Search for Dark Matter in Proton-Proton Collisions at a Center-of-Mass Energy of 13 TeV in the Higgs Boson associated b-anti-b quark channel

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ABSTRACT

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Jue Chen

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Dedication text

Part I

Introduction

Chapter 1

Introduction

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Part II

The standard model and Dark Matter

Chapter 2

The standard model

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2.1 Introduction

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2.1.1 Sample subsection

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2.2 Challenges

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2.2.1 Sample subsection

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Chapter 3

The Dark Matter

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3.1 Two-Higgs-doublet model

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3.1.1 Sample subsection

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Part III

The LHC and ATLAS experiment

Chapter 4

The LHC

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The ATLAS experiment

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5.1 ATLAS detector system

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5.3.1 Event generator

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Part IV

Dark Matter search in the Higgs Boson associated $b\bar{b}$ decay

Chapter 6

Introduction

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Chapter 7

Boosted Xbb tagging

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7.1 Sample section

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7.1.1 Sample subsection

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7.1.2 Sample subsubsection

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Chapter 8

Signal selection

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8.1 Sample section

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8.1.1 Sample subsection

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9.1.1 Sample subsection

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9.2.1 Sample subsection

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Chapter 10

Result

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10.1 Sample section

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10.1.1 Sample subsection

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10.1.2 Sample subsubsection

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10.2.1 Sample subsection

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Part V

Conclusions

Chapter 11

Conclusions

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Part VI

Appendices

Appendix A

The ATLAS detector service work

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A.1.1 Sample subsection

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A.1.2 Sample subsubsection

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A.2 Sample section

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A.2.1 Sample subsection

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Appendix B

Analysis supplementary materials

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B.1 $pp \to Hb\bar{b}$

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B.1.1 Sample subsection

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B.1.2 Sample subsubsection

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B.2 $pp \to q\bar{q}b\bar{b}$

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B.2.1 Sample subsection

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Part VII

Bibliography

Bibliography

[Grosz and Sidner, 1986] Barbara Grosz and Candace Sidner. Attention, intention, and the structure of discourse. *Computational Linguistics*, 12(3):175–204, July-September 1986.