Prospects for Observing $t\bar{t}HH$ Production with the ATLAS Experiment at the HL-LHC

The ATLAS Collaboration

Abstract

Measuring the self-coupling of the Higgs boson is one of the primary goals of the High Luminosity-LHC. In this note, the prospects for the study of $t\bar{t}HH$ production, with both Higgs bosons decaying to $H \rightarrow b\bar{b}$, using 3000 fb$^{-1}$ of proton-proton collisions at $\sqrt{s} = 14$ TeV with an average pile-up of 200 at the ATLAS detector are presented.

The study uses stable particles from generated Monte Carlo events. The energy and momentum of leptons and jets are smeared to simulate the response of the upgraded ATLAS detector and pile-up collisions. Events are selected from the semi-leptonic final state of the $t\bar{t}$ system with one electron or muon, two $b$-quark jets, two light jets and missing momentum from the neutrino, along with an additional four $b$-jets from the Higgs boson decay.

After applying event selections requiring at least 5 jets to be $b$-tagged, and assuming Standard Model rates of signal and background processes, 25 $t\bar{t}HH$ events are selected, with a background of 7,100 events. By considering events in the 5 $b$-tag and $\geq 6$ $b$-tag regions separately, the statistical significance of $t\bar{t}HH$ production is estimated to be 0.35 $\sigma$. It is concluded that, once systematic uncertainties are included, the $t\bar{t}HH$ production mechanism at the level predicted in the Standard Model will make, at best, a small contribution to evidence of Higgs boson pair production and to a measurement of the Higgs self-coupling parameter $\lambda_{HHH}$ at the High Luminosity-LHC.

© 2016 CERN for the benefit of the ATLAS Collaboration.
Reproduction of this article or parts of it is allowed as specified in the CC-BY-4.0 license.
1 Introduction

One of the primary goals of the High Luminosity-LHC (HL-LHC) is to fully characterise the nature of the Higgs boson, $H$. In the Standard Model, the Higgs boson has two self-coupling vertices: an $HHH$ vertex with a coupling strength of $\lambda v$ and an $HHHH$ vertex with a coupling strength of $\frac{1}{4}\lambda v$, where $v$ is the vacuum expectation value and $\lambda$ is the parameter in the Higgs boson potential that can be written in terms of the Higgs boson mass as $m_H = \sqrt{2\lambda} v$. The value of $\lambda$ at the $HHH$ vertex, $\lambda_{HHH}$, can be probed by measuring final states with two Higgs bosons, while there are no realistic prospects of measuring the $HHHH$ vertex.

The cross section for various $HH$ production processes in proton-proton collisions with a centre-of-mass energy of $\sqrt{s} = 14$ TeV are shown in Figure 1, as a function of the parameter $\lambda_{HHH}$ in terms of the Standard Model value $\lambda_{SM}$. The cross sections for many $HH$ production process suffer from negative interference between the two leading Feynman diagrams - the box and triangle diagrams as shown in Figure 2 - leading to a reduced cross section for Standard Model values of $\lambda$. The process with the largest cross section is gluon-gluon fusion: $pp \rightarrow HH$. This process has been studied with the Higgs bosons decaying into $b\bar{b}\gamma\gamma$ and $b\bar{b}\tau\tau$ with the upgraded ATLAS detector at the HL-LHC [1, 2].

For $\lambda_{HHH} = \lambda_{SM}$, both Vector Boson Fusion, $pp \rightarrow HHjj$ and associated production with top quarks, $t\bar{t}HH$ have similar cross sections. The Feynman diagrams for $t\bar{t}HH$ production are shown in Figure 3. Recent phenomenological studies [3, 4] have suggested that $t\bar{t}HH$ is a promising channel to study Higgs boson pair production if both Higgs bosons decay into $b\bar{b}$. The cross section for this process is more than an order of magnitude smaller than $HH$ in gluon gluon fusion, however the presence of a top quark pair also reduces the backgrounds compared to other Higgs boson pair production channels. In addition the $t\bar{t}HH$ production mechanism does not suffer from destructive interference in the cross section as there are no loops in the leading order Feynman diagrams. In this note a study of $t\bar{t}HH$ production in $\sqrt{s} = 14$ TeV collision at the HL-LHC with an upgraded ATLAS detector and an integrated luminosity of 3000 fb$^{-1}$ are presented.

HL-LHC running will be characterised by high levels of pile-up. Pile-up refers to the number of proton-proton collisions in each proton bunch crossing, denoted by $\mu_{pu}$. Ongoing studies for the design of the HL-LHC predict a mean value of $\langle \mu_{pu} \rangle$ 140 or 200, depending on the final choice of design parameters [5].

The analysis presented in this note uses generator-level Monte Carlo samples to which functions are applied to simulate the response of the Reference design of the upgraded ATLAS detector described in the ATLAS Phase-II Scoping Document [6], and the effect of pile-up in collisions.

Before object reconstruction, each generator-level event is first overlaid with simulated pile-up jets, from a library, corresponding to a mean pile-up of $\langle \mu_{pu} \rangle = 200$. Smearing functions, which typically depend on momentum and position, are then applied to the generator-level analysis objects. The smearing functions are obtained from studies of fully simulated samples generated with $\langle \mu_{pu} \rangle = 200$ and the Reference design for the upgraded ATLAS detector.

The rest of the note is organised as follows: Section 2 discusses the signal and background samples used in this analysis and the application of the smearing functions. Section 3 discusses the selection criteria and analysis. Section 4 presents the results and discussion, and conclusions are presented in Section 5.
Figure 1: Total cross sections at the LO and NLO in QCD for $HH$ production channels, as a function of the self-interaction coupling $\lambda$, taken from Ref. [7]. $\lambda$ is varied for the self-interaction couplings, but the mass of the Higgs boson is fixed to be $m_H = 125$ GeV. The dashed (solid) lines and light- (dark-)coloured bands correspond to the LO (NLO) results and to the scale and PDF uncertainties added linearly. The SM values of the cross sections are obtained at $\lambda/\lambda_{SM} = 1$.

![Figure 1](image1.png)

Figure 2: Feynman diagrams for $gg \to HH$ production.

2 Signal and Background Generation

The signal and background Monte Carlo samples used for this analysis are summarised in Table 1. In all samples a Higgs boson of $m_H = 125.0$ GeV is used. The branching ratio for $H \to b\bar{b}$ of 0.5824 is taken from Ref. [8].

The signal $t\bar{t}HH(HH \to b\bar{b}b\bar{b})$ is generated using the MadGraph [9] generator at leading order. Showering and hadronization are simulated using are Pythia8 [10]. The A14 tune [11] of shower and multiple parton interactions parameters is used together with the NNPDF2.3 PDF set [12].

Following the approach in Refs [3, 4], the following irreducible backgrounds are considered: $t\bar{t}b\bar{b}$+jets, $t\bar{t}Z(Z \to b\bar{b})$+jets and $t\bar{t}H(H \to b\bar{b})$+jets. It should be noted that in Ref. [3] $t\bar{t}bb\bar{b}\bar{b}$ is considered as a background, whereas this analysis considers $t\bar{t}b\bar{b}$+jets such that additional heavy quarks are generated.
in the parton shower. Each background process is generated using Sherpa2.2 [13] at leading order, using massless b-quarks, and with up to two additional jets generated in the matrix element; the NNPDF3.0 PDF set is used [14]. As this analysis considers only final states containing electrons or muons, a filter is applied to select events with at least one electron, muon or tau with \( p_T > 20 \text{ GeV} \). An additional filter on the \( t\bar{t}b\bar{b} \) at the a matrix element level requires \( b \)-quarks to have \( p_T > 15 \text{ GeV} \) and \( m_{bb} > 30 \text{ GeV} \).

The cross section for \( t\bar{t}HH \) sample is normalised to the next-to-leading-order prediction of \( \sigma_{t\bar{t}HH} = 0.981 \text{ fb} \) (before the Higgs boson branching ratio is applied) presented in Ref. [7]. The background samples are normalised to leading order, using the cross section calculated by the generator.

Additional background from, e.g., \( t\bar{t}cc \), \( t\bar{t}W+\text{jets} \), \( t\bar{t}ZZ \), \( t\bar{t}HZ \), \( t\bar{t}\tau \) and \( Wb\bar{b}b\bar{b} \) production are not considered in this analysis. In particular the \( t\bar{t}cc \) background would contribute due to a significant mistag rate in the \( b \)-tagging algorithm used in this analysis, as discussed in section 3.1.2. These backgrounds are not expected to significantly change the conclusions.

### 3 Analysis

The analysis presented in this note, uses the semi-leptonic final state of the \( t\bar{t} \) where one of the top quarks decays to an electron or muon, including decay through a tau lepton. Therefore the final state of \( t\bar{t}HH \) is one electron or muon, two light jets, six \( b \)-jets and missing transverse momentum.

Studies of potential trigger menus which could be employed at ATLAS for the HL-LHC suggest it will be possible to use single electron and muon triggers with \( p_T \) thresholds of 22 GeV for electrons and 20 GeV for muons. The efficiency of these triggers is discussed in Section 3.2.
3.1 Object Selection

Events are selected using the properties of the jets, electrons, muons and missing transverse momentum in the event. After applying trigger and isolation requirements, described below, no further consideration is made for the reconstruction efficiency for electrons and muons.

Before event objects are reconstructed, each event is overlayed with simulated pile-up jets; the simulated pile-up jets have a value of $\mu_{pu}$ between 190 and 210 with a flat probability. The mean number of such pile-up jets per event is 4.8. As discussed in section 3.1.2 below, a track confirmation requirement is applied to reconstructed jets to reduce the dependence on pile-up.

3.1.1 Electrons and Muons

Electrons and muons are taken from the stable particle record of the Monte Carlo event. The energy and $p_T$ of electrons and muons are smeared using $p_T$ and $\eta$-dependent functions, as described in Ref. [6]. In the rest of this note, $p_T$ and energy for electrons and muon refers to the smeared values. Electrons and muons are required to have $p_T > 25$ GeV. Electrons are required to have $|\eta| \leq 4.0$; muons are required to have $|\eta| \leq 2.5$. An isolation requirement is placed on the electrons and muons, such that, in a cone of $\Delta R$ of 0.2, they have $E_T$ of less than $0.2 \times p_T$. The isolation requirement removes around 2% of electrons and muons.

3.1.2 Jets

So-called truth jets are reconstructed from particles in the pile-up overlayed event record; all stable particles, excluding muons and neutrinos, are clustered using the anti-$k_t$ algorithm [15] with radius parameter of $R = 0.4$. Truth jets within $\Delta R$ of 0.1 of a selected electron or muon are removed from consideration.

The $p_T$ of the truth jets are smeared by an $\eta$- and $p_T$-dependent parameterisation described in Ref. [6]. For central jets with $p_T$ around 30 GeV the smearing has a standard deviation of approximately $50\% \times p_T$; for central jets with $p_T > 100$ GeV, the smearing has a standard deviation of approximately $12\% \times p_T$.

In the rest of this note, jet-$p_T$ refers to the smeared $p_T$ values. All jets are required to have $p_T > 30$ GeV and $|\eta| \leq 4.0$.

To reduce the dependence on pile-up, reconstructed jets with $|\eta| < 3.8$ are required to pass the track confirmation requirement as described in Ref. [6]: the ratio of the scalar $p_T$ sum of the tracks that are associated with the jet, and originate from the hard-scatter vertex, is divided by jet $p_T$. Small ratios of this quantity typically arise from pile-up jets, while the ratio is larger for hard-scatter jets.

Using this method, a typical rejection (dependent on $p_T$ and $\eta$) of 50 is found for pile-up jets. Therefore, on average around 0.1 pile-up jets survive per event. This track confirmation procedure is not applied to $b$-tagged jets (described below) as such jets are unlikely to be reconstructed from pile-up.

To identify $b$- and $c$-jets, the following procedure is used. $b$- and $c$-hadrons are identified in the stable particle record. These hadrons are matched to the closest truth jet with $\Delta R < 0.2$; such jets are labeled as

---

1 $\Delta R$ is defined as $\sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$. 
truth-\(b\)-jets and truth-\(c\)-jets, as appropriate. Truth jets not labeled as \(b\)- or \(c\)-jets are considered to be light jets.

All truth jets passing the initial selection, along with their flavour information, are used as input to a parameterisation of the ATLAS MV1 \(b\)-jet tagger algorithm [16]. The tagger provides 70\% efficiency working point for \(b\)-tagging such that 70\% of truth-\(b\)-jets are labeled as \(b\)-tagged. The MV1 tagger is trained on a fully simulated sample with pile-up of \(\langle \mu_{\text{pu}} \rangle = 200\). This models \(b\)-tagging performance as functions of \(p_T\) and \(\eta\) of the jets. The mistag rate for \(c\)-jets is around 20\% and the mistag rate for light-jets is around 0.2\%.

### 3.2 Event Selection

Two different, overlapping, event selections are considered: one with at least 5 jets \(b\)-tagged and one with at least 6 jets \(b\)-tagged. These are referred to as the \(\geq 5 \, b\)-tag selection and the \(\geq 6 \, b\)-tag selection respectively, the selection criteria are summarised as:

- Events must have exactly one electron or one muon (with \(p_T\) and \(\eta\) criteria as detailed in section 3.1.1).
- A *single lepton* trigger requirement for HL-LHC running is emulated: each event must have an electron or muon consistent with trigger requirements.
- Events must have \(\geq 7\) jets with \(p_T > 30\) GeV and \(|\eta| \leq 4.0\).
- For \(\geq 5\) \(b\)-tag selection: at least 5 jets are required to be \(b\)-tagged.
- For \(\geq 6\) \(b\)-tag selection: at least 6 jets are required to be \(b\)-tagged.
- No requirement is made on the missing transverse momentum.

The single electron trigger selects electrons with \(|\eta| < 2.5\) with an efficiency of 95\% for \(22 \, \text{GeV} < p_T < 35\) GeV and 100\% for \(p_T > 35\) GeV; for electrons with \(2.5 < |\eta| < 4.9\) and \(p_T > 35\) GeV, the efficiency is 90\%. The single muon trigger selects muons with \(p_T > 20\) GeV and \(|\eta| < 2.4\) with an efficiency of around 96\%.

The event selection is optimised to maximise the statistical significance, \(S/\sqrt{B}\), where \(S\) is the number of signal events and \(B\) is the number of background events.

#### 3.2.1 Event Shape Variables

Several event shape variables are studied in order to discriminate the \(t\bar{t}HH\) signal from the background processes. The following variables are found to have the most discriminating power:

1. The average separation in pseudorapidity between two \(b\)-tagged jets: \(\langle \eta(b_i, b_j) \rangle\),
2. Centrality, defined as the scalar sum of \(p_T\) for all jets, divided by the energy sum of all jets.
3. The scalar sum of \(p_T\) for \(b\)-tagged jets, \(H_B\).
The distributions for these variables are shown in Figures 4, 5 and 6.

After examining the numbers of events passing selections on the above variables, and optimising the statistical significance using $S/\sqrt{B}$, a single selection criteria of $\langle \eta(b_i,b_j) \rangle < 1.25$ is applied. This selection criterion is optimal for both the $\geq 5$ $b$-tag and $\geq 6$ $b$-tag selection. No selection on either centrality or $H_B$ is made as these made only minimal improvements to the significance.

### 3.2.2 Higgs Boson Candidate Reconstruction

The Higgs bosons in events may be fully reconstructed by assigning the $b$-jets and light jets to the top and Higgs boson candidates. However, due to the large number of jets in the event, this poses a combinatorial problem. Two different methods are studied to assign the $b$-tagged jets to the Higgs boson candidates.

The first method follows the procedure performed in the phenomenological analyses in Refs [3, 4]. It selects $b$-tag jet pairs that minimise the following quantity:

$$\chi^2 = (m_{b_1b_2} - m_H)^2 + (m_{b_3b_4} - m_H)^2$$

where $m_H$ is set to 120 GeV. The choice of 120 GeV, not the 125 GeV used for simulation follows the method in the above references and is motivated by the loss of some the jet energy through decays to neutrinos.

A second method finds the pair of $b$-tagged jets which had the largest vector sum $p_T$ and assigns this pair as a Higgs boson candidate; this is shown in Figure 5.

In contrast with Refs [3, 4], it is found that making a requirement on $m_{bb}$ does not improve the statistical significance in either case and therefore no requirement is made on the mass of the Higgs boson candidates.
Figure 5: Left: average separation in pseudorapidity between two $b$-tagged jets $\langle \eta(b_i, b_j) \rangle$, after trigger, lepton and number of jets requirements with $\geq 5$ $b$-tags. Right: Higgs boson candidate mass, $m_{bb}$, found from selecting the $b$-tagged jets which have the largest vector sum $p_T$ shown for events that have passed the $\geq 5$ $b$-tag selection, normalised to unity.

Figure 6: Left: centrality; Right: $H_B$. Both variables are plotted after after trigger, lepton and number of jets requirements with $\geq 5$ $b$-jets.

4 Results

The results for the $t\bar{t}HH$ signal and backgrounds are shown in Table 2. For the $\geq 5$ $b$-tag selection, the number of signal and background events in 3000 fb$^{-1}$ is 25 and 7,100 respectively, with the largest background contribution from the $t\bar{t}b\bar{b} +$ jets. For exactly 5 $b$-tags, the number of signal and background events is 19 and 6,600 events, resulting in a significance of 0.23 $\sigma$. For the $\geq 6$ $b$-tag selection, the number of signal and background events is 6 and 510 respectively, resulting in a statistical significance of 0.26 $\sigma$. Combining these two significances in quadrature results in an overall significance of 0.35 $\sigma$.

A full consideration of the systematic uncertainties on the background is beyond the scope of this note. Background uncertainties will be constrained using HL-LHC data. Additionally, there is likely to be more accurate theoretical predictions available when the full HL-LHC dataset has been collected. Tables 3 and 4 present the limits that can be set on the cross section for $t\bar{t}HH$ production for different systematic uncertainties on the production of the backgrounds.

Table 5 shows an analysis of events in the $t\bar{t}b\bar{b}+$jets sample which pass the event selection criteria in the $\geq 5$ $b$-tag selection. Only 3% of this background comes from events with 6 true $b$-jets. The main
component of this background is due to $c$-jets from $W$-boson decays that are mistagged as $b$-jets; the $W$-bosons originate from the decay of the $t$-quarks.

There is a large $c$-jet mistag rate of $\sim 20\%$. The $b$-tagger used in this analysis is not optimised to reject $c$-jets. Future developments of $b$-tagging algorithms for HL-LHC conditions will be better optimised to reject $c$-jet backgrounds and it is therefore anticipated that such backgrounds can be reduced. Studies performed in Run 2 of the ATLAS MV2 [17] $b$-tagging algorithm have already demonstrated a 40% improvement in $c$-jet rejection compared to the MV1 $b$-tagging algorithm. The $b$-tagging algorithm used in this analysis is a modified version of MV1.

The use of multivariate techniques, further categorisation or kinematic likelihood fitter techniques similar to KLFitter [18], may allow for further improvements in distinguishing the $t\bar{t}HH$ signal from backgrounds.

However even if the $t\bar{t}bb\bar{b}$ backgrounds can be controlled, there will still be a significant background from $t\bar{t}H$ production which will ultimately limit the sensitivity of this analysis.

Even assuming a small systematic uncertainty on $t\bar{t}bb\bar{b}$ and $t\bar{t}H$ production, $t\bar{t}HH$ production will only make a small contribution to evidence for Higgs boson pair production or a measurement of $\lambda_{HHH}$, in comparison to $HH$ production to $b\bar{b}\gamma\gamma$ and $b\bar{b}\tau\tau$.

Figure 7: $H_T$, the scalar sum of jet $p_T$ shown for events after all selections with the $t\bar{t}HH$ signal scaled by a factor of 200.
Sample No cuts Trigger One lepton ≥7 jets ≥5 b-tags η(b_i, bj) ≥6 b-tags

\(t\bar{t}HH(HH \rightarrow b\bar{b}b\bar{b})\) 990 513 253 139 29 25 6
\(t\bar{t}H(H \rightarrow b\bar{b}) + \text{jets}\) 610,000 500,000 290,000 69,000 1,580 1,200 90
\(t\bar{t}Z(Z \rightarrow b\bar{b}) + \text{jets}\) 270,000 220,000 125,000 26,000 600 390 30
\(t\bar{t}b\bar{b} + \text{jets}\) 5,900,000 4,800,000 2,800,000 460,000 9,700 5,500 400
Total background 6,800,000 5,500,000 3,200,000 550,000 11,900 7,100 520

Table 2: Summary of event selection criteria applied to signal and background events for 3000 fb⁻¹. The background samples are filtered to require a charged lepton with \(p_T > 20\) GeV, whereas no filter is required on the signal sample; this leads to the appearance of a smaller trigger efficiency for the signal sample. \(\eta(b_i, bj)\) refers to \(\langle \eta(b_i, bj) \rangle < 1.25\).

<table>
<thead>
<tr>
<th>Background uncertainty</th>
<th>95% CL limit on (\sigma(t\bar{t}HH)/\sigma_{SM})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.8</td>
</tr>
<tr>
<td>5%</td>
<td>20</td>
</tr>
<tr>
<td>10%</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 3: 95% limits on the cross section for \(t\bar{t}HH\) production for the ≥5 b-tag selection, assuming different systematic uncertainties on the backgrounds. The same percentage uncertainty is applied to all the background processes considered.

<table>
<thead>
<tr>
<th>Background uncertainty</th>
<th>95% CL limit on (\sigma(t\bar{t}HH)/\sigma_{SM})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8.0</td>
</tr>
<tr>
<td>5%</td>
<td>10</td>
</tr>
<tr>
<td>10%</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 4: 95% limits on the cross section for \(t\bar{t}HH\) production, for the ≥6 b-tag selection assuming different systematic uncertainties on the backgrounds. The same percentage uncertainty is applied to all the background processes considered.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>all events with c-jet from W with c-jets not from W</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>2 ≥ 1</td>
<td>100 90 10</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
</tr>
<tr>
<td>3 ≥ 1</td>
<td>1170 1020 150</td>
</tr>
<tr>
<td>4</td>
<td>1130</td>
</tr>
<tr>
<td>4 ≥ 1</td>
<td>4630 3890 740</td>
</tr>
<tr>
<td>5</td>
<td>1950</td>
</tr>
<tr>
<td>6</td>
<td>410</td>
</tr>
</tbody>
</table>

Table 5: Classification of truth jets in the \(t\bar{t}b\bar{b}\) sample for the ≥5 b-jet selection. The main component of the background is due to real charm jets from the decay of W-bosons, that are mistaken for b-jets.
5 Conclusion

A cut-based analysis has been presented for $t\bar{t}HH(HH \rightarrow b\bar{b}b\bar{b})$ targeting the semileptonic decay of the top quark pairs and employing a parameterisation of the upgraded ATLAS detector with HL-LHC conditions. The event selection is optimised for the statistical significance of $S/\sqrt{B}$. After applying event selections requiring at least 5 jets to be $b$-tagged and assuming Standard Model rates of signal and background processes, 25 $t\bar{t}HH$ events are selected, with a background of 7,100 events. By considering events in the 5 $b$-tag and $\geq 6$ $b$-tag regions separately, the statistical significance of $t\bar{t}HH$ production is estimated to be 0.35 $\sigma$.

The main background after event selection is from $t\bar{t}b\bar{b}+$jet events where $c$-jets from the decay of $W$-bosons are mistagged as $b$-jets. Backgrounds considered in this analysis are also likely to have considerable systematic uncertainties associated with them.

Although it will likely only provide a small contribution to the overall precision, searches for $t\bar{t}HH$ production mechanism can be combined with searches for direct $HH$ production, such as in $b\bar{b}\gamma\gamma$ [1], $b\bar{b}\tau\tau$ [2] and $bbbb$ final states in order to provide information on $HH$ pair production and the Higgs self-coupling parameter $\lambda_{HHH}$.

Acknowledgements

We thank C. Englert and F. Krauss for useful discussions during the preparation of this analysis.
References


[4] T. Liu and H. Zhang, Measuring Di-Higgs Physics via the \( t\bar{t}hh \rightarrow t\bar{t}b\bar{b}b \) Channel, (2014), arXiv: 1410.1855 [hep-ph].


[18] J. Erdmann et al.,