Analysis of the current trigger and selection efficiency for the process $H \to J/\psi\gamma \to \mu\mu\gamma$ at CMS and comparison with new trigger proposals

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Research Activities
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Outline

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Introduction

A word on physics motivations

The Higgs boson is considered to be discovered in 2012, when a new particle with the properties predicted by the Standard Model (SM) was observed by CMS and ATLAS collaborations. Yukawa couplings to first and second-generation quarks are still to be measured.

- Rare exclusive decays of the Higgs boson to mesons in association with a photon can be used to explore these couplings.
- $\mathrm{H} \to \mathrm{J}/\psi\gamma$ can be used to explore the Higgs boson coupling to the charm quark $\Rightarrow$ test of SM predictions.
- $\mathrm{Z} \to \mathrm{J}/\psi\gamma$ can be used as an experimental benchmark.

Introduction

- Both decays receive contributions from direct and indirect processes

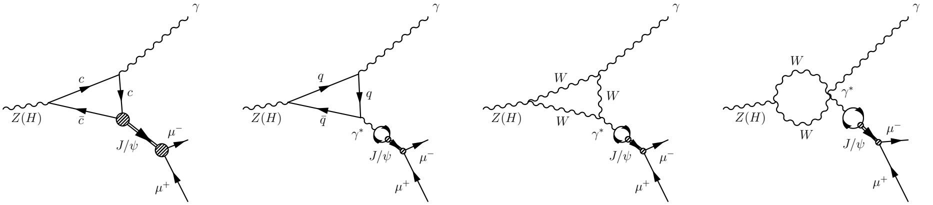

Figure: Lowest order Feynman diagrams for the Z (or H) $\rightarrow J/\psi\gamma$ decay. The left-most diagram shows the direct and the remaining diagrams the indirect processes†.

- The BR($H \rightarrow J/\psi\gamma$) is proportional to the $Hc\bar{c}$ coupling.

†Sirunyan et al., "Search for rare decays of Z and Higgs bosons to J/ψ and a photon in proton-proton collisions at $\sqrt{s} = 13$ TeV".

Introduction

- Experimental efforts have only established an upper bound 200 times the SM predicted value.
- The main challenge is the discrimination between background and signal ⇒ higher luminosity and more efficient trigger needed.

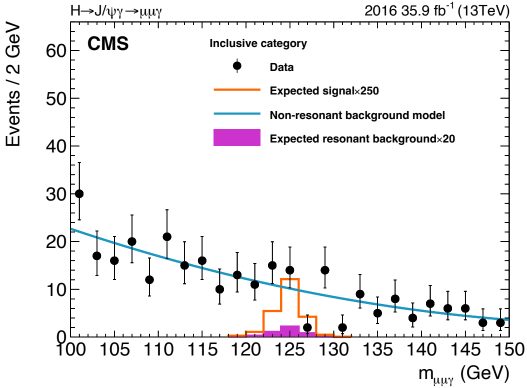

Figure: $m_{\mu\mu\gamma}$ in Higgs boson exotic decay‡.

‡Sirunyan et al., "Search for rare decays of Z and Higgs bosons to J/ψ and a photon in proton-proton collisions at $\sqrt{s} = 13$ TeV".

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Objectives

Trigger

In order to filter the amount of data that is recorded from each collision at the LHC, L1 and High Level triggers are used. Current High Level Trigger requires the presence of a muon and a photon exceeding 17 and 30 GeV, respectively, in the final state.

Goal

Design a new trigger that can outperform *HLT_Mu17_Photon30*.

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Trigger and selection efficiencies

The selection efficiency:

$$\varepsilon_{\text{selection}} = \frac{\#\ \text{events passing selection}}{\#\ \text{total events}}$$

The trigger efficiency:

$$\varepsilon_{\text{trigger}} = \frac{\#\ \text{events passing HLT \& selection}}{\#\ \text{events passing selection}}$$

Muons	**Photons**
nMuon ≥ 2	nPhoton ≥ 1
Opposite charges: $\mu^-,\ \mu^+$	-
$\lvert\eta\rvert < 2.4$	$\lvert\eta\rvert < 2.4$
Retain pair with min. $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$	-
$p_{\mathrm{T}}^{\mu_1} > 10$ GeV, $p_{\mathrm{T}}^{\mu_2} > 5$ GeV	$p_{\mathrm{T}}^{\gamma} > 15$ GeV
mediumId	mvaID_WP90
-	pixel_Seed $= 0$

Figure: Kinematic, charge and quality selection criteria imposed to the muons and photons in the final state.

Example calculation of ε for *HLT_Mu17_Photon30*

	HLT_Mu17_Photon30				
				Efficiencies (%)	
	# total events	# passing sel.	# passing HLT & sel.	**Trigger**	**Selection**
QCD	$(21336 \pm 5) \cdot 10^3$	34 ± 6	26 ± 5	76 ± 7	$(1.6 \pm 0.3) \cdot 10^{-4}$
Z	$(4590 \pm 7) \cdot 10^2$	$(986 \pm 3) \cdot 10^2$	$(818 \pm 3) \cdot 10^2$	83.0 ± 0.1	21.49 ± 0.06
H	$(4480 \pm 7) \cdot 10^2$	$(1606 \pm 4) \cdot 10^2$	$(1421 \pm 4) \cdot 10^2$	88.49 ± 0.08	35.85 ± 0.07

Figure: Example calculation of the trigger and selection efficiencies for the trigger *HLT_Mu17_Photon30* and selection cuts: $p_{\mathrm{T}}^{\mu} > 18$ GeV and $p_{\mathrm{T}}^{\gamma} > 32$ GeV.

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Muon1: $p_{\mathrm{T}} > 15$ GeV, muon2: $p_{\mathrm{T}} > 10$ GeV, photon: $p_{\mathrm{T}} > 15$ GeV

	Selection efficiencies (%)	
	$p_{\mathrm{T}}^{\mu 1} > 18$ GeV, $p_{\mathrm{T}}^{\gamma} > 32$ GeV	$p_{\mathrm{T}}^{\mu 1} > 15$ GeV, $p_{\mathrm{T}}^{\mu 2} > 10$ GeV, $p_{\mathrm{T}}^{\gamma} > 15$ GeV
QCD	$(1.6 \pm 0.3) \cdot 10^{-4}$	$(4.4 \pm 0.5) \cdot 10^{-4}$
Z	21.49 ± 0.06	20.55 ± 0.06
H	35.85 ± 0.07	28.65 ± 0.07

Figure: Selection efficiencies obtained for the selection cuts: $p_{\mathrm{T}}^{\mu 1} > 15$ GeV, $p_{\mathrm{T}}^{\mu 2} > 10$ GeV, $p_{\mathrm{T}}^{\gamma} > 15$ GeV (right column) compared to the ones obtained for $p_{\mathrm{T}}^{\mu 1} > 18$ GeV, $p_{\mathrm{T}}^{\gamma} > 32$ GeV (left column).

- Efficiency of QCD increases while Z and Higgs efficiencies decrease $\Rightarrow$ scheme is discarded.

Muon1: $p_{\mathrm{T}} > 18$ GeV, photon: $p_{\mathrm{T}} > 24$ GeV, $\Delta R(\mu - \mu) < 0.4$

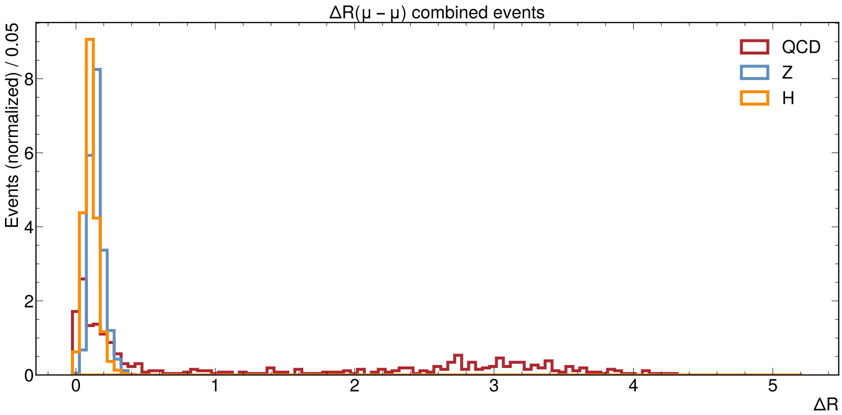


Figure: Normalized histogram for angular separation ΔR between the two muons reconstructed in the final state.

Muon1: $p_T > 18$ GeV, photon: $p_T > 24$ GeV, $\Delta R(\mu - \mu) < 0.4$

	Selection efficiencies (%)	
	$p_T^{\mu 1} > 18$ GeV, $p_T^{\gamma} > 32$ GeV	$p_T^{\mu 1} > 18$ GeV, $p_T^{\gamma} > 24$ GeV, $\Delta R(\mu - \mu) < 0.4$
QCD	$(1.6 \pm 0.3) \cdot 10^{-4}$	$(1.4 \pm 0.3) \cdot 10^{-4}$
Z	21.49 ± 0.06	24.73 ± 0.06
H	35.85 ± 0.07	37.65 ± 0.07

Figure: Selection efficiencies obtained for the selection cuts: $p_T^{\mu 1} > 18$ GeV, $p_T^{\gamma} > 24$ GeV, $\Delta R(\mu - \mu) < 0.4$ (right column) compared to the ones obtained for $p_T^{\mu 1} > 18$ GeV, $p_T^{\gamma} > 32$ GeV (left column).

- QCD selection efficiency: -10%
- Z selection efficiency: $+15\%$
- H selection efficiency: $+5\%$

Muon1: $p_{\mathrm{T}} > 15$ GeV, photon: $p_{\mathrm{T}} > 20$ GeV, 2 GeV $< m_{\mu\mu} <$ 4 GeV

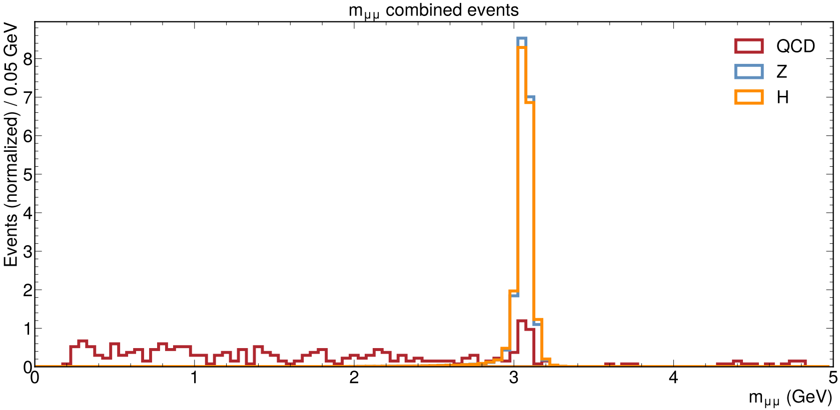


Figure: Normalized histogram for invariant mass of the muon pair system reconstructed in the final state.

Muon1: $p_\mathrm{T} > 15$ GeV, photon: $p_\mathrm{T} > 20$ GeV, 2 GeV $< m_{\mu\mu} <$ 4 GeV

	Selection efficiencies (%)	
	$p_\mathrm{T}^{\mu1} > 18$ GeV, $p_\mathrm{T}^{\gamma} > 32$ GeV	$p_\mathrm{T}^{\mu1} > 15$ GeV, $p_\mathrm{T}^{\gamma} > 20$ GeV, $2 < m_{\mu\mu} < 4$ GeV
QCD	$(1.6 \pm 0.3) \cdot 10^{-4}$	$(1.3 \pm 0.2) \cdot 10^{-4}$
Z	21.49 ± 0.06	27.42 ± 0.07
H	35.85 ± 0.07	38.75 ± 0.07

Figure: Selection efficiencies obtained for the selection cuts: $p_\mathrm{T}^{\mu1} > 15$ GeV, $p_\mathrm{T}^{\gamma} > 20$ GeV, $2 < m_{\mu\mu} < 4$ GeV (right column) compared to the ones obtained for $p_\mathrm{T}^{\mu1} > 18$ GeV, $p_\mathrm{T}^{\gamma} > 32$ GeV (left column).

- QCD selection efficiency: -25%
- Z selection efficiency: $+28\%$
- H selection efficiency: $+8\%$

Muon1: $p_T > 10$ GeV, muon2: $p_T > 5$ GeV, photon: $p_T > 15$ GeV, $2 \text{ GeV} < m_{\mu\mu} < 4$ GeV

	Selection efficiencies (%)	
	$p_T^{\mu 1} > 18$ GeV, $p_T^{\gamma} > 32$ GeV	$p_T^{\mu 1} > 10$ GeV, $p_T^{\mu 2} > 5$ GeV, $p_T^{\gamma} > 15$ GeV, $2 \text{ GeV} < m_{\mu\mu} < 4$ GeV
QCD	$(1.6 \pm 0.3) \cdot 10^{-4}$	$(4.5 \pm 0.5) \cdot 10^{-4}$
Z	21.49 ± 0.06	29.83 ± 0.07
H	35.85 ± 0.07	39.81 ± 0.07

Figure: Selection efficiencies obtained for the selection cuts: $p_T^{\mu 1} > 10$ GeV, $p_T^{\mu 2} > 5$ GeV, $p_T^{\gamma} > 15$ GeV, $2 \text{ GeV} < m_{\mu\mu} < 4$ GeV (right column) compared to the ones obtained for $p_T^{\mu 1} > 18$ GeV, $p_T^{\gamma} > 32$ GeV (left column).

- QCD selection efficiency: +181%
- Z selection efficiency: +38%
- H selection efficiency: +11%

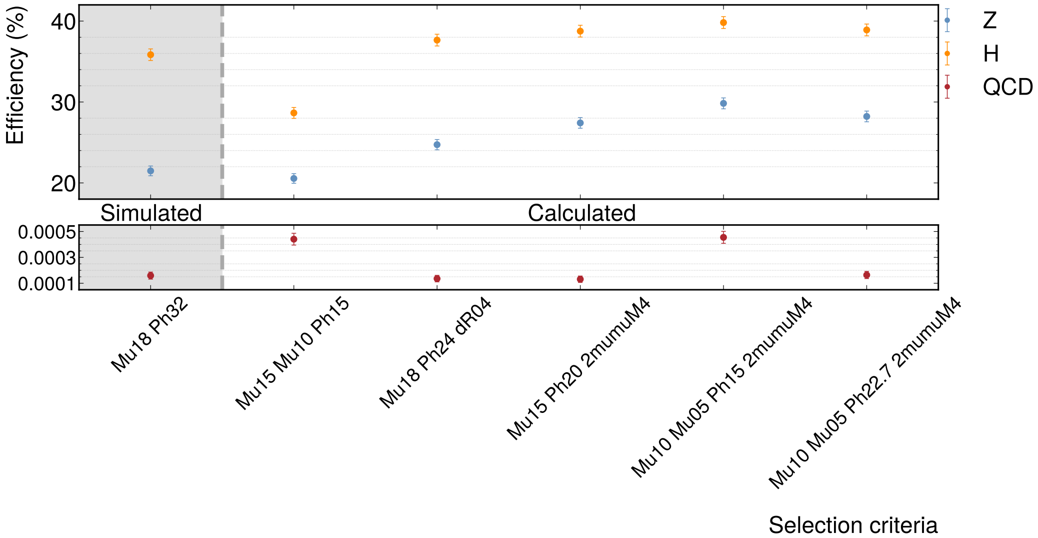
Muon1: $p_{\mathrm{T}} > 10$ GeV, muon2: $p_{\mathrm{T}} > 5$ GeV, photon: $p_{\mathrm{T}} > 22.7$ GeV, 2 GeV $< m_{\mu\mu} <$ 4 GeV

	Selection efficiencies (%)	
	$p_{\mathrm{T}}^{\mu 1} > 18$ GeV, $p_{\mathrm{T}}^{\gamma} > 32$ GeV	$p_{\mathrm{T}}^{\mu 1} > 10$ GeV, $p_{\mathrm{T}}^{\mu 2} > 5$ GeV, $p_{\mathrm{T}}^{\gamma} > 22.7$ GeV, 2 GeV $< m_{\mu\mu} <$ 4 GeV
QCD	$(1.6 \pm 0.3) \cdot 10^{-4}$	$(1.6 \pm 0.3) \cdot 10^{-4}$
Z	21.49 ± 0.06	28.22 ± 0.07
H	35.85 ± 0.07	38.90 ± 0.07

Figure: Selection efficiencies obtained for the selection cuts: $p_{\mathrm{T}}^{\mu 1} > 10$ GeV, $p_{\mathrm{T}}^{\mu 2} > 5$ GeV, $p_{\mathrm{T}}^{\gamma} > 22.7$ GeV, 2 GeV $< m_{\mu\mu} <$ 4 GeV (right column) compared to the ones obtained for $p_{\mathrm{T}}^{\mu 1} > 18$ GeV, $p_{\mathrm{T}}^{\gamma} > 32$ GeV (left column).

- QCD selection efficiency: $+3\%$
- Z selection efficiency: $+31\%$
- H selection efficiency: $+9\%$

Summary of results



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Conclusions

- Comparison between the standard selection associated to *HLT_Mu17_Photon30* and other possibilities has been made.
- Increases on efficiency of the Higgs boson signal are very limited.
- Selections including criteria beyond purely kinematical cuts are more efficient.
- Rising slightly the photon momentum threshold decreases QCD efficiency.
- Four selection criteria are more efficient than the current one.
- The trigger efficiency corresponding to these cuts should be obtained in dedicated simulations.

References

Sirunyan, Albert M et al. "Search for rare decays of Z and Higgs bosons to J/ψ and a photon in proton-proton collisions at $\sqrt{s} = 13$ TeV". In: *The European Physical Journal C* 79.2 (2019), pp. 1–27.

Thanks for your attention!