

**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**

Jue Chen

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in the Graduate School of Arts and Sciences

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ABSTRACT

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

Jue Chen

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Acknowledgments

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Part I

The standard model and Dark Matter

Sample part

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Chapter 3

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Chapter 4

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Chapter 5

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Part II

The LHC and ATLAS experiment

Sample part

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Chapter 7

Sample chapter

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Chapter 8

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Chapter 9

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9.2 Sample section

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Part III

Dark Matter search in the Higgs

Boson associated $b\bar{b}$ decay

Sample part

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Chapter 11

Sample chapter

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Chapter 12

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Chapter 13

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Part IV

Conclusions

Conclusions

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Part V

Appendices

Appendix title

A.1 Sample section

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A.1.2 Sample subsubsection

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A.2.1 Sample subsection

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Appendix title

B.1 Sample section

B.1.1 Sample subsection

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Part VI

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.