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## **Probing Heavy Majorana Neutrinos and the Weinberg Operator through Vector Boson Fusion Processes in Proton-Proton Collisions at $\sqrt{s} = 13$ TeV**

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# Probing Heavy Majorana Neutrinos and the Weinberg Operator through Vector Boson Fusion Processes in Proton-Proton Collisions at $\sqrt{s}=13$ TeV

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The first search exploiting the vector boson fusion process to probe heavy Majorana neutrinos and the Weinberg operator at the LHC is presented. The search is performed in the same-sign dimuon final state using a proton-proton collision dataset recorded at  $\sqrt{s} = 13$  TeV, collected with the CMS detector and corresponding to a total integrated luminosity of  $138 \text{ fb}^{-1}$ . The results are found to agree with the predictions of the standard model. For heavy Majorana neutrinos, constraints on the squared mixing element between the muon and the heavy neutrino are derived in the heavy neutrino mass range  $50 \text{ GeV} - 25 \text{ TeV}$ ; for masses above  $650 \text{ GeV}$  these are the most stringent constraints from searches at the LHC to date. A first test of the Weinberg operator at colliders provides an observed upper limit at 95% confidence level on the effective  $\mu\mu$  Majorana neutrino mass of  $10.8 \text{ GeV}$ .

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Despite the enormous success of the standard model (SM) of particle physics over the last fifty years, the observation of neutrino oscillations [1,2] has confirmed that at least two SM neutrinos have small, but nonzero, masses. This provides a compelling hint of physics beyond the SM. Efforts to determine each neutrino mass are being pursued by many experiments within different research fields, including cosmology and tritium beta decay [3–5], and various theoretical explanations of these observations have been proposed [6–13].

A natural formalism for generating neutrino masses is through a dimension-five operator, proposed by Weinberg [10], which extends the SM Lagrangian with

$$\mathcal{L}_5 = \frac{C_5^{\ell\ell'}}{\Lambda} [\Phi \cdot \bar{L}_{\ell'}^c] [L_{\ell'} \cdot \Phi], \quad (1)$$

where  $\ell, \ell'$  are the flavors of the leptons, which can be electrons, muons, or taus;  $\Lambda$  is the scale at which the particles responsible for neutrino masses become relevant degrees of freedom;  $C_5^{\ell\ell'}$  is a flavor-dependent Wilson coefficient;  $L_{\ell} = (\nu_{\ell}, \ell)$  is the left-handed lepton doublet; and  $\Phi$  is the SM Higgs doublet with a vacuum expectation value  $v = \sqrt{2}\langle\Phi\rangle \approx 246 \text{ GeV}$ . This operator, known as the Weinberg operator, generates the Majorana neutrino masses as

$$m_{\ell\ell'} = C_5^{\ell\ell'} v^2 / \Lambda, \quad (2)$$

and introduces lepton number violation (LNV), as the Majorana neutrino is its own antiparticle. The LNV processes have been tested extensively in searches for neutrinoless double beta decays of heavy nuclei. These experiments search for events with two same-sign (SS) charge electrons and the absence of neutrinos in the final state, and set stringent upper limits on the associated Majorana neutrino mass ( $|m_{ee}|$ ) at 90% confidence level (C.L.) in the ranges  $61\text{--}165 \text{ meV}$  [14] and  $79\text{--}180 \text{ meV}$  [15]. Since muons and tau leptons are much heavier than electrons, SS final states involving these heavier leptons are kinematically forbidden in low-energy nuclear experiments and can only be studied at colliders [16]. As the study of tau leptons is experimentally more challenging, the final state with SS muons is investigated in this search. The observed upper limit on the effective  $\mu\mu$  Majorana neutrino mass ( $|m_{\mu\mu}|$ ), translated from the searches for LNV decays of charged kaons at the NA62 experiment [17], is around  $55 \text{ GeV}$  at 90% C.L. [16].

The Weinberg operator can be realized in the context of “seesaw” models [6–9], assuming the existence of hypothetical heavy states, for example a heavy Majorana neutrino ( $N$ ) in the type-I seesaw model. The small mass of the SM neutrinos can thus be explained by a suppression due to the high mass of new particles, because  $m_{\nu} \sim y_{\nu}^2 v^2 / m_N$ . In this expression,  $m_{\nu}$  is the SM neutrino mass,  $m_N$  is the mass of the heavy Majorana neutrino, and  $y_{\nu}$  is the Yukawa coupling. This ability to explain the small mass of the SM neutrinos motivates the search for heavy Majorana neutrinos. Heavy Majorana neutrinos can only couple to the SM through mixing with SM neutrinos, which

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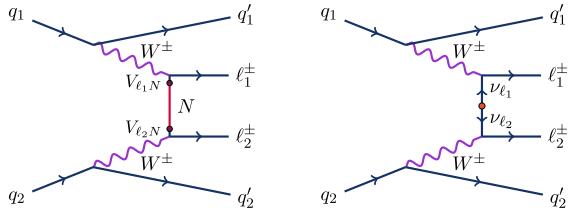


FIG. 1. Example Feynman diagrams of VBF processes with heavy Majorana neutrino production (left) and processes mediated by the Weinberg operator (right) at the LHC.

is characterized by the mixing element,  $V_{\ell N}$ , between a SM neutrino in its left-handed interaction state and a heavy Majorana neutrino in its mass eigenstate. The searches that have set limits on  $V_{\ell N}$  were based on the production of a heavy Majorana neutrino through either quark-antiquark annihilation or  $W\gamma$ , with different analysis strategies based on various decay modes, such as many leptons in the final state [18–20], and in final states containing LNV lepton pairs [21,22]. For  $m_N$  at a few GeV, the constraints on  $|V_{\ell N}|^2$ , where  $\ell = \{e, \mu\}$ , are around  $10^{-7} - 10^{-5}$ , while at around 1 TeV, the constraints approach unity.

This Letter reports the first search probing Majorana neutrinos and the Weinberg operator in vector boson fusion (VBF) processes [16,23] at the CERN LHC, studying events with SS muon pairs. As shown in Fig. 1 by the two representative Feynman diagrams, in the  $t$  channel, SS  $W$  boson pairs may convert to SS lepton pairs via a TeV-scale Majorana neutrino or through a Weinberg operator process. Because the cross section of  $t$ -channel processes is less sensitive to the mass of the intermediate particle compared with  $s$ -channel quark-antiquark annihilation processes, the VBF process can complement searches for heavy Majorana neutrinos at the TeV mass scale as its cross section decreases more slowly with increasing  $N$  mass compared with the values from  $s$ -channel production. Although the various seesaw mechanisms can be considered as realizations of the Weinberg operator, an alternative implementation is considered in this Letter, as shown in Fig. 1 (right). The two VBF processes considered in this work differ primarily in that the Majorana process is assumed to be mediated by a heavy  $t$ -channel neutrino whereas the Weinberg operator process is mediated by a lighter  $t$ -channel neutrino.

This analysis is based on proton-proton ( $pp$ ) collision data collected at  $\sqrt{s} = 13$  TeV by the CMS experiment at the CERN LHC during 2016–2018, corresponding to an integrated luminosity of  $138 \text{ fb}^{-1}$ .

Tabulated results are provided in the HEPData record for this analysis [24].

The CMS apparatus [25] is a multipurpose, nearly hermetic detector, designed to trigger on [26,27] and identify electrons, muons, photons, and hadrons [28–30]. A global “particle-flow” algorithm [31] aims to reconstruct all individual particles in an event, combining information

provided by the all-silicon inner tracker and by the crystal electromagnetic and brass-scintillator hadron calorimeters, operating inside a 3.8 T superconducting solenoid, with data from gas-ionization muon detectors embedded in the flux-return yoke outside the solenoid. The reconstructed particles are used to build charged leptons, jets, and missing transverse momentum ( $\vec{p}_T^{\text{miss}}$ ) [32–34].

Samples of signal events are simulated with next-to-leading order (NLO) precision using the MadGraph5\_aMC@NLO 2.6.5 generator [35], based on model implementations from Refs. [16,23,36,37]. For the heavy Majorana neutrino, we assume only one heavy state and scan its mass in a range from 50 GeV to 25 TeV. The process induced by the Weinberg operator is simulated using a novel approach, established in Ref. [16], which approximates the internal neutrino lines and vertex insertion with an effective light Majorana neutrino. The Wilson coefficient  $C_5^{\ell\ell}$  is set to 1, and the energy scale  $\Lambda$  to 200 TeV. The production cross sections scale with  $V_{\ell N}^2 V_{\ell' N}^2$  and  $|C_5^{\ell\ell}/\Lambda|^2$  for the VBF processes with heavy Majorana neutrinos [23] and the Weinberg operator [16], respectively. Since the kinematic shape of the signal is independent of  $|V_{\mu N}|$ , we set  $|V_{\mu N}| = 1$  for the signal simulation to ensure efficient generation of signal events.

The SM electroweak  $W^\pm W^\pm$  and  $W^\pm Z$  processes, where both bosons decay leptonically, are simulated using MadGraph5\_aMC@NLO 2.4.2 [35] at leading order (LO) with six electroweak [ $\mathcal{O}(\alpha^6)$ ] and zero quantum chromodynamics (QCD) vertices. The QCD-induced  $W^\pm W^\pm$  process is also simulated using MadGraph5\_aMC@NLO 2.4.2 at LO. Contributions with an initial-state  $b$  quark are excluded from the electroweak  $W^\pm Z$  simulation because they are included in the production of a  $Z$  boson in association with a single top quark, known as the  $tZq$  process, which is simulated at NLO using MadGraph5\_aMC@NLO 2.3.3. The  $ZZ \rightarrow 4\ell$  and  $gg \rightarrow ZZ$  processes are simulated with the POWHEG v2 [38] and MCFM 7.0.1 [39] generators, respectively. The production of  $t\bar{t}W^\pm$ ,  $t\bar{t}Z$ , and triple vector boson ( $VVV$ ) background events is simulated at NLO in QCD using the MadGraph5\_aMC@NLO 2.2.2 (2.4.2) generator [35,40,41] for the samples corresponding to the 2016 (2017–2018) data-taking period. The production of  $W^\pm W^\pm$  events through double-parton scattering is generated at LO using PYTHIA 8.226 (8.230) [42] for 2016 (2017–2018).

The simulated samples for the 2016 (2017–2018) data-taking period use the NNPDF 3.0 (3.1) parton distribution functions [43,44], and are interfaced with PYTHIA to model the fragmentation and hadronization of partons in the initial and final states, along with the underlying event. The CUETP8M1 (CP5) tune [45,46] is used in the simulation for the 2016 (2017–2018) data-taking period. In LO (NLO) simulations performed with MadGraph5\_aMC@NLO, jets are matched to the parton shower produced by PYTHIA 8.2 following the MLM [47] (FxFx [41]) prescription. The interactions of all final-state particles with the CMS

detector are simulated using GEANT4 [48]. Simulated events are mixed with the contribution of particles from additional  $p_T$  interactions within the same or nearby bunch crossings (pileup); the pileup distribution in the simulated samples matches that observed in data.

Collision events are collected using single-muon triggers [27] that require the presence of an isolated muon with transverse momentum  $p_T > 24$  or 27 GeV, depending on the data-taking period. In addition, a set of dimuon triggers [27] with lower  $p_T$  thresholds is used to ensure a trigger efficiency above 90% for events with muons. Depending on the subsequent off-line selection, the dimuon triggers increase the event acceptance by up to 4%. The primary vertex (PV) is taken to be the vertex corresponding to the hardest scattering in the event, evaluated using tracking information alone, as described in Section 9.4.1 of Ref. [49]. The jets are clustered using the anti- $k_T$  algorithm [50,51] with a distance parameter of 0.4, with the tracks assigned to the candidate vertices as inputs. To mitigate the impact from pileup, tracks identified to be originating from pileup vertices are discarded and calorimeter energies are corrected to account for charged and neutral particles originating from those vertices. The  $\vec{p}_T^{\text{miss}}$  is then defined as the negative vector  $p_T$  sum of all reconstructed particles in an event. Its magnitude is referred to as  $p_T^{\text{miss}}$ . Jets arising from  $b$  quark hadronization and decay ( $b$  jets) are identified using a deep neural network algorithm, termed DeepCSV, whose inputs are tracks displaced from the primary interaction vertex, details of secondary vertices, and the kinematical variables of jets [52]. To classify jets as  $b$  tagged, we use a requirement on the score of the DeepCSV algorithm for which the  $b$  jet identification efficiency ranges from 65% to 75% and the rate at which gluon or light-flavor jets are misidentified as  $b$  jets is around 1%. The fraction of jets originating from the hadronization of  $c$  quarks that are incorrectly identified as  $b$  jets is about 10%. Starting from the constituents of reconstructed jets, hadronically decaying  $\tau$  leptons are identified via the “hadrons-plus-strips” algorithm [32].

The final states analyzed contain two well-identified SS muons with  $p_T > 30$  GeV and pseudorapidity  $|\eta| < 2.4$ , and at least two jets with  $p_T > 30$  GeV and  $|\eta| < 4.7$ . The two selected jets with the largest  $p_T$  are considered as the VBF jet candidates, which must satisfy a large pseudorapidity separation  $|\Delta\eta_{jj}| > 2.5$  and a large dijet invariant mass  $m_{jj} > 750$  GeV. Events produced via VBF are expected to contain rapidity gaps between the muons and the VBF jets. To utilize this signature, we require  $\max(\mathcal{Z}_\ell) < 0.75$ , where  $\mathcal{Z}_\ell$  is the Zeppenfeld variable [53] of a lepton  $\ell$ :  $\mathcal{Z}_\ell = |\eta_\ell - (\eta_{j1} + \eta_{j2})/2|/|\Delta\eta_{jj}|$ , where  $\eta_\ell$  is the pseudorapidity of the lepton, and  $\eta_{j1}$  and  $\eta_{j2}$  are of the two VBF jets. Events with an additional loosely identified muon (electron) with  $p_T > 10$  GeV and  $|\eta| < 2.5(2.4)$  or an identified hadronically decaying tau lepton with  $p_T > 20$  GeV and  $|\eta| < 2.3$  are rejected to suppress backgrounds

such as  $W^\pm Z$  production. Because the signal processes do not produce final state neutrinos other than those produced in hadron decays,  $p_T^{\text{miss}}$  is a useful discriminant to separate the signal and backgrounds. For the analysis targeting processes with heavy Majorana neutrinos, the azimuthal separation variable  $\Delta\phi_{\ell\ell}$  is better for improving the sensitivity to the signal than  $p_T^{\text{miss}}$  because the two muons in the final state tend to be more back-to-back than in background processes [23]. However,  $p_T^{\text{miss}}$  is more discriminating than azimuthal separation for the Weinberg operator process because of the different event topology resulting from the discrepancy between the two  $t$ -channel propagators. To separate the signal and the SM electroweak  $W^\pm W^\pm$  events, signal regions (SRs) for the heavy Majorana neutrino and Weinberg operator analyses are defined in bins of  $\Delta\phi_{\ell\ell}$  and  $p_T^{\text{miss}}$ , respectively. For the heavy Majorana neutrino analysis, we define a high- $\Delta\phi_{\ell\ell}$  bin ( $\Delta\phi_{\ell\ell} > 2$ ) and a low- $\Delta\phi_{\ell\ell}$  bin ( $\Delta\phi_{\ell\ell} < 2$ ) in the SR. For the Weinberg operator analysis, a low- $p_T^{\text{miss}}$  bin ( $< 50$  GeV) and a high- $p_T^{\text{miss}}$  bin ( $> 50$  GeV) are defined in the SR.

The background from opposite-sign dilepton events where one of the lepton charges is misidentified is negligible for events with muon pairs [54,55]. The so-called nonprompt-lepton backgrounds, originating from leptonic decays of heavy quarks or hadrons misidentified as leptons, are suppressed by identification and isolation requirements. Events from  $t\bar{t}$  pair where only one  $W$  boson decays leptonically are the main source of nonprompt-lepton backgrounds. To reduce this contribution, events with at least one  $b$ -tagged jet with  $p_T > 20$  GeV and  $|\eta| < 2.4$  are rejected. The remaining contribution of the nonprompt-lepton background is estimated directly from a data sample by applying weights to events containing muon candidates that fail the nominal selection criteria while passing a less stringent isolation requirement. These weights, called fake-lepton factors, are obtained from the probability of a jet being misidentified as a lepton and the efficiency of correctly reconstructing and identifying a lepton. More details about this method are given in Refs. [56,57].

To constrain the reducible background contributions, which include  $W^\pm Z$  production and backgrounds from nonprompt leptons, several control regions (CRs) in data are used. These CRs are defined to select samples of events enriched in those background processes, following the procedure described in Refs. [58–60]. A  $WZ$  CR, requiring the presence of three muons in an event, is used to estimate  $W^\pm Z$  background contributions. The opposite-sign dimuon combination with invariant mass closest to the  $Z$  boson mass ( $m_Z$ ) is considered as the  $Z$  boson decay product, whereas the remaining muon is assumed to originate from the decay of the  $W$  boson. The selection criteria defining the SR and the  $WZ$  CR are summarized in Table I. To select event samples enriched in nonprompt leptons, a  $b$ -tagged

TABLE I. Signal region and  $WZ$  control region definitions. The signal region is binned differently for the heavy Majorana neutrino and Weinberg operator analyses. A  $b$ -tagged CR is defined by using the same selection as for the SR, however requiring the presence of a  $b$ -tagged jet. A  $WZb$  CR is defined by requiring the same selection as for the  $WZ$  CR, but requiring at least one  $b$ -tagged jet.

Variable	SR	$WZ$ CR
Number of leptons	Exactly 2 same-sign muons	Exactly 3 muons
Lepton $p_T$	$>30/30$ GeV	$>25/25/10$ GeV
Lepton $ \eta $	$<2.4$	$<2.4$
Jet $p_T$	$>30$ GeV	$>30$ GeV
Jet $ \eta $	$<4.7$	$<4.7$
Dilepton mass $m_{\ell\ell}$	$>20$ GeV	...
$ m_{\ell\ell} - m_Z $	...	$<15$ GeV (for one $\mu^+\mu^-$ pair)
Trilepton mass $m_{\ell\ell\ell}$	...	$>100$ GeV
Max ( $\mathcal{Z}_\ell$ )	$<0.75$	$<1.0$
$p_T^{\text{miss}}$	...	$>30$ GeV
$b$ -tagged jet veto	Required	Required
Hadronic $\tau$ veto	Required	Required
$m_{jj}$	$>750$ GeV	$>750$ GeV
$ \Delta\eta_{jj} $	$>2.5$	$>2.5$

CR is defined by using the same selection as for the SR, however requiring the presence of a  $b$ -tagged jet. Similarly, the  $WZb$  CR is defined by requiring the same selection as for the  $WZ$  CR, but requiring at least one  $b$ -tagged jet. The dominant backgrounds in the SR are SM electroweak  $W^\pm W^\pm$  production and the contribution from nonprompt leptons.

The discriminating variable used to search for a signal for both analyses is  $H_T/p_T^{\mu_1}$ . Here,  $H_T$  is the scalar sum of jet  $p_T$  for all jets with  $p_T > 30$  GeV and  $|\eta| < 4.7$ ,  $\mu_1$  indicates the highest  $p_T$  muon. This discriminating variable measures the amount of hadronic activity relative to leptonic activity in a given event, and is sensitive to the color structure of the hard scattering processes as discussed in Ref. [16]. As hadronic activity is typically suppressed in VBF production processes,  $H_T/p_T^{\mu_1}$  tends to be smaller for signal events than for background events [16,23].

The statistical analysis is performed with a profile likelihood ratio test statistic in which systematic uncertainties are modeled as constrained nuisance parameters. Limits are set using the modified frequentist  $CL_s$  criterion [61,62], and the asymptotic approximation [63] is used in the limit setting procedure. The integrated luminosities of the 2016, 2017, and 2018 data-taking periods are individually known with uncertainties in the range 1.2%–2.5% [64–66], while the uncertainty in the total integrated luminosity in 2016–2018 is 1.6%. The simulation of pileup events assumes a total inelastic  $pp$  cross section of 69.2 mb, with an associated uncertainty of 5% [67,68], which has an impact of approximately 1% on the expected signal and

background yields. Discrepancies in the lepton reconstruction and identification efficiencies between data and simulation are corrected for by applying scale factors to all simulated samples, and the associated uncertainty is around 2%. Uncertainties in both the muon momentum scale and resolution individually amount to about 0.2%. The simulated muon momentum resolution is corrected by applying a 15% Gaussian smearing to muons with  $p_T > 200$  GeV [55].

The resolution uncertainty and the momentum scale uncertainty for high- $p_T$  muons are less than 1%. The uncertainty in the calibration of the jet energy scale (JES) directly affects the acceptance of the jet multiplicity requirement and the  $p_T^{\text{miss}}$  measurement. These effects are estimated by shifting the JES in the simulation up and down by 1 standard deviation. The uncertainty in the JES is 2%–5%, depending on the jet  $p_T$  and  $\eta$  [33,69]. Uncertainties in the  $b$  tagging algorithm are introduced by various sources [52], and the overall impact on the simulated samples is less than 1%. Theoretical uncertainties arising from the choice of the renormalization and factorization scales are estimated by varying these scales independently up and down by a factor of 2 from their nominal values, excluding the two extreme variations [70]. The largest cross section variations from this procedure are taken as the uncertainty [71], which is about 6%, and which is applied to both the signal and the SM electroweak  $W^\pm W^\pm$  processes. The parton distribution function uncertainty of the signal and the SM electroweak  $W^\pm W^\pm$  processes is evaluated according to the procedure described in Ref. [72], and is found to be about 1%. These uncertainties are not applied to the subdominant  $W^\pm Z$  background, where they are not significant compared to other uncertainties considered. For the nonprompt-lepton background prediction, systematic uncertainties arise from the limited size of the sample used to measure the efficiency and from the difference in the flavor composition of the jets that are misidentified as leptons between the measured sample and the signal region, estimated to amount to at most 5% and 7%, respectively. An additional normalization uncertainty of 30% is assigned to the nonprompt-lepton background, based on studies of simulated events [57]. The statistical uncertainty in the signal and background templates is introduced as a systematic uncertainty via the Barlow-Beeston-lite approach [73]. This is the systematic uncertainty that has the largest impact on the results derived from the simultaneous fits described below. Uncertainties related to pileup, theoretical calculations, and the muon trigger and identification are correlated across the three data-taking years. The luminosity and  $b$  tagging uncertainties are partially correlated through some of the individual uncertainty sources, and the remaining uncertainties are uncorrelated across the three datasets. The total uncertainties on the results are dominated by the statistical uncertainties.

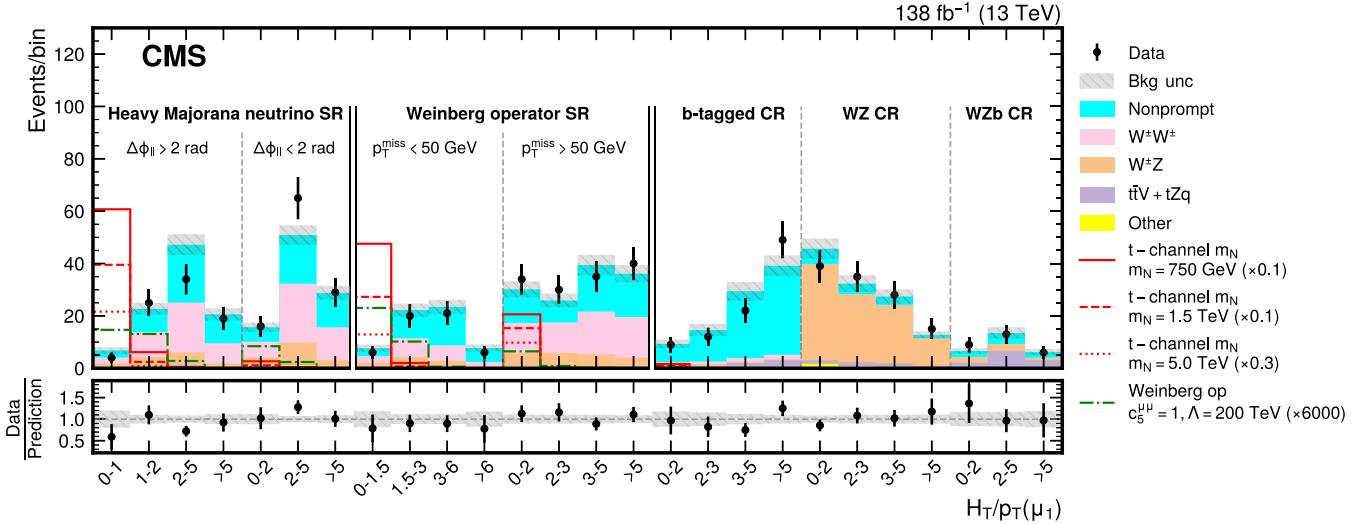


FIG. 2. The  $H_T/p_T^{\mu_1}$  distribution in the SRs and CRs. The horizontal axis indicates the bin width. The predicted yields of the backgrounds are shown with their best fit normalizations from the simultaneous fits for the background-only hypothesis. The lines indicate the scaled expected distributions of the heavy Majorana neutrino process with  $m_N = 750$  GeV (solid red line), 1.5 TeV (dashed red line), 5.0 TeV (dotted red line), and of the Weinberg operator process (dash-dotted green line). The heavy Majorana neutrino processes are characterized by the azimuthal separation variable  $\Delta\phi_{\ell\ell}$ , while the Weinberg operator process features in low missing transverse momentum.

Two separate fits are performed, based on the SR and the  $b$ -tagged, WZ, and  $WZb$  CRs: one for the heavy Majorana neutrino analysis using  $\Delta\phi_{\ell\ell}$  bins in the SR, and a second for the Weinberg operator analysis with the  $p_T^{\text{miss}}$  bins in the SR. The normalization factors for the  $W^\pm W^\pm$ ,  $W^\pm Z$ , and  $tZq$  background processes, affecting both the SRs and CRs, are included as free parameters in the fit together with the signal strength. The predicted yields are shown in Fig. 2 with their best fit normalizations from the simultaneous fits for the background-only hypothesis, i.e., assuming no contributions from processes involving heavy Majorana neutrinos and the Weinberg operator. The bin boundaries are chosen to optimize the signal sensitivity while leaving the major background contributions in each bin at a reasonable level.

The data are found to be consistent with the background expectation. Using the relationship between the cross section and the mixing elements for the heavy Majorana neutrino analysis, upper limits at the 95% C.L. are derived on  $|V_{\mu N}|^2$  as shown in Fig. 3. These results surpass those obtained in previous searches by the ATLAS and CMS Collaborations [18,19,21] for  $m_N \gtrsim 650$  GeV, and set the first direct limits for  $m_N > 2$  TeV. Previous upper limits on the mixing elements from the CMS Collaboration [18,21] are plotted in Fig. 3 for comparison. These limits on  $|V_{\mu N}|^2$  approach unity at around 1 TeV. As the mixing element describes the oscillation probability between the SM neutrinos and the heavy Majorana neutrino, results with  $|V_{\mu N}|^2 > 1$  are not physically meaningful.

Equation (2) is used to convert the limit on  $|C_5^{\ell\ell}/\Lambda|^2$  extracted from the Weinberg operator analysis into a limit on  $|m_{\mu\mu}|$ . The observed (expected) 95% C.L. upper limit on

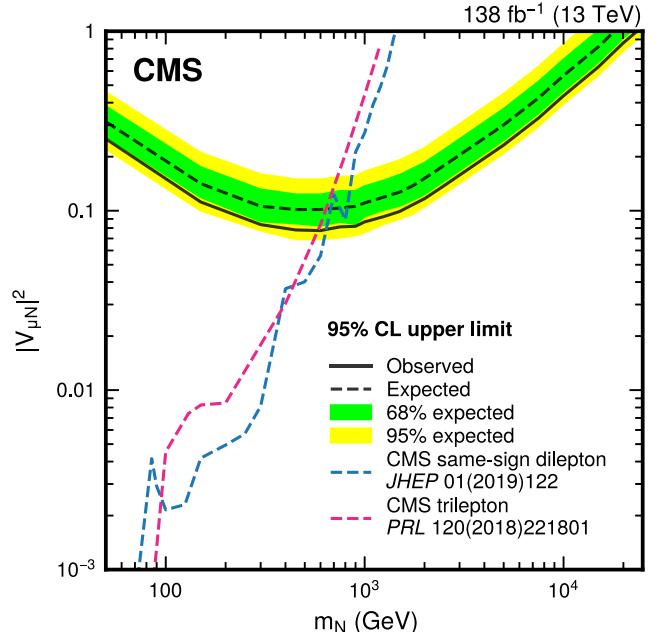


FIG. 3. Upper limits on the heavy neutrino mixing element  $|V_{\mu N}|^2$  at the 95% C.L. as a function of the heavy neutrino mass  $m_N$ . The black dashed curve shows the expected upper limit, with the 1 and 2 standard deviation bands are indicated in lime green and light yellow, respectively. The solid black curve is the observed upper limit. The red dashed curve indicates observed upper limits from Ref. [18], while the blue dashed curve shows the observed upper limits from Ref. [21]. The result from Ref. [19] is not shown since it focuses on low  $m_N$ . Starting from  $m_N$  around 650 GeV, the analysis presented in this Letter improves upon the upper limits from those references.

$|m_{\mu\mu}|$  is found to be 10.8(12.8) GeV. This is the first upper limit from a collider experiment, and it improves upon a previous limit set in Ref. [16] using the results from the NA62 experiment [17].

In summary, this Letter presents the first search for Majorana neutrinos at several TeV and a first probe of the Weinberg operator at the LHC. These achievements were made possible by considering for the first time vector boson fusion processes resulting in a same-sign dimuon final state. The results are consistent with the predictions from the standard model. For heavy Majorana neutrinos, upper limits on the mixing element  $|V_{\mu N}|^2$  are set for the mass range  $50 \text{ GeV} < m_N < 25 \text{ TeV}$  and the best sensitivity is reached for  $m_N \gtrsim 650 \text{ GeV}$ . The phase space explored exceeds the center-of-mass energy of the LHC, improving previous limits for direct production of Majorana neutrinos. The highest mass for which  $|V_{\mu N}|^2 = 1$  is excluded is around 23 TeV. The observed (expected) 95% confidence level upper limit on the effective  $\mu\mu$  Majorana mass associated with the Weinberg operator is 10.8 (12.8) GeV, exceeding the current best limit from high intensity Kaon experiments.

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- [1] Q. R. Ahmad *et al.* (SNO Collaboration), Direct Evidence for Neutrino Flavor Transformation from Neutral Current Interactions in the Sudbury Neutrino Observatory, *Phys. Rev. Lett.* **89**, 011301 (2002).
- [2] Y. Ashie *et al.* (Super-Kamiokande Collaboration), A measurement of atmospheric neutrino oscillation parameters by SUPER-KAMIOKANDE I, *Phys. Rev. D* **71**, 112005 (2005).
- [3] A. Loureiro, A. Cuceu, F. B. Abdalla, B. Moraes, L. Whiteway, M. McLeod, S. T. Balan, O. Lahav, A. Benoit-Lévy, M. Manera, R. P. Rollins, and H. S. Xavier, Upper Bound of Neutrino Masses from Combined Cosmological Observations and Particle Physics Experiments, *Phys. Rev. Lett.* **123**, 081301 (2019).
- [4] S. Alam *et al.* (eBOSS Collaboration), Completed SDSS-IV extended baryon oscillation spectroscopic survey: Cosmological implications from two decades of spectroscopic surveys at the apache point observatory, *Phys. Rev. D* **103**, 083533 (2021).
- [5] M. Aker *et al.* (KATRIN Collaboration), Direct neutrino-mass measurement with sub-electronvolt sensitivity, *Nat. Phys.* **18**, 160 (2022).
- [6] P. Minkowski,  $\mu \rightarrow e\gamma$  at a rate of one out of 1-billion muon decays?, *Phys. Lett.* **67B**, 421 (1977).
- [7] M. Gell-Mann, P. Ramond, and R. Slansky, Complex spinors and unified theories, in *Supergravity* (North-Holland, Amsterdam, 1979), p. 315; *Conf. Proc. C* 790927, 315 (1979).
- [8] *Proceedings of the Workshop on the Unified Theories and the Baryon Number in the Universe*, edited by O. Sawada and A. Sugamoto (National Laboratories High Energy Physics, Tsukuba, Japan, 1979).
- [9] R. N. Mohapatra and G. Senjanović, Neutrino Mass and Spontaneous Parity Violation, *Phys. Rev. Lett.* **44**, 912 (1980).
- [10] S. Weinberg, Baryon- and Lepton-Nonconserving Processes, *Phys. Rev. Lett.* **43**, 1566 (1979).
- [11] A. Das and N. Okada, Improved bounds on the heavy neutrino productions at the LHC, *Phys. Rev. D* **93**, 033003 (2016).
- [12] A. Das, P. Konar, and S. Majhi, Production of heavy neutrino in next-to-leading order QCD at the LHC and beyond, *J. High Energy Phys.* **06** (2016) 019.
- [13] A. Das and N. Okada, Bounds on heavy Majorana neutrinos in type-I seesaw and implications for collider searches, *Phys. Lett. B* **774**, 32 (2017).
- [14] A. Gando *et al.* (KamLAND-Zen Collaboration), Search for Majorana Neutrinos Near the Inverted Mass Hierarchy Region with KamLAND-Zen, *Phys. Rev. Lett.* **117**, 082503 (2016); **117**, 109903(A) (2016).
- [15] M. Agostini *et al.* (GERDA Collaboration), Final Results of GERDA on the Search for Neutrinoless Double- $\beta$  Decay, *Phys. Rev. Lett.* **125**, 252502 (2020).
- [16] B. Fuks, J. Neundorf, K. Peters, R. Ruiz, and M. Saimpert, Probing the Weinberg operator at colliders, *Phys. Rev. D* **103**, 115014 (2021).
- [17] E. Cortina Gil *et al.* (NA62 Collaboration), Searches for lepton number violating  $K^+$  decays, *Phys. Lett. B* **797**, 134794 (2019).

- [18] CMS Collaboration, Search for Heavy Neutral Leptons in Events with Three Charged Leptons in Proton-Proton Collisions at  $\sqrt{s} = 13$  TeV, *Phys. Rev. Lett.* **120**, 221801 (2018).
- [19] ATLAS Collaboration, Search for heavy neutral leptons in decays of  $W$  bosons produced in 13 TeV  $pp$  collisions using prompt and displaced signatures with the ATLAS detector, *J. High Energy Phys.* **10** (2019) 265.
- [20] CMS Collaboration, Search for physics beyond the standard model in multilepton final states in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. High Energy Phys.* **03** (2020) 051.
- [21] CMS Collaboration, Search for heavy Majorana neutrinos in same-sign dilepton channels in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. High Energy Phys.* **01** (2019) 122.
- [22] ATLAS Collaboration, Search for heavy Majorana or Dirac neutrinos and right-handed  $W$  gauge bosons in final states with two charged leptons and two jets at  $\sqrt{s} = 13$  TeV with the ATLAS detector, *J. High Energy Phys.* **01** (2019) 016.
- [23] B. Fuks, J. Neundorf, K. Peters, R. Ruiz, and M. Saimpert, Majorana neutrinos in same-sign  $W^\pm W^\pm$  scattering at the LHC: Breaking the TeV barrier, *Phys. Rev. D* **103**, 055005 (2021).
- [24] HEPData record for this analysis (2022), [10.17182/hepdata.130825](https://doi.org/10.17182/hepdata.130825).
- [25] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [26] CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. Instrum.* **15**, P10017 (2020).
- [27] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [28] CMS Collaboration, Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC, *J. Instrum.* **16**, P05014 (2021).
- [29] CMS Collaboration, Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. Instrum.* **13**, P06015 (2018).
- [30] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, *J. Instrum.* **9**, P10009 (2014).
- [31] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [32] CMS Collaboration, Performance of reconstruction and identification of  $\tau$  leptons decaying to hadrons and  $\nu_\tau$  in  $pp$  collisions at  $\sqrt{s} = 13$  TeV, *J. Instrum.* **13**, P10005 (2018).
- [33] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in  $pp$  collisions at 8 TeV, *J. Instrum.* **12**, P02014 (2017).
- [34] CMS Collaboration, Performance of missing transverse momentum reconstruction in proton-proton collisions at  $\sqrt{s} = 13$  TeV using the CMS detector, *J. Instrum.* **14**, P07004 (2019).
- [35] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* **07** (2014) 079.
- [36] D. Alva, T. Han, and R. Ruiz, Heavy Majorana neutrinos from  $wy$  fusion at hadron colliders, *J. High Energy Phys.* **02** (2015) 072.
- [37] C. Degrande, O. Mattelaer, R. Ruiz, and J. Turner, Fully-automated precision predictions for heavy neutrino production mechanisms at hadron colliders, *Phys. Rev. D* **94**, 053002 (2016).
- [38] P. Nason and G. Zanderighi,  $W^+W^-$ ,  $WZ$  and  $ZZ$  production in the POWHEG-BOX-V2, *Eur. Phys. J. C* **74**, 2702 (2014).
- [39] J. M. Campbell, R. K. Ellis, and C. Williams, Vector boson pair production at the LHC, *J. High Energy Phys.* **07** (2011) 018.
- [40] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, and T. Stelzer, MadGraph 5: Going beyond, *J. High Energy Phys.* **06** (2011) 128.
- [41] R. Frederix and S. Frixione, Merging meets matching in MC@NLO, *J. High Energy Phys.* **12** (2012) 061.
- [42] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [43] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions for the LHC Run II, *J. High Energy Phys.* **04** (2015) 040.
- [44] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions from high-precision collider data, *Eur. Phys. J. C* **77**, 663 (2017).
- [45] CMS Collaboration, Event generator tunes obtained from underlying event and multiparton scattering measurements, *Eur. Phys. J. C* **76**, 155 (2016).
- [46] CMS Collaboration, Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements, *Eur. Phys. J. C* **80**, 4 (2020).
- [47] J. Alwall, S. Höche, F. Krauss, N. Lavesson, L. Lönnblad, F. Maltoni, M. L. Mangano, M. Moretti, C. G. Papadopoulos, F. Piccinini, S. Schumann, M. Treccani, J. Winter, and M. Worek, Comparative study of various algorithms for the merging of parton showers and matrix elements in hadronic collisions, *Eur. Phys. J. C* **53**, 473 (2008).
- [48] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [49] CMS Collaboration (CMS Collaboration), Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid, CMS Technical Proposal, Reports No. CERN-LHCC-2015-010, No. CMS-TDR-15-02, 2015, [10.17182/cern.vu81.d59j](https://doi.org/10.17182/cern.vu81.d59j).
- [50] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [51] M. Cacciari, G. P. Salam, and G. Soyez, The anti- $k_T$  jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [52] CMS Collaboration, Identification of heavy-flavour jets with the CMS detector in  $pp$  collisions at 13 TeV, *J. Instrum.* **13**, P05011 (2018).
- [53] D. L. Rainwater, R. Szalapski, and D. Zeppenfeld, Probing color-singlet exchange in  $Z + 2$ -jet events at the CERN LHC, *Phys. Rev. D* **54**, 6680 (1996).
- [54] CMS Collaboration, Performance of CMS muon reconstruction in cosmic-ray events, *J. Instrum.* **5**, T03022 (2010).

- [55] CMS Collaboration, Performance of the reconstruction and identification of high-momentum muons in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. Instrum.* **15**, P02027 (2020).
- [56] CMS Collaboration, Measurements of properties of the Higgs boson decaying to a W boson pair in pp collisions at  $\sqrt{s} = 13$  TeV, *Phys. Lett. B* **791**, 96 (2019).
- [57] CMS Collaboration, Measurement of the inclusive and differential Higgs boson production cross sections in the leptonic WW decay mode at  $\sqrt{s} = 13$  TeV, *J. High Energy Phys.* **03** (2021) 003.
- [58] CMS Collaboration, Observation of Electroweak Production of Same-Sign W Boson Pairs in the Two Jet and Two Same-Sign Lepton Final State in Proton-Proton Collisions at  $\sqrt{s} = 13$  TeV, *Phys. Rev. Lett.* **120**, 081801 (2018).
- [59] CMS Collaboration, Measurements of production cross sections of WZ and same-sign WW boson pairs in association with two jets in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *Phys. Lett. B* **809**, 135710 (2020).
- [60] CMS Collaboration, Measurements of production cross sections of polarized same-sign W boson pairs in association with two jets in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *Phys. Lett. B* **812**, 136018 (2021).
- [61] T. Junk, Confidence level computation for combining searches with small statistics, *Nucl. Instrum. Methods Phys. Res., Sect. A* **434**, 435 (1999).
- [62] A. L. Read, Presentation of search results: The  $CL_s$  technique, *J. Phys. G* **28**, 2693 (2002).
- [63] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, Asymptotic formulae for likelihood-based tests of new physics, *Eur. Phys. J. C* **71**, 1554 (2011); **73**, 2501(E) (2013).
- [64] CMS Collaboration, Precision luminosity measurement in proton-proton collisions at  $\sqrt{s} = 13$  TeV in 2015 and 2016 at CMS, *Eur. Phys. J. C* **81**, 800 (2021).
- [65] CMS Collaboration (CMS Collaboration), CMS luminosity measurement for the 2017 data-taking period at  $\sqrt{s} = 13$  TeV, CMS Physics Analysis Summary Report No. CMS-PAS-LUM-17-004, 2018, <https://cds.cern.ch/record/2621960>.
- [66] CMS Collaboration (CMS Collaboration), CMS luminosity measurement for the 2018 data-taking period at  $\sqrt{s} = 13$  TeV, CMS Physics Analysis Summary, Report No. CMS-PAS-LUM-18-002, 2019, <https://cds.cern.ch/record/2676164>.
- [67] ATLAS Collaboration, Measurement of the Inelastic Proton-Proton Cross Section at  $\sqrt{s} = 13$  TeV with the ATLAS Detector at the LHC, *Phys. Rev. Lett.* **117**, 182002 (2016).
- [68] CMS Collaboration, Measurement of the inelastic proton-proton cross section at  $\sqrt{s} = 13$  TeV, *J. High Energy Phys.* **07** (2018) 161.
- [69] CMS Collaboration, Jet energy scale and resolution performance with 13 TeV data collected by CMS in 2016-2018, CMS Detector Performance Summary, Report No. CMS-DP-2020-019, 2020, <https://cds.cern.ch/record/2715872>.
- [70] B. Biedermann, A. Denner, and M. Pellen, Complete NLO corrections to  $W^+W^+$  scattering and its irreducible background at the LHC, *J. High Energy Phys.* **10** (2017) 124.
- [71] A. Ballestrero *et al.*, Precise predictions for same-sign W-boson scattering at the LHC, *Eur. Phys. J. C* **78**, 671 (2018).
- [72] J. Butterworth, S. Carrazza, A. Cooper-Sarkar, A. De Roeck, J. Feltesse, J. Forte, Stefano Gao, S. Glazov, J. Huston, and Z. Kassabov, PDF4LHC recommendations for LHC Run II, *J. Phys. G* **43**, 023001 (2016).
- [73] R. J. Barlow and C. Beeston, Fitting using finite Monte Carlo samples, *Comput. Phys. Commun.* **77**, 219 (1993).

- A. Tumasyan<sup>1,b</sup>, W. Adam<sup>1</sup>, J. W. Andrejkovic,<sup>2</sup> T. Bergauer<sup>1</sup>, S. Chatterjee<sup>1</sup>, K. Damanakis<sup>1</sup>, M. Dragicevic<sup>1</sup>, A. Escalante Del Valle<sup>1</sup>, P. S. Hussain<sup>1</sup>, M. Jeitler<sup>1</sup>, N. Krammer<sup>1</sup>, L. Lechner<sup>1</sup>, D. Liko<sup>1</sup>, I. Mikulec<sup>1</sup>, P. Paulitsch<sup>1</sup>, F. M. Pitters<sup>1</sup>, J. Schieck<sup>1</sup>, R. Schöfbeck<sup>1</sup>, D. Schwarz<sup>1</sup>, S. Templer<sup>1</sup>, W. Waltenberger<sup>1</sup>, C.-E. Wulz<sup>1</sup>, M. R. Darwish<sup>2,c</sup>, T. Janssen<sup>1</sup>, T. Kello<sup>3,e</sup>, H. Rejeb Sfar<sup>3</sup>, P. Van Mechelen<sup>1</sup>, E. S. Bols<sup>1</sup>, J. D'Hondt<sup>1</sup>, A. De Moor<sup>1</sup>, M. Delcourt<sup>1</sup>, H. El Faham<sup>1</sup>, S. Lowette<sup>1</sup>, S. Moortgat<sup>1</sup>, A. Morton<sup>1</sup>, D. Müller<sup>1</sup>, A. R. Sahasransu<sup>1</sup>, S. Tavernier<sup>1</sup>, W. Van Doninck<sup>1</sup>, D. Vannerom<sup>1</sup>, B. Clerbaux<sup>1</sup>, G. De Lentdecker<sup>1</sup>, L. Favart<sup>1</sup>, D. Hohov<sup>1</sup>, J. Jaramillo<sup>1</sup>, K. Lee<sup>1</sup>, M. Mahdavikhorrami<sup>1</sup>, I. Makarenko<sup>1</sup>, A. Malara<sup>1</sup>, S. Paredes<sup>1</sup>, L. Pétré<sup>1</sup>, N. Postiau<sup>1</sup>, E. Starling<sup>1</sup>, L. Thomas<sup>1</sup>, M. Vanden Bemden<sup>1</sup>, C. Vander Velde<sup>1</sup>, P. Vanlaer<sup>1</sup>, D. Dobur<sup>1</sup>, J. Knolle<sup>1</sup>, L. Lambrecht<sup>1</sup>, G. Mestdach<sup>1</sup>, M. Niedziela<sup>1</sup>, C. Rendón<sup>1</sup>, C. Roskas<sup>1</sup>, A. Samalan<sup>1</sup>, K. Skovpen<sup>1</sup>, M. Tytgat<sup>1</sup>, N. Van Den Bossche<sup>1</sup>, B. Vermassen<sup>1</sup>, L. Wezenbeek<sup>1</sup>, A. Benecke<sup>1</sup>, G. Bruno<sup>1</sup>, F. Bury<sup>1</sup>, C. Caputo<sup>1</sup>, P. David<sup>1</sup>, C. Delaere<sup>1</sup>, I. S. Donertas<sup>1</sup>, A. Giannanco<sup>1</sup>, K. Jaffel<sup>1</sup>, Sa. Jain<sup>1</sup>, V. Lemaitre<sup>1</sup>, K. Mondal<sup>1</sup>, J. Prisciandaro<sup>1</sup>, A. Taliercio<sup>1</sup>, T. T. Tran<sup>1</sup>, P. Vischia<sup>1</sup>, S. Wertz<sup>1</sup>, G. A. Alves<sup>2</sup>, E. Coelho<sup>2</sup>, C. Hensel<sup>2</sup>, A. Moraes<sup>2</sup>, P. Rebello Teles<sup>2</sup>, W. L. Aldá Júnior<sup>2</sup>, M. Alves Gallo Pereira<sup>2</sup>, M. Barroso Ferreira Filho<sup>2</sup>, H. Brando Malbouisson<sup>2</sup>, W. Carvalho<sup>2</sup>, J. Chinellato<sup>2,f</sup>, E. M. Da Costa<sup>2</sup>, G. G. Da Silveira<sup>2,g</sup>, D. De Jesus Damiao<sup>2</sup>, V. Dos Santos Sousa<sup>2</sup>, S. Fonseca De Souza<sup>2</sup>, J. Martins<sup>2,h</sup>, C. Mora Herrera<sup>2</sup>, K. Mota Amarilo<sup>2</sup>, L. Mundim<sup>2</sup>, H. Nogima<sup>2</sup>, A. Santoro<sup>2</sup>, S. M. Silva Do Amaral<sup>2</sup>, A. Sznajder<sup>2</sup>, M. Thiel<sup>2</sup>, F. Torres Da Silva De Araujo<sup>2,i</sup>, A. Vilela Pereira<sup>2</sup>, C. A. Bernardes<sup>10,g</sup>, L. Calligaris<sup>10</sup>, T. R. Fernandez Perez Tomei<sup>10</sup>, E. M. Gregores<sup>10</sup>, P. G. Mercadante<sup>10</sup>, S. F. Novaes<sup>10</sup>, Sandra S. Padula<sup>10</sup>

- A. Aleksandrov<sup>11</sup>, G. Antchev<sup>11</sup>, R. Hadjiiska<sup>11</sup>, P. Iaydjiev<sup>11</sup>, M. Misheva<sup>11</sup>, M. Rodozov,<sup>11</sup> M. Shopova<sup>11</sup>, G. Sultanov<sup>11</sup>, A. Dimitrov<sup>12</sup>, T. Ivanov<sup>12</sup>, L. Litov<sup>12</sup>, B. Pavlov<sup>12</sup>, P. Petkov<sup>12</sup>, A. Petrov,<sup>12</sup> E. Shumka<sup>12</sup>, T. Cheng<sup>13</sup>, T. Javaid,<sup>13,j</sup> M. Mittal<sup>13</sup>, L. Yuan<sup>13</sup>, M. Ahmad<sup>14</sup>, G. Bauer,<sup>14,k</sup> Z. Hu<sup>14</sup>, S. Lezki<sup>14</sup>, K. Yi,<sup>14,k</sup> G. M. Chen<sup>15,j</sup>, H. S. Chen<sup>15,j</sup>, M. Chen<sup>15,j</sup>, F. Iemmi<sup>15</sup>, C. H. Jiang,<sup>15</sup>, A. Kapoor<sup>15</sup>, H. Liao<sup>15</sup>, Z.-A. Liu<sup>15,m</sup>, V. Milosevic<sup>15</sup>, F. Monti<sup>15</sup>, R. Sharma<sup>15</sup>, J. Tao<sup>15</sup>, J. Thomas-Wilsker<sup>15</sup>, J. Wang<sup>15</sup>, H. Zhang<sup>15</sup>, J. Zhao<sup>15</sup>, A. 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