Correction reply format.

All significant changes to the thesis are listed here in two sections.
The list of formal corrections responds to the list of corrections provided.
The list of annotated corrections responds to comments written in the thesis copies.

Each correction is listed with a page and paragraph or figure reference.
The most significant corrections are listed in blue.

Corrections that were simple textual suggestions/fixing typos are not included here.
In addition, there has been changes to the positioning of some figures within the text to maintain a logical structure on the page, these changes are also not included here.

Sunday, 1 July 2018

List of formal corrections:

1. **P38: First Para**:
   Are these branching ratios mass dependent? Specify any mass assumptions.

   Additional text added to clarify

   For the mass range considered the branching ratios are not mass dependant**.** Evidence for this statement is found in [43]

2. **P46: Para 2**:
   "Large density of charged particles (high Z)" : note how large-Z is even more important than density (they are related of course) due to the scaling behaviour of the cross-sections.

   Additional text added

3. **P53, Eq. 4.1** :
   Specify the momentum or curvature resolution for tracks.

   Equation added

4. **P58, Bullet Point (2) and (3)**
   Does the pile-up correction also depend on the jet area "A" ? You should make sure you fully understand the different steps in the jet energy correction algorithm.

   A description of ρ has been added

   A is used in the "jet-area based correction" but is not used in "residual correction". Additional text added to clarify.

   The residual pile-up correction does not depend on *A*. I think that *A* is effectively taken account for in alpha and beta, which are fitted parameters.

5. **P64, Last Para and P65, Table 4.1**
   What sample have the numbers in Table 4.1 been calculated for ?

   Additional text added

6. **P67, Para 1**
   It feels like a plot would be useful to illustrate the b-tagging efficiency extrapolation. Check if such a plot exists.

   Unfortunately, no such public plot exists. No change made to thesis.

   I confirmed the absence of a good plot with the b-tagging community in ATLAS.

7. **P75, Para 3 :**
   Why can't the online b-tagging algorithms be run offline ?

   They can, but using a b-perf trigger is preferred, see reasons below. Paragraph 3 is added to add details to why b-perf is preferred.

   There are two reasons why using the online algorithms (i.e. using a b-perf trigger) is preferred.

   Firstly, using a b-perf trigger calibrate the *actual* output of the online algorithms and therefore is calibrating the true performance of the b-jet trigger. For example if the real online hardware was not performing the expected algorithm (for example if there was some faulty hardware) then we are able to detect and adjust for this effect.

Secondly, it is important to note that the b-perf trigger are used to provide in-time monitoring of the b-jet trigger, which cannot be done by running online b-tagging offline due to the additional time taken. Therefore, given that the online algorithms are already run online, it is simplest to record the weights for calibration as well.

8. **P89; Table 5.2** :
 Explain (or remove ?) 0.0% normalisation entries in Table 5.2.
 Changed to '< 0.01%'

9. **P100 Para**: 4
 Theoretical motivation for setting the Z' width to be 3% of the mass ?

 Text added to clarify.

 This is reality the default value from Pythia. As long as the resonance is relatively narrow (width is not >> dijet resolution) then this a reasonable model to choose for our given search.

10. **P99-100, Section 6.3**:
 Does the Z' cross-section normalisation (at NLO) affect the setting of limits on sigma-times-BR ? Perhaps all of the signal physics discussion should come earlier, rather being in this chapter.

 Yes it does. Text rearranged for clarity
 Signal discussion moved to newly formed outline chapter. In addition it is specifically mentioned that these signal models are used in all three parts of the di-b-jet analysis.

11. **P171 Para 5:**
 It is stated that the LowMass data-set upper bound is 1533 GeV to avoid a gap, but this isn't what I see on page 160. Somewhere, there needs to be a clear discussion on this point.
 Text added to discuss this point.

12. **P115 Para 2:**
 Can you explain the trend in inclusive (acceptance*efficiency) in Figure 7.8(a) ?

 Text added *('Thirdly, for the Z' boson model…')*

 This is caused by a large low mass tail for the high mass Z' boson signal dijet mass spectrum, due to the low mass enhancement of the BW shape.

 This is known to be the cause by comparing two DM Z' boson models, which are identical before PDFs and b-tagging were considered except that in one model the tail of the BW resonance shape considered is truncated.

 In the model with no truncation, a large low mass tail was observed in the dijet mass spectrum, similar to that which caused the trend observed in Figure 7.8(a). In the model with no truncation, no such low mass tail was observed.

 This shows that the large low mass tail (and hence the trend line of acc*eff) is caused by the events in the BW tail. There is no affect of the large low mass tail on the analysis, as the wide tail is indistinguishable from background.

13. **P122-128 Section 8.4**:
    Why is figure 8.2 for the 4-parameter fit function while it was concluded earlier than 3-parameters is better ? Overall, it is rather easy for the reader to become confused about the choice of number of parameters.

    Rearranged order of (8.4.1-8.4.4) The order now reflects the true time order studies were performed in.

    Section 8.4.2 uses the 4 parameter function and, in P123 para 1, justifies this choice.
    Section 8.4.3 then shows how the 3 parameter is selected
    Section 8.4.4 and onwards then use the 3 parameter fit function.
    The introductory paragraph to this section is changed to represent the new structure.

14. **P137 Para 4** : Discrepancy between p-values in text and on plot.

    Corrected

15. **P140 Para 1**
    Clarify some aspects of the binning and window definition (for example the window is not symmetric in mass due to non-constant bin width).

    Additional text added

16. **P148-149, Section 8.5.7**
    Clarify certain aspects of the “exclusion region procedure” (make sure all steps are precisely written).

    Additional text added to the numerated list.

17. **P153, Last Para to P154 Para 1 :**
    How do I draw the stated conclusions from the contents of Table 8.4 ?

    Additional text added with explicit reference to table.

18. **P159, Para 4** :
    Explain Gaussian modelling which later (page 163) seems to be also applied to broad resonances. Why not use a Breit-Wigner lineshape for broad resonances (i.e. not resolution dominated) ?

    Additional text added

    In addition a reference is added that specifically describes how a theorist should interpret Gaussian limits. Discussion on why using a BW resonance line shape is not used is also added.

19. **P166, Fig 9.4, accompanying text P165 Para 3-5**
    How well do the morphed and explicitly generated distributions compare ?

    They are consistent within statistical uncertainties of the generated models.

    Figure 9.4 changed to show a comparison, additional text added

20. **P173, Para 1**:
    Why the different Gaussian limit setting treatment for HighMass and LowMass ? Explain that this kind of inconsistency will be resolved in the final joint analysis/publication

    Additional text added

List of annotated corrections

- **Chapter 1: Introduction**

1. P18, Para 2: Line now reads “when the invariant mass of the *colliding partons* is equal to the mass of the BSM particle”
2. P19: Correctly list chapter structure for addition of new analysis chapter
3. P20-21, in the bullet points listing personal contributions: explicitly state for each bullet point if the work is presented in this thesis and, if so, where.
4. P19 Para 1, P21 Para 3 and 4: The *Full16_LowMass* and *Full16_HighMass* data-sets have now been submitted to a journal and have a public reference [11].

- **Chapter 2: Theory**

5. P25, Section 2.2.1: Renormalisation explanation expanded.

- **Chapter 3: Detector**

6. P39; Para 3: Added definition ‘bunch spacing’ in the sentence.
7. P40; Para 2: Added description in-time and out-of-time pile-up.
8. P46; Para 1: “The ATLAS calorimeter is designed such that *as much as possible of* the full particle shower of the initial particle will occur within its volume, …”
9. P47; Final Para: I had misread the units of granularity on the forward calorimeter. Now reads: “*The finest granularity of the LAr calorimeter in the x–y plane is 3.0 cm x 2.6 cm.”*
10. P49; Table 3.2: Add a noise term. In text in previous paragraph, ‘*The noise term depends strongly on η and pile-up conditions, so an approximate order of magnitude is given*.’

- **Chapter 4: Object**

11. P52, Para 3: This paragraph is slightly rewritten to be clearer.
12. P57, Para 1: Slight rewrite of this section for clarity.
13. P62, Fig. 4.5 : Remove proton beams from diagram
14. P62, Final sentence : Explanation of why IP2D is more robust to pile-up
15. P64, Last Para to P65 Para 1 and Table 4.1: Increased explanation of what an operating point is.
16. P67: Section 4.3.5 (bJES) rewritten to described the 2.6% uncertainty actually used in the analyses.

- **Chapter 5: Trigger**

17. P69: Removed Figure of ATLAS trigger. It was noted that this figure was not described fully in the caption. As the details of the figure went beyond the scope of the work, I decided to remove the item. The text provides a verbal description at the level of detail that is required to put my work in context.

18. P76 Para 5: Description of GRL moved here to reduce forward referencing.
19. P78 Table 5.1: Range of run numbers included

- **<u>Chapter 6: Analysis Outline</u>**

20. A new chapter formed from the parts of the old event selection chapter that were too general to be part of the event selection
21. P96, Para 2 and 3. As a new chapter there is a different introduction to the chapter.
22. P97 para 2: Here I note the interplay between the validation studies for the search phase and the event selection making the structure of those two chapters easier for a reader to follow.
23. P98-100: Data-sets and signals described here as these affect all three parts of the analysis.
24. P99 Para 1-2 Both analyses are now submitted "to Phys. Rev. D. [11]."
25. P99 Para 2; Explicitly state reason for mentioning the Full16_HighMass analysis.

- **<u>Chapter 7: Event Selection</u>**

26. P102, Para 1-4. Chapter now only focuses on event selection; introduction and outline hence changed.
27. P114. Fig 7.8a. Inclusive added to legend text.

- **<u>Chapter 8: Search Phase</u>**

28. P117, final para: Added text to explain form in Eq. 8.1
29. P137 Para 3: ‘chi^2/n.d.f. = 3.65’ in place of ‘chi^2/n.d.f. >> 1’
30. P143 Figure 8.16(b), P152 Figure 8.23(b), and P155 Figure 8.24(b) : Title of y-axis changed.

- **<u>Chapter 9: Limit Setting</u>**

31. P160, Para 4 : Correct statement of bJES uncertainty used in dibjet analyses.
32. P161 Final Para: Fuller description of how the function parameter uncertainty is implemented.
33. P162, Figure 9.1 and P167 Figure 9.5(b).
    Figures changed from around 1 to around 0. y-axis title changed.
    Title and style based on ratio of a previous public plot:
    https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2016-21/figaux_08.png.
    Text in paragraph above figures changed to add clarity.
34. P171 Para 4 and P174 Final Para.
    As the results are now formally approved by ATLAS I removed the statements that were adding caution that these are not final results. e.g. “The results have not yet been published so should be considered as preliminary.” has been removed.

- **Chapter 10: Future Prospects**

35. P175, Para 2: “13 or 14 TeV” instead of “13 TeV”.
36. P176, Table 10.1 updated to reflect that the End of 2016 results are public.

- **Chapter 11: Conclusions**

37. P179, Para 3, Last sentence: Paper now stated as submitted to journal.

- **Appendix C**

38. P184-191: All plots made larger. To fit on page all figures split into two parts, one containing plots showing the 4 parameter fits and the other has the 5 parameter fits.