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Application of Particle Physics Detector in Medical Science

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Abstract
Initially, the growth of particle detectors was focused on the identification of particles, but new detector designs have made it possible to build new diagnostic techniques. Clinical settings and medical research facilities utilize cutting-edge methods developed from particle accelerators, detectors, and physics computers, including imaging technologies, accelerators specifically designed for cancer therapy, simulations, data analysis, and nuclear medicine. It is still obvious that research in nuclear and basic particle physics is what motivates and propels the development of particle detectors for medical applications. The applications of the particle physics detector in medical science will be the main topic of this paper.

Keywords Particle physics · detectors · accelerators · imaging · hadron therapy

Introduction

In addition to expanding our understanding of the universe, basic research in particle physics also serves as a catalyst for new technological advancements. The three technological foundations of particle physics, accelerators, detectors, and computer tools, have all entered the medical industry. Modern methods drawn from particle accelerators, detectors, and physics computers are often employed in clinical settings and medical research facilities.[1] Thanks to the development of innovative particle detectors, which was motivated by and is currently supported by elementary particle and nuclear physics, other fields of investigation now have more options. Medicine and bio-medicine would not be possible without the use of particle radiation, which was long ago developed into a technology unto itself. The most widely used particle detector in medicine is still x-ray film. Alternative detector types, such as scintillation detectors or ionization chambers used in scanning equipment, were introduced as a result of the development of the tomographic technique in nuclear medicine.[2]

Modern medicine relies heavily on particle accelerators and detectors to investigate, diagnose, and treat illnesses in humans. Today, many hospitals will have equipment produced by physics fundamental research. While many applications are well known, many more are the subject of scientific study, and fresh concepts are constantly on the horizon. Experimental particle physicists may make significant contributions and offer fresh perspectives in this exciting and dynamic environment, thanks to their knowledge gained from fundamental research. Accelerated beams of charged hadrons, in particular, protons and carbon ions, allow for the precise external irradiation of solid tumors. Particle detectors with high performance are essential for both scientific research and applications.[3]

CERN has grown to be the largest particle physics laboratory in the world since its founding in September 1954. The facility presently employs more than 12,000 scientists from the more than 22 countries that make up CERN, as well as from other nations. The goal of particle physics is to provide a basic explanation for how the universe formed, how it is structured, and how it has changed through time. These technical advancements are essential building blocks for particle physics research, but they may also be used for a variety of other purposes that directly benefit society, such as vital medical applications like imaging and radiation treatment. The scale of particle accelerators has steadily expanded to allow for fresh research and discoveries as both our technological process and our comprehension of physics have improved.[4] Scientists are able to both confirm the existence of theoretically expected particles and find new ones,

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thanks to the Large Hadron Collider (LHC) use in studying the results of collisions between proton beams traveling at almost the speed of light. The technologies used in each experiment's many detectors are what set it apart from others. Beyond the achievements of the LHC in particle physics, several additional discoveries in various other scientific disciplines and applications, such as radiation treatment and medical imaging, are now being driven by the technological advancements required to implement the LHC and its experiments.[5]

Particle Physics Applications in Medical Science

It is evident that physics, particularly particle physics, has greatly influenced the creation of instruments for bio-medical study, diagnosis, and treatment. The therapeutic value of ionizing radiation is real. The groundbreaking work has been utilized in the treatment of malignancies ever since. X-rays and other forms of imaging technology were first discovered by physicists and physicians. The end of the nineteenth century saw the discovery of radiation. Since 1953, when the first linear accelerator specifically designed for medical purposes began treating patients at the Hammersmith Hospital in London, accelerators have been utilized to treat cancer.[6] Beyond the actual technology, the collaborative nature of particle physics can also significantly increase the likelihood that ground-breaking innovations will be used to advance medical diagnosis and therapy. In other words, to maximize the benefits of particle physics for society, it will be essential for physicists and medical specialists to collaborate on their study.

Imaging-Related Particle Detectors

A wide range of disorders may now be detected, diagnosed, and treated differently thanks to medical imaging. Technology advancements have made imaging quicker, more accurate, and less intrusive. Georges Charpak, who in 1968 created the multiwire proportional chamber (MWPC), which revolutionized particle physics, and two crucial pioneers were David Townsend and the development of positron emission tomography (PET) imaging for medical applications. The top quark was discovered at Fermilab in Chicago, while the charm quark was discovered at Stanford linear accelerator laboratory and Brookhaven national laboratory. The Z and W bosons were first observed at CERN in 1983, thanks to the MWPC, which quickly established itself as a crucial tool in particle physics.[5,7] Charpak worked hard to make sure that these detectors could be used in radiography for medicinal purposes. Given that digital read-out enhances both sensitivity and spatial resolution, it is becoming more common to replace photographic film in this situation. Faster scanning as well as lower body doses are also made achievable when using radiation or particle beam-based medical diagnostic equipment by accelerating the recording speed. A positron-emitting radioactive tracer must first be administered into the body while still connected to a physiologically active molecule in order to produce a PET image. The tracer emits positron particles that travel just 1 mm into the body before colliding with an electron nearby and splitting into two gamma rays that go in opposing directions. These gamma rays are picked up by PET scanners, and computational techniques may be used to recreate a picture from the data collected, while employing radiation or particle-based diagnostic techniques in medicine.[5]

Modern PET scanners, which now frequently have high-end multi-detector CT scanners built in, have evolved into crucial imaging tools for a variety of medical purposes. PET scans are used in normal medical treatment to visualize cancer metastases about 90% of the time, with other uses in neuroimaging, cardiology, and drug research.[7] By enabling more rapid and precise localization of positron annihilation events within the patient, time-of-flight (TOF) PET will enhance image quality. Scientists are currently developing TOF PET to be more exact. In order to determine the location of the annihilation event that is most likely to occur, the time interval between the detection of the two photons generated during the positron–electron annihilation is measured by TOF PET.[5,7]

Hadron Therapy

Particle physics-related innovations and technology in particular have been playing an ever more significant role in medicine. The relationship between basic physics (the ability of particles to go through matter) and medicine (the cure for cancer) is best exemplified by hadron therapy, sometimes referred to as particle therapy.[1] In 1946, physicist and Fermilab creator Robert Wilson made the first mention of the possibility of using high-energy charged particle beams to treat cancer. Exactly 1 month and 1 year after the founding of CERN, in September 1954, patients received the first protons from the Lawrence brothers and their Berkeley colleagues.[8] Particle therapy is thought to be preferable to even the most advanced x-ray delivery techniques, since the dose may be concentrated on the tumor without harming the nearby healthy tissue. Charged particles can enter the body deeply because, unlike photons, they only leave a small amount of their energy behind when they move through it. Because the particles only release their energy until they come to a complete halt, the energy at which they enter the body can be altered to change the depth of penetration. This suggests that the radiation dose can be precisely targeted inside the tumor area, utilizing pencil beams that are finely focused, scanned, and have varying levels of penetration, and that the dose profile can be adjusted to the geometry of the tumor.[5] While the majority of the radiation from x-rays is delivered to the patient's skin within a few centimeters, part of the dosage is sent to healthy tissue before and after it reaches the tumor in a more continuous manner. Charged particles can cure tumors more successfully than x-rays because their increased relative biological efficacy can inflict more damage to cancer cells per unit of energy deposited in the tissue. This is because charged particles interact with human tissue at a higher density of ionization events, which also suggests that heavier ions, like carbon, may be even more successful in treating radio-resistant tumors than protons. Numerous research facilities have shown that proton therapy is helpful in treating cancer since the first patient was treated there.[5] These include the Uppsala accelerator in Sweden, the Harvard cyclotron laboratory in Boston, three Russian facilities in Moscow, Dubna, and St. Petersburg, as well as the first patient ever treated in Europe at the Uppsala Accelerator. Additionally, research investigations have been conducted at the Paul Scherrer Institute in Switzerland, the Clatterbridge Hospital in the United Kingdom, and the Japanese accelerators in Chiba and Tsukuba.[5,8] Following these fruitful researches, Fermilab assisted in the construction of the first center specifically dedicated to proton treatment at the Loma Linda University medical center in California.[5] Since the first patient was treated here in 1990, more than 17,000 cancer patients have received care at this pioneering hospital-based institution. Since 1994, a heavy-ion accelerator made expressly for medical applications has been used in Chiba, Japan, to launch the first clinical application of carbon ions.[5]

Conclusion and Future Outlook

The impact on medicine and biology becomes clearer when one considers the advancements made in fields like radiography, diffractive photon, electron, and neutron scattering, and emission tomography, none of which would have been possible without suitable detectors. The advancement of particle detectors for use in medicine is still clearly influenced and driven by work in nuclear and basic particle physics.

Modern clinical settings and medical research facilities frequently employ cutting-edge techniques generated from particle accelerators, detectors, and physics computers. Examples include the use of data analysis, specific cancer therapy accelerators, simulations, and PET scanning technology. PET, a direct application of light-sensing methods, is a prime example of a particle detector's medical uses. Tools for data management and simulation created by physicists are used in the biomedical industry, for instance, in the creation of individualized treatment programs. It is important to coordinate the research efforts of physicists and physicians in order to maximize the benefits of particle physics for society. Particle and accelerator physics expertise may affect future medical practices in ways more than merely technology. Since ENLIGHT's inception, hadron treatment research and development has changed its direction, which is due to the sharp rise in the number of clinical centers, particularly those offering proton treatment.

Conflict of interest The authors declare that they have no conflict of interest.

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