LHCb

the collaboration in photos
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Flavour physics, or the study of relationships between different kinds of quarks, has an excellent track record for making discoveries. New physics has been deduced on several occasions by precise observations of the behaviour of known particles, before any direct measurements of the new phenomena, such as detection of a new particle.

Already in 1992, several ideas were under discussion to explore flavour physics at CERN’s Large Hadron Collider. By 1995, these ideas had evolved into a design for a single fully-optimized detector: the LHCb experiment. It then took almost 15 years of effort by over 730 people from many universities and institutes across 15 countries, to complete the construction of LHCb.

Today, LHCb has successfully started to take data and we are very excited by the prospect of starting to look for clues to understanding how our universe evolved to the way it is now - something that cannot be explained by our current knowledge of elementary particle physics. LHCb will address this problem by studying flavour physics with unprecedented precision.

Analysis of our early data already demonstrates that the detector is working to full design performance. With this book, which represents many aspects of the LHCb experiment, we would like to thank all our colleagues for making this possible.

Tatsuya Nakada & Andrei Golutvin
LHCb spokesperson 1995-2008
LHCb spokesperson 2008-present

September 2010
LHCb explores the fundamental constituents of matter making up our universe.
The experiment

Fourteen billion years ago, the universe began with a bang. Crammed within an infinitely small space, energy coalesced to form equal quantities of matter and antimatter.

As the universe cooled and expanded, its composition changed. Just one second after the Big Bang, antimatter had all but disappeared, leaving matter to form everything that we see around us – from the stars and galaxies, to the Earth and all life that it supports.

LHCb is an experiment set up to explore what happened after the Big Bang to allow matter to survive over antimatter and build the universe we inhabit today.
The 27km LHC and its four large experiments.
The Large Hadron Collider

The CERN laboratory straddles the Franco-Swiss border near Geneva. A hundred metres below ground is the Large Hadron Collider (LHC), the world’s highest energy particle accelerator. The LHC sends beams of protons round a 27km circuit at almost the speed of light. Collisions between protons recreate the conditions of the early universe, just a hundredth of a billionth of a second after the Big Bang. LHCb is one of four major experiments built around these collision points.

LHCb

All of the layers of the LHCb experiment have been carefully designed with a specific purpose in mind – studying the elusive beauty quark. Although almost absent from the universe today, beauty quarks were common in the aftermath of the Big Bang, and will be generated in their billions by the LHC collisions, along with their antimatter counterparts, anti-beauty quarks. ‘b’ and ‘anti-b’ quarks are unstable and short-lived, decaying rapidly into a range of other particles. Comparing these decays will give clues as to why nature prefers matter over antimatter.
Nicola Cabibbo, Makoto Kobayashi and Toshihide Maskawa (left to right) developed an important part of the well-established theoretical framework called the Standard Model. The LHCb experiment explores their ideas further to see if there is something beyond.
Looking for new particles

Elusive beauty quarks exist for only about a trillionth of a second in LHCb before decaying into lighter particles. But this is long enough for them to be affected by subtle quantum effects, for example ‘penguin loops’ – so called because the diagram portraying these particle interactions looks rather like a penguin.

These quantum loopholes allow ephemeral virtual particles to be momentarily created for an extremely short time. These virtual particles can influence the behaviour of beauty quarks, thus leaving clues about particles that are too heavy to be produced directly.

This opens up a window onto a whole array of possible new discoveries. For example, LHCb is on the lookout for signs of a new family of particles that could make up some of the dark matter that pervades the universe. This mystery matter makes galaxies spin faster than expected and deviates the light from stars.
LHCb is a truly international collaboration. Over 700 scientists from 54 different universities and laboratories are involved in the project, with support from many hundreds of other technicians and engineers.

For 10 years the collaboration worked together from the initial proposal, through design then on to installation to make this scientific adventure possible. Challenging to build, the detector represents the ingenuity and creativity of physicists around the world.

730 members
15 countries
54 institutes
The LHCb cavern

The LHCb experiment is constructed in an underground cavern at point 8 on the LHC ring. The cavern previously housed the DELPHI experiment at CERN’s earlier Large Electron Positron collider. DELPHI’s central barrel still sits at the entrance to the LHCb cavern today and for many years served as an attraction for visiting schools and other visitors.
The big build

The components of the LHCb experiment were not manufactured in situ. Indeed major elements of the detector had to be brought to the site from Bulgaria, France, Germany, Italy, the Netherlands, Russia and the UK. This in itself presented a whole new challenge.

Transportation was anything but simple. Even if the distance was short, the transportation of the parts had to be meticulously planned to ensure the delicate equipment was not damaged.

Once on-site, the components of the detector were lowered into the underground chamber through a narrow access shaft. Upon arrival in the cavern, each piece was then eased into place with great precision. Most of the components now sit on mechanical rails so that they can be moved in and out of place.
The secretariat.

Installation of the calorimeters in 2005.

View of the completed LHCb experiment in 2008. Major construction work was over, calibration and physics could begin!
An efficient operation

The organization, construction and maintenance of LHCb would be impossible without the work of groups such as the secretariat and technical staff. Their support ensures that the experiment runs smoothly and safely both down in the pit, and across the collaboration.
The LHCb sub-detectors.
The beauty particles that LHCb studies fly out from the collision close to the path of the incoming proton beams, rather than spraying out in all directions. This is reflected in the design of the experiment: the sub-detectors sit side by side, like books on a giant bookshelf.

Each sub-detector specializes in measuring a different characteristic of the particles. Collectively, the experiment’s layers track, measure and identify individual particles from the billions that spray out from the collision point every second. It is the comparison of the decays of beauty particles and their antimatter counterparts that reveals the subtle differences between matter and antimatter.
Assembling the VELO’s silicon sensors.
The Vertex Locator

The journey of the beauty particles through LHCb begins – and ends – inside the VErtex LOcator (VELO). The LHC brings proton beams into collisions within the very jaws of the detector, in between the rows of precision silicon sensors.

The B and anti-B particles containing b and anti-b quarks created in the collision last for about a trillionth of a second, before decaying into sprays of other particles. During this time, they travel just a few millimetres. Their fleeting existence is inferred by measuring the distance between the point of collision of the protons and the point of departure of the spray of new particles, which live long enough to leave signals in the detectors. This is the job of the VELO, which makes this measurement to the nearest few hundredths of a millimetre.

The VELO detector modules were built in the UK. Airline security measures prevented the detector from being transported by plane to Geneva, so the detector was chauffeur-driven for its 1300km journey. This was no easy task, as the equipment is so sensitive that a falling pin is enough to break the delicate wiring. The journey was therefore slow and steady, and the detector survived its trip unscathed and arrived safely at CERN.
Preparing the VELO for transport.
Installing the VELO in the LHCb cavern.
The RICH photon detectors.

Installing mirrors into the RICH detector.
The Ring Imaging Cherenkov detectors

Travelling faster than light through the Cherenkov detectors’ dense gas mixture, particles radiate cones of light. These cones of light are focussed by high-precision mirrors onto photon detectors. Measuring the diameter of the cone reveals the particle’s speed, an important clue used for identification purposes.

LHCb’s two Ring Imaging CHerenkov detectors (RICH) lie on either side of the experiment’s powerful magnet. The mirrors are some of the experiment’s most fragile components. They are contained in immense structures some 7m high, 10m wide and nearly 2.5m deep, which were assembled at the main CERN site, so had just 8km to travel in order to reach the LHCb cavern. However, owing to their delicate nature, the lorry was restricted to a maximum speed of 1km per hour and levels and balances were needed to ensure that movement was kept to a minimum.
Transport of the RICH detectors to the LHCb cavern.

Installing RICH mirrors.
Testing the RICH set-up with a laser beam.
Inside LHCb’s giant magnet coils.
Another key part of the LHCb experiment is the powerful magnet, generating a magnetic field 25,000 times stronger than the Earth’s. The path of charged particles curves as they pass through the magnetic field. This curvature is then used to determine the particle’s momentum and electric charge in the tracking detectors situated on either side of the magnet.

LHCb’s enormous magnet consists of two coils, both weighing 27 tonnes, mounted inside a 1450 tonne steel yoke. Each coil is constructed from 15 ‘pancakes’, wound from almost 3000m of aluminium cable.
The experiment’s spokesperson and deputy inspect the magnet assembly in 2004.

Transport and installation of LHCb’s magnet coils.
Testing a prototype for the silicon tracker.

A view of the LHCb trackers seen through the magnet.
Charged particles, such as electrons and protons, leave behind trails when passing through certain substances. The trackers are specifically designed to exploit this and can track the trajectory of each particle passing through the detector. Trackers are crucial in the reconstruction of B particle decays, as they help to link together the signals left in the other parts of the detector and are important in measuring momentum.

The Trackers

Testing a prototype for the silicon tracker.
The first of LHCb’s outer trackers is installed.

Meticulous care is needed in constructing one of the silicon tracker modules.
LHCb’s tracking system consists of a series of four large rectangular stations, one in front of the magnet, and three behind it. The stations behind the magnet each cover an area of about 40 m².

Two different detector technologies are employed. In the tracker Turicensis and in the inner tracker, charged particles pass through thin layers of silicon, creating signals which reveal their path.

The outer trackers are made up of thousands of gas-filled straw tubes. Whenever a charged particle passes through, it ionizes the gas molecules, producing electrons. The position of the track is found by timing how long the electrons take to reach an anode wire situated in the centre of each tube.
Inserting the plastic scintillating plates into the hadron calorimeter.

Changing photomultipliers in the electromagnetic calorimeter.
The next layer of the LHCb experiment is designed to stop particles and measure the energy they deposit as they grind to a halt. There are two types of calorimeter, each designed to stop a different class of particle. In both cases, size and density are of utmost importance. The second layer alone weighs about 500 tonnes, the equivalent of around 100 adult elephants!

Both calorimeters have a sandwich-like structure, with alternating layers of metal and plastic plates. When particles hit the metal plates, they produce showers of secondary particles. These, in turn, excite polystyrene molecules within the plastic plates, which emit ultraviolet light. The amount of UV produced is proportional to the energy of the particles entering the calorimeter.

The calorimeter system includes two other sub-detectors that are used for triggering and particle identification.
Installation of LHCb’s calorimeters.

The calorimeters’ scintillator pad detector.

The calorimeters’ pre-shower detector.

The calorimeters’ pre-shower detector.
A view of the LHCb cavern in 2005, showing the electromagnetic calorimeter to the right.
Fast-reacting electronics for the muon detector.

LHCb’s muon detector.
The Muon Detector

Muons are tiny, electron-like particles which are important to LHCb as they are present in the final stages of many B particle decays. They make it through all the layers of LHCb, including the calorimeters, without being stopped. So this one particle has a whole series of dedicated detectors to track it.

Located at the far end of the experiment, the muon detector is comprised of five rectangular ‘stations’, gradually increasing in size and covering a combined area of 435m² - about the same size as a basketball court. Each station contains chambers filled with a combination of three gases: carbon dioxide, argon, and tetrafluoromethane. The passing muons ionize this mixture, and wire electrodes detect the signals. In total, the muon detectors contain around 1400 chambers and some 2.5 million wires - enough to stretch from Geneva to Saint Petersburg in Russia, where many of the chambers were built.
The first muon sub-detector is installed in the cavern.

Testing the muon sub-detectors before installation.

The beam-pipe passing through the muon detector.
Alignment of the muon substation.
Installing the beam-pipe.

The LHCb beam-pipe team.
Right in the centre of the experiment, the beam-pipe through which the protons circuit needed some careful attention. Particles produced in the collisions would interact with the denser material of the normal LHC beam-pipe, so a new design was needed for the segment running through LHCb.

The solution was a specially shaped pipe made of beryllium, which keeps disturbances to a minimum. Beryllium is an extremely fragile material so it took three days of patience and precision to insert just the first section of the new beam-pipe into the experiment.
The LHCb control room.
24 hours a day, 7 days a week, whenever the Large Hadron Collider operates, LHCb’s control room is staffed and the experiment runs. The action is not all localised at the LHCb cavern: with distributed computing, data lights up processing centres around the globe.

Technical stops are a flurry of activity, to upgrade and replace electronics, change detector modules and make improvements before collisions start again.
Piloting the experiment

The LHCb control room is a continual hive of activity, with physicists monitoring the functioning of the different sub-detectors, the stream of data from the experiment and the correct synchronisation of the many timing signals.

The different layers of the experiment contribute between them over 600 000 data channels. When protons are colliding in the heart of LHCb, data pours into the computers in an unrelenting stream. In the control room, arrays of screens display elements of this collision data in real-time and also flag any performance fluctuations in the different sub-detectors, such as changes in voltage or temperature, that might need intervention.

Each sub-detector has its own area of screens in the control room, with an overall shift leader and data manager who together ensure everything runs smoothly.
In the hot seat: the shift leader's chair.
Monitoring the experiment 24/7 in the LHCb control room.
Taking data

For every second the LHC runs, up to 10 million protons collide in the heart of the LHCb experiment. Recording data from every single collision would put too big a strain on storage capacity, so LHCb employs an electronic system called a ‘trigger’ which identifies the most interesting collisions to store.

The LHCb trigger system operates on two levels. The first uses information taken in real-time from the detector – specifically the calorimeter, the muon system and part of the VELO. It selects around 1 million events per second for further processing, while discarding information from the remaining 9 million. The first-level trigger works incredibly fast, making its decision in just four millionths of a second.

After filtering by the first-level trigger, a very large amount of data still remains. Thirty five gigabytes – equivalent to seven and a half DVDs worth of information – are fed every second into 2000 state-of-the-art computers, located deep underground at the LHCb site. These machines select interesting events to save for analysis, further trimming the 1 million events per second to a more manageable 2000 per second.
Supervising the LHCb computing farm.
Storage solutions

All of the data filtered by the trigger are rapidly transmitted to the CERN computing centre. At a rate of 2000 events per second, the amount of information stored by LHCb is enough to fill a 4.7 gigabyte DVD every minute.

In order to cope with the massive amount of data generated by LHCb and other experiments, CERN has created a global computing system called the LHC Grid. Data from the LHCb experiment will be replicated throughout a network of computer centres around the world, meaning tens of thousands of computers will be able to analyse LHCb data simultaneously.
Row upon row of servers in CERN’s computing centre.
Reconstructing the particle puzzle

The stream of 1s and 0s from the different detector layers is fed into computers that reconstruct an overall picture of the particles created by the collision. This ‘event display’ shows how the different particles evolve through the different layers of LHCb. It is used to work backwards and calculate the properties of the exotic particles created right at the point of collision.

The timing and positioning information coming from the different layers of detector provides an important key to reconstructing the paths of the particles. The sheer number of collisions and volume of data means that several collisions-worth of information is travelling down cables at any given time.
Reconstructed data from collisions in LHCb.
Applause at the first high-energy proton collisions in LHCb.
The adventure begins

After 10 years of intense activity, the LHCb experiment can finally begin taking data: expectations are high.

Starting up the Large Hadron Collider, colliding the first protons and bringing LHCb into full operation is already an achievement of monumental proportions.

This is just the start. LHCb is now on the road to discovery, but that road will be long. Millions of B particles must be measured and compared to their anti-B counterparts before results can be announced. And, as with any voyage into uncharted territory, the experiment must also be prepared to expect the unexpected. Exciting discoveries are just over the horizon!
Starting up the Large Hadron Collider

Starting up a machine as complex as this one, it is not just a question of simply pressing a button. Careful control and precision are of the essence. Just cooling the LHC magnets to operational temperature takes four weeks. The current is then slowly ramped up to full performance. The beam-pipe where the protons travel is pumped down to emptier than interplanetary space and the full 300kW of accelerating power is made ready for action. And that’s just for the LHC. On their way there, protons pass through a whole network of smaller accelerators, which also all have to be synchronised to within a billionth of a second.

On 21 November 2009, it all happened according to plan. And as the protons began their elaborate waltz through the machines, LHCb was ready and waiting.
Pre-dawn on the day of first high-energy collisions, the LHCb control room is already a hive of activity.

Suspense mounts as LHCb waits for news from the machine operators.

First high-energy collisions

While the LHC start-up was exciting, it was the day the first high-energy collisions took place that really heralded the start of LHCb’s voyage into the unknown.

Bringing the LHC’s two beams of protons into collision in the heart of LHCb is equivalent to firing two knitting needles across the Atlantic and getting them to meet half way, such is the precision required. On 30 March 2010, after an expectant 6 hours wait while machine operators prepared the beams, collisions were achieved at an energy of 7 trillion electron volts*, trebling the world record for the highest energy particle collisions. The hunt for new physics could begin.

* An electron volt is the amount of energy gained by an electron when it accelerates across one volt of potential difference.
An event display showing data from one of the first high-energy collisions.

Long awaited real data in the Ring Imaging Cherenkov detectors.

LHCb’s deputy spokesperson is interviewed, whilst it’s business as usual for the shifters.

Live to the world: the LHCb spokesperson is interviewed for the CERN broadcast.
A resounding success

During the first weeks following high-energy collisions, LHCb already started detecting and measuring the family of known fundamental particles. Such measurements are crucial before moving on to the unknown. Not only is the experiment exploring the behaviour of these particles in a new energy regime, but also, importantly, checking the performance of the different sub-detectors and perfecting the functioning of the triggers. And it’s all working perfectly.
The first beauty particle

It was the first of many, but the first is symbolic. On 5 April 2010, LHCb’s triggers flagged a spray of muons that indicated the presence of something interesting. Closer examination revealed that the muons were indeed decay products of the first B particle seen by LHCb. With just one particle, there can be no statistics and no new discovery, but the adventure had well and truly begun.
LHCb’s 2010 summer students arrive at CERN from universities around the world.
Whether you visit the control room with a school class, or spend a summer holiday contributing to the design of a detector, there are many opportunities to take part in LHCb.

If you live in one of the 15 countries that built and run the experiment, you are already involved! You help support the basic research and the accompanying technological development that makes this adventure possible.

For more information on CERN’s summer student programme and other opportunities for working at CERN, please contact recruitment.service@cern.ch
Join the adventure

If you are studying physics at university, why not apply to work at CERN one summer on a student programme? Or you might consider going on to further studies in beauty physics and carry out your PhD working on LHCb.

As this book goes to print, 54 physics institutes around the globe are contributing to the LHCb experiment and some 150 PhD students are carrying out crucial work on the experiment.

Regular travel between Geneva and home institutes spreads the benefit of a training that covers a wide variety of specialisations, from computing, to detector development and advanced statistics to modelling the behaviour of fundamental particles... and sometimes even the techniques of mountain climbing! Indeed, there aren’t many careers where one day you might go to work in a safety harness and hard-hat to spend the day suspended in mid air, installing complex electronics, and the next you find yourself at the controls of an experiment that recreates the conditions just moments after the beginnings of the universe.
Colliding ideas, advancing technology

Experiments at the Large Hadron Collider require giant leaps in technological know-how to push further into the unexplored reaches of the universe. Thus, the experiments are not only catalysts for knowledge transfer, training students from around the globe, but also a driving force for progress in industry. LHCb is no exception in this.

Be it the development of a new bump-bonding technique used in the Ring Imaging Cherenkov detectors, large size printed circuit boards for muon chambers or indeed finding solutions for the sheer volume of data flow, LHCb shows the role of fundamental research as a driver for innovation. Such technological advances deliver value to the community in addition to the inherent contributions to the advancement of basic science.
An invitation to visit

From the crowds of tourists that fill the experimental areas on open days, to the more intimate press visits and tours for school classes, LHCb is a much-visited experiment. As the underground cavern closes for operation, the ground level adjoining the control room is installed with an exhibition area containing models, films and real detector pieces.

Reserve your visit to CERN by contacting visits.service@cern.ch
Swedish high-school students visit LHCb in 2005.

Visits to the LHCb cavern prove popular during CERN’s 2008 open day.
An actor plays the role of Paul Dirac in a short film about antimatter and the LHCb experiment.

Videos on the website include an explanation of the science behind the movie Angels & Demons.

Find out more: cern.ch/lhcb

LHCb has a dedicated outreach programme designed to inspire the scientists of tomorrow. From films of the experiment to teaching material and the latest photos and news, you can find it all on the web. All scientific results are published and openly available.
High school students learn about particle physics with the Zurich LHCb group.

Primary school students meet LHCb physicists in 2010.
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The LHCb collaboration

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