Monophoton Dark Matter Studies at Muon Colliders

DELPHES Simulation

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Motivation

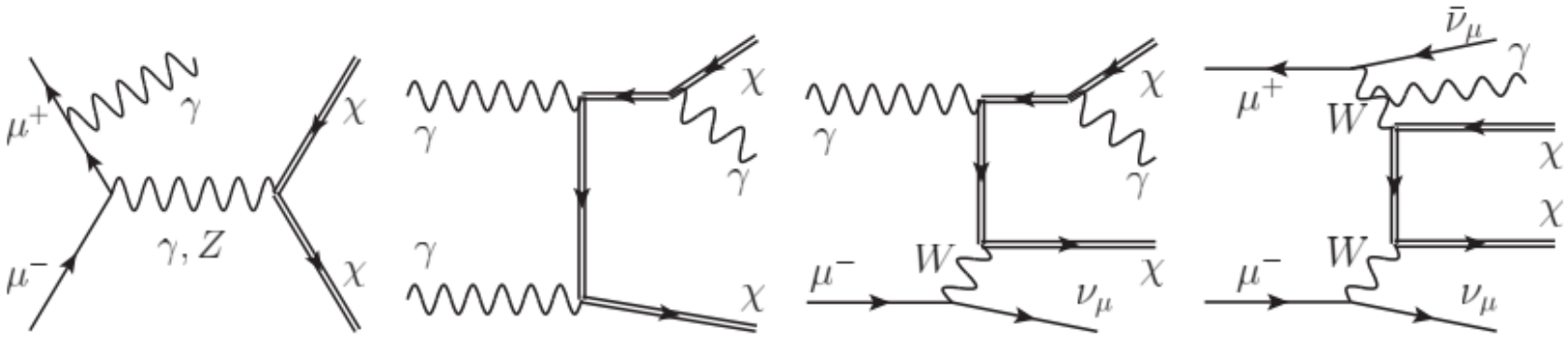
- Weakly Interacting Massive Particles (WIMP) are natural cold DM candidates
- Muon Colliders offer great potential in discovering new physics, particularly in probing WIMP dark matter
- With a large event sample, the monophoton channel of production offers good prospects

Theory

- Theory from “WIMPs at High Energy Muon Colliders” *
- Results in paper produced from signal and background events generated through MadGraph
- Events generated with COM energy = 14 TeV and two DM masses = 1 TeV, 3 TeV

* https://arxiv.org/abs/2009.11287

Monophoton Channel – Signal



1 2 3 4

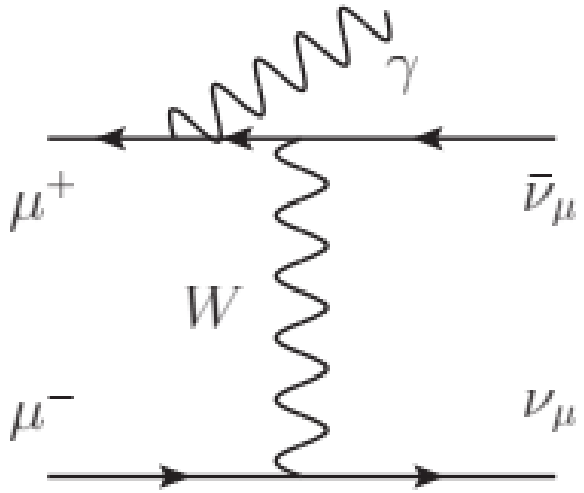
1 $\mu^+\mu^- \rightarrow \gamma\chi\chi$

2 $\gamma\gamma \rightarrow \gamma\chi\chi$

3 $\gamma\mu^\pm \rightarrow \gamma\nu\chi\chi$

4 $\mu^+\mu^- \rightarrow \gamma\nu\nu\chi\chi$

Monophoton Channel – Background



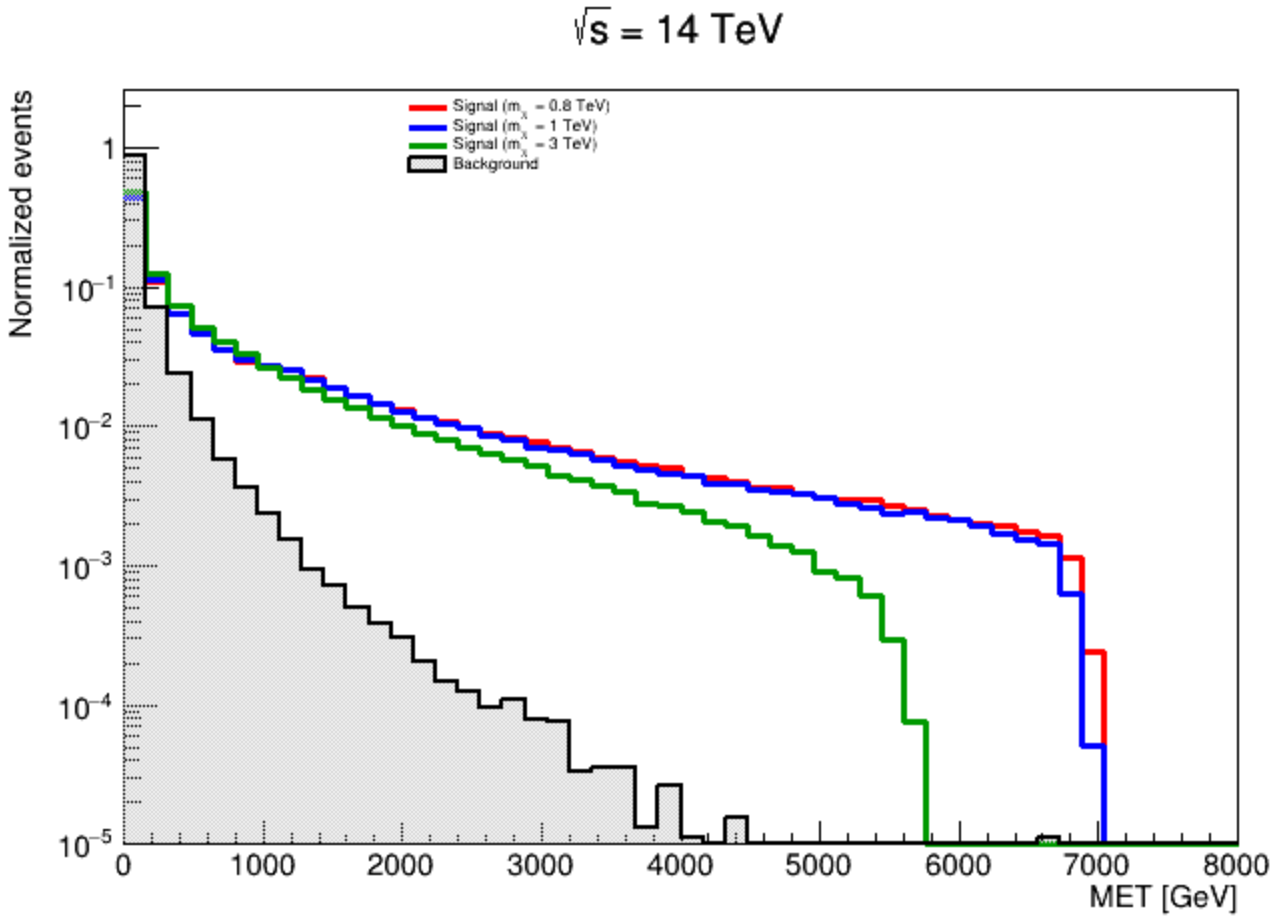
Most significant background:

$$\mu^+\mu^- \rightarrow \gamma\nu\bar{\nu}$$

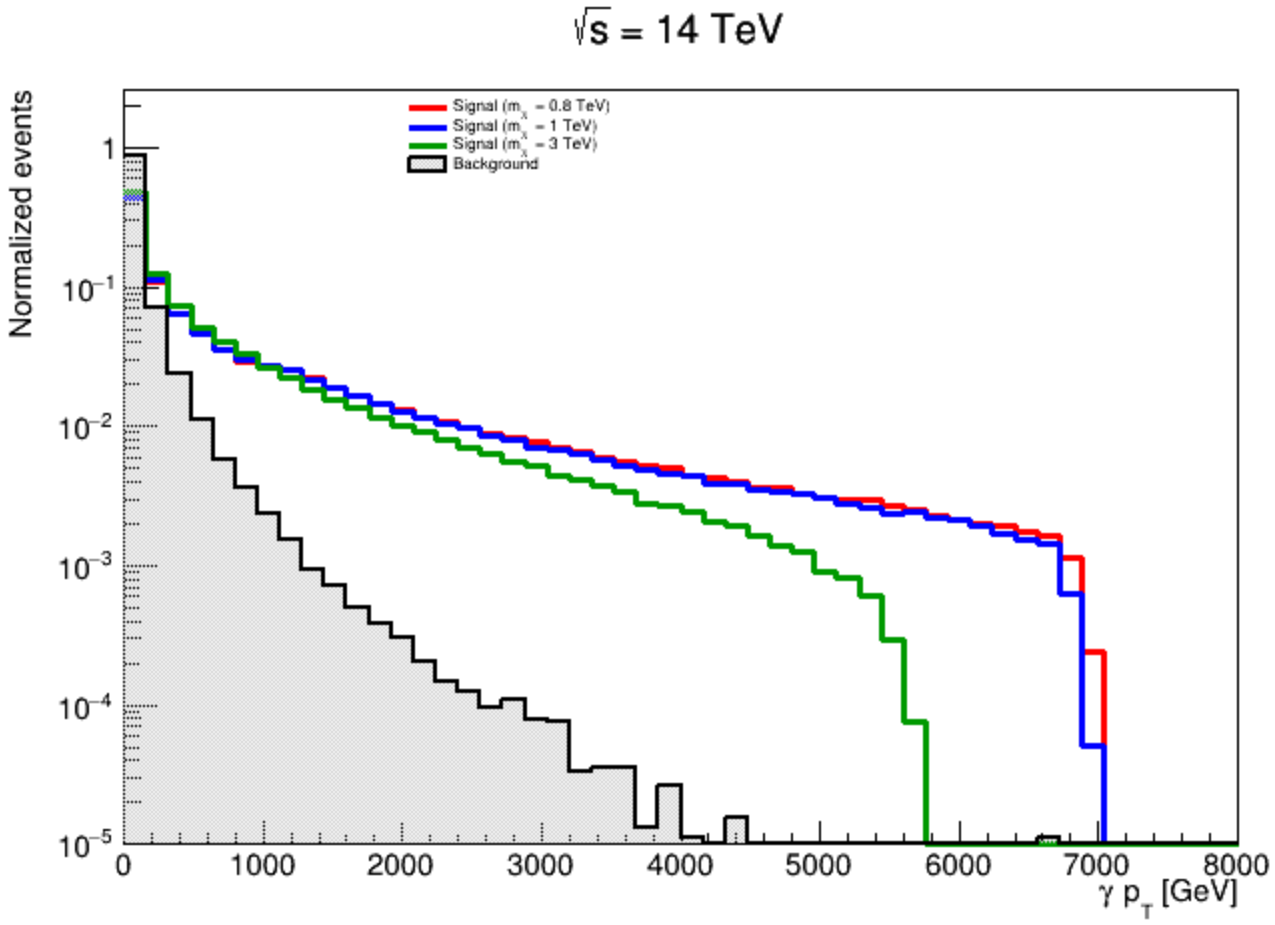
Current progress

- Studying the primary signal process: $\mu^+\mu^- \rightarrow \gamma\chi\chi$
- Using the major SM background: $\mu^+\mu^- \rightarrow \gamma\nu\bar{\nu}$
- Generating 500,000 events with MadGraph, hadronizing with Pythia and simulating detector response with DELPHES
- Currently working with COM energy = 14 TeV with with DM mass = 0.8, 1, 3 TeV
- Studying the following discriminating variables

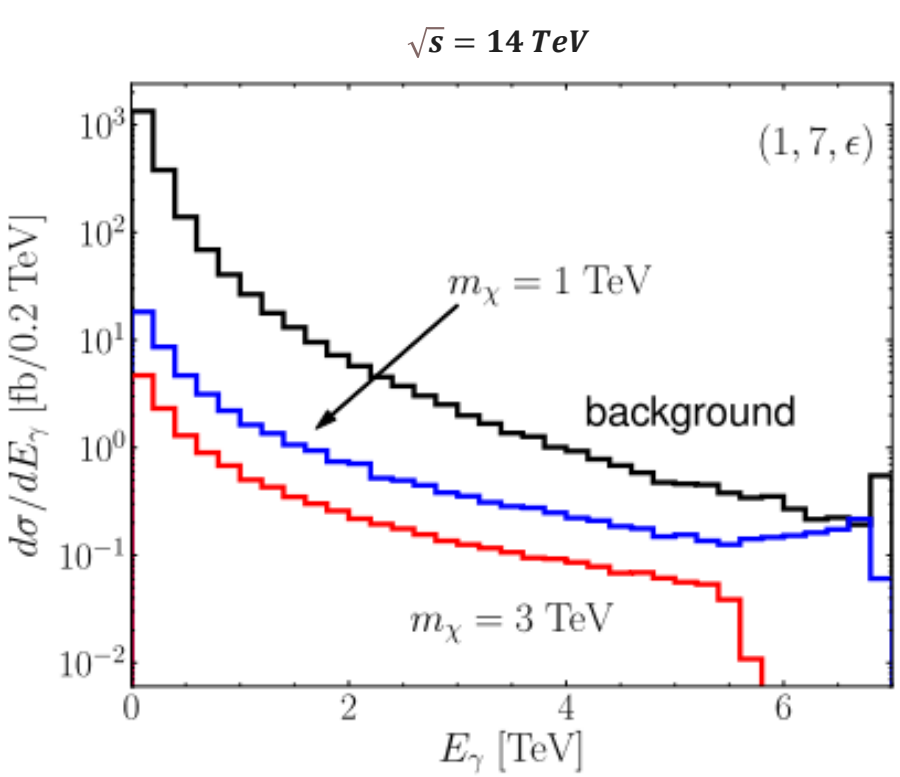
MET

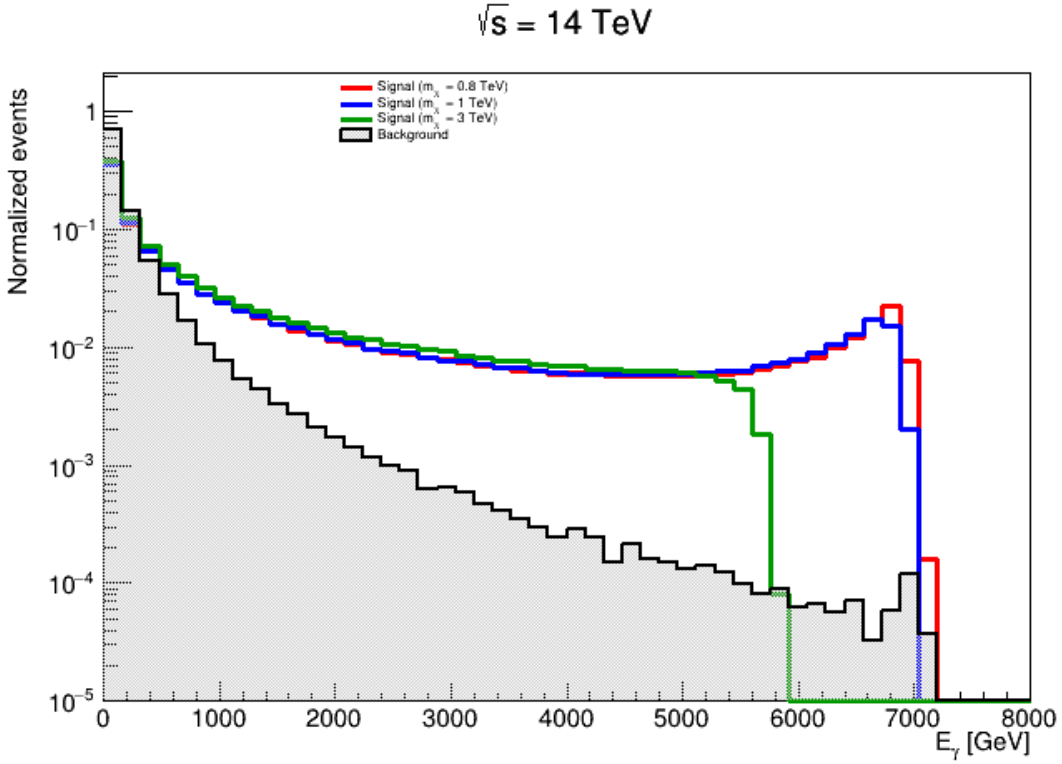

√s = 14 TeV
Signal (m_{χ} = 0.8 TeV)
Signal (m_{χ} = 1 TeV)
Signal (m_{χ} = 3 TeV)
Background
Normalized events
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
1000
2000
3000
4000
5000
6000
7000
8000
MET [GeV]

Photon p_T


√s = 14 TeV
Signal (m_χ = 0.8 TeV)
Signal (m_χ = 1 TeV)
Signal (m_χ = 3 TeV)
Background
Normalized events
1
10^-1
10^-2
10^-3
10^-4
10^-5
0
1000
2000
3000
4000
5000
6000
7000
8000
γ p_T [GeV]

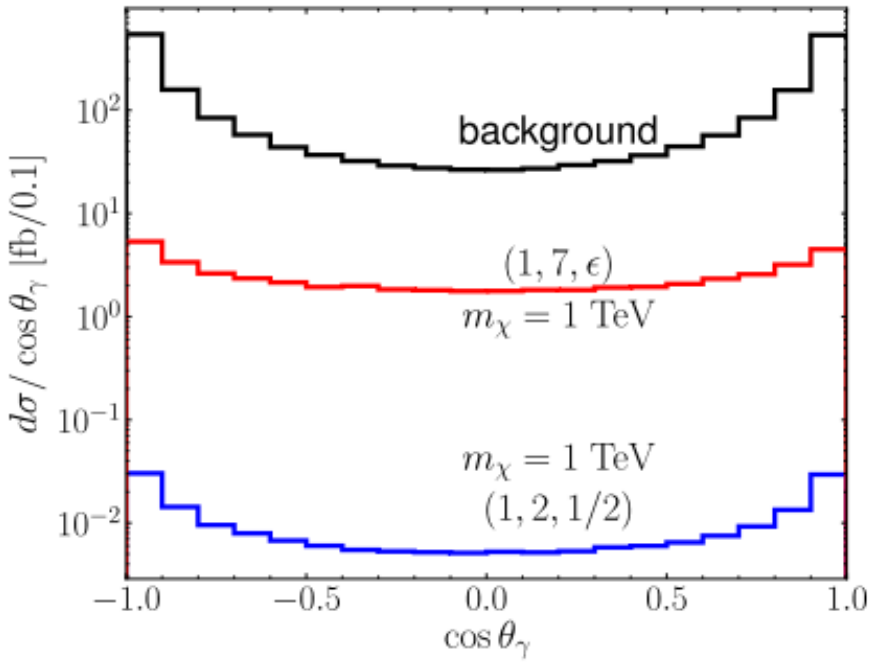
Energy of photon

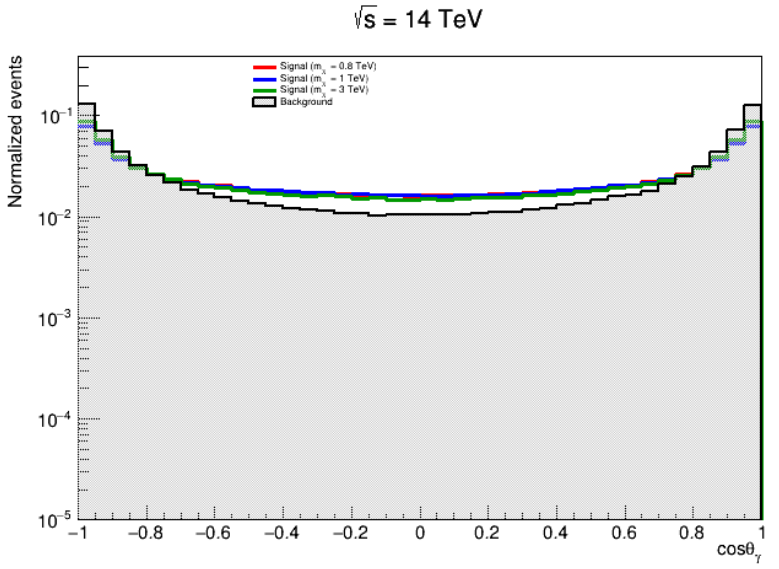


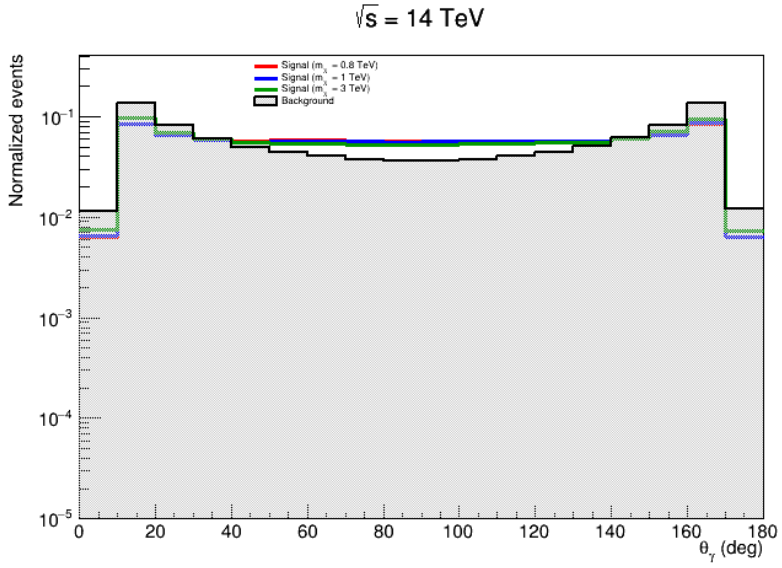


$cos\,\theta$ of photon

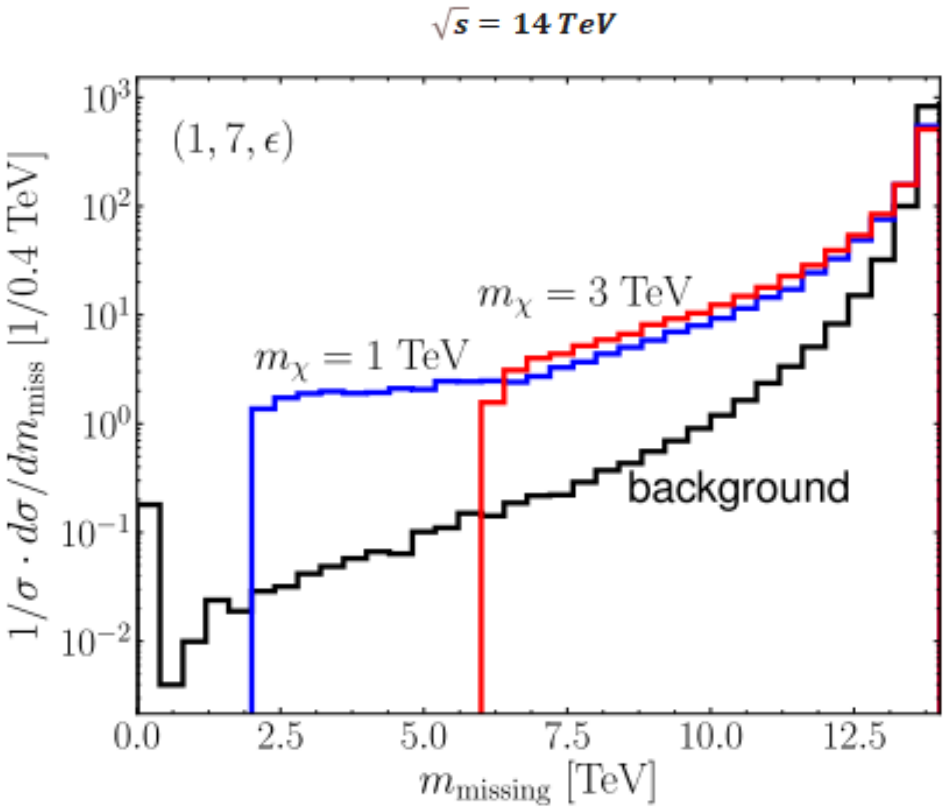
$\sqrt{s} = 14\ TeV$

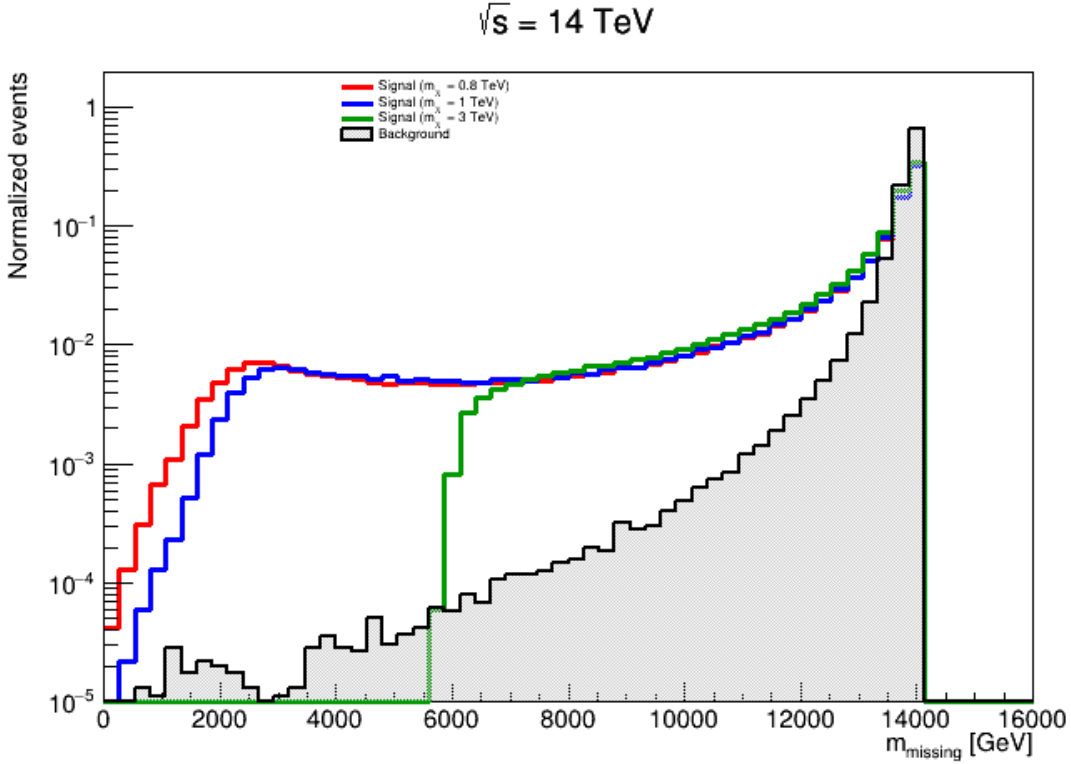






Missing mass





Sensitivity Studies

- Signal sensitivity measured using the Figure Of Merit (FOM) calculated as follows:

$$FOM = \frac{s}{\sqrt{b}}$$

$s =$ Number of normalized signal events

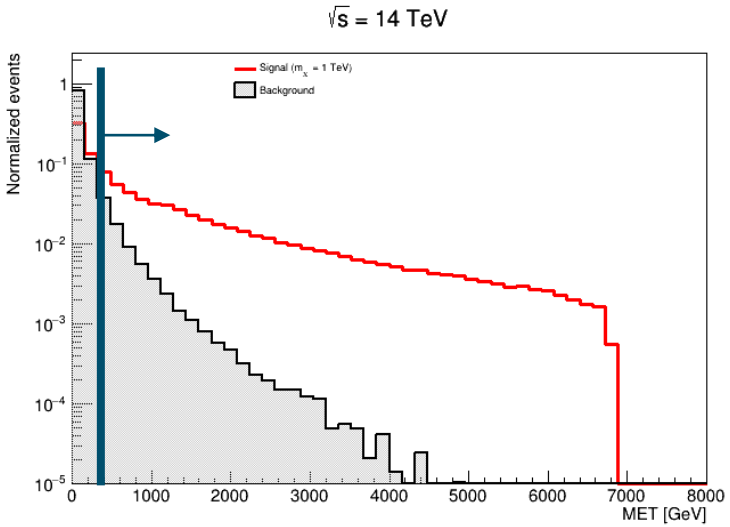
$b =$ Number of normalized background events

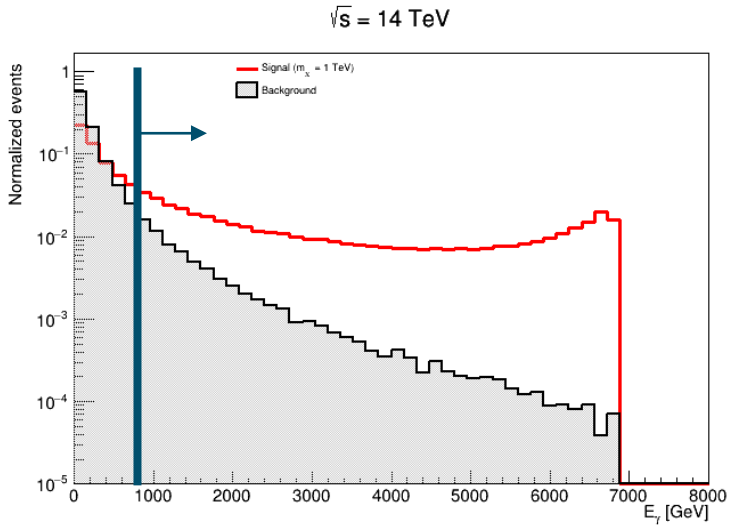
- Calculated the FOM with a single photon selection, selections from paper and selections based on discriminating variables

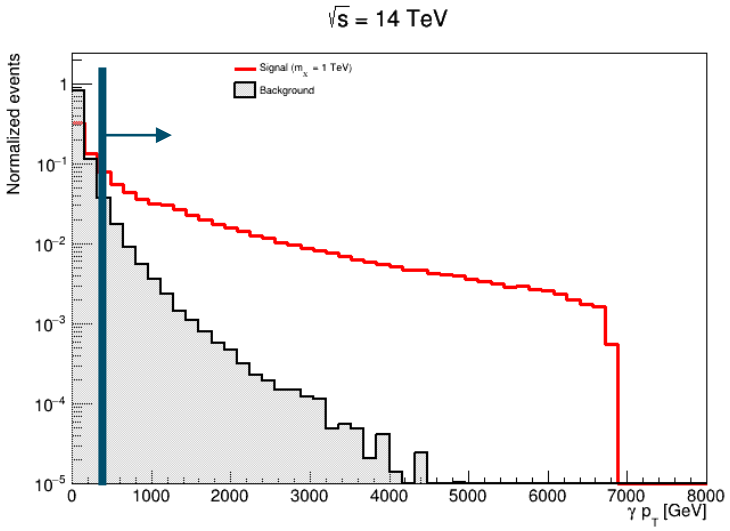
Sensitivity Studies

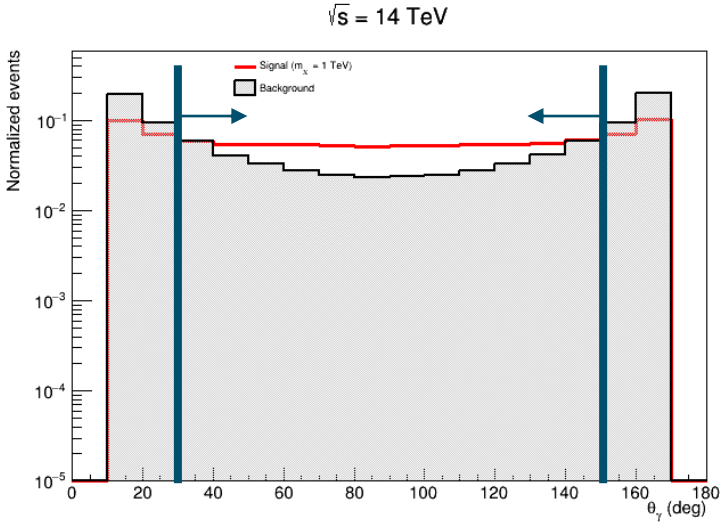
- Applied selections from paper and generated plots for the various discriminating variables
- Based on shapes of the signal and background, applied modified selections to the same variables to improve the FOM values

Selections for DM mass = 1 TeV









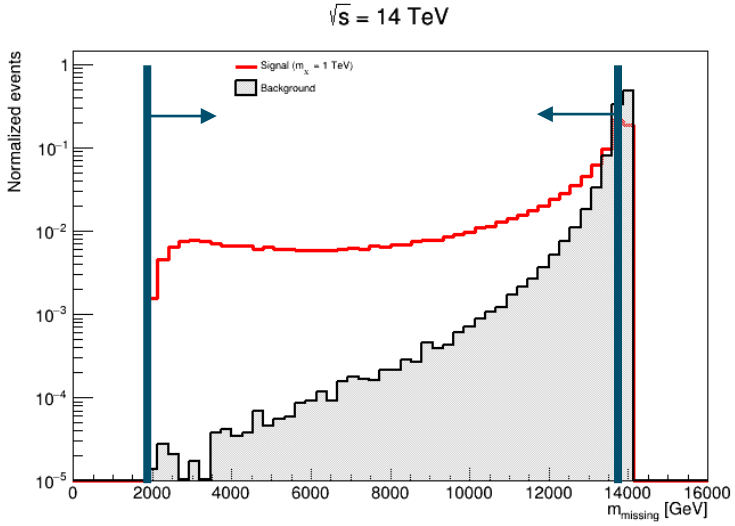


Figure of Merit for COM = 14 Tev, DM mass = 1 TeV

Selections	FOM Values
Single Photon Selection $Photon\ size > 0$	0.0917
	+2.8% ↓
Selections from Theory Paper $Photon\ size > 0$ $10^\circ < \theta_\gamma < 170^\circ$ $E_\gamma > 50\ GeV$ $m^2_{missing} > 4m^2_\chi$	0.0943
	+107% ↓
Selections based on Discriminating variables Photon size> 0 $30^\circ < \theta_\gamma < 150^\circ$ $E_\gamma > 800$ GeV $m^2_{missing} > 4m^2_\chi$ $m^2_{missing} < 13800$ GeV MET>400 GeV $\gamma_{pT} > 400$ GeV	0.1960

Conclusions and further studies

- We see that applying additional selections to the discriminating variables results in a considerable increase in FOM
- Next steps would be to run similar sensitivity analyses with different DM masses and COM energies
- Implement a cut-based or a multivariate selection method to further improve the FOM.