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

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Research Activities
Academic year: 2021/2022

Università degli studi di Padova

October 25, 2022

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 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

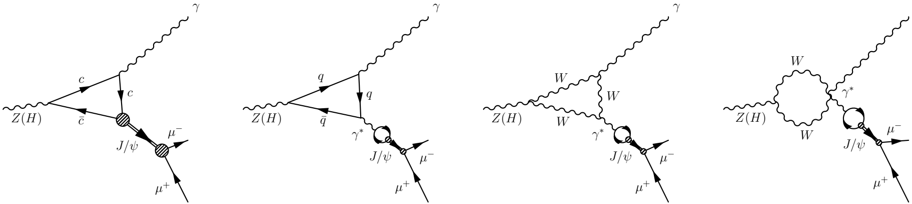

Figure: Lowest order Feynman diagrams for the Z (or H) $\rightarrow$ J/$\psi\gamma$ decay. The left-most diagram shows the direct and the remaining diagrams the indirect processes[†].

- The cumulative yield of the decay is proportional to the branching ratio (BR).

[†] 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.

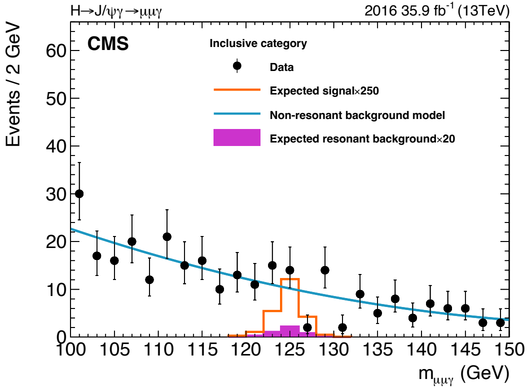

Figure: $m_{\mu\mu\gamma}$ in Higgs boson exotic decay‡.

‡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, triggers are used. Current High Level Trigger requires the presence of a muon and a photon exceeding 17 and 30 GeV in the final state.

Goal

Design a new trigger that can outperform *HLT_Mu17_Photon30*.

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Trigger and selection efficiencies

The trigger efficiency:

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

The selection efficiency:

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

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	21 335 910	34	26	76(7)	0.00016(3)
Z	459 000	98 630	81 829	83.0(1)	21.49(6)
H	448 000	160 587	142 102	88.49(8)	35.85(7)

Figure: Example calculation of the trigger and selection efficiencies for the trigger *HLT_Mu17_Photon30* and selection cuts: $p_T^\mu > 18$ GeV and $p_T^\gamma > 32$ 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: $p_T > 18$ GeV, photon: $p_T > 24$ GeV, $\Delta R(\mu - \mu) < 0.4$

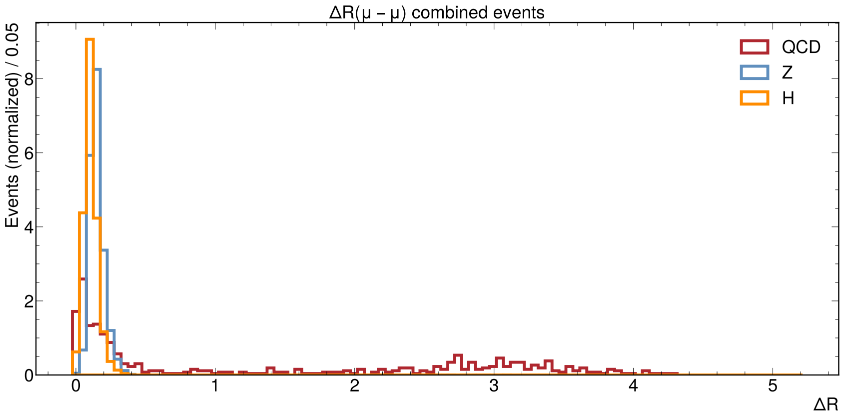


Figure: Normalized histogram for angular separation ΔR between the two muons reconstructed in the final state.

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

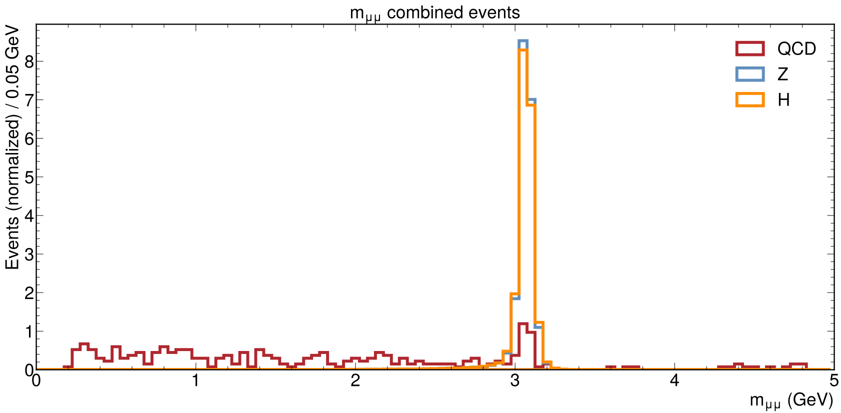


Figure: Normalized histogram for invariant mass of the muon pair system reconstructed in the final state.

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

	Selection efficiencies (%)	
	$p_T^{\mu 1} > 18$ GeV, $p_T^{\gamma} > 32$ GeV	$p_T^{\mu 1} > 15$ GeV, $p_T^{\gamma} > 20$ 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: $p_T^{\mu 1} > 15$ GeV, $p_T^{\gamma} > 20$ GeV, $2 < m_{\mu\mu} < 4$ 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: -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 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 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 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%

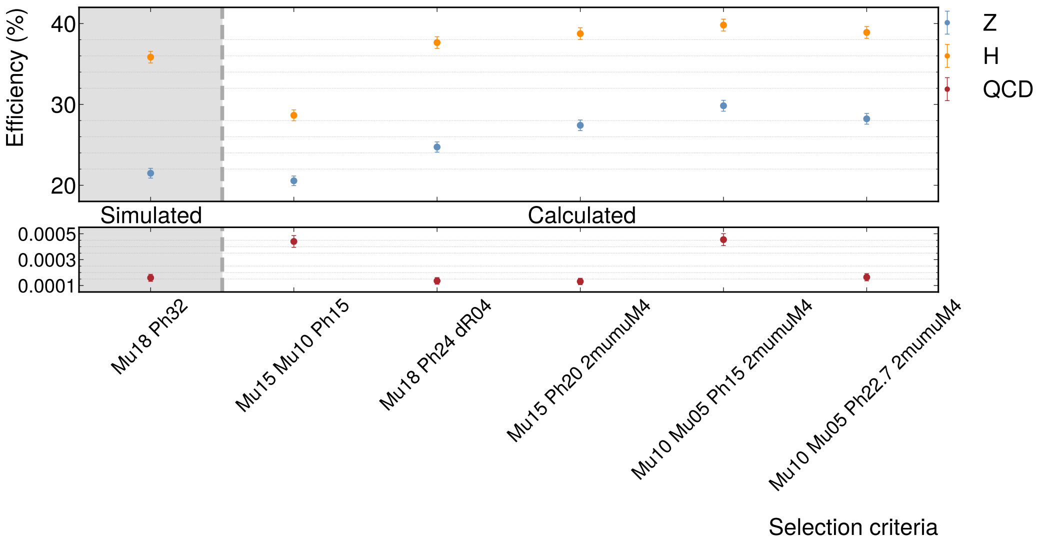
Muon1: $p_{\mathrm{T}} > 10$ GeV, muon2: $p_{\mathrm{T}} > 5$ GeV, photon: $p_{\mathrm{T}} > 22.7$ GeV, $2 \text{ GeV} < m_{\mu\mu} < 4$ GeV

	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, $2 \text{ GeV} < m_{\mu\mu} < 4$ 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, $2 \text{ GeV} < m_{\mu\mu} < 4$ 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.
- 3-4 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!