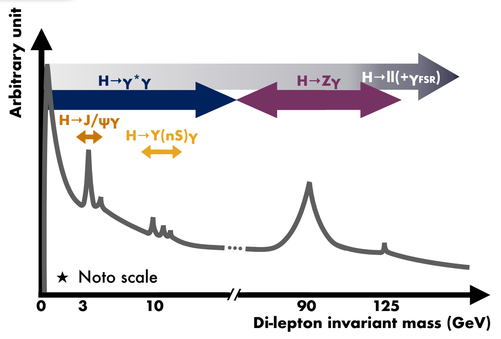
Rare decays of the Higgs boson in the two leptons and photon final state, including the H→Z/γ*+γ and the H→J/ψγ processes, are of importance in various Higgs boson decays. Results on searches for the H→llγ using data from proton-proton collisions with an integrated luminosity of 35.9 fb^{-1} at √s = 13 TeV collected with the CMS detector at the LHC are presented.

Introduction

H→Z/γ*+γ

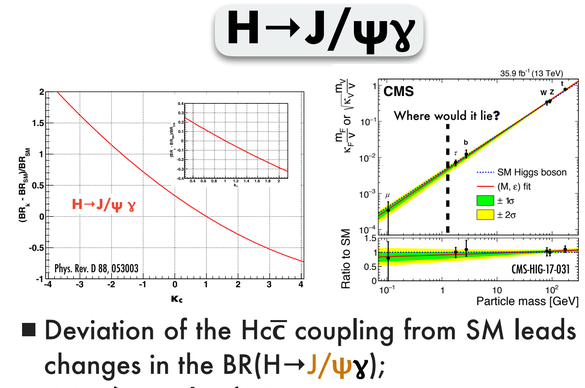
- Loop-induced diagrams, new physics present in the loop will modify the decay rates
- Additional constraint on the Higgs coupling measurement (by resolving the loop)
- Some extensions of SM suggest more complex Higgs sectors where CP violation may be induced. Measuring the forward-backward asymmetry of the decay precisely provides us a test for the CP property of the Higgs boson
- **$BR_{SM}(H→Zγ)≃1.5×10^{-3}$, $BR_{SM}(H→γ^*γ→μμγ)≃3.8×10^{-5}$**





charm quarks hardronize to form J/ψ	direct amplitude of H→J/ψγ
quark/W loop to Z/γ*	H→ Z/γ*+γ
quark/W loop to γ*, then γ* converts into J/ψ	indirect amplitude of H→J/ψγ

H→J/ψγ



- Deviation of the Hcc̄ coupling from SM leads to changes in the BR(H→J/ψγ); **$BR_{SM}(H→J/ψγ)≃3.0×10^{-6}$**
- Extensions of the SM modify the Hcc̄ coupling
- A similar search on Z→J/ψγ is jointly performed; **$BR_{SM}(Z→J/ψγ)≃9.0×10^{-8}$**

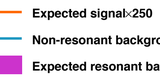
Analysis Strategy

Event selection

- Two well-identified leptons originated from PV. Leptons must be isolated in H→Zγ to reject decays of hadrons within jets
- The low masses of J/ψ and γ* result in collimated leptons, leading to challenges in trigger and reconstruction
  - Dedicated HLT requires a muon and a photon
  - Only the decay into muons is considered
  - Isolation only applied on μ_{lead}
- Energetic & isolated photon
- Kinematic cuts to reject pp→Z/γ*+γ_{FSR}, pp→γ*+jets, and pp→γ+jets backgrounds

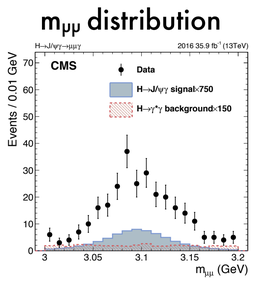
Event classification

Order of categorization ↓

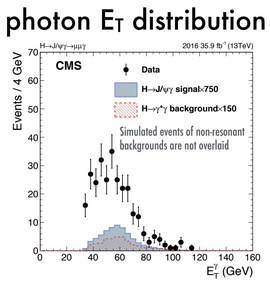
	H→Zγ	H→γ*γ	H/Z→J/ψγ	
	Lepton tag			VH & ttH production 
	Di-jet tag	Di-jet tag		VBF production 
	Boosted tag			A boosted Higgs boson recoiling against a jet 
	4 Untagged categories	3 Untagged categories	3 Untagged categories	Based on photon η_{SC} & R9 variable
Improvement in sensitivity	18%	11%	2%	▪ The order of the categorization is optimized such that a better purity of the specific production in its associated category is obtained

- H→Zγ→llγ: expected signal yield, of O(50), is at the same order as H→4l, but with much larger irreducible backgrounds
- H→γ*γ→μμγ: smaller signal yield, of O(20), and also smaller background than H→Zγ owing to the special event signature
- H/Z→J/ψγ→μμγ: much smaller signal expectation, of O(<10^{-1} for H & ~1 for Z), than above two channels, and with large J/ψ+γ/jets backgrounds

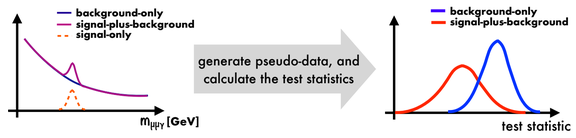
$m_{\mu\mu}$ distribution



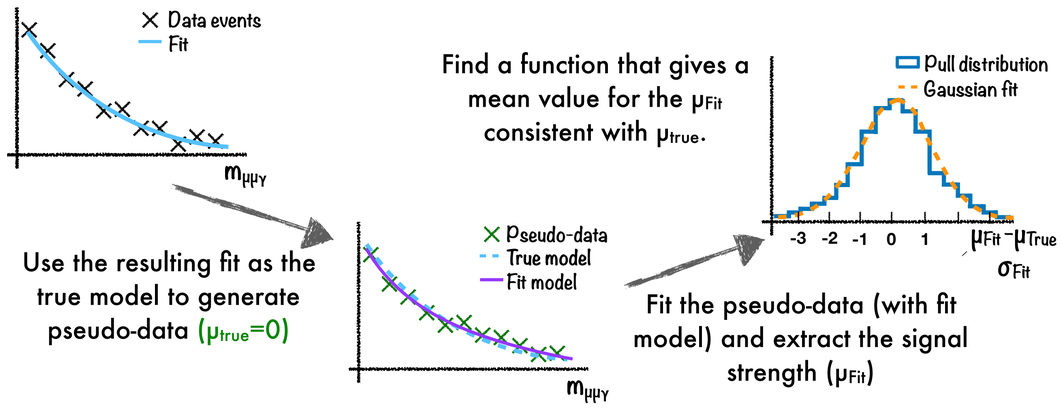
photon E_T distribution



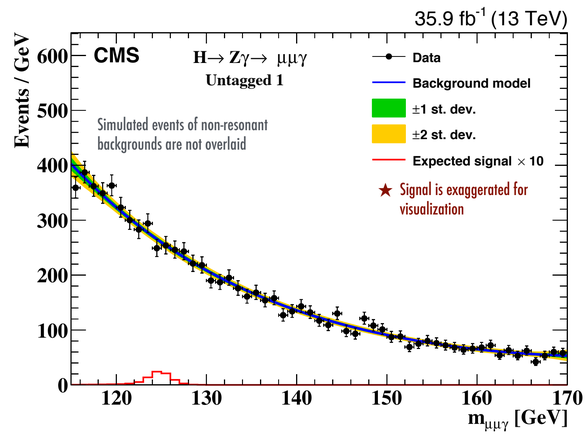
⇒ **$m_{llγ}$ is used as signal/background discriminating variable** in the hypothesis test. The profile likelihood ratio is used as test statistic

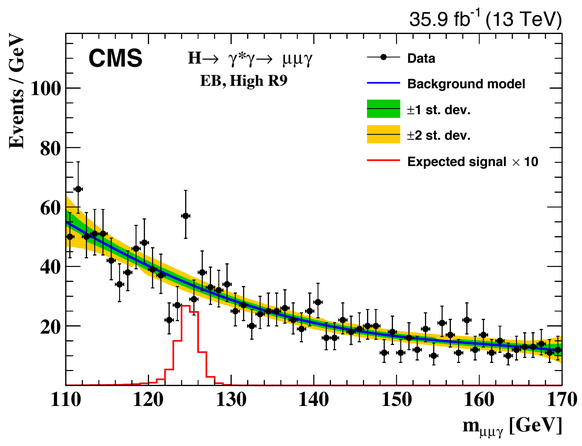


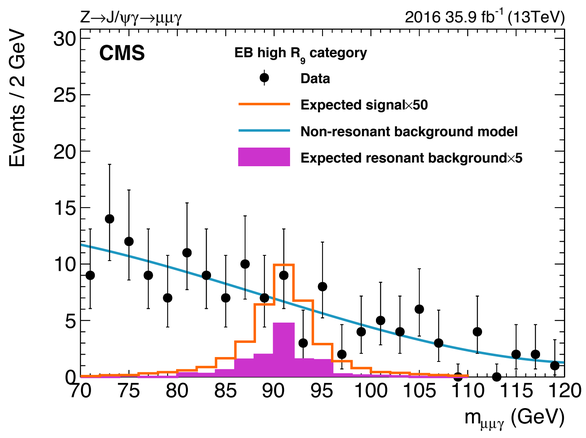
- **Resonant background** (H/Z→J/ψγ): background processes that produce the same final state as the signal and exhibit a resonant peak at the Higgs (Z) boson mass
  - Need to be modeled independently
  - Estimated from simulated events
- **Non-resonant background**: background processes that do not exhibit a resonant peak at the Higgs (Z) boson mass
  - Proper simulation samples are only available for H→Zγ
  - Estimated from data using the fits with analytic functions (unbinned evaluation of the likelihood) to the $m_{llγ}$ distributions in data (Same approach for the signal shapes)



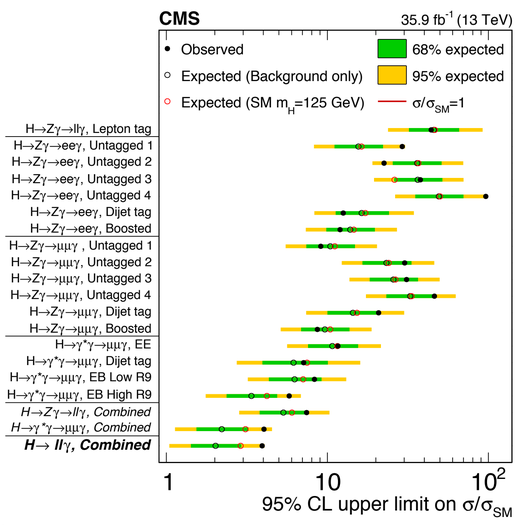
$m_{llγ}$ distributions & Non-resonant background models



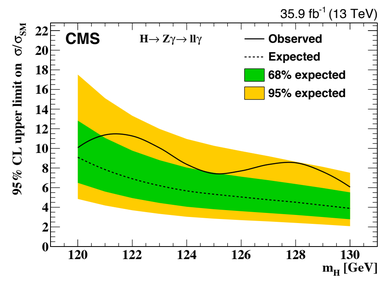


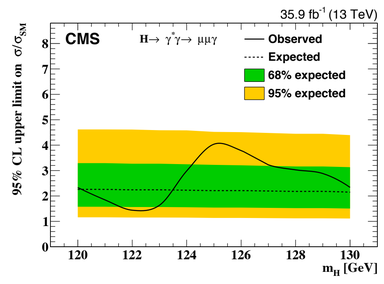


Results & Summary



✦Observed (expected) upper limit for σ/σ_{SM} is 3.9 (2.0), with corresponding p-value of ~2σ (1σ)





Channel	Obs. (exp.) upper limit BR	BR / BR$_{SM}$	Run1 results ATLAS Phys. Rev. Lett. 114, 121801	Run1 results CMS Phys. Lett. B 753 (2016) 341
Z→J/ψγ	$1.4(1.6^{+0.7}_{-0.5})\times10^{-6}$	15 (17)	$2.6(2.0^{+1.0}_{-0.6})\times10^{-6}$	—
H→J/ψγ	$7.6(5.2^{+2.4}_{-1.6})\times10^{-4}$	260 (170)	$1.5(1.2^{+0.6}_{-0.3})\times10^{-3}$	$1.5(1.6^{+0.8}_{-0.8})\times10^{-3}$
	Combination with CMS Run1 result leads to an upper limit of **220 (160)**×SM			

- **Searches for rare decays of the Higgs boson in the llγ final state in pp collisions with an integrated luminosity of 35.9 fb^{-1} at √s=13 TeV are presented**
- **The paper CMS-HIG-17-007 for the H→Z/γ*+γ search was published in JHEP 11 (2018) 152, while the paper CMS-SMP-17-012 for the H/Z→J/ψγ search was accepted by EPJC**
- **First search of Z→J/ψγ decay in CMS, leading to other rare decays of the Higgs and Z boson into quarkonia states (for example, the searches of H/Z→Υ(nS)γ, H/Z→Υ+Υ, H/Z→J/ψ+J/ψ, H→Z+J/ψ decays are currently underway)**
- **More data are required to approach the SM sensitivity. Meanwhile, advanced analysis techniques are being developed (see P2-MH-014). With current sensitivities and foreseeable improvements, ~4σ of significance for the H→Z/γ*+γ decay is promising at HL-LHC**