LHCb Masterclass: An Introduction to the Exercise

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Introduction

Below *"Oppenheimer* Poster", Universal Studios, https://www.universalpictures.com/movies/oppenheimer, accessed 16/3/2024.



"As *hibakusha* – survivors of the atomic bombings – we know firsthand the horror of these weapons and have been calling for abolition for decades.

As survivors of atomic weapons testing, we are still demanding justice for the damage governments worldwide have inflicted upon our bodies, our lives and our families.

As young people, we understand how the current nuclear weapons order in which we live converges with the global climate crisis that threatens current and future generations, particularly marginalized communities."

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Quoted from "Open Letter from Atomic Bombing Survivors, victims of Nuclear Testing and Youth Campaigners to Christopher Nolan on Oppenheimer Film", available at http://youthfortpnw.net/open-letter-from-atomic-bombing-survivors-victims-of-nuclear-testing-and-youth-campaigners-to-christopher-nolan-on-oppenheimer-film/ , accessed 16/3/2024.

Further Reading:

John Hersey, *Hiroshima.*

Michihiko Hachiya*, The Doctor of Hiroshima.*

Bethaine Alderson, "Nuclear test survivors' plea for Australia to sign treaty, as they speak at UN meeting" published in *ABC North and West SA,* 20 June, 2022. URL: https://www.abc.net.au/news/2022-06-20/nuclear-test-survivors-plea-for-australia-to-sign-treaty/101167332

Nuclear Fission

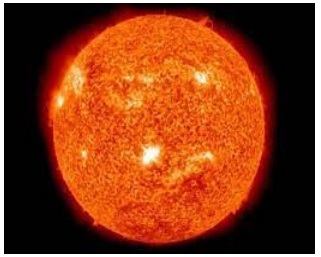
Provides example of how physical laws can be inferred from studying (sub)atomic processes.

Original mechanism described by Lise Meitner and Otto Frisch.

Meitner, L., Frisch, O.R. Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction. *Nature* 143, 239–240 (1939). https://doi.org/10.1038/143239a0



[1].



[2].



Left to right: Otto Hahn, Werner Heisenberg, Lise Meitner, and Max Born at Lindau Conference of Nobel Laureates in 1962.

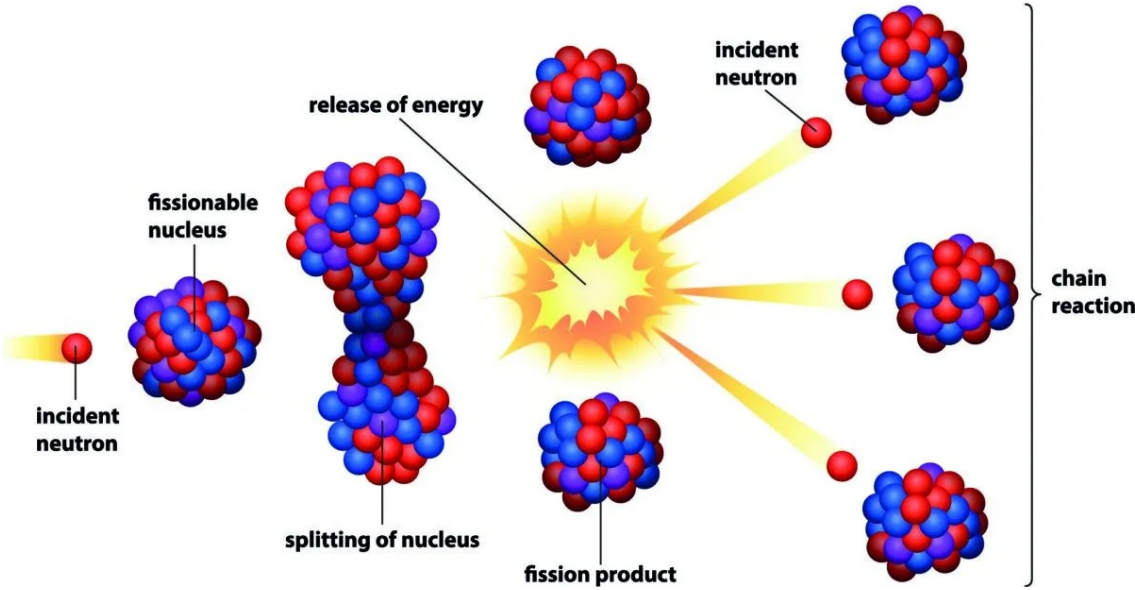


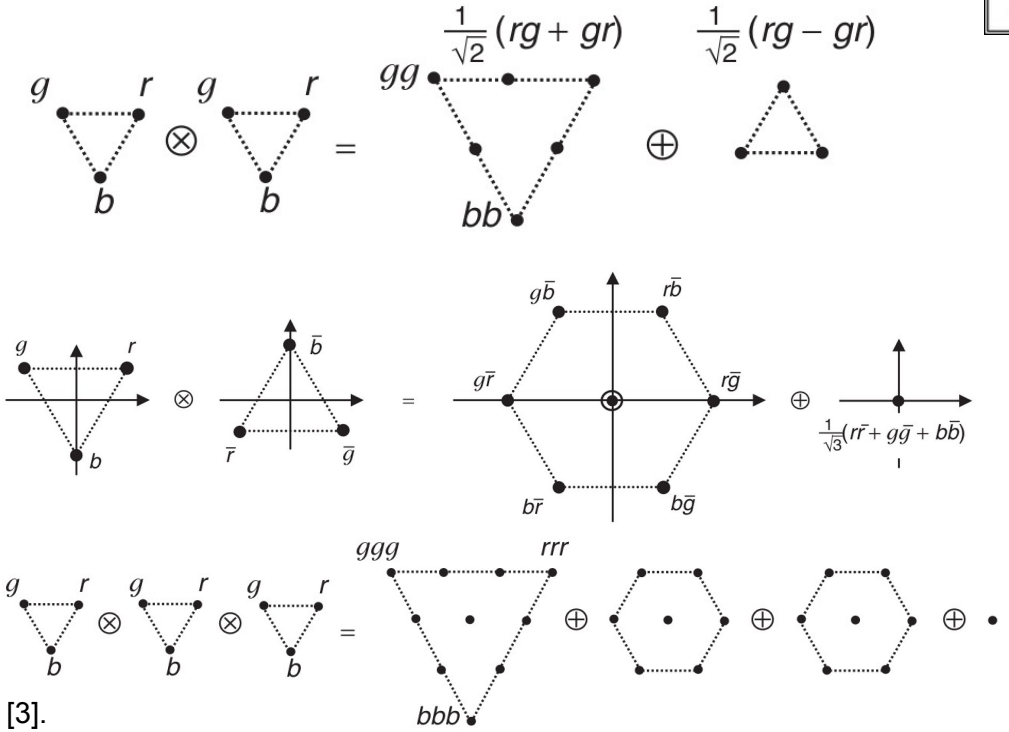
Image and photo from “A Lifetime of Fission: The Discovery of Nuclear Energy”, Judith M. Reichel, https://www.lindau-nobel.org/de/blog-lifetime-of-fission/, Accessed 16/3/2024 (iStock, © blueringmedia).

The Colour of Matter

Colour helps explain the stability of nuclear matter.

Flavour helps explain particle masses and decays.

An example is the difference between protons and neutrons.



[3].

Particle	Mass	
	kg	Relative
Proton (m_p)	1.673×10^{-27}	1 836.15
Neutron (m_n)	1.675×10^{-27}	1 838.68
Electron (m_e)	9.109×10^{-31}	1

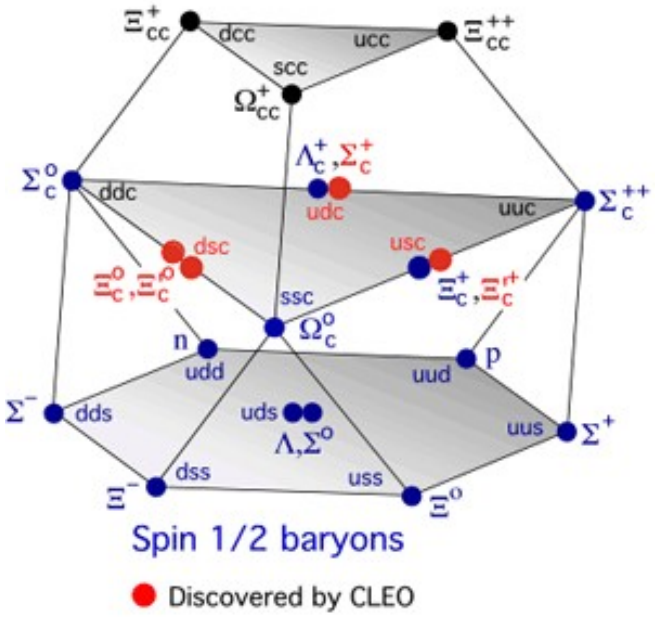
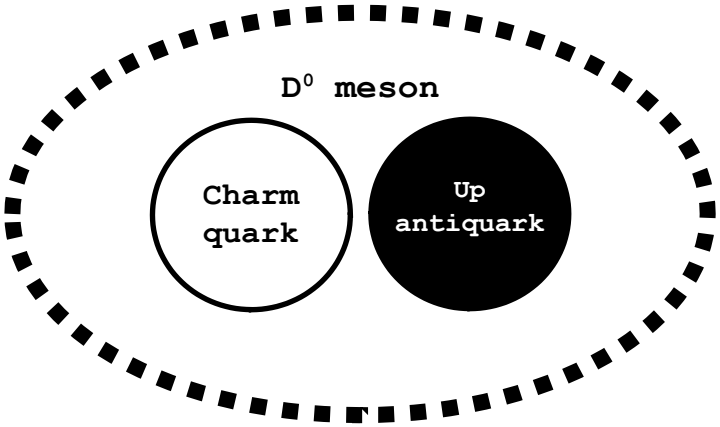
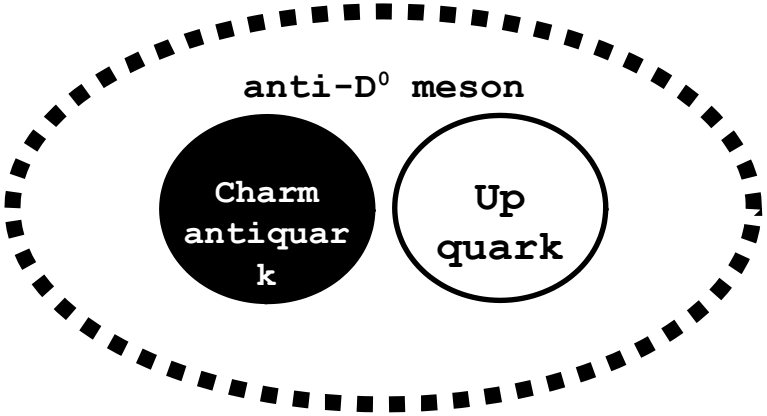


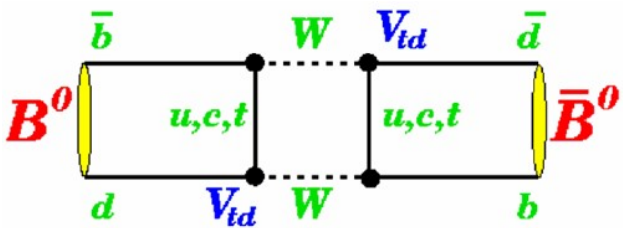
Table from “What is the relative mass of a neutron, electron, and a proton?”, Henry K.O. Norman, posted 2017 on *Quora,* accessed 16/3/2024. https://www.quora.com/What-is-the-relative-mass-of-a-neutron-electron-and-a-proton

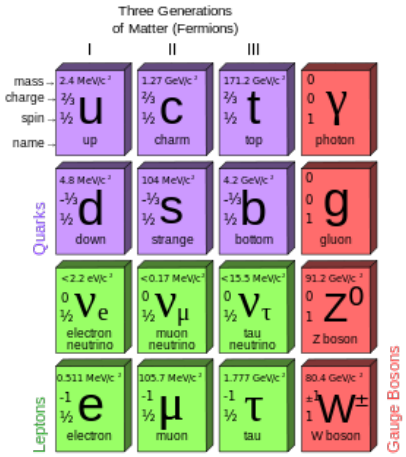
“Spin ½ Baryons” from slides provided by V. V. Gligorov, https://lhcb-outreach.web.cern.ch/wp-content/uploads/2022/02/IntroSlides.pdf , accessed 16/3/2024.

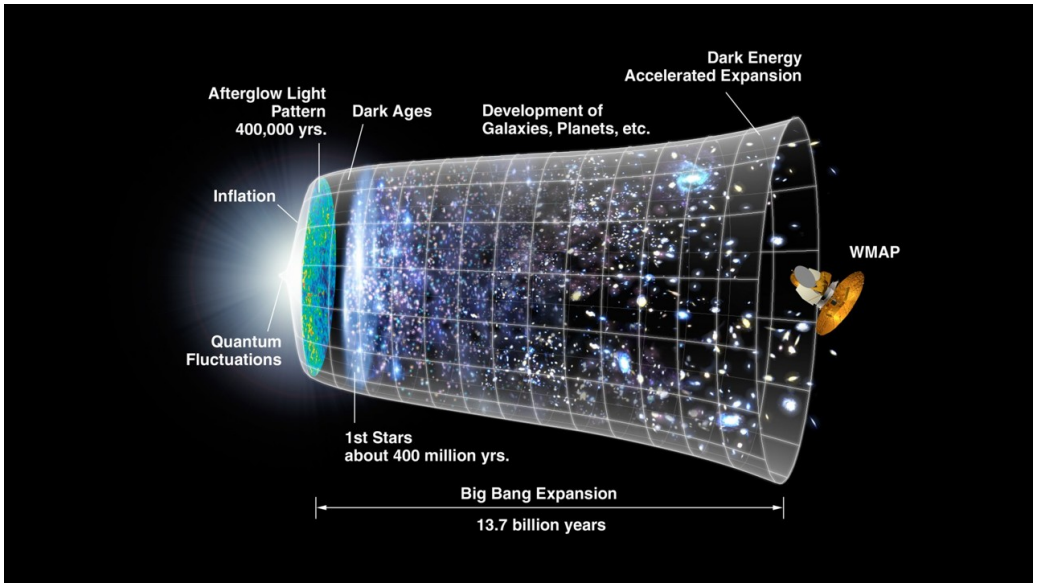
Our Candidate











All images from slides provided by V. V. Gligorov, https://lhcb-outreach.web.cern.ch/wp-content/uploads/2022/02/IntroSlides.pdf, accessed 16/3/2024.

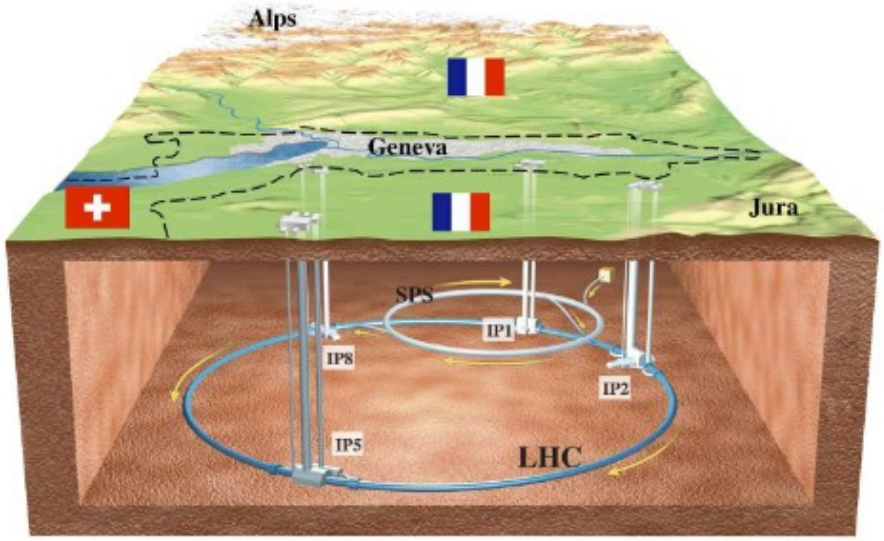
The LHC: An Engine of Discovery

Around 30,000 particle accelerators are in operation today of which the Large Hadron Collider is the largest of them with a 27km (16.6 mile) circumference

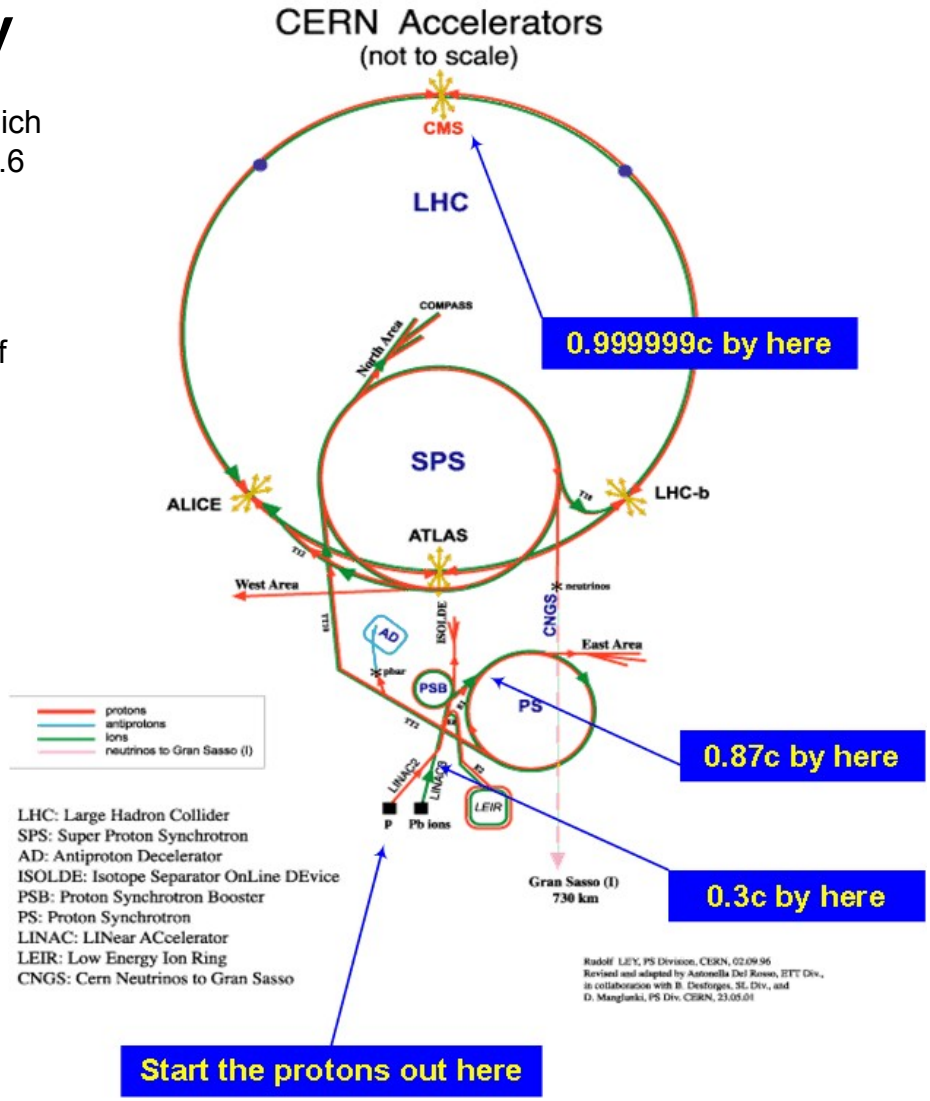
Proton-proton collisions occur at 13 TeV.

The LHC cost approximately 4332 MCHF (£2.6 billion) to build of which the UK contributed £95 million per year **[4,5]**.

The operational cost of the LHC is about 1.1 billion CHF **[4]**.

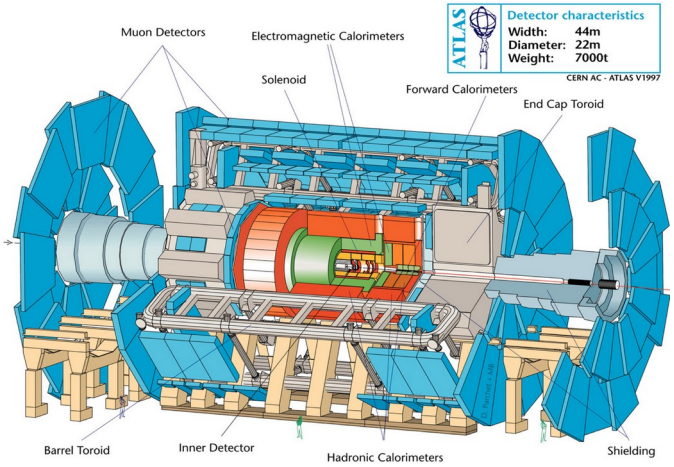


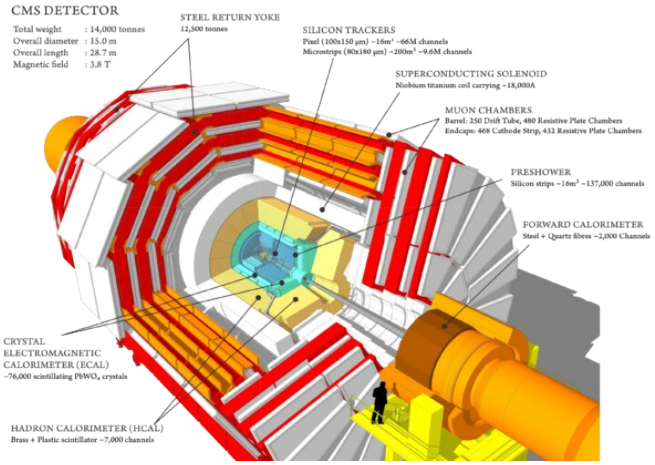
Above "Schematic diagram of the LHC collider", O. Brüning, H. Burkhardt, S. Myers, https://cds.cern.ch/record/1443022/files/CERN-ATS-2012-064.pdf, accessed 16/3/2024

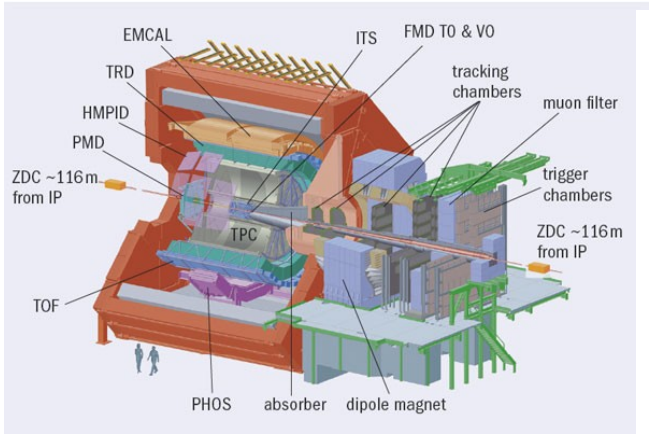


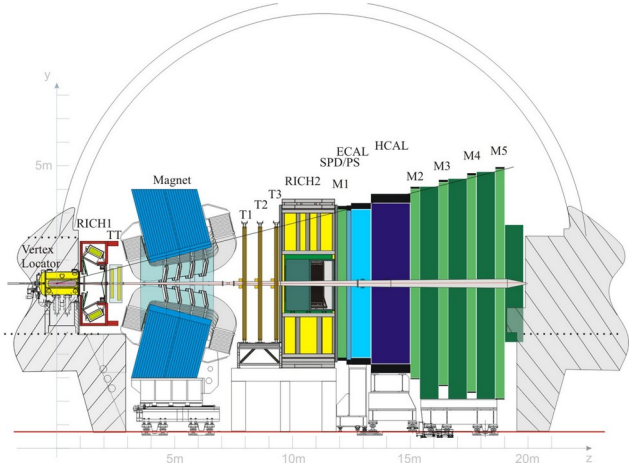
Above, "CERN Accelerators", from slides provided by V. V. Gligorov, https://lhcb-outreach.web.cern.ch/wp-content/uploads/2022/02/IntroSlides.pdf, accessed 16/3/2024.

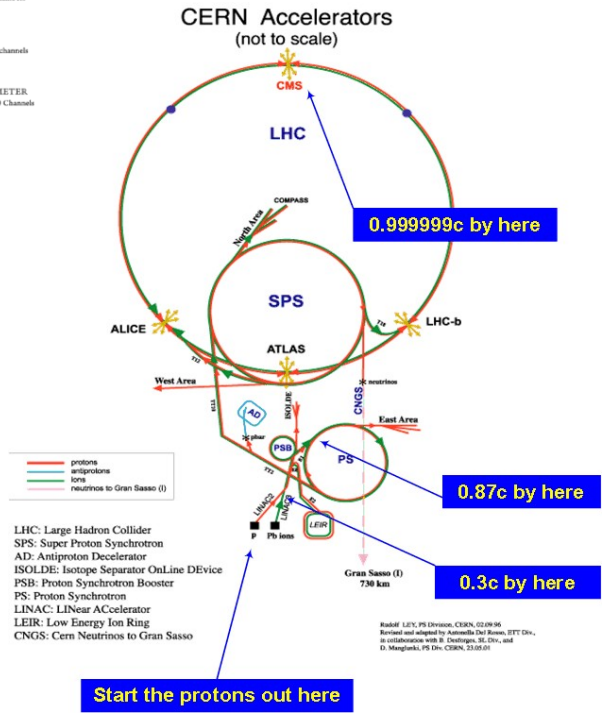
The LHC Experiments











All images from slides provided by V. V. Gligorov, https://lhcb-outreach.web.cern.ch/wp-content/uploads/2022/02/IntroSlides.pdf, accessed 16/3/2024.

The LHCb Detector

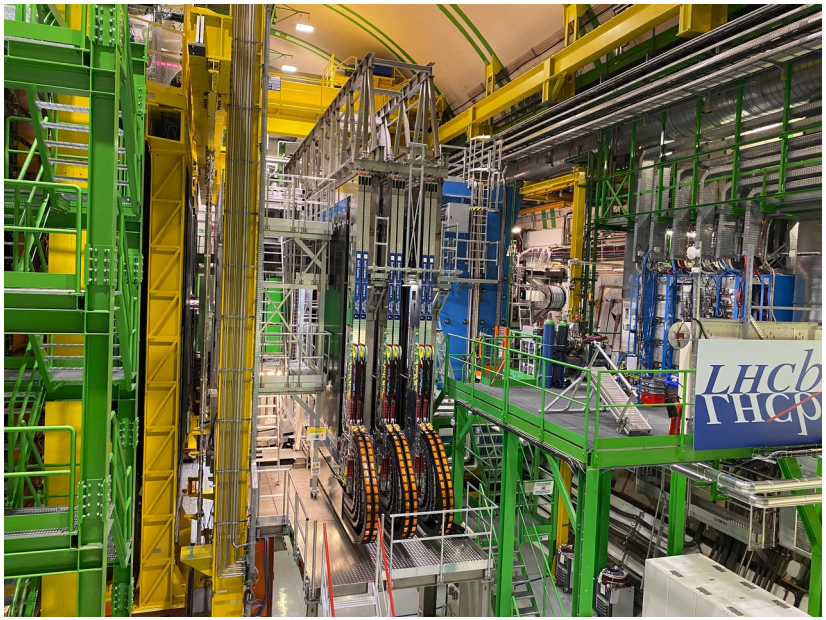
Specialises in studying the decays of particles with *b*-quarks.

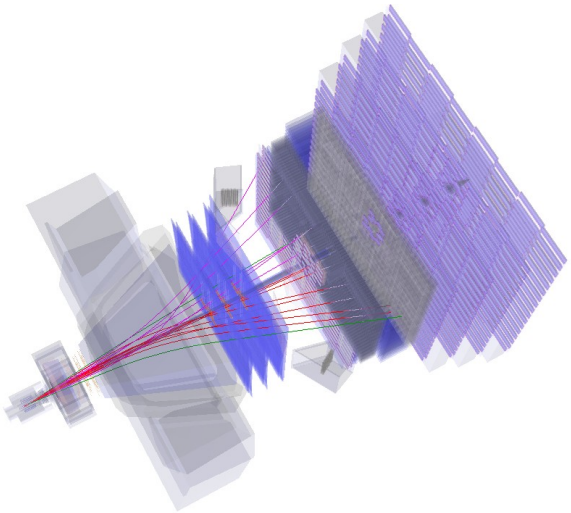
It is about 1 metres long, 10 metres high and 13 metres wide, and weights 5600 tonnes **[6]**.

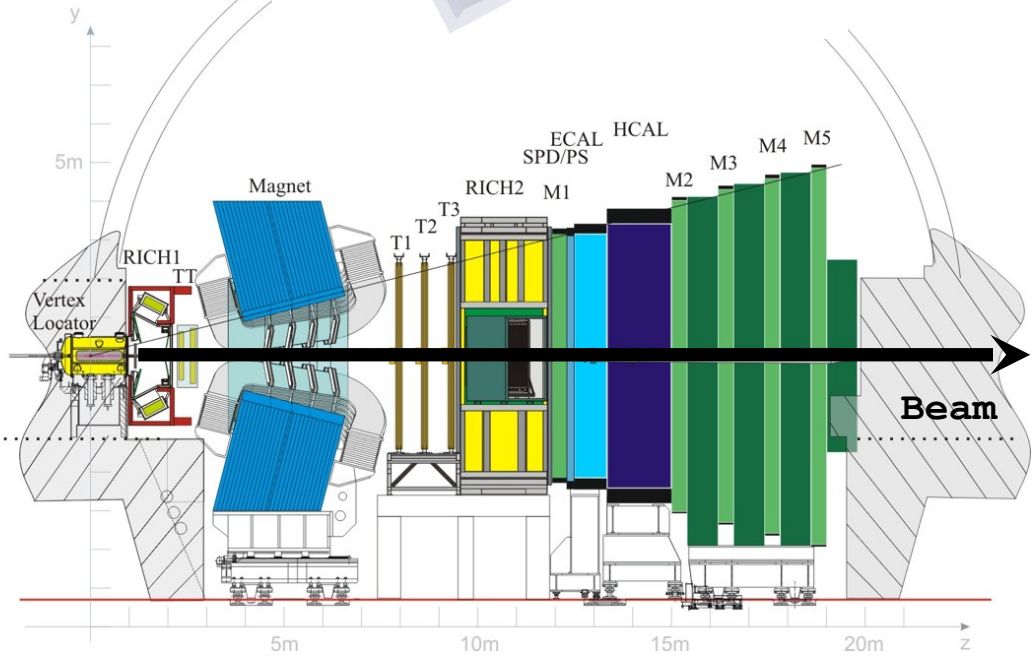
The detectors is 100 metres below ground near the town of Ferney-Voltaire, France **[6]**.

As of March 2022, the collaboration was composed of 1 scientists, engineers and technicians from 20 countries

72 new hadrons discovered at the LHC, 64 by LHCb **[7]**







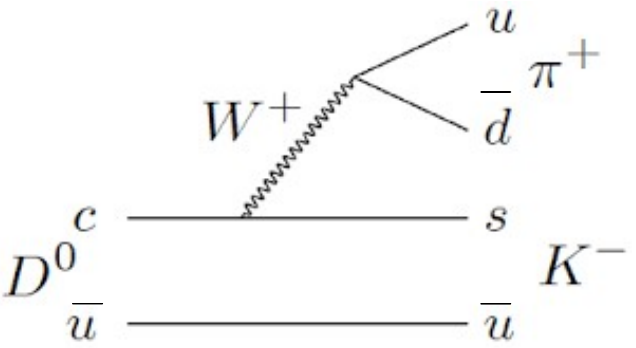
Above, “LHCb Diagrams”, from slides provided by V. V. Gligorov, https://lhcb-outreach.web.cern.ch/wp-content/uploads/2022/02/IntroSlides.pdf, accessed 16/3/2024.

Today's Exercise: Decay Topology

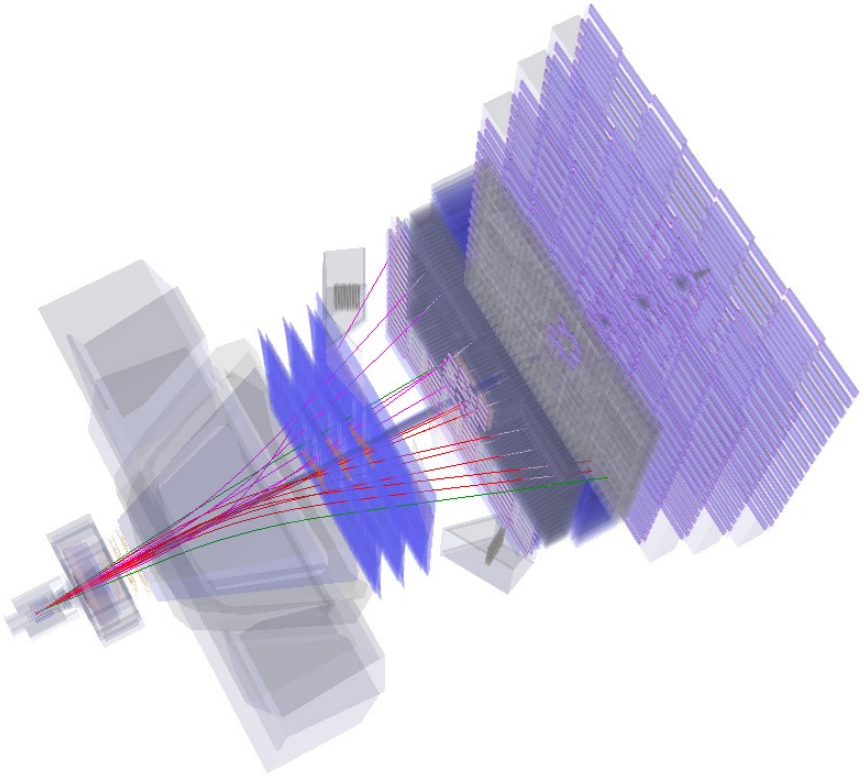
Live Demonstration:
https://lhcb-outreach.web.cern.ch/lhcbinternationalmasterclasses/d0-lifetime/

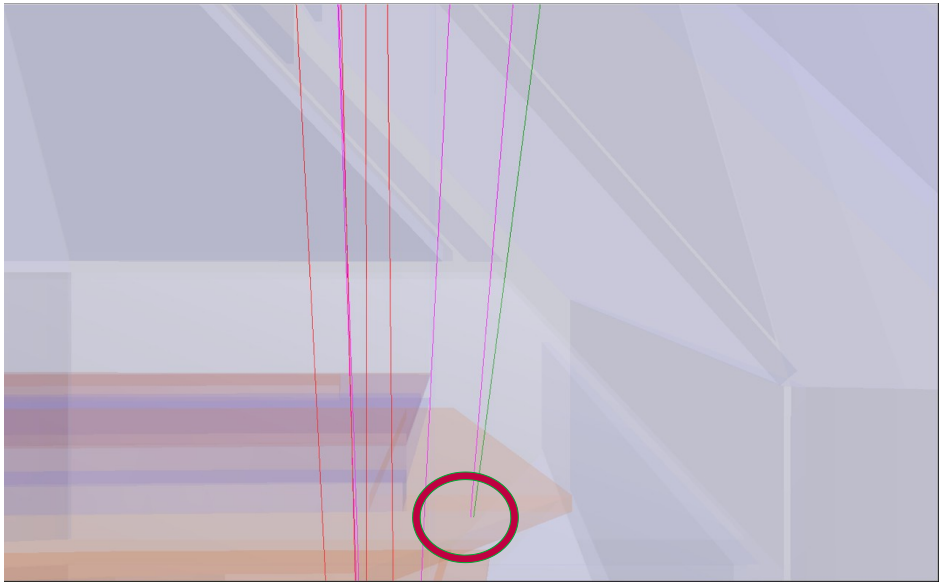
Many interesting candidates decay in flight through the detector

The tracks produced by these candidates can often be identified by distinctive features.



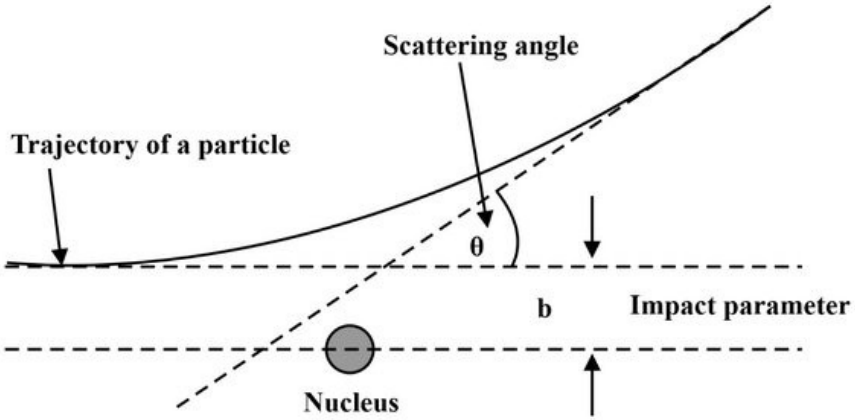
[8].





Above and left, "Event Displays" from slides provided by V. V. Gligorov, https://lhcb-outreach.web.cern.ch/wp-content/uploads/2022/02/IntroSlides.pdf, accessed 16/3/2024.

Today's Exercise: Variables



p_T = Transverse momentum
E_T = Transverse energy

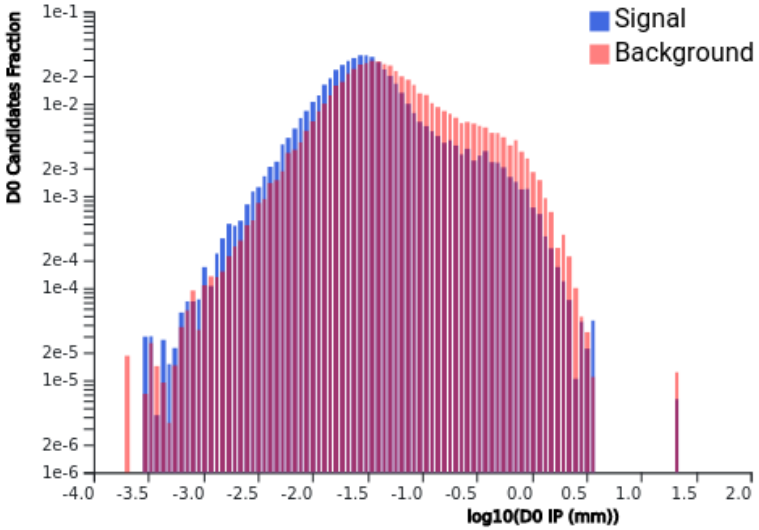
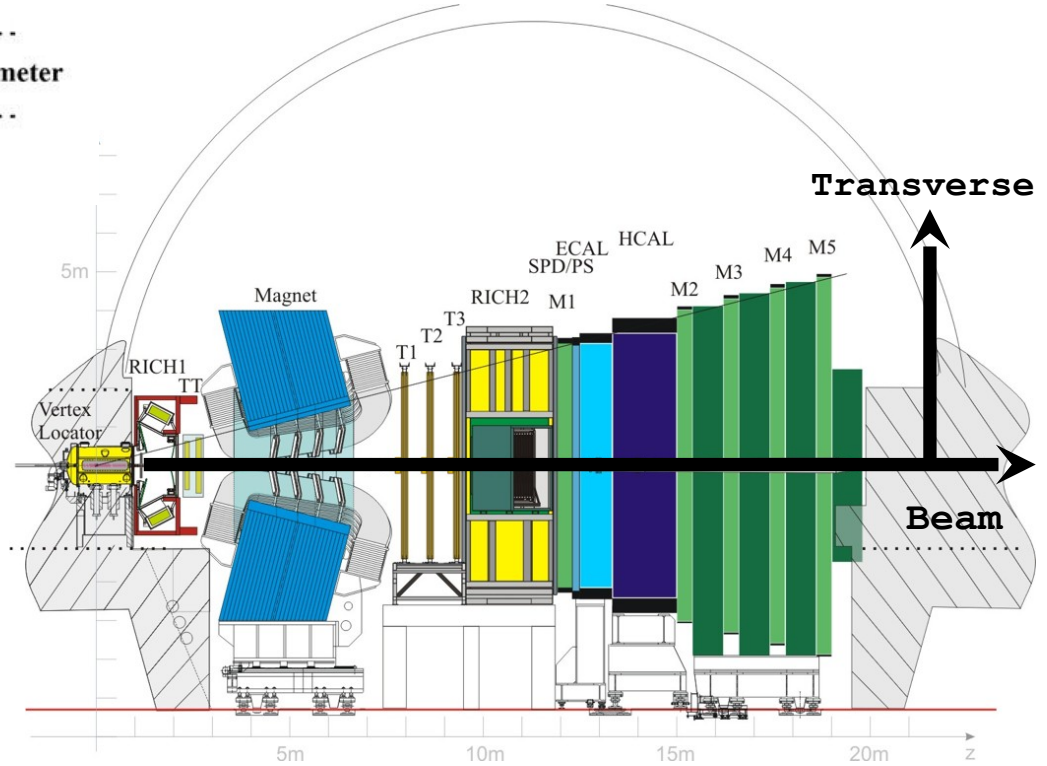


Diagram from "What is impact parameter?" Mazeen Muneez, posted 2018 on *Quora,* accessed 16/3/2024. https://www.quora.com/What-is-impact-parameter.



Above, "Annotated LHCb Diagrams", from slides provided by V. V. Gligorov, https://lhcb-outreach.web.cern.ch/wp-content/uploads/2022/02/IntroSlides.pdf, accessed 16/3/2024.

References

[1]. ThomasVogel. “Waterdrop. Water Drop Leaf Environmental Conservation Balance Green Nature stock photo”, https://www.istockphoto.com/photo/waterdrop-water-drop-leaf-environmental-conservation-balance-green-nature-gm157429894-10083565 accessed 16/3/2024.

[2]. NASA/SDO/AIA, “Sun Blasts a M6.6 Flare”, from *National Geographic.* https://education.nationalgeographic.org/resource/sun, accessed 16/3/2024.

[3]. “Visual Representation of SU(3)” from M. Thomson, *Modern Particle Physics*, Cambridge University Press, 2013.

[4]. “Facts and Figures about the LHC” from CERN, https://home.cern/resources/faqs/facts-and-figures-about-lhc, accessed 17/3/2024.

[5]. “Perspective: Colliding at Colossal Costs” from Richard Thomson, https://www.bluesci.co.uk/posts/perspective-colliding-at-colossal-costs, accessed 17/3/2024.

[6]. “LHCb” from CERN, https://www.home.cern/science/experiments/lhcb, accessed 17/3/2024.

[7]. “New Particles discovered at LHC” from Patrick Koppenburg, https://www.nikhef.nl/~pkoppenb/particles.html, accessed 17/3/2024.

[8]. “Fig 2.2” [cropped] from Martin Florian Bessner, *Study of the ratio of D0 → K+π− to D0 → K−π+ decays with the LHCb detector*, Diploma thesis in Physics, University of Heidelberg.