# Searches for dark photon via portal matter decay at the Large Hadron Collider

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Submitted by


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# Abstract

This Ph.D. thesis investigates a novel source of dark photon production at the Large Hadron Collider and presents two complementary searches for dark photon exploring distinct decay scenarios of this elusive particle. This has been realized in an extension of the Standard Model (SM) with an $SU(2)_L$ singlet vector-like quark (VLQ) mixing with only the third-general up-type quark, and a dark sector comprising a dark photon ($\gamma_d$) corresponding to a local $U(1)_d$ symmetry and a dark Higgs ($h_d$). The VLQ is also charged under this local $U(1)_d$ symmetry and acts as a portal matter between the two sectors. In this framework, conventional decay channels of the VLQ–referred to as a "maverick top partner"–($T_p \to bW, tZ, th$) are suppressed, and it predominantly decays via non-standard modes: $T_p \to t\gamma_d/h_d$.

The first study addresses the case where the dark photon either decays in the invisible mode or is stable at the length scale of the detector, either way manifesting as missing transverse energy ($\not{E}_T$) in the detector. We analyze both pair ($t\bar{t} + \not{E}_T$) and single ($t + \not{E}_T$) production modes at both 13 and 14 TeV LHC center of mass energies. We demonstrate exclusion limits on $m_{T_p} < 2.0$ (2.6) TeV for $\sin\theta_L \sim 0.025$ (0.05) at the HL-LHC using the single top partner production channel.

The second study focuses on the visible decay regime, where $\gamma_d$ decays promptly into a pair of SM fermions. We develop a novel Hybrid Deep Neural Network (HDNN) approach to tag dark photon jets in hadronic final states arising from top partner decays. The analysis targets two final states: (i) one tagged $\gamma_d$ jet plus one top jet (ED1ET1), and (ii) $\geq 2$ $\gamma_d$ jets plus $\geq 1$ top jet (AD2AT1). These final states have an admixture of both single and pair production processes. Strong background rejection is achieved using distinctive signal event topology and kinematic variable reconstruction. We establish a $2\sigma$ exclusion reach of $m_{T_p} \sim 2.4$ TeV for $\sin\theta_L = 0.1$ at $\sqrt{s} = 14$ TeV with 300 fb$^{-1}$ luminosity, assuming 100% branching ratio for $T_p \to t\gamma_d$.

Together, these studies provide a detailed examination of both invisible and visible signatures of dark photons produced via portal matter decays. The results underscore the relevance of non-standard decay modes in VLQ searches and introduce novel analysis strategies that significantly enhance sensitivity to dark sector dynamics at high-energy colliders.

# List of Publications

## Publications and preprint included in the thesis

### Peer-Reviewed Journal Articles

1. Shivam Verma, Sanjoy Biswas, Anirban Chatterjee and Joy Ganguly, *Exploring maverick top partner decays at the LHC,* Phys. Rev. D **107** (2023) no.11, 115024 doi:10.1103/PhysRevD.107.115024 [arXiv:2209.13888 [hep-ph]].

### Preprint

1. Shivam Verma, Sanjoy Biswas, Tanmoy Mandal and Subhadip Mitra, *Machine learning tagged boosted dark photon: A signature of fermionic portal matter at the LHC,*[arXiv:2410.06925 [hep-ph]].

### Conference proceedings

1. Shivam Verma, Sanjoy Biswas, Anirban Chatterjee and Joy Ganguly, "Probing Maverick Top Partner at the LHC", Springer Proc. Phys. 304 (2024), 277-281 doi:10.1007/978-981-97-0289-3_60