A search for dark matter produced in association with $t\bar{t}$ at $\sqrt{s}$ =13 TeV in the dilepton final state with the CMS experiment

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Abstract

4.5 years of POOP!

Declaration

I haz dun most of dis werk.

Stanislava Sevova

Acknowledgements

H8rz gonna h8.

Preface

This thesis describes my research on various aspects of the CMS particle physics program, centred around the CMS detector and LHC accelerator at CERN in Geneva.

For this example, I'll just mention Chapter 1 and Chapter 2.

Contents

Chapter 1.

$\mathcal{CP}$ violation in the B-meson system

"Laws were made to be broken."
— Christopher North, 1785–1854

Symmetries, either intact or broken, have proved to be at the heart of how matter interacts. The Standard Model of fundamental interactions (SM) is composed of three independent continuous symmetry groups denoted $\mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)$, representing the strong force, weak isospin and hypercharge respectively [1–3].

1.1. Neutral meson mixing

We can go a long way with an effective Hamiltonian approach in canonical single-particle quantum mechanics. To do this we construct a wavefunction from a combination of a generic neutral meson state $|X^0\rangle$ and its anti-state $|\bar{X}^0\rangle$:

$$|\psi(t)\rangle = a(t)|X^0\rangle + b(t)|\bar{X}^0\rangle \tag{1.1}$$

which is governed by a time-dependent matrix differential equation,

$$\imath\frac{\partial}{\partial t}\begin{pmatrix} a \\ b \end{pmatrix} = \underbrace{\begin{pmatrix} M_{11} - \frac{\imath}{2}\Gamma_{11} & M_{12} - \frac{\imath}{2}\Gamma_{12} \\ M_{12}^* - \frac{\imath}{2}\Gamma_{12}^* & M_{22} - \frac{\imath}{2}\Gamma_{22} \end{pmatrix}}_{\mathbf{H}} \begin{pmatrix} a \\ b \end{pmatrix}. \tag{1.2}$$

Chapter 2.

The CMS experiment

2.1. The LHC

The Large Hadron Collider (LHC) at CERN is the most powerful particle accelerator in the world, located in the same tunnel as the Large Electron-Positron collider (LEP) [4]. The mandate of the LHC experimental program is two-fold: to probe the electroweak symmetry breaking mechanism via which particles in the Standard Model (SM) attain mass, and to explore an energy frontier in the search for new physics beyond the SM (BSM).

2.2. The CMS experiment

⋮

The detector is illustrated in Figure **??**, showing the overall scale of the experiment and the surrounding cavern structure.

The single-sided detector design was chosen in preference to a two-armed design since the detector dimensions are restricted by the layout of the IP8 (ex-Delphi) cavern in which LHCb is located. Using all the available space for a single-arm spectrometer more than compensates in performance for the ∼50% drop in luminosity.

2.3. The Čerenkov mechanism

A Huygens construction in terms of spherical shells of probability for photon emission as the particle progresses along its track shows an effective "shock-front" of Čerenkov emission. This corresponds to an emission cone of opening angle θ_C around the momentum vector for each point on the track,

$$\cos\theta_C = \frac{1}{n\beta} + \frac{\hbar k}{2p}\left(1 - \frac{1}{n^2}\right) \tag{2.1a}$$

$$\sim \frac{1}{n\beta} \tag{2.1b}$$

where $\beta \equiv v/c$, the relativistic velocity fraction.

2.4. Trigger system

An overview of the LHCb trigger characteristics broken down by level is shown in Table 2.1.

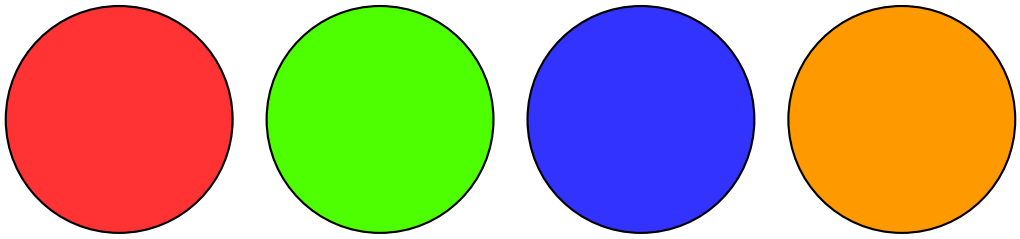
	L0	L1	HLT
Input rate	40 MHz	1 MHz	40 kHz
Output rate	1 MHz	40 kHz	2 kHz
Location	On detector	Counting room	Counting room

Table 2.1.: Characteristics of the trigger levels and offline analysis.

Chapter 3.

Continued captions

Here are some funky floats using "continued captions", i.e. for a semantically collected group of float contents which are too numerous to fit into a single float, such as the pretty circles in the following figure:

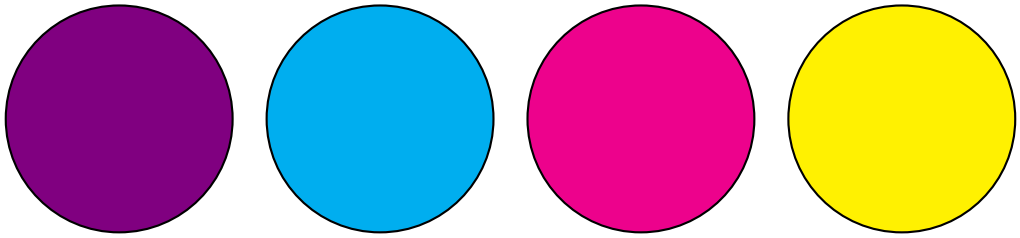


(a) Example 1a **(b)** Example 1b **(c)** Example 1c **(d)** Example 1d

Figure 3.1.: Demonstration of `subfig` continued captions.

This mechanism means that the same float label is used for both pages of floats. Note that we can refer to Figure 3.1 in general, or to Figure 3.1g on page 6 in particular!

Just for the hell of it, let's also refer to Section 1.1.



(e) Example 1e **(f)** Example 1f **(g)** Example 1g **(h)** Example 1h

Figure 3.1.: Demonstration of `subfig` continued captions (continued).

Appendix A.

Pointless extras

"Le savant n'étudie pas la nature parce que cela est utile;
il l'étudie parce qu'il y prend plaisir,
et il y prend plaisir parce qu'elle est belle."
— Henri Poincaré, 1854–1912

Appendixes (or should that be "appendices"?) make you look really clever, 'cos it's like you had more clever stuff to say than could be fitted into the main bit of your thesis. Yeah. So everyone should have at least three of them…

A.1. Like, duh

Padding? What do you mean?

A.2. $y = \alpha x^2$

See, maths in titles automatically goes bold where it should (and check the table of contents: it *isn't* bold there!) Check the source: nothing needs to be specified to make this work. Thanks to Donald Arsenau for the teeny hack that makes this work.

Colophon

This thesis was made in LaTeX 2_ε using the "hepthesis" class [5].

Bibliography

[1] S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967).

[2] S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. **D2**, 1285 (1970).

[3] S. Willenbrock, (2004), hep-ph/0410370.

[4] G. Brianti, Phys. Rept. **403-404**, 349 (2004).

[5] A. Buckley, The hepthesis LaTeX class.

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