

The European Organization for Nuclear Research: Exploration, Encounter, and Exchange Through Particle Physics

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Introduction

By the close of World War II, many European physicists had moved to the United States to support the creation of the atomic bomb. Europe's infrastructure was in ruins, and "eminent physicists... had recognized that Europe would be competitive in nuclear physics only if the countries joined forces" (Schopper 87). The European Organization for Nuclear Research, or CERN, as it is more commonly known, became the solution to this European "brain drain". CERN was established in 1954 as a supranational laboratory dedicated to the peaceful exploration and application of atomic and subatomic physics. CERN's creation helped revive the European physics community; aided reconstruction of European economy; eased international tensions brought on by World War II; led to the invention of the World Wide Web, with its aim of exchanging information on a global scale; and encountered subatomic particles that may have played a role in the creation of our universe.

Historical Context

Prior to the 1800s, worldwide atomic theory in physics had been shunned in favor of the traditional theory of the four basic elements (water, air, fire, and earth), proposed by the Greek Empedocles in the fourth century B.C.E. ("Empedocles"). A fifth element, ether, was later added by Aristotle ("Ether"). This universal acceptance of traditional theory was challenged by Englishman John Dalton's studies of chemical elements around the turn of the nineteenth century. Dalton theorized that each element was made of its own atom, creating the basis of modern particle physics ("Subatomic particle"). J. J. Thomson's discovery of the electron in 1898 illustrated that the atom is composed of even smaller particles (Aczel 73). Modern particle

physics theories stem from the work of Ernest Rutherford who, in 1911, discovered that the atom consisted mostly of an atomic nucleus. Following this discovery, Englishman Paul Dirac proposed the first quantum field theory in 1927 that described the electromagnetic field as a cloud of photons and explained the activity of electrons in an atom. James Chadwick supported Dirac's theory with the discovery of the neutron in 1932, the event normally associated with the birth of particle physics ("Subatomic particle").

In the years surrounding World War II, particle physics centered primarily on military purposes - the creation of the atomic bomb. The exchange of information between countries was discouraged due to wartime security (Krige 44). Through the Manhattan Project, the United States produced and used the first atomic bombs in 1945, gaining a near monopoly on atomic warfare. Following World War II, however, European countries split alliances between the Soviet Union and the US, a period known as the Cold War ("The Cold War"). The Cold War rose in severity from 1948 to 1953 as the Soviets developed and detonated their own atomic bomb (Britannica's "Cold War"). During this period of instability, the countries of Europe, decimated by war, struggled to recover (Lincoln 42). The European physics community experienced a "brain drain", in which "young and gifted nuclear scientists, in particular, would be attracted across the Atlantic to work on facilities available there" (Krige 1).

Background Information

In counterpoint to this global paranoia and divisiveness, the idea of an international European physics laboratory was proposed by Louis de Broglie in 1949. About a year later, Isidor Rabi supported this idea at the Fifth General Conference of the United Nations

Educational, Scientific, and Cultural Organization (UNESCO) in Florence, Italy, asserting that an international organization would “make more fruitful the international collaboration of scientists” (UNESCO 38). Rabi based the CERN proposal on the principles of the Marshall Plan and the Schuman Plan. The Marshall Plan, put into effect in June of 1947 by American General George Marshall, advocated for “the revival of a working economy in the world, so as to permit the emergence of political and social conditions in which free institutions can exist” (“Marshall Plan Announced” 0:43-0:52). One month before Rabi’s proposal in Florence, France’s Robert Schuman proposed a “Schuman Plan” that would link France’s and Germany’s coal and steel industries and place the union under international control. The Marshall and Schuman Plans hoped to facilitate the reconstruction of Western Europe’s economy and were key in the opposition of Communism during the Cold War (Krige 153, 159, 161). Rabi gained the support of America and France by incorporating these objectives into his proposal for CERN.

In addition to combatting Communism and restoring European economy, CERN’s founders envisioned a physics laboratory that would bring European scientists back to the continent and reunite the war-divided countries of the region. The laboratory’s primary focus would be to explore high-energy physics using particle accelerators - machines that generate continuous beams of subatomic particles (“Particle accelerator”) - while pursuing other fields such as computing and biology (Krige 44). In this way, CERN sought to quickly re-strengthen European physics so the continent could continue particle physics exploration soon after the end of World War II (Lincoln 42).

CERN’s creation would serve an additional, critical function: to allow the United States to “be kept currently aware of the latest advances of modern technology, in whatever nation

these may occur” (“Science and Foreign Relations” 3). Transparency was a crucial asset for the US in the context of the Cold War (Krige 44-46).

Opposition

The proposal to establish a European nuclear physics laboratory was accompanied by some doubts and dissent. Given the destructive use of atomic power during World War II, European nations stressed that if a nuclear research facility was to be established, it would be for non-military purposes only (Aczel 71). As stated within the CERN establishment convention, “The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and... shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available” (5). Due to these non-military parameters, CERN encountered restraints on the use of its equipment - the technology and research could not be used to strengthen the military or economic might of any one member nation (Krige 45).

In addition to military and commercial restrictions, the CERN initiative encountered opposition from some European governments who felt that the project would put their countries at further economic risk following the hardships of World War II. Germany’s Werner Heisenberg voiced disapproval at a UNESCO meeting in Paris in 1951: “Our country is in an extremely difficult economic position and I am not entitled at the present time to commit our government to any expense in this connection” (de Rose 174-175). The inclusion of West Germany as a founding member proved to be another obstacle in CERN’s creation. While Rabi and company believed this incorporation was crucial in order to counteract Communism during

the Cold War, fear of a Nazi resurgence caused disagreements over how many scientific and industrial opportunities West Germany was granted (Krige 47).

Another form of opposition came with doubts regarding the practicality of a new physics organization. Some countries, such as the United Kingdom, suggested using existing facilities rather than constructing a new international laboratory. Britain's George Paget Thomson advocated for this action at the Paris 1951 meeting, and felt that by using existing facilities, "physicists could begin work immediately and not have to wait many years for a new facility to be completed. As a sign of the seriousness of his proposal, Thomson offered the use of a 400-MeV [mega-electron volt] cyclotron at Liverpool University, which was nearing completion." Frenchman Francis Perrin countered that "the lack of more powerful equipment in the physics of fundamental particles would have the effect of 'prejudicing European states and the aspects of civilization that they represent'. Perrin reminded the meeting that Europe's scientists would move to America if they couldn't find good facilities at home; and he said that building a machine comparable to those being constructed in the United States would be 'far beyond the means of any single European state.'" This logic displays that France supported the idea of an organization with powerful equipment that would attract European scientists back to their home continent, but asserted that a project of that scale could only be accomplished through widespread international cooperation, and by the end of the conference most countries became supportive of this thinking (de Rose 175).

Impacts

The Paris 1951 conference eventually prompted the first resolution regarding the creation of an international physics laboratory. In the following two months, 11 countries established a provisional “Conseil Européen pour la Recherche Nucléaire”, or CERN. In mid-1953, CERN’s establishment convention was signed and ratified over the next 14 months by 12 member states (France, the United Kingdom, Denmark, West Germany, Switzerland, Belgium, Sweden, Norway, the Netherlands, Italy, Greece, and Yugoslavia). Finally, on 29 September 1954, CERN was officially established and the original acronym retained (CERN’s “The History of CERN”).

Upon its establishment, CERN sought to answer questions about the universe’s earliest moments following the Big Bang by constructing particle accelerators, colliding subatomic particles together, and interpreting the findings produced by these collisions (Perritano). In 1957 and 1959, respectively, a 600-MeV accelerator and the 28 GeV (giga-electron volt) Proton Synchrotron (PS) became operational and were the highest-quality and best performing machinery of their kind (de Rose 175), thus kickstarting CERN’s prominence in particle physics. According to “The History of CERN”, the PS in particular was an early success in nuclear physics exploration. Through the PS, CERN was able to break world records in physics, which led to a surge of global recognition (Lincoln 42-43).

Additionally, both accelerators provided European physicists with powerful research machinery that equaled that of the United States, which brought back a sizeable amount of scientists from America to work at CERN. As physicist Valentine Telegdi commented in a personal interview, “There was very little of this begging for money. They supplied you with instruments and money. CERN was well funded... From that point of view, it was an enormous

advantage” (Lippincott 449). This technological impact on the global physics community allowed for more extensive, higher-quality research, and allowed scientists to explore new subatomic phenomena (de Rose 175). Therefore, CERN’s creation fulfilled its founders’ vision of a Europe with strengthened ties through high-energy physics (Kowarski 381).

CERN also fulfilled its mission of strengthening the Western European economy after the war. The organization allowed multiple countries access to its advanced technology because the nations cooperated to purchase the equipment needed. No country was burdened economically because costs were shared, and each country was able to use the equipment for a manageable price. These savings were crucial to a war-ravaged Europe (“The Significance of CERN” 49:59-50:15).

However, not all of CERN’s impacts were positive: “American support for CERN may have come at a price for American physicists. In later years, US policy-makers... used the existence of CERN as a reason to refuse requests from the US scientific community for expensive high-energy machines in their own country” (de Rose 175). American physicists were further impacted when scientists were directed to use the accelerators at CERN facilities for their research, which led to a decrease of employment at American physics laboratories (de Rose 175).

Legacy

Over 60 years after its creation, CERN remains a source of international collaboration and a focal point for groundbreaking research. CERN has added member states, including some from Eastern Europe following the Cold War (Krige 44). CERN has been a gathering place for scientists and physicists, and its diversity has led to new methods of cooperation between

professionals in different fields (Aczel 60-61). CERN scientists have also “worked together for decades... to ensure that the spirit of competitive collaboration, unique to science, continues to thrive in particle physics” with its American counterpart Fermilab (Heuer and Oddone).

One of CERN’s legacies, the World Wide Web, grew out of this spirit of cooperation. In 1989, Tim Berners-Lee invented the Web at CERN to fulfill the need for a method of exchanging information between universities (CERN “The Birth of the Web”). Public access to the Web was granted in 1993, and 22 years later, use of the Web has permeated our culture. To oversee the use of the Web, Berners-Lee organized the World Wide Web Consortium in 1994 (Britannica’s “Sir Tim Berners-Lee”). Although the World Wide Web was initially focused on easing the exchange of information and ideas between researchers, society as a whole can thank CERN for what has been deemed one of history’s greatest inventions (Aczel 15-16).

The creation of CERN also produced what some consider the pinnacle of scientific collaboration - the Large Hadron Collider, or LHC. Completed in 2008, the LHC’s aims are simple: to utilize past knowledge to make advances in particle physics and to further understand the universe’s creation (Aczel 8). On 4 July 2012, the LHC revealed the discovery of a particle consistent with the theorized Higgs boson (CERN “The Higgs Boson”). Britannica’s “Higgs boson” states that the particle is thought to bestow mass on other subatomic particles and may have played a role in the universe’s creation. As John Butterworth communicated in his book *Most Wanted Particle*, the Higgs discovery “is surely a sense of progress: there are things to find out that are important... and that once you have found them out are added to the body of human knowledge to the eventual benefit of us all.” Butterworth speculated that the Higgs “can look forward to a period of intense scrutiny, where particle physicists... measure its properties as

precisely as we can to see... whether it will yield any clues that might help us solve some of the remaining puzzles in physics” (245-248). In short, the global physics community is optimistic that encounters made at the LHC may be used to advance scientific knowledge and answer questions that have been debated for centuries (Giudice 241).

Conclusion

CERN began in 1954 as a method of reuniting and restrengthening the countries of Europe after World War II, uncovering the early universe’s secrets, and bringing European particle physics back to its previous glory. Since its creation, the organization has explored new forms of international cooperation and new theories in particle physics. Its scientists have encountered subatomic particles including the Higgs boson, and exchanged a vast array of information globally through the World Wide Web, resulting in worldwide recognition. The organization accomplished this despite opposition to its initiative from countries such as the United Kingdom and Germany. CERN has impacted science, politics, and technology, and if history is any indicator, will continue to succeed, perhaps putting to rest the great questions of how the universe came to be.

Annotated Bibliography

Primary Sources

Butterworth, Jon. *Most Wanted Particle: The inside Story of the Hunt for the Higgs, the Heart of the Future of Physics*. New York: Experiment, LLC, 2015. Print.

This source is a book written by a researcher at the Large Hadron Collider (LHC) at CERN, specifically the ATLAS experiment. The book covers the search for the Higgs boson, or the particle thought to supply other particles with mass and to have played a role in the beginnings of the universe and matter as we know them today. I used this source for information about the significance of the Higgs boson discovery in 2011-2012 (research data collected in both years confirmed its existence), as well as thoughts on the future uses of how the Higgs boson may be put to use in particle physics. The book also helped me understand why the Higgs boson was named after Peter Higgs, a physicist who proposed the particle's existence, as well as how the Higgs particle is a step towards the expansion of common knowledge and human thirst for discovery.

CERN. *Convention for the Establishment of a European Organization for Nuclear Research: Paris, 1st July, 1953: as Amended*. Geneva: CERN, 1971 - 57 p. Print.

This source is a document accessed from a webpage containing conference proceedings which officially establish the European Organization for Nuclear Research. The source was used to highlight the purpose of the creation and research of CERN. It also helped me better understand the limits imposed on what was done with the research, such as the prohibition of any military-related assistance for any of CERN's member nations.

de Rose, François. "Meetings That Changed The World: Paris 1951: The Birth Of CERN." *Nature* 455.7210 (2008): 174. *Advanced Placement Source*. Web. 16 Oct. 2015.

This source is an article accessed from the Ebsco database. Written by the chairman of the Paris 1951 meeting at the UNESCO headquarters regarding the establishment of what would eventually become CERN, the source gives a firsthand report of conflicting opinions and resolution at the influential meeting, now viewed as the true beginning of CERN. I used this source to show the widespread cooperation and interest in the idea of a new particle physics laboratory, but also how financial deprivation of many of the countries, as well as the favoring of the use of existing regional laboratories, led to the opposition of the construction and maintenance of a new laboratory and equipment to be operated at such a facility. The source also gave insight on the meeting from the leading chairman, which helped me understand how the meeting unfolded, including the opposition and support for the creation of CERN, as well as how a consensus was reached and how plans for funding and construction were put into action.

Heuer, Rolf, and Pier Oddone. *Scientific Opportunity: The Tevatron and the LHC* (15 Sept. 2010). *CERN Document Server*. CERN, 6 Oct. 2014. Web. 04 Mar. 2016. <<http://cds.cern.ch/record/1291610?ln=en>>.

This source is an article accessed from the CERN document server that is written by the director-generals of CERN and Fermilab regarding public understanding that the two organizations were locked in fierce competition and trying to uncover the mysteries behind the Higgs boson before the other organization. The authors speak contrarily to this understanding, stating that CERN and Fermilab actually collaborate more often than not, and each organization has played a key role in some momentous event at the other, such as the discovery of the top quark at Fermilab or the construction of the LHC at CERN. I used this source to describe the relationship between the two physics laboratories and to show that the United States and Europe have continued to cooperate since the origins of CERN when Isidor Rabi proposed the establishment of such a laboratory in Florence. The article also amended my previous understanding that Fermilab and CERN were sworn rivals and did not collaborate in any way to achieve goals such as the discovery of the Higgs boson.

International Science Policy Survey Group. *Science and Foreign Relations: International Flow of Scientific and Technological Information*. Washington: Office of Public Affairs, Division of Publications, 1950. Print. General Foreign Policy Ser.

This source is an article explaining the influence of international scientific collaboration on the foreign policies of the United States following World War II. I used this source to illustrate how the US benefited from the revival of the European scientific community through the creation of an international laboratory. The source helped me to realize that the main influences of US support of CERN came from the desire of political stability and security, as well as economic welfare, among other points.

Kowarski, L. "The Making Of CERN--An Experiment In Cooperation." *Bulletin Of The Atomic Scientists* 11.10 (1955): 354. *Science Reference Center*. Web. 16 Oct. 2015.

This source is an article accessed from the Ebsco database. Written by physicist Lew Kowarski less than a year after the official establishment of CERN, the article illustrates the beginnings of CERN, from the first meetings to the provisional stages to the official ratification process. The article also gives Kowarski's thoughts on the future success of CERN and how it has already become a focal point in European collaboration and cooperation in high-energy physics. I mainly used this source to collect background information, as well as information about early cooperation across national governments. The source also furthered my understanding about the communication efforts between different countries and amongst different professions, such as the many exchanges between physicists and financialists.

Lippincott, Sara. "A Conversation With Valentine L. Telegdi – Part I." *Physics In Perspective* 9.4 (2007): 434. *Advanced Placement Source*. Web. 25 Jan. 2016.

This source is an article accessed from the Ebsco database containing a personal interview with physicist Valentine L. Telegdi about his life in physics and his endeavors which took him from Europe to the United States and back again, at which point Telegdi worked at CERN for a short period of time. I used this source to provide an example of one of many physicists who traveled back to their home continent to work at CERN after World War II. Telegdi states in his reasons for returning to Europe that CERN was “well funded” and provided him and other physicists with advanced equipment to do research. The personal interview gave a firsthand account of what job opportunities in physics were like during the war, and gave me insight on how these opportunities and the war itself influenced physicists’ decisions during and after the war regarding the location of their studies.

"Marshall Plan Announced." Harvard University, Cambridge. 5 June 1947. *History.com*. Web. 21 Jan. 2016.
<<http://www.history.com/topics/world-war-ii/marshall-plan/speeches/marshall-plan-announced>>.

This source is an audio recording accessed from a website of Secretary of State George C. Marshall initiating the Marshall Plan in a speech at Harvard University on 5 June 1947. In his speech Marshall talks about the purpose of his plan - to rebuild European economy and maintain international political stability through this economic reconstruction. I used this source to highlight the purpose of the Marshall Plan and to show how the purpose served as part of the foundation for Isidor Rabi’s initiative at the Fifth General Conference of UNESCO in 1950. The speech helped me understand how the United States, despite its openness to assisting European countries, refused to help any country that would restrict the reconstruction of another.

Noyes, Dan. "About CERN." *CERN Accelerating Science*. CERN, 19 Jan. 2012. Web. 2 Nov. 2015. <<http://home.cern/about>>.

This source is a webpage on the CERN website containing a timeline of the influential events in CERN’s history. Clicking on the timeline gives one access to a detailed overview of the history of CERN, from its origins in the late 1940s to the recent discovery of pentaquarks in 2015. Many of the timeline entries have accompanying images, such as a paper with the signatures of the delegates from the twelve founding member states to ratify the CERN convention and officially establish the organization. I used this source to find information on CERN’s Proton Synchrotron (PS) and how it was a key advance in particle physics at the time. The source also helped me understand the order in which CERN’s accelerators were inaugurated and decommissioned, and how each contributed to CERN’s overall objective: to research and to solve the mysteries of the early universe. I also used the timeline to gain a basic overview of CERN’s creation, from the formation of the provisional CERN in 1952 to the establishment of the official organization in September 1954.

O'Lunaigh, Cian. "The Birth of the Web." *CERN Accelerating Science*. CERN, 11 Dec. 2013. Web. 1 Nov. 2015. <<http://home.cern/topics/birth-web>>.

This source is a webpage explaining how Tim Berners-Lee, a scientist at CERN, created the World Wide Web in 1989. This development has drastically influenced the world as we know it today by allowing for mass distribution and unclassified viewing of information worldwide. I used this source to provide an example of CERN's legacy and how the organization has contributed to modern global society. It also helped me understand the purpose of the first web server and how the web was released for public use.

O'Lunaigh, Cian. "The Higgs Boson." *CERN Accelerating Science*. CERN, 21 Jan. 2014. Web. 9 Nov. 2015. <<http://home.cern/topics/higgs-boson>>.

This source is a webpage from the CERN website on the Higgs boson. The article basically states that the Higgs was discovered on 4 July 2012 at CERN's Large Hadron Collider, and the source was solely used for this information. I also came to understand how the Higgs relates to modern particle physics and how Peter Higgs and François Englert, particle theorists who proposed the idea of a "Higgs field", of which the Higgs boson is a carrier, were awarded the Nobel Prize as a result of this discovery.

Schopper, Herwig. "CERN's Early History Revisited." *Physics Today* 58.4 (2005): 87. *Advanced Placement Source*. Web. 16 Oct. 2015.

This source is an article accessed from the Ebsco database, and is the first of three letters to the editor on influential figures in the establishment of CERN. The letter is written by a former director-general of CERN, and gives credit to Isidor I. Rabi as well as many renowned European physicists who supported Rabi's initiative and helped to create CERN, including some Nobel Prize laureates. This source was used for background information, such as the initial purpose behind CERN's creation and how World War II influenced Rabi's initiative. It also gives a quote from Rabi stating that the creation of the atomic bomb "had a large part in making CERN possible...", which helped me understand how recent advances in physics paved the way for CERN's creation.

"The Significance of Cern." *CERN Document Server*. N.p., 29 Mar. 2006. Web. 9 Nov. 2015. <<https://cds.cern.ch/record/938897?ln=en>>.

This source is an audio recording accessed from the CERN document database, containing a speech by CERN Director-General Victor F. Weisskopf from 1976. Weisskopf talks about the political, economic, and social influence that CERN had on Europe in its early years as an international organization. I used this source as a reference for early impacts of CERN in the context of World War II, such as the reunification of Europe's scientific community and the division of the cost of research equipment so as not to endanger any specific country economically. The source also gave me a firsthand account of CERN's significance from a leader of the organization.

United Nations Educational, Scientific and Cultural Organization (UNESCO). *RECORDS OF THE GENERAL CONFERENCE OF THE UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION - FIFTH SESSION - FLORENCE, 1950*. Paris: UNESCO, July 1950. Print.

This source is a compilation of the resolutions put forth and adopted at the Fifth General Conference of UNESCO in Florence, Italy, in 1950. The document was accessed from the UNESCO database. I used the records for Isidor Rabi's initiative and resolution in particular, as Rabi's proposal triggered the series of events that would eventually culminate in the creation of CERN. I discovered that Rabi advocated for international European physics laboratories to improve and restrengthen European physics collaboration in the wake of World War II. The size of the document also helped me gain insight on the surplus of issues UNESCO had to deal with around the time period that the idea that would become CERN was first proposed.

Secondary Sources

Aczel, Amir D. *Present at the Creation: The Story of CERN and the Large Hadron Collider*. New York: Crown, 2010. Print.

This source is a book about the Large Hadron Collider at CERN, how it was created, how it operates, and what scientists and researchers hope to accomplish through the use of the “ultimate particle accelerator”. I used this source as a reference for information on how CERN scientists, from CERN’s creation in 1954 until present day, have explored subatomic particles for peaceful purposes, and how they have exchanged their findings with the world and each other. The book also gave some historical context information, such as J. J. Thomson’s discovery of the electron in 1898, and some background on the creation of CERN. It helped me understand the inner workings of CERN and how multiple diversified teams “compete” against each other in a friendly, productive, collaborative fashion, while at the same time gathering crucial information on what the universe was like in its early moments.

Bailey, Ellen. "Enrico Fermi." *Enrico Fermi* (2006): 1-3. *History Reference Center*. Web. 31 Oct. 2015.

This source is an article accessed from the Ebsco database that gives an overview of Enrico Fermi, credited to be the “father of the atom bomb”. The source was used to gather information about Fermi and how he influenced the trajectory of nuclear physics during the end of World War II and the beginning of the Cold War. I also came to understand how Fermi was able to make a name for himself after immigrating to the United States and stemming from a family that could not afford a high-quality education.

"CERN." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 26 Oct. 2015. <<http://school.eb.com/levels/high/article/22146#>>.

This source is an article accessed from the Britannica database which gives an overview of CERN, its history, its achievements, and its purpose. I used the source to gain basic information on the topic, such as the change in the name of the organization (from “Conseil Européen pour la Recherche Nucléaire” to “Organisation Européen pour la Recherche Nucléaire”) and the size of the CERN laboratory in Geneva. This source also helped me solidify my knowledge of the purpose of CERN’s existence and the notable accelerators in the organization’s history.

"Cold War." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 31 Oct. 2015. <<http://school.eb.com/levels/high/article/24721>>.

This source is an article accessed from the Britannica database that gives an overview of the Cold War, its origins, the happenings in the countries involved, and its end. I used the webpage to pinpoint the “pinnacle” of the Cold War, from 1948 to 1953. I came to understand that in that time period the international tensions between the democratic

United States alliance and the Communist Soviet alliance as both countries began inching closer and closer to armed conflict though never actually reaching that point.

"The Cold War." - *John F. Kennedy Presidential Library & Museum*. N.p., n.d. Web. 01 Nov. 2015. <<http://www.jfklibrary.org/JFK/JFK-in-History/The-Cold-War.aspx>>.

This source is a webpage that describes the Cold War and John F. Kennedy's influence on the United States' role in the international tensions. I used this source as an overview of the Cold War and its beginnings, such as how the Soviets assumed control over Eastern Europe with their Communist regime while the United States and the United Kingdom worked to preserve traditional government control in Western Europe. This gave me an understanding of the context of CERN's existence and why the creation of CERN was such an influential step in the reunification of Western European countries.

"Empedocles." *Britannica School*. Encyclopædia Britannica, Inc., 2016. Web. 19 Jan. 2016. <<http://school.eb.com/levels/high/article/32550>>.

This source is an article accessed from the Britannica database which gives a description of the ancient Greek Empedocles, known for his theory of the four elements, which was favored and accepted by the world until the turn of the nineteenth century. I used this source to gain an overview of who Empedocles was and what he accomplished to provide context for the birth of particle physics. I also came to understand how Empedocles theorized that nothing is created or destroyed, but instead that everything is transformed, a theory humans still acknowledge today.

"Ether." *Britannica School*. Encyclopædia Britannica, Inc., 2016. Web. 16 Mar. 2016. <<http://school.eb.com/levels/high/article/33121>>.

This source is a concise article accessed from the Britannica database which summarizes the origins, role in pre-19th century physics, and eventual disregard of the classical element called "ether" or "aether", focusing mainly on ether's undetectability and virtual transparency. I used this article to display how the theory of the existence of ether was created and introduced by Aristotle and how it became the fifth classical element along with earth, water, air and fire. The webpage also revealed to me the invalidation of the ether element specifically, and how its invalidation paved the way for Albert Einstein to develop his theory of relativity with no restrictions that would have been brought on by the existence of ether.

"Fermi National Accelerator Laboratory." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 22 Nov. 2015. <<http://school.eb.com/levels/high/article/34056>>.

This source is an article accessed from the Britannica database that gives an overview of Fermilab, an American particle physics laboratory in Illinois. The webpage briefly explains the establishment of Fermilab, named after renowned physicist Enrico Fermi, and the organization's achievements, including the construction and use of the Tevatron,

for a while the world's most powerful particle accelerator with maximum energies of up to about 1 teraelectron volt. I used this source to give an example of an organization that rivaled CERN's scientific endeavors and to show why America supported the existence of CERN but did not decide to actively participate in the international physics activity conducted at CERN. The source also helped me understand that until Fermilab's establishment in the 1960s and the inauguration of the Tevatron in the 1980s, CERN was close to unrivaled in advances in particle physics research.

Giudice, Gian Francesco. *A Zeptospace Odyssey: A Journey into the Physics of the LHC*. Oxford: Oxford UP, 2010. Print.

This source is a book about the Large Hadron Collider and the expectations that particle physicists have for the new particle accelerator. The source also talks about how the LHC is a step in the direction of a new age in discovery and research. I used this source to illustrate how the LHC is not to be used solely for discovery, but also for answers to questions and debates yet to be solved. The source was also key in helping me understand how physicists used previous theories, such as the theory of the existence of the Higgs particle, to predict what will be discovered at the LHC.

Halpern, Paul. *Collider: The Search for the World's Smallest Particles*. Hoboken, NJ: John Wiley & Sons, 2009. Print.

This source is a book explaining the purpose of the Large Hadron Collider at CERN and predicting what mysteries the machine will reveal in its lifetime. The book also talks about particle accelerators and colliders before the LHC and the laws and forces of physics that drive the colliders. I used this source as a reference for some of CERN's first colliders and how the technologies at CERN have developed since the organization's establishment, as well as some controversy over developments at the LHC between physicists and the general public, namely the fear that microscopic black holes would be produced during research and swallow up the world. The book helped me to better understand CERN's initial methods of finding out more about the universe, such as early accelerators like the Proton Synchrotron (PS). I also found information on how CERN's founders, including Isidor I. Rabi, were against the idea of a military-based organization and did not approve of the destructive use of any research conducted at CERN, especially in the wake of the Second World War.

Herd, Alex. "Cold War." *The Canadian Encyclopedia*. Historica Canada, 6 Feb. 2006. Web. 2 Nov. 2015. <<http://www.thecanadianencyclopedia.com/en/article/cold-war/>>.

This source is a webpage that gives an overview of the Cold War and Canada's position during the Cold War. I used this source to strengthen my historical context regarding the Cold War and to make note of the collapse of the previously sturdy Soviet-American alliance that crumbled into opposing viewpoints. The webpage also helped me understand what points of interest influenced this collapse, such as diplomacy (democracy vs. Communism).

Hermann, Armin, John Krige, Ulriche Mersists, Dominique Pestre, and Lanfranco Belloni. *Vol. 1: Launching the European Organization for Nuclear Research*. Amsterdam: North Holland, 1987. Print.

This source is a book explaining in depth the history of the European Organization for Nuclear Research, from its first beginnings through the provisional stage of its existence to the ratification of its twelve founding member states in 1953 and 1954. The source highlighted the influential conferences in the establishment of CERN, including the Fifth General Conference of UNESCO, at which Isidor Rabi proposed his initiative to construct a nuclear physics laboratory in Western Europe. The book also contained a brief section on historical context, mainly how high-energy accelerator physics had developed over time up to the origins of CERN. I used this source to make note of how not all of Europe's scientists approved initially of the idea of a supranational organization for particle physics and how many believed that there was an easier method for European scientific reintegration. The source also helped me in understanding the reactions from each participating country to each conference held for the establishment of CERN and the opinions expressed by different countries at such conferences.

"Higgs boson." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 3 Sep. 2015. <<http://school.eb.com/levels/high/article/40396>>.

This source is an article accessed from the Britannica database which gives an overview of the Higgs boson, a subatomic particle thought to make other particles massive. The webpage was used to gain basic information on the Higgs, such as how it was named after Peter Higgs, a physicist who proposed the existence of a mass-bestowing "Higgs field" in 1964. I also used this source to acquire a basic understanding of what the Higgs particle means for physics, such as what it explains and what laws of physics it dictates.

Khan, Sameen Ahmed. "CERN's Early History Revisited." *Physics Today* 58.4 (2005): 87. *Advanced Placement Source*. Web. 16 Oct. 2015.

This source is an article accessed from the Ebsco database, and is the second of three letters to the editor on influential figures in the establishment of CERN. The letter talks about physicist Edoardo Amaldi and his contributions to the organization, and highlights as well early skepticism and opposition to Amaldi's and CERN's initiative. I used this source to broaden my range of people in the history of CERN beyond Isidor Rabi. The letter helped me understand how Amaldi assisted other physicists and called meetings to complete crucial steps in the making of CERN.

Krige, John. "CERN's Early History Revisited." *Physics Today* 58.4 (2005): 89. *Advanced Placement Source*. Web. 16 Oct. 2015.

This source is an article accessed from the Ebsco database, and is the third of three letters to the editor on influential figures in the establishment of CERN. The letter gives credit

and respect to the previous two entries and reminds readers of the author's intent on describing Isidor I. Rabi's influence on CERN's creation. I used this source to show that Rabi abided by the previously instituted Marshall Plan and Schuman Plan, designed to rebuild the demolished European economy after World War II, when proposing his initiative to establish CERN. The letter also helped me understand how Rabi was opposed to the idea that CERN would be used for military purposes, and how he stressed that all research done at CERN would be publicized and used for peaceful advances in particle physics.

Krige, John. "I. I. Rabi And The Birth Of CERN." *Physics Today* 57.9 (2004): 44. *Advanced Placement Source*. Web. 21 Oct. 2015.

This source is an article accessed from the Ebsco database which elaborates on Isidor I. Rabi's influence on the creation of CERN. I used this source to gather information on the historical context of the time period of CERN's establishment and on Rabi, credited to be the "father" of CERN. The source was also used to highlight how America was involved with the creation of CERN, a European organization, and why Rabi was the person to propose CERN's establishment even though he was not a European. The article also helped me understand Rabi's motivation behind lobbying for the creation of a multinational physics lab in Europe, as well as the status of particle physics during World War II and the Cold War.

Krige, John. "The Influence of Developments in American Nuclear Science on the Pioneers of CERN." (1983): *CERN Document Server*. Web. 25 Jan. 2016.
<<https://cds.cern.ch/record/151765/files/CERN-CHS-1.pdf>>.

This source is an article accessed from the CERN document server about how advances in American physics and other nuclear sciences affected the judgment of European physicists who were influential in the creation of CERN. The author explains that America served as a model and a resource for the European physics community, but also a threat to young physicists and the community itself in the aftermath of the Second World War and the beginning of the Cold War. I used this source to show that many of Europe's physicists did end up being drawn to the United States for its advances in physics, referred to now as the European "brain drain". The article also gave me the understanding that American physics advances had a positive affect as well as a negative effect on the European community, and that physicists such as Isidor Rabi and company took both sides of the issue into account when making decisions.

Krige, John. "Isidor I. Rabi And CERN." *Physics In Perspective* 7.2 (2005): 150. *Advanced Placement Source*. Web. 30 Sept. 2015.

This source is an article accessed from the Ebsco database describing Isidor I. Rabi's involvement and initiative in the creation of CERN. The article stresses Rabi's adherence to the Marshall and Schuman Plans and how he shaped his initiative around the aims of the two plans: to reunify and reconstruct the Western European governments and

economy. This article was used to highlight those purposes of Rabi's initiative. The source also helped me understand how Rabi's plan for CERN would combat the Communist regime that had taken control of Eastern Europe during the Cold War.

Lecuyer, Christophe, and David C. Brock. "From Nuclear Physics To Semiconductor Manufacturing: The Making Of Ion Implantation." *History & Technology* 25.3 (2009): 193. *Advanced Placement Source*. Web. 27 Oct. 2015.

This source is an article accessed from the Ebsco database that elaborates on ion implantation, its origins in nuclear physics, and how it was used in the manufacturing process. I used this source specifically to gather information on Robert Van de Graaff, a physicist from MIT, and how he built signature "Van de Graaff" accelerators for the United States during World War II. This helped me understand how particle physics and particle accelerators gradually emerged in the 1930s and 1940s, all culminating into the creation of CERN and the United States-based Fermilab.

Lincoln, Don. *The Large Hadron Collider: The Extraordinary Story of the Higgs Boson and Other Stuff That Will Blow Your Mind*. Baltimore: Johns Hopkins University Press, 2014. Print.

This source is a book published after the discovery of the Higgs boson that elaborates on the Large Hadron Collider and the events leading up to the discovery of the particle thought to bestow mass on other particles. The source also had a small section dedicated to a concise history of CERN, which I used to gather information about early accelerators at CERN and how their turn-ons propelled CERN into the global scientific spotlight. The source also helped me understand how CERN reunified the countries of Europe after the continent was swept by war and destruction.

"Manhattan Project." *Britannica School*. Encyclopædia Britannica, Inc., 2016. Web. 19 Jan. 2016. <<http://school.eb.com/levels/high/article/50535>>.

This source is an article accessed from the Britannica database which gives an overview of the Manhattan Project, which produced and detonated the first atomic bombs during World War II. The article also gives information about the funding and leadership for the project, as well as scientists involved in the project such as Albert Einstein and J. Robert Oppenheimer. I used the source to provide evidence on how the United States used the Manhattan Project to become the first country to wield the power of the atom in such a way that entire cities could be demolished, as evident by the bombings of Hiroshima and Nagasaki, and I came to understand how America's detonation of the atomic bomb made the country the most powerful country in military force and gave them a near monopoly on atomic warfare until the detonation of the first Soviet atomic bomb a few years later.

"North Atlantic Treaty Organization (NATO)." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 1 Nov. 2015. <<http://school.eb.com/levels/high/article/56176>>.

This source is an article accessed from the Britannica database which gives an overview of NATO, short for the North Atlantic Treaty Organization. The article was used to acquire historical context during CERN's creation and to give an additional example of post-World War II European collaboration through the establishment of an international organization. It helped me to understand that there were other ongoing projects in fields other than science and physics whose aims were to reintegrate the war-torn countries of Europe and resist the impending Soviet threats brought on by the Cold War.

"Particle accelerator." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 31 Dec. 2015. <<http://school.eb.com/levels/high/article/108531>>.

This source is an article accessed from the Britannica database that describes the properties of a particle accelerator and its uses in society, including nuclear physics. I used the article to acquire a brief overview of what a particle accelerator does and how its function relates to nuclear physics. I also came to understand how particle accelerators are used in professions other than subatomic physics, such as radiography and radiation therapy.

Perritano, John. "How CERN Works." *HowStuffWorks*. HowStuffWorks.com, 1 July 2008. Web. 2 Nov. 2015. <<http://science.howstuffworks.com/science-vs-myth/everyday-myths/cern1.htm>>.

This source is a webpage which gives an overview of CERN, its history, its purpose, and its latest achievements, particularly the discovery of the Higgs boson. I used the webpage to explain the reasons CERN exists, which are to explore the secrets of particle physics and to solve the mysteries of the universe immediately after the Big Bang, and how CERN has worked towards this goal through the construction of high-energy accelerators such as the Large Hadron Collider. The source also helped me understand how the CERN community has expanded and developed to encompass 21 member states, and how the central leadership at CERN functions.

"Physics." *Funk & Wagnalls New World Encyclopedia* (2014): 1p. 1. *Funk & Wagnalls New World Encyclopedia*. Web. 31 Oct. 2015.

This source is an article accessed from the Ebsco database that gives a description of the concept of physics, its history, its uses, and key events in its development. The source was used to collect examples of advances in physics, such as the discovery of the neutron by Sir James Chadwick in 1932. This helped me understand what events leading up to and during World War II resulted in the opportunity of making CERN to utilize these new discoveries.

Rigden, John S. "Isidor Isaac Rabi." *Great Lives From History: Scientists & Science* (2012): 738. *Science Reference Center*. Web. 30 Sept. 2015.

This source is an article accessed from the Ebsco database in which a description of Isidor I. Rabi is given, including his background, his work in atomic physics, and his contributions to both American and European physics. I used this source to show that before his involvement with CERN, Rabi supported and helped strengthen the American physics program to match their European competitors, and only after the Second World War did he switch gears and support the European scientific community. I also came to understand how Rabi used science to promote international peace and cooperation.

Sample, Ian. *Massive: The Missing Particle That Sparked the Greatest Hunt in Science*. New York: Basic, 2010. Print.

This source is a book about Peter Higgs and his theory of a “god particle” that gave other particles mass, what we now know today as the Higgs boson. I used this source minimally as an example of a setback that CERN encountered in the process of building the Large Electron-Positron collider (LEP) and how the fact that CERN straddled the French-Swiss border led to detriments from some of the surrounding community. I also came to understand how different land ownership laws in different countries can affect the construction of a facility that spans the border between the two nations.

"Sir Tim Berners-Lee." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 15 Nov. 2015. <<http://school.eb.com/levels/high/article/389930>>.

This source is an article accessed from the Britannica database, which gives an overview of Sir Tim Berners-Lee, the father of the World Wide Web, including his background in computing and his involvement with CERN. I used this source to provide supporting information for the creation of the Web, which changed modern society and allowed for the nearly limitless exchange of information. The source also helped me understand how Berners-Lee took up computing due to his parents’ involvement in the construction of the first commercially utilized computer.

"Subatomic particle." *Britannica School*. Encyclopædia Britannica, Inc., 2015. Web. 3 Sep. 2015. <<http://school.eb.com/levels/high/article/108593>>.

This source is an article accessed from the Britannica database that describes subatomic particles, how they operate, how they were discovered, and how they are put to use today. I used this source to acquire information about the origins of particle physics and early theories regarding what subatomic particles were known to exist at the time. From this I could understand how older theories, such as P.A.M. Dirac’s quantum field theory, were challenged by the discovery of new particles, such as the discovery of the positron (anti-electron) by Carl Anderson in 1932. I also used this source to show how the birth of particle physics and particle theory contradicted popular belief of the constitution of all things by the four universal elements (earth, water, air, fire).