Information for guides

for Underground Visits

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1. Introduction

This document is intended to provide you with material on which you can base your discussion with the visitors, along with more detailed background information for those not familiar with LHCb. It is not be intended to provide a word-by-word account of what an ideal visit underground to LHCb (and Delphi) should contain, nor what you should say on the surface. Everyone is specialized in different fields and the best is to convey the key messages from a personal and enthusiastic angle, and react to the response from your group.

The main idea while underground is to explain what the visitors can see, at each stopping point of the itinerary.

Discussions of more abstract concepts such as particle physics, the Standard Model, etc, should be done on the surface, either before or after the visit underground. Guides at the Exhibit are also encouraged to explain the various detectors on display.

Pages 1 to 2 may be useful to all guides, while 2 to 5 are mostly intended for underground guides. The rest gives some general background for the LHCb experiment and detector and on the DELPHI experiment. Some summary facts and numbers are listed at the end.

2. When you first meet the visitors

The first thing you should do is to introduce yourself, then check they are all present and they wear closed shoes and don't have big bags with them. You may have to wait before going underground and you can use this time and that on the lift going underground to give visitors some general information. They may have already heard some of it at the 'LHCb Exhibit', possibly from another guide so it may be a good idea to ask what introduction they already had…

Introducing yourself. People may have "stereotypical" ideas of a laboratory and what a researcher and people working at CERN looks like. Let them know what you do when you introduce yourself and explain that not only researchers but also technicians and engineers in many different fields and others people work at CERN.

Where are they? You can start out mentioning that the site they visit is nothing but a modern laboratory where the table-top experiments have been replaced by larger scale instruments. Explain with a few words that they are at Point 8, one of the interaction points for the LHCs counter-rotating beams, the home of the LHCb experiment.

What is particle physics? It's about continuing seeking the answers to the same questions that man asked himself as soon as we acquired consciousness. Today it has become more specifically the quest to understand the fundamental particles and interactions in order to build a model that can help us to understand the evolution of the Universe. By looking out in the Universe with various instruments such as telescopes we can explore the Universe back to about 400 000 years after the Big Bang. To understand the first 400 000 years we have to rely on experiments in which we try to recreate the conditions of the early Universe in small scale and study the behaviour of particles and interactions. The "how to do this" comes naturally and the answer is CERN and particle accelerators.

What is CERN? First of all it is a laboratory that provides accelerator beams with which physicists can do experiments. A second key message is the international aspect of CERN. In the post-war world one of CERNs major tasks was to stimulate international collaboration. It also functions as a knowledge bank beyond economical and political interests. CERN has 20 European member states "owning" CERN. However many other also non-European countries are involved in different ways. Researchers from ~ 90 nations come to profit from the CERN infrastructure, to make experiments and develop the technologies required to make the experiments. Some also contribute to the accelerator's complex. Few scientists are employed; out of around 10000 only about 2500 are employed by CERN, this include everybody, only ~ 1100 are physicist and engineers! The others scientists come from universities and institutes around the world contributing with a large turnover and exchange of knowledge and ideas, and they disseminate this information in teaching at universities, in collaboration with national industry and to the public.

What are the experiments at CERN? There are many experiments at CERN and not only at the LHC. The main experiments at the LHC are ALICE, ATLAS, CMS and LHCb but there are also three smaller one that make use of the collisions produced in the others (TOTEM, LHCf and MoEDAL, the last one is hosted by LHCb!). If you want you may mention that some of the smaller experiments study nuclei and atoms (ISOLDE), antimatter by making and studying atoms of anti-Hydrogen (ATRAP, ASACUSA), or the relation between cosmic rays and the formation of clouds (CLOUD).

Around the LHCb Exhibit there are posters that can help explaining some of these points.

3. Underground Visit

You may want to take advantage of the ride down on the lift to tell people that you will explain what they will see, that there will not be much time for questions but that they can pose them when back on the surface. You should also remind them of the safety rules if you have not yet done it and that they are to stay with the group. While they should not touch any equipment, they are welcome to take any picture they want.

Each following section will give you a general suggestion and some points that may be of interest. The idea is not for you to say everything that is written here but give you some hints of what may be interesting. The best is that you adapt what you say to the interest of the group you are guiding.

3.1 DELPHI barrel

The first point of interest exiting the PZ safe area is by the DELPHI barrel, where you may stop for 2-3 minutes. There will be a big photo of the barrel on the left going out of the door to help you (the photo shows the barrel from one floor up) and you will be able to show the DELPHI barrel from the cavern's floor. You can also see the DELPHI vertex detector with its silicon layers as they would have surrounded the collision point

The visit path then does go upstairs on the DELPHI visitors' platform.

The DELPHI barrel is an excellent example of a collider detector (just like ATLAS or CMS, just smaller…) and it allows you to explain the principle of the instruments used in particle physics. Whereas in most other scientific fields (chemistry, medicine, etc) the instruments are bought off the shelf, in particle physics we are obliged to develop new types of instruments. It sometimes happens that these instruments later show up on the shelf…

Few messages you can convey here are:

• The LHC re-uses the tunnel (~100 m underground) that was dug for the previous major accelerator at CERN, called LEP (Large Electron Positron collider). LEP had energy 100 times lower then the LHC and ran from 1989 to 2000.

• DELPHI was one of the four experiments at LEP and was housed in this interaction point, now occupied by LHCb. Its barrel part was maintained as a visitor attraction for after LHC starts up.

• DELPHI used to be one of largest particle physics experiments, now small compared to LHCb and dwarfed by ATLAS (which is 25 m high).

• Its detectors are arranged in cylindrical layers around the beam-pipe: vertex detector, tracking chambers, RICH, solenoid magnet, calorimeters, muon detector.

• LHCb has a different geometry, like a slice taken out of the DELPHI barrel and rotated to go in the same directions as the beam, but the detector principles are similar.

3.2 LHCb Counting Rooms

The visit goes back on the ground following the reverse direction and continues along the LHCb counting room barracks on your way to LHCb passing through the shielding wall.

Along the way there are posters with information on different LHCb components with photos during their constructions (e.g. magnet, ECAL, etc.).

While walking you can explain that:

• The barracks house the experiment control's electronics, the data acquisitions and the computer farm of about 1500 PC boxes (each with 8, 24 or 32 CPUs) that are used for the online processing of the LHCb data. When a PCs breaks it is replaced with a more recent and performing one.

• An average of 16 millions collisions per second took place in LHCb, only a few of them are interesting for the physics measurements of the experiment. Dedicated electronics and software running on the PC farm allows selecting those that may be interesting and discard the others, this is what physicists call a trigger. The LHCb trigger reduces by a factor of ~ 4000 the amount of events to write out and we ship them all over the world to reconstruct and analyze (from 16 millions per second to 4000 per second).

• You could also mention that the concrete wall that you pass through (3.2 meters thick) is there to shield the electronics of the experiment from radiation, which is present when the LHC is switched on. The levels are low enough in the barracks that we can always access them to intervene if there is a problem, even when there is beam.

3.3 LHCb viewing platform

The main points of interest is the LHCb viewing platform offering also a good opportunity to take photos! There are two levels in the view platform and the view is not quite the same from them, you may want to spend some time on both levels.

In this vantage point you can explain the overall layout of LHCb, with the interaction point (where protons collide) on the right-hand side, then the large dipole magnet, the tracking stations, RICH-2, calorimeters and muon detector.

On the lower level platform you are about 1.5 meters below the beam line while on upper level you are just about 1 meter above the beam line.

• Here you have the opportunity to point out that each detector is specialized in a given measurement; physicists need to combine the information from all the detectors to get the whole picture of what happens when the protons collide. While the picture is made of electronics signals it is not so dissimilar to those they are taking.

• After having given the layout of LHCb you can return on the different detectors and pick one where you can go in more details. Some more information is listed later or on the guide of the surface exhibit. If you are an LHCb collaborator working directly on one of the detectors you may want to point that out.

• When pointing out the detectors you may want to give reference points to identify them. The detectors close to the interaction point, including the VELO with its retractable silicon detectors, the RICH-1 with aerogel and gas radiators, and the TT station for tracking cannot be clearly seen but they are behind the panel with the LHCb logo on the right. Then the big blue dipole magnet and on its left the large red planes of the Outer Tracker straw detectors with the Inner Tracker just in its center close to beam line and not easily visible. Following the RICH-2, hidden behind the metallic stairways with its big volume of gas radiator, the Electromagnetic and Hadronic Calorimeters with their layers of absorbers (lead and iron respectively) and scintillators of which their yellow support structures are clearly visible. At the most left the massive muon system with layers of chambers interspersed within iron shielding walls of which are clearly visible their electronics' towers. Some panels are there to help you on the upper level platform.

• You will not be able to see the beam pipe, you can explain that it has been removed at the start of the Long Shutdown (LS1) and it will be reinstalled toward the end of the year. You may explain how it allows the beams to circulate without loosing to many protons that would interact with Air molecules.

From the visitors' platform you can glance on the far right the equipment shaft (PX). The shaft is 103 metres deep and 10 metres in diameter, and was used to lower parts of the detector down before their final assembly in the cavern. The shaft is also used to lower all the equipment needed for maintenance during the shutdown like the forklifts that may be around in the cavern.

• Most of the detectors have been brought down in pieces and assembled in situ like big legos. This has been the case for most of the detectors, particularly the 'big' one like the Calorimeters and the Outer Tracker. But there are notable exceptions: for example, RICH-2 was lowered down after being completely constructed on the surface, with its optical system already installed (and nothing broke).

From the visitors platforms you can also clear see the 'bunker' through which it is possible to walk under the LHCb detector. The 'bunker' not only allows to reach the other side of the detector but is also supporting the trackers and RICH-2.

• You can mention that given the shape of LHCb most of the sub-detectors open left and right with respect to the beam line allowing an easy access if it is necessary to intervene on them. In fact many of them can be in the open position during LS1. As a curiosity the only one that cannot be open at all in the cavern is RICH-2.

• The bunker is a 'protected' area: low voltage power supplies, gas distribution racks and some electronics is located there because the concrete shields them from particles produced in the collisions.

• In fact the particles LHCb is interested in are mostly produced along the beam line hence the shape of the detector, even though particles are produced in all directions around the collisions points.

• During operation some particles reach the visitors platform and no one is allowed in this side of the cavern. The concrete blocks on rail on the floor on the right are used to hermetically seal the passage in the shielding wall you went through so that there is no direct line of sight. People working in LHCb that need to access the detector can do when beam is not present through a dedicated access via a chicane that can be seen of the left.

3.8 Going back to the surface

You will walk back along the same path to the PZ lift. If the lift is not there wait for it. You may want to tell people that you are at the end of the tour and headed back to the surface. This may be a good moment to ask if they have questions on what they have seen.

Don't forget to collect the helmets and the visitors tokens once you are on the surface.

4. Experiments at the LHC

The LHC experimental facility consist of the older CERN accelerator complex, the LHC accelerator and four main experiments ATLAS, ALICE, CMS and LHCb.

The ATLAS and the CMS detectors are so called general-purpose detectors aimed at discoveries, by directly producing new particles, such as the Higgs boson, Supersymmetric partners, and other things we least expect. The two detectors are built in a very general way but are not specifically aimed at making precision measurements. The reason for having two detectors is that discoveries need to be verified or falsified so it is very important to have a second setup that is able to see the same thing independently and preferably with a slightly different method.

The ALICE experiment is an experiment dedicated to the study of lead ion collisions. A state of matter called quark-gluon plasma would occur when the temperature and the pressure is so high that the quarks are no longer bound together in hadrons, such as protons and neutrons, but are asymptotically free to form a gas of quarks and gluons. Previous experiments have seen hints of this new state of matter but ALICE is set out to investigate this carefully. Colliding lead ions together means that a dense and hot ball of some 1200 quarks is formed. ALICE is built to study how this object behaves and how the hadronisation happens as the ball expands, namely how the quarks combine back into protons and neutrons and their heavier relatives again. It can be seen like a condensation of steam into water droplets as the steam is cooled by for instance expansion. This in fact occurs also in proton-Ion collisions and in 2012 and early this year collisions of this type where collected by ALICE and the other LHC experiments.

LHCb is also a special purpose experiment dedicated to beauty and charm particle search for new physics in CP violation and rare decays. The LHCb physicists hope to indirectly see new particles (or even discover them) by their effect on the properties measured of the beauty and charm particles because they could be produced in "loops", i.e. a virtual production due to the quantum mechanical uncertainty principle. LHCb was initially designed to make precision measurements with B mesons (mesons containing b-quarks), but LHCb it is doing much more that it was designed for, not only probing all type of hadrons that contain the b-quark, but also doing very precise measurements of charm particles (hadrons containing the c-quark). The very special shape of the LHCb detector also allows to probe particle production mechanisms is an area not covered by the other three big LHC experiments.

5. LHCb's physics aims

• Matter is made up of atoms, with nuclei surrounded by electrons – example of a fundamental particle (without visible substructure).

• Nuclei are made up of protons and neutrons that were initially thought to be fundamental particles.

• We now know that protons and neutron have internal structures and are make of fundamental particles, called quarks. Six types of quark exist, given exotic names: up, down, charm, strange, top and bottom (or beauty). It is the last of these that LHCb has been designed to study, hence the b in the name, LHCb in fact stands for Large Hadron Collider beauty experiment, in other words the experiment to study beauty at the LHC.

• Quarks are always coupled with an anti-quark or in triplets with two other quarks, so they cannot be observed directly but through particles that contains them.

• In the Standard Model, particles have antiparticles (same mass, opposite charge) When particles meets their antiparticles, they annihilate to give photons. It is expected that matter and antimatter equally produced at the beginning of the Universe, but that most annihilated. However, some matter was left over and it is responsible for world we live in. Imbalance between matter and antimatter requires breaking the symmetry between them, known as CP violation: a combined operation of C = charge conjugation (swapping particles for antiparticles) and P = parity (spatial inversion, like reflection in a mirror)

• Particles that contain the b-quark exhibit this CP violation, so are a good place to study it.

• 100,000 such particles are produced every second in LHCb, far more than ever produced before, so we can be selective and study the interesting ones.

5.1 Cosmological perspective

The Universe began about 13.7 billion years ago as an extremely hot, dense and homogenous 'soup' of energy and particles. The energy was converted into particles of matter and antimatter. As pairs of matter and antimatter particles collided they annihilated each other, turning back into energy. For a short time there was a perfect balance, or symmetry, between matter and antimatter. However, as the Universe expanded and cooled it went through a series of drastic changes in its composition.

Shortly after the birth of the Universe, the particles acquired their characteristic masses and a phenomenon occurred that differentiated matter and antimatter, causing asymmetry between the two.

One hundredth of a billionth of a second after the Big Bang, the quantity of matter in the Universe already outweighed antimatter, but only by one particle in a billion. At this stage the Universe was an opaque plasma of matter particles called quarks and antiquarks, and force-carrying particles called bosons and energy carried by photons.

As the Universe cooled, this plasma condensed into hadrons, a class of particles that includes protons and neutrons. Matter and antimatter particles continued to annihilate each other into photons but the falling temperature meant that new particles were no longer produced. The Universe was left with more than a billion photons for each surviving proton.

It took just over a minute for the Universe to cool enough for the protons and neutrons to fuse together to form the first atomic nuclei.

When the Universe had cooled to a temperature of a few thousand degrees, the atomic nuclei could capture electrons to form atoms. This made the Universe transparent. The radiation from this epoch can be detected today as the afterglow of the Big Bang - the so called cosmic microwave background.

After about a billion years, the first stars were born in an otherwise dark Universe. Galaxies formed, and the Universe continued to expand. Today, at a temperature of just 2.7K, we see a Universe made entirely of matter. All astronomical searches for celestial objects made of antimatter have failed.

In the 1960s Russian physicist Andrei Sakharov outlined three conditions necessary for the matter to predominate in the Universe, one of which says that there should be a measurable difference between matter and antimatter - the mirror image is not perfect. Observations of certain particle collisions have shown that the mirror symmetry is imperfect in about one in a thousand collisions (for the kaon system). In technical terms this is called CP violation. Calculations indicate, however, the observed level of this is not sufficient to account for the observed matter-antimatter asymmetry in our Universe.

The full explanation for this imperfect symmetry looks like it requires new physics that could be revealed by studying collisions at higher energy – by recreating the moment, 13.7 million years ago, when particles called beauty and anti-beauty quarks were produced in pairs and for which CP violation occurs more frequently.

6. The LHCb detector

About a thousand billion pairs of anti-beauty and beauty quarks are produced in LHCb per year, and we select a few tens of million of their decays to study carefully off-line using computers to reconstruct the events that were recorded. By measuring their properties extremely precisely we detect asymmetries between particles and antiparticles, that should help explain how it is that nature prefers matter to antimatter.

Despite being very big and heavy, the LHCb detector is a high-precision instrument based on the latest cutting-edge technology. The size comes from that fact that, at a closer look, it actually consists of several different types of subdetectors, each one specialized at measuring a different aspect of what happens in the particle collisions. As a whole, the detector provides information about the trajectory, the identity, the momentum and the energy of each particle produced in the collisions. Each subdetector is also very big in order to make precise measurements of the extremely fast and energetic particles that are produced.

Tracking - The topology of the particle reaction is recorded using tracking detectors. LHCb has four trackers: Vertex Locator (VELO), Silicon Tracker (ST), Outer Tracker (OT) and muon detector.

Momentum - The momentum of each charged particle is obtained by measuring the curvature of the particle trajectory, as recorded by the tracking detectors combined with the magnetic field of the spectrometer dipole.

Energy - The energy of particles is measured using calorimeters. The LHCb calorimeter system consists of a PreShower (PS) and a Scintillator Pad Detector followed by an Electromagnetic Calorimeter (ECAL) and a Hadron Calorimeter (HCAL).

Particle Identification - The particles are identified by the signatures they leave in different type of detectors. The LHCb particle identification is based on two Ring Imaging Cherenkov detectors (RICH-1 and -2), the calorimeters and the muon detector.

6.1 Vertex Locator (VELO)

The VELO tracks the particles close to the collision with a precision of ~10μm to find decays of particles containing b-quarks. Finding B-mesons is based on finding secondary vertices that is a short distance away from the primary collision vertex. Typically the B-mesons may travel as far as 1 cm before decaying (1.5 ps lifetime). The high track resolution means that the flight distance can be reconstructed so precisely that a proper lifetime resolution of 40 fs is achieved.

The VELO consists of a row of 0.3 mm thick silicon detectors (21) measuring the particle trajectories in cylindrical coordinates (r, ϕ, z) and has 22000 signal cables which carry data from some 200 000 sensor channels. The sensitive area of the silicon plates starts at about 8 mm from the beam line. During the injection the detector must be retracted by 30 mm from the beam to avoid possible damage.

The Pile-Up system consisting of a veto detector similar to the VELO ensures that bunch crossings with only few proton-proton interactions are recorded by vetoing high multiple interaction crossing in the first level trigger (L0).

6.2 Silicon Tracker (ST)

The Silicon Tracker consists of a Trigger Tracker (TT) and an Inner Tracker (IT). The TT is based on silicon microstrip detectors of about 100μm pitch, covering a large area of a few square metres arranged in layers of ~ 1 square metre each. It has the task of tracking low-momentum particles that are bent out of the acceptance of the experiment by the magnetic field such that they are not detected by the Inner Tracker and the Outer Tracker. In addition the stray-field from the magnet allows the transverse momentum to be estimated for tracks with large-impact parameters, quickly enough for the information to be used early in the trigger decision (although this is not used in the current version of our trigger selections, it was the original motivation for the name of TT).

The three stations of IT are also based on similar silicon microstrip detectors and they have the task of tracking particles that travel close to the beam line. Although only covering about 2% of the area of the OT, about 20% of tracks pass through the IT, due to the higher density of tracks close to the beam pipe.

6.3 Outer Tracker (OT)

Together with the Silicon Tracker, the Outer Tracker forms the main tracking system in LHCb. The tracking is needed to reconstruct the charged particles and measure their momenta in the magnetic field. The tracking is also crucial to know the direction of the particles that produce Cherenkov light in the RICH detectors, and to associate calorimeter showers to either charged or neutral particles, and to associate tracks in the VELO with muons seen in the muon detectors.

Each station of the OT is based on four layers of detector modules measuring X,U,V,X. The two central modules are installed with a stereo angle of +/- 5o with respect to vertical. Each detector module consist of 5 mm straw tube drift chambers, in two layers which are staggered with respect to each other and which are packed into a gas-tight box.

6.4 Magnet

Despite the fact that the LHCb magnet is a conventional warm magnet and not superconducting, it provides a field of 4 Tm over the entire acceptance of the experiment with a power consumption of 4.2 MW. The polarity can be changed in order to eliminate systematic errors that can enter into the precision asymmetry measurements.

The magnet contains two coils, each weighing 27 tons, mounted inside a 1450-tonne steel yoke. Each coil is 7.5 m long, 4.6 m wide and 2.5 m high, made of a pure aluminium conductor which is 50 x 50 mm^2. The conductors have a 24mm bore to circulate cooling water through the entire magnet.

6.5 Ring Imaging Cherenkov detectors (RICH 1 and 2)

The RICH detectors are based on several types of radiators in which charged particles emit Cherenkov photons in the form of a light cone around the particle trajectory. The angle of the cone depends on the velocity of the particles. Focusing mirrors reflect the Cherenkov photons onto position-sensitive photon detectors (Hybrid Photon Detectors, HPDs, that were specially developed for LHCb). The cone is reflected in a circle such that the angle can be known by measuring the radius of the circle hence the name of the detector Ring Imaging Cherenkov, in short RICH. Knowing the trajectory and momentum of the particle (via the trackers and the magnetic field) allows computing its mass which is unique for its identity. To satisfy the physics aim of LHCb, the RICH photon detection must be cable of resolving single photons down to an angle of ~0.02 degrees over a detection area of 3 m^2.

6.6 Electromagnetic and Hadronic Calorimeters

The main purpose of the calorimeter system is the identification of electrons, photons and hadrons and the measurement of their energies and positions.

The electromagnetic calorimeter (ECAL) is based on modules (about 12 x 12 x 41 cm^3) containing a stack of 66 layers of 2 mm lead and 4 mm scintillator plates ("Shashlik" structure). There are ~3300 such modules weighing about 30 kg each, that is in total ~100 tonnes. Each module is traversed by either 64 (outer modules) or 144 (middle and inner modules) Wave-Length Shifting fibres which are read out at the back of the structure by photomultipliers. The ECAL covers an area of 50 m^2.

Electrons, positrons and photons interact in the lead layers and produce showers of particles. The charged particles (electrons and positrons) in the shower produce scintillating light in the scintillators which summed up, and is proportional to the energy of the incoming electrons, positron or photon.

The electromagnetic calorimeter is preceded by a Scintillator Pad Detector (SPD) and a Pre-Shower (PS) detector. The SPD and the PS signal the presence of charged particles.

The HCAL principally identifies and measures energy of particles containing quarks, i.e. hadrons (HCAL = Hadron CALorimeter). It consists of tile structure of iron and 3 mm scintillating plates which is parallel to the LHC beam pipe. A hadron interacting in the iron produces a shower of particles in the structure. As in the case of the ECAL the charged particles in the shower produces scintillating light that summed up is proportional to the initial incoming hadron.

The scintillation induced by the particles is also readout via Wave-Length Shifting fibres. In total the HCAL has 80 km of fibre and weighs ~500 tonnes.

6.7 Muon Detector

As muons are present in the final states of many CP-sensitive B-meson decays, muon detection is a fundamental requirement of the LHCb experiment. The muon system consists of 5 stations of Multi-Wire Proportional Chambers ranging from 8 x 6 m² (M1) to 12 x 10 m² (M5). The total number of wires in the chambers is about 2.5*106, which corresponds to a total wire length of about 1200 km (30 μm thick). The innermost region where the radiation and particle rate is the highest consists of Gas Electron Multiplier (GEM) detectors.

In between each muon station there is a muon filter consisting of iron blocks. The muon filter serves to attenuate hadrons behind the calorimeters that can lead to muon misidentification. Muons interacting very little with matter are not stopped by these iron walls. The total weight of the muon filter is 2100 tonnes.

6.8 Trigger and data acquisition

The LHCb detector registers particle collisions at a rate of 40 million per second. The readout system comprises two levels of triggers to reject uninteresting events. The first level trigger decision (L0) has a latency of 4 μs meaning that 160 events have to be stored while waiting for the decisions to arrive. The trigger decisions are based on information from the Pile-up system, the calorimeters and the muon chambers. The trigger is implemented in hardware (L0 trigger processors and L0 decision unit) and selects events from about 1/40 of the bunch crossings, i.e. the accept rate is 1 MHz. The full detector is then read out.

The remainder of the trigger is known as the High Level Trigger, which is a software trigger that runs on the online processing farm and will reduce the data rate to 5 kHz which are sent to storage. This data-rate includes events suitable for calibration of the detector. The rate for our physics analyses is 4 kHz. The data acquisition system is able to cope with a data rate of 12 Gbytes/s – equivalent to 17 CDs per second.

7. The DELPHI experiment

To be added.

8. LHCb general facts

• LHCb measures rare processes with extremely high precision, Discrepancies from what the Standard Model predicts will give us hints of what physicists call "New Physics" leading to a more complete theory

• The 'b' in the name stands for the b-quark. The name was chosen when it was designed to indicate that its initial purpose was to make measurement at the LHC of particles containing the b-quark. While the experiment is now doing much more than that the name remains.

• Many physics results have already been produced with the data collected in the past 2 years, about 170 physics papers have been published as of February 2014 and many more are on the way.

• Collaboration 912 members from 65 institutes in 16 countries in February 2014

• The detector covers a "forward" region from ~ 1° to 17° from the beam line, because most b hadrons are produced in that forward cone

• B hadrons are detected from the way they decay to give other particles, which leave tracks in the detectors (or energy deposits in the calorimeters)

• The typical b-hadron lifetime ~ 10^{-12} s (1 millionth of a millionth of a second) but at close to speed of light this corresponds to ~ 1 cm in LHCb, so that tracks from decay don't point exactly at the b-hadron production point

• B-hadrons are quite heavy, so decay products have high transverse momentum (i.e. a kick in the direction transverse to the beam line)

• Characteristic particles are produced in the decay of b and c-hadrons, e.g. electrons, muons, kaons

• The sub-detectors are designed to detect these different aspects of b decays. The complete detector is 20 m long, 10 m high, 12 m wide and weighs 5600 tonnes.

• The channel count ranges from few thousand individual elements (HCAL) to 500,000 (RICH), read out electronically a million times a second.

• The Trigger system selects interesting events for writing to storage at 5 kHz by making a fast study of a limited part of the detector.

• Event size ~ 50 kbytes × 10^{10} events per year → million GB/year of data would require a stack of CDs ~ a kilometer high.

• Computing power for trigger provided by farm of ~1500 commercial computers, each with 8, 24 or 32 CPUs.

• Data analyzed by physicists around the world using the Grid of interlinked computers

• Cavern length 70 m

• Cavern maximum width 20 m

• Height 18.60 m

• The LHCb detector cost is 75 million CHF (~ 15% of general-purpose detectors).

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