Models with extra gauge symmetry were well motivated extensions of the Standard Model. In this paper, we search for excess of events in search of a heavy neutral gauge boson $Z'$ which is fermiophobic. We are looking at $llbb$ final states where the dilepton channel provides the most stringent constraint on the fermiophobic (FB) model. Since, $Z'$ is fermiophobic, the production of such particle can occur via vector boson fusion, with subsequent decays into $WW$ or $Zh$. We observe no significant excess of events over background only hypothesis and are able to put the constrain on efficiency times cross-section ($\epsilon \sigma$).

Keywords: Standard Model, Beyond Standard Model, Fermiophobic gauge boson, ATLAS detector, Confidence limit

I. INTRODUCTION

The Standard Model (SM) of particle physics describes with high accuracy a multitude of experimental and observational data ranging ranging from the smallest energy scales up to the scale of several TeV set by the center-of-mass energy of the Large Hadron Collider (LHC) at CERN. With the recent discovery of the Higgs boson[1, 2], the particle content of the SM corresponds to a renormalizable theory and is in this sense complete. Nevertheless, the SM does not accommodate phenomena such as gravity or dark matter and dark energy inferred from cosmological observations, prompting theoretical work on its extensions. Over the years, many models addressing these shortcomings purport to go "beyond the Standard Model (BSM)". These models predict new particles in the form of new heavy vector, scalar or fermion resonances which can potentially be observed at the CERN LHC.

On the earliest BSM scenarios to emerge was Technicolor (TC)[3] but these did not rely on the existence of fundamental scalar particle (Higgs). With the discovery of the Higgs boson at CERN LHC implies the Higgsful extension of the SM. To this end Ref[4], constructed a UV completion of the three site model introducing two Higgs doublets to break the gauge symmetries in the way: $SU(2)_L \times SU(2)_R \times U(1)_Y \rightarrow U(1)_{em}$ (which is called 221 model). This extension of the SM predicts the new heavy gauge bosons $W'$ and $Z'$. In addition, it has certain distinguishing features that these $W'$ and $Z'$ are fermiophobic. The fermiophobic particles are the one that do not couple to fermions.

This article presents the search of new heavy neutral gauge boson $Z'$ which is fermiophobic in the dilepton channel using the ATLAS Open Data, $10 fb^{-1}$ of pp collision at a center-of-mass energy of 13 TeV. More details regarding the motivation for the fermiophobic gauge boson in the di-leptons channel can be found in ref[4].

II. SEARCH STRATEGIES

We begin our search for fermiophobic $Z'$ boson with specific strategy involving the identification of the production and decays of the $Z'$. In the absence of the fermionic couplings, the production of the $Z'$ may proceed via vector boson fusion however, the decay can proceed via multiple mechanism depending on the strength of couplings and the available phase space. In particular $Z'$ decays to $Zh$, $ZW$, where $h$ could be SM like Higgs boson or any other heavier scalar particle. Thus, the signal for our search is $pp \rightarrow Z' \rightarrow Zh \rightarrow llbb$, with the Higgs decaying to a pair of bottom quarks and $Z$ decaying leptonically. The $h \rightarrow bb$ channel has large BR, providing strong signal strength where as the dilepton search provides the most stringent constraint, reducing the pure QCD background.

The search for a heavy neutral gauge boson has been performed at both Tevatron and the LHC. The exper-
At the LHC, the ATLAS and CMS experiment have an extensive physics program to search for $Z'$ [5, 6]. A widely used model in these searches is the Sequential Standard Model (SeqSM) [7], which predicts a spin-1 neutral boson ($Z_{\text{SeqSM}}$) with SM-like couplings. The strategy pursued in those analyses is a simple and robust dilepton selection targeting production via Drell-Yan (DY) process ($q \bar{q} \rightarrow Z' + 0j$), with high signal acceptance that produces a resonance peak in the reconstructed invariant mass spectrum of the lepton pairs that sits above the background.

The analysis uses the 13 TeV ATLAS Open Data [10] events that belongs to 61 runs from the first four periods of the 2016 pp data-taking. The data-set corresponds to an integrated luminosity of $10.06 \pm 0.37 \text{ fb}^{-1}$, after data quality requirements have been applied.

The dominant SM background comes from $t\bar{t}$, WZ, ZZ, $Z$+jets processes. We demand at least 4 jets, exactly two b-quarks and 2 leptons (either e or $\mu$) in the final state, which reduces the background considerably. Background processes were modelled using Monte Carlo (MC) event generators to study kinematic distributions, to evaluate background contamination in the signal region and to interpret the results. WZ & ZZ were modelled using SHERPA 2.2 [11], while $t\bar{t}$, $Z$+jets, were modelled using POWHEG-Box v2 [12] + Pythia 8 [13].

### III. ATLAS DETECTOR

The ATLAS Detector [9] is a multipurpose detector at LHC with a forward-backward symmetric cylindrical geometry and nearly 4$\pi$ coverage in solid angle. It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer. The ID includes two silicon subdetectors, namely an inner pixel detector and an outer microstrip tracker, inside a transition radiation tracker (TRT) based on gas-filled drift tubes. The muon spectrometer (MS) surrounds the calorimeters and measures muon tracks within a system of three superconducting air-core toroidal magnets with eight coils each. The MS consists of three layers of precision tracking and triggering chambers. The more details regarding the ATLAS Detector can be found in ref [9].

### IV. DATA SAMPLES AND BACKGROUND

The analysis uses the 13 TeV ATLAS Open Data [10] events that belongs to 61 runs from the first four periods of the 2016 pp data-taking. The data-set corresponds to an integrated luminosity of $10.06 \pm 0.37 \text{ fb}^{-1}$, after data quality requirements have been applied.

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where $\eta_{\text{cluster}}$ is the pseudorapidity of the calorimeter energy deposit associated with the electron candidate. Muon candidates are reconstructed by combining tracks reconstructed in both the inner detector and the muon spectrometer (MS). Both electron and muon candidates are required to have $P_T > 7$ GeV and to pass the “loose” identification criteria to reduce the contribution from non-prompt leptons (e.g. from the semileptonic $b$-or $c$-hadron decays), photon conversion and hadrons.

If multiple vertices are reconstructed, the vertex with the largest sum of the squares of the transverse momenta of the associated tracks is taken as the primary vertex of the event: the longitudinal impact parameter $z_0$ is required to satisfy $|z_0 \sin \theta| < 0.5$ mm, where $\theta$ is the polar angle of the track.

The jet candidates are reconstructed from three-dimensional topological energy clusters in the EMCAL and hadronic calorimeter (HCAL) using the anti-$k_t$ jet algorithm with a radius parameter of 0.4, and these are referred to as “small-R Jets”. After energy calibration, all jets candidates are required to have $P_T > 20$ GeV and $|\eta| < 2.5$. To reduce the effect of pileup, and additional requirement is made on the jets with $P_T < 60$ GeV and $|\eta| < 2.4$. Identification of jets containing $b$-hadrons ($b$-tagging) is performed with a multivariate discriminant, MV2c10, making use of track impact parameter, the $b$-tagging discriminant is calculated, and the jet is considered $b$-tagged if this value is above a given threshold: the so-called algorithm “working point (WP)” with $\Delta R = \Delta R_{bb} = \Delta R_{ll} = \Delta R_{d} \geq 0.4$.

The basic identification cut on $P_T$ will help to eliminate the soft jets and leptons which arise during hadronization. The $\Delta R \geq 0.4$ ensures that all pair of final states are optimally separated.

![FIG. 3. Fitting the data with MC events using TFraction Fit](image)

**TABLE II. MC Sample Fit Fractions results**

| MC Sample | Fraction | Uncertainty | Expected events at mode |
|-----------|----------|-------------|------------------------|
| ZZ        | 0.144382 | ±0.04290    | 79±9                   |
| WZ        | 0.236027 | ±0.01690    | 75±12                  |
| $t\bar{t}$ | 0.567863 | ±0.03514    | 312±19                 |
| $Z+\text{jets}$ | 0.151728 | ±0.04290    | 83±23                  |

**C. Kinetic discriminants**

We consider important kinetic variables, the transverse momentum of the leading $b$-jet and lepton, the missing transverse energy ($E_T^m$) and various invariant mass. Based on the kinetic variable, we define a control region that has background rich events. In the control region, we apply the TFraction Fit to determine the contributions of each of the background on data and hence the scaling factor. Based on this scaling factor, we filled our histograms in the signal region. The background along with data are stacked to see the excess of events over background only hypothesis. And the cut and count technique is applied in case of not significant excess to determine the confidence limit.

**VI. UNCERTAINTIES**

The systematic uncertainties include those due to the limited numbers of simulated events and to the measurement of integrated luminosity. Experimental uncertainties arising from the trigger efficiencies, lepton and jet
VII. RESULTS

We defined a scale factor for each MC samples based on TFraction Fit root class. The fitted results are shown in Table II. The defined scale factor matches nicely for the leading transverse momentum of leptons and jets as shown in Fig 7 and Fig 8. We did not observe any excess of events over background only hypothesis as shown in Fig 9. In Table III, we show the number of events passing the various cut selection. In Fig 6, we define the signal region as shown in the red curve. The width of the ellipse axes are taken from the half width maxima of the invariant of di-leptons and di-bjets shown in Fig 4 and Fig 5. Based on Bayes theorem, we are able to set limit on $\epsilon \sigma \times BR$. The obtained constrain was $\epsilon \sigma \times BR < 0.25$ fb.

VIII. CONCLUSION

This paper presents search for fermiophobic gauge boson in the di-lepton channel using ATLAS Open Data at $\sqrt{s} = 14$ TeV. The analysis uses TFraction Fit to calculate the fraction of MC samples contributing to the data. No excess of data with respect to SM predictions are observed. Hence, we are able to put a constrain on
FIG. 7. Comparison between data and MC predictions for the leading transverse momentum for the leptons ($P_T^{lead}$)

FIG. 8. Comparison between data and MC predictions for the leading transverse momentum for the b-tagged jets ($P_T^{lead}$)

FIG. 9. Comparison between data and MC predictions for the invariant mass of the final states particles ($M_{l_1l_2b_1b_2}$)

FIG. 10. Plot showing the Confidence level (CL) vs efficiency times production cross-section times branching fractions ($\epsilon \sigma \times BR$). The region shown in the color is the feasible region and outside that is the excluded. The value $> \epsilon \sigma \times BR$ is excluded.

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