Something something something physics

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for the degree of Doctor of Philosophy

Abstract

LHCb is a b-physics detector experiment which will take data at the 14 TeV LHC accelerator at CERN from 2007 onward…

Declaration

This dissertation is the result of my own work, except where explicit reference is made to the work of others, and has not been submitted for another qualification to this or any other university. This dissertation does not exceed the word limit for the respective Degree Committee.

Andy Buckley

Acknowledgements

Of the many people who deserve thanks, some are particularly prominent, such as my supervisor…

Preface

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

For this example, I'll just mention Chapter 1 and Chapter 4.

Contents

“Writing in English is the most ingenious torture ever devised for sins committed in previous lives.”
— James Joyce

Chapter 1.

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

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

I am testing changes again!

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 LHCb experiment

"There, sir! that is the perfection of vessels!"
— Jules Verne, 1828–1905

2.1. The LHC

The Large Hadron Collider (LHC) at CERN is a new hadron collider, located in the same tunnel as the Large Electron-Positron collider (LEP) [4]. Where LEP's chief task was the use of 90–207 GeV e^+e^- collisions to establish the precision physics of electroweak unification…

2.2. The LHCb experiment

Since both b-hadrons are preferentially produced in the same direction and are forward-boosted along the beam-pipe, the detector is not required to have full 4π solid-angle coverage. LHCb takes advantage of this by using a wedge-shaped single-arm detector with angular acceptance 10-300 mrad in the horizontal (bending) plane [5].

⋮

The detector is illustrated in Figure 2.1, 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.

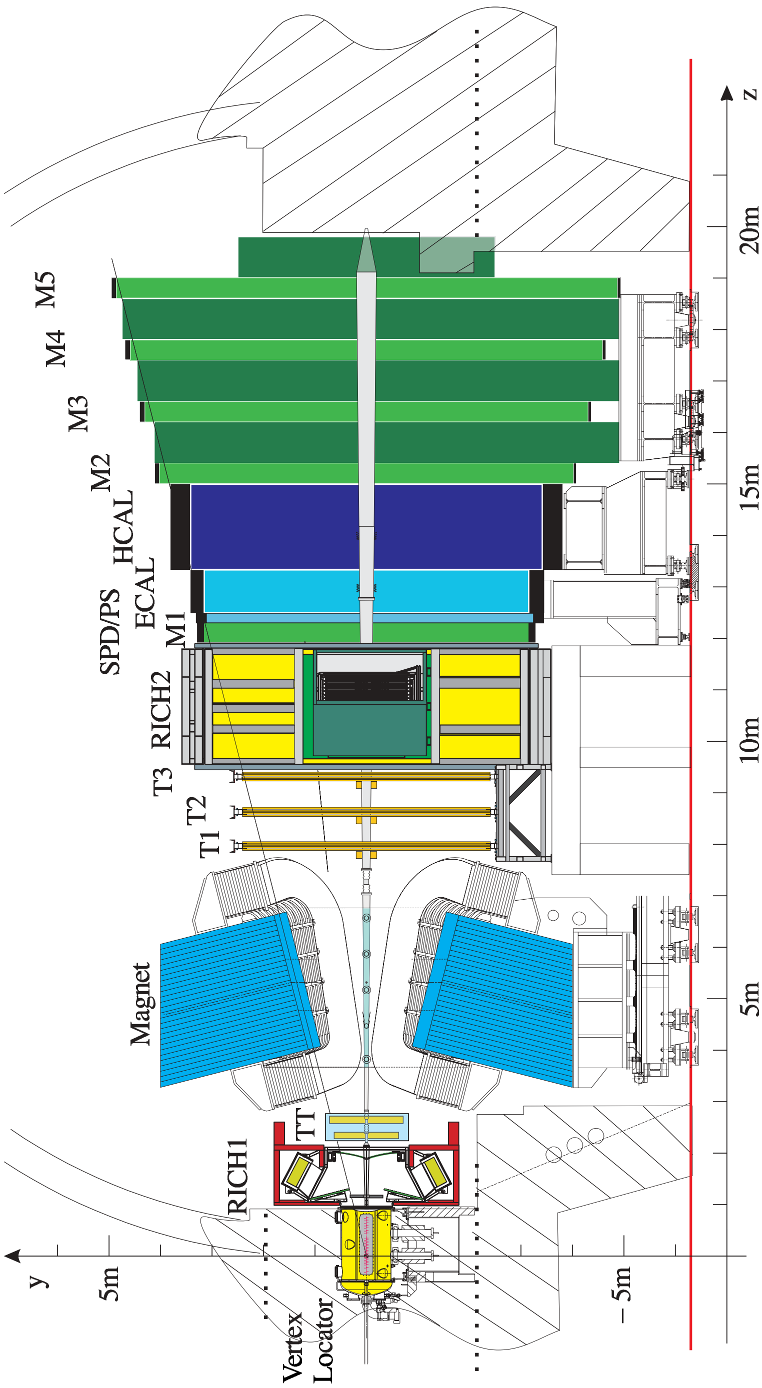

Figure 2.1.: Cross-section view of LHCb, cut in the non-bending y–z plane.

Chapter 3.

The LHCb experiment

"Now, Now, There Will Be Plenty Of Time To Discuss Your Objections When And If You Return."
— Professor Futurama

3.1. Energy Estimators

3.2. Energy Estimators in Particle Flow Calorimetry

In particle flow calorimetery the two methods of determining the energy of particles passing through the detector are calorimetric energy deposits and track fitting. Due to the presence of a uniform magnetic field in the detector charged particles will bend and trace out a helix. The radius of this helix will yeild the momenta of the charged particle in question and so the energy can be inferred assuming the mass of the particle is negligible in comparison to the momenta.

$$E^2 = |\mathbf{p}|^2 + m^2 \approx |\mathbf{p}|^2 \tag{3.1a}$$

Chapter 4.

Calorimeter Optimisation Studies

"There, sir! that is the perfection of vessels!"
— Jules Verne, 1828–1905

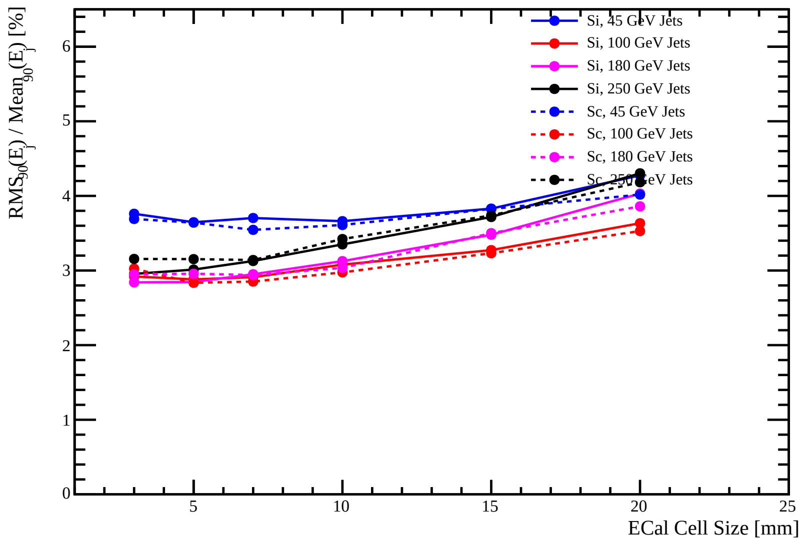

Figure 4.1.: Jet energy resolution is shown for several fixed energy jets as a function of ECal cell size for the silicon tungsten ECal option.

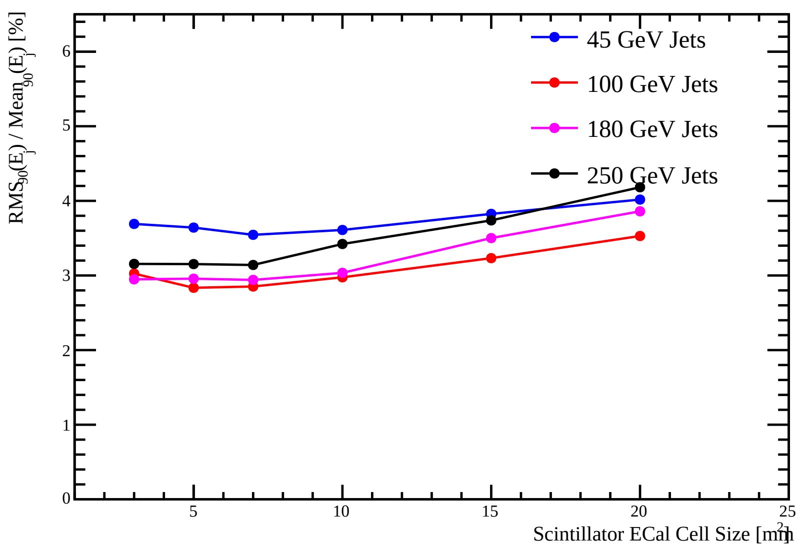

Figure 4.2.: Jet energy resolution is shown for several fixed energy jets as a function of ECal cell size for the scintillator tungsten ECal option.

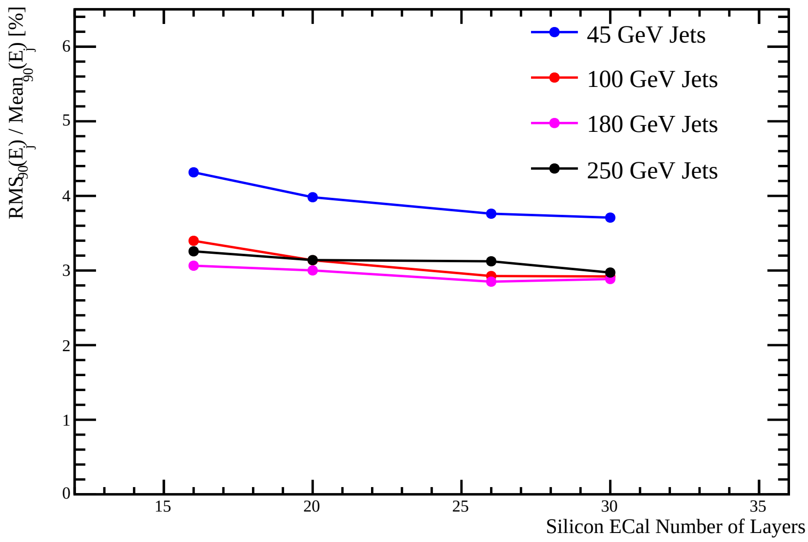

Figure 4.3.: Jet energy resolution is shown for several fixed energy jets as a function of the number of layers in the ECal for the silicon tungsten ECal option.

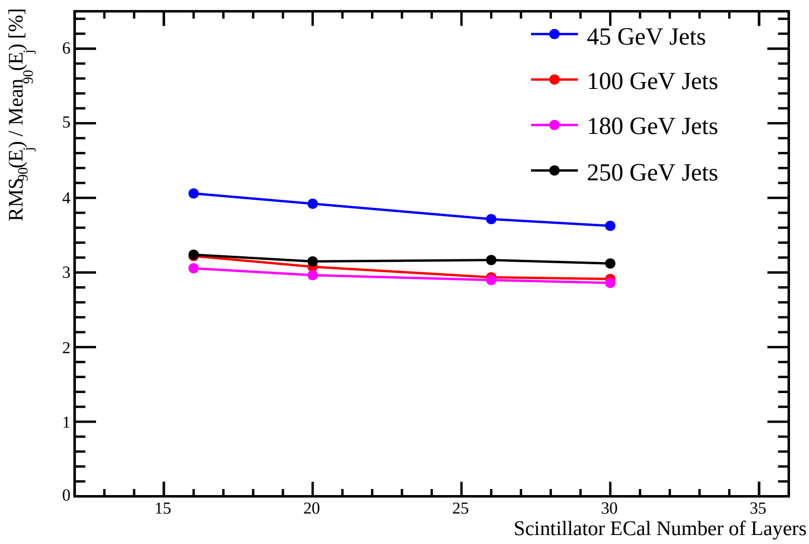

Figure 4.4.: Jet energy resolution is shown for several fixed energy jets as a function of the number of layers in the ECal for the scintillator tungsten ECal option.

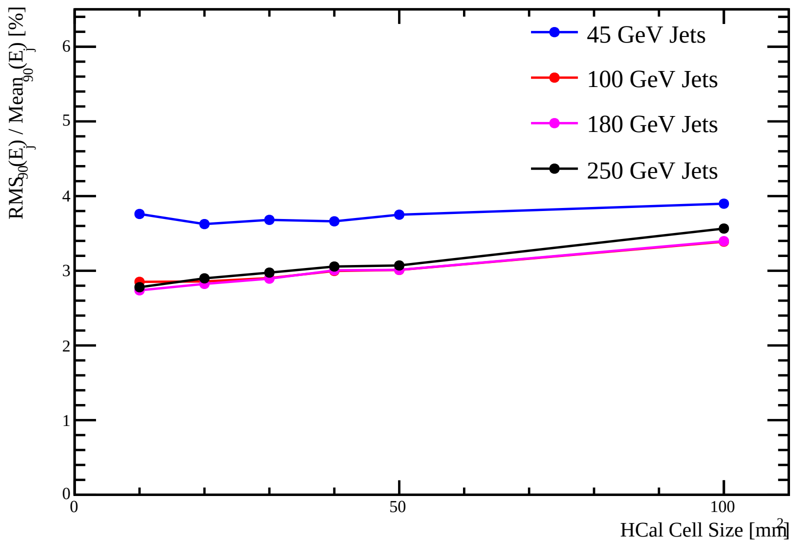

Figure 4.5.: Jet energy resolution is shown for several fixed energy jets as a function of HCal cell size for the scintillator steel HCal option.

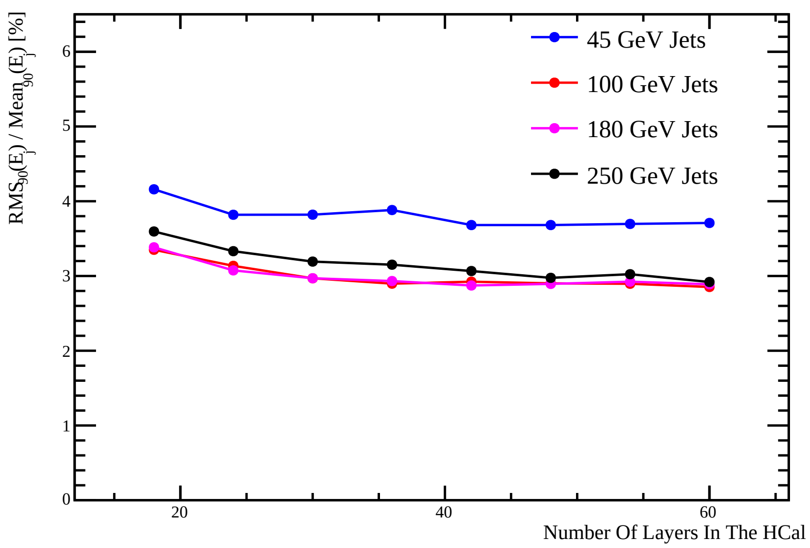

Figure 4.6.: Jet energy resolution is shown for several fixed energy jets as a function of the number of layers in the HCal for the scintillator steel HCal option.

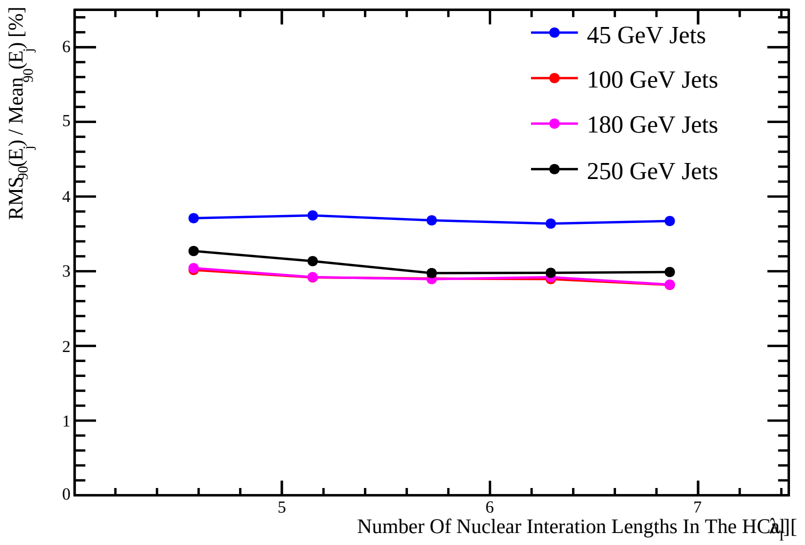

Figure 4.7.: Jet energy resolution is shown for several fixed energy jets as a function of the number of nuclear interation lenghts in the HCal for the scintillator steel HCal option.

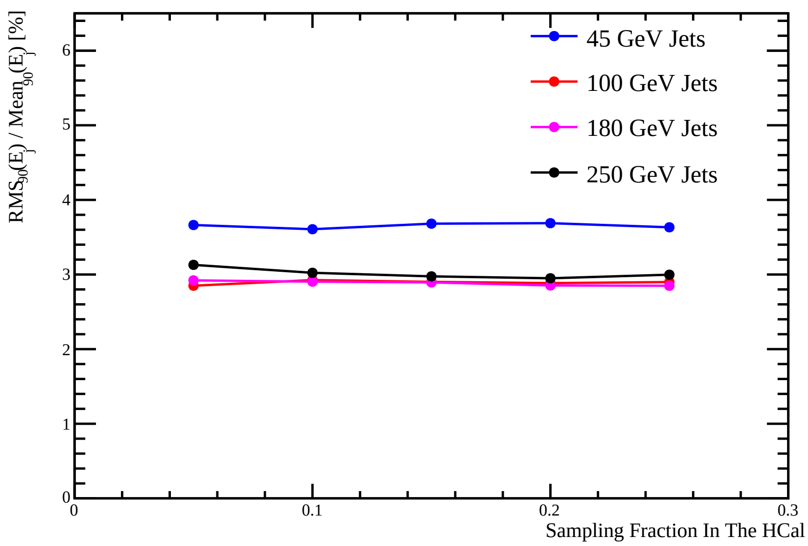

Figure 4.8.: Jet energy resolution is shown for several fixed energy jets as a function of the sampling fraction in the HCal for the scintillator steel HCal option.

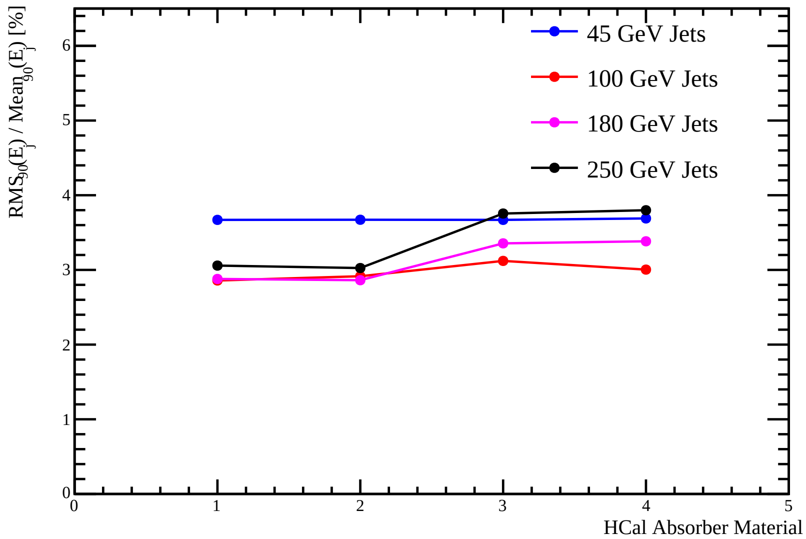

Figure 4.9.: Jet energy resolution is shown for several fixed energy jets as a function of the absorber material in the HCal.

4.1. Calorimeter Optimisation Studies

4.2. Electromagnetic Calorimeter Optimisation

4.2.1. ECal Transverse Granularity

4.2.2. ECal Longitudinal Granularity

4.3. Hadronic Calorimeter Optimsation

4.3.1. HCal Transverse Granularity

4.3.2. HCal Longitudinal Granularity

4.3.3. HCal Absorber Material

4.4. Global Detector Parameter Optimisation

4.4.1. Magnetic Field Strength

4.4.2. Inner ECal Radius

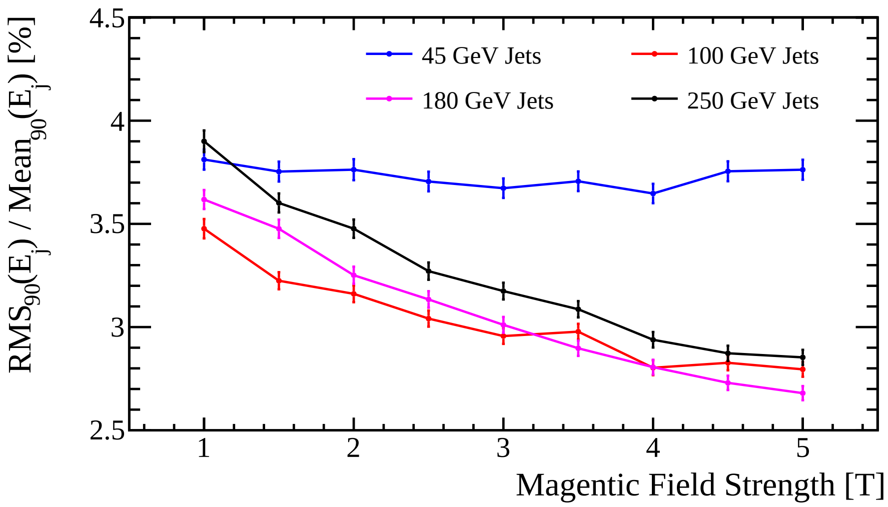

Figure 4.10.: Jet energy resolution is shown for several fixed energy jets as a function of magetic field strength.

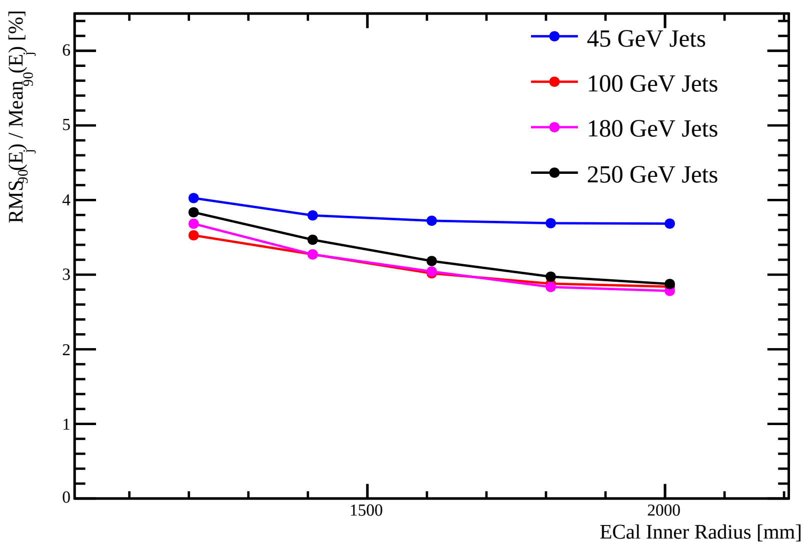

Figure 4.11.: Jet energy resolution is shown for several fixed energy jets as a function of the inner ECal radius.

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 $\LaTeX\,2_\varepsilon$ using the “hepthesis” class [6].

Bibliography

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