
Accelerators Working Group

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3.1 Introduction and Motivation

Accelerator physics is the study of the design, operation, and applications of particle accelerators, which are devices that use electromagnetic fields to accelerate and manipulate charged particles. Particle accelerators have many uses in science, medicine, industry, and security, such as producing beams of high-energy photons, electrons, protons, or ions for nuclear physics, nuclear medicine, materials science, radiation therapy, and nuclear security. This field holds the key to transformative advancements in various scientific and technological domains. While this discipline has made significant strides globally, the landscape of accelerator physics in Africa presents a unique set of challenges and opportunities.

In recent years, accelerator facilities have become indispensable tools for fundamental research, material science, medical applications, and industrial processes. However, despite the increasing importance of accelerator-based technologies, Africa faces distinctive hurdles in establishing and maintaining state-of-the-art accelerator facilities. The demand for accelerator physics expertise in Africa is experiencing remarkable growth, fueled by the continent's ambitious pursuit of scientific and technological advancements. However, this progress is met with considerable challenges that arise from limited resources, infrastructure, and research funding. Despite these barriers, notable strides are being made in accelerator science across the continent. With over 578 accelerator facilities that support scientific research and offer some analytical or irradiation services to diverse community of users, distributed in 59 countries around the world, several accelerator facilities have been established in Africa, showcasing a commitment to advancing nuclear and particle physics research [1]. In particular, Algeria hosts one electrostatic accelerator at the Center de Recherche Nucleaire d'Alger [2], while Tunisia operates an Accelerator-Based Neutron Source at the Centre National de Sciences et Technologies Nucleaires [17]. In Egypt, the Atomic Energy Authority oversees one Electrostatic Accelerator, and Zagazig University houses an Accelerator-Based Neutron Source [18]. Ghana boasts an Electrostatic Accelerator at the Accelerator Research Centre, while Nigeria is equipped with an Electrostatic Accelerator at the Centre for Energy Research and Development [19]. South Africa leads the continent with six accelerator facilities, including three Accelerator-Based Neutron Sources at Nesca and iThemba, and three Electrostatic Accelerators at the University of Pretoria, iThemba Labs in Johannesburg, and iThemba Labs in Cape Town. These installations stand as beacons of scientific progress, contributing to the broader landscape of accelerator physics in Africa (see Fig. 3-1).

The field of accelerator physics in Africa has also experienced a steady increase in research output over recent decades. Fig. 3-2 shows a review of publication trends from 1967 to 2024 reveals minimal activity during



Figure 3-1: IAEA Physics Section's Developed and Maintained Interactive Map Showcasing Accelerators Across Africa [1]

599 the early years, with significant growth beginning in the late 1990s. The 2012s marked a peak in publication
600 activity, reflecting the impact of international collaborations, regional initiatives, and the establishment of
601 new facilities. Although fluctuations are evident, particularly after 2020 due to factors like the COVID-19
602 pandemic, recent years show a strong upward trajectory, underscoring the continent's expanding role in
603 the global accelerator-physics community. This growing body of research demonstrates Africa's potential to
604 contribute to fundamental and applied science, despite the challenges of limited infrastructure and funding.

605 Collaborative efforts among African nations and international partnerships have further accelerated progress,
606 fostering the establishment of facilities aimed at addressing both local and global challenges. From funda-
607 mental research in nuclear and particle physics to applications in medical diagnostics and materials science,
608 African scientists are actively involved in pioneering initiatives that will pave the way for transformative
609 advancements in science and technology.

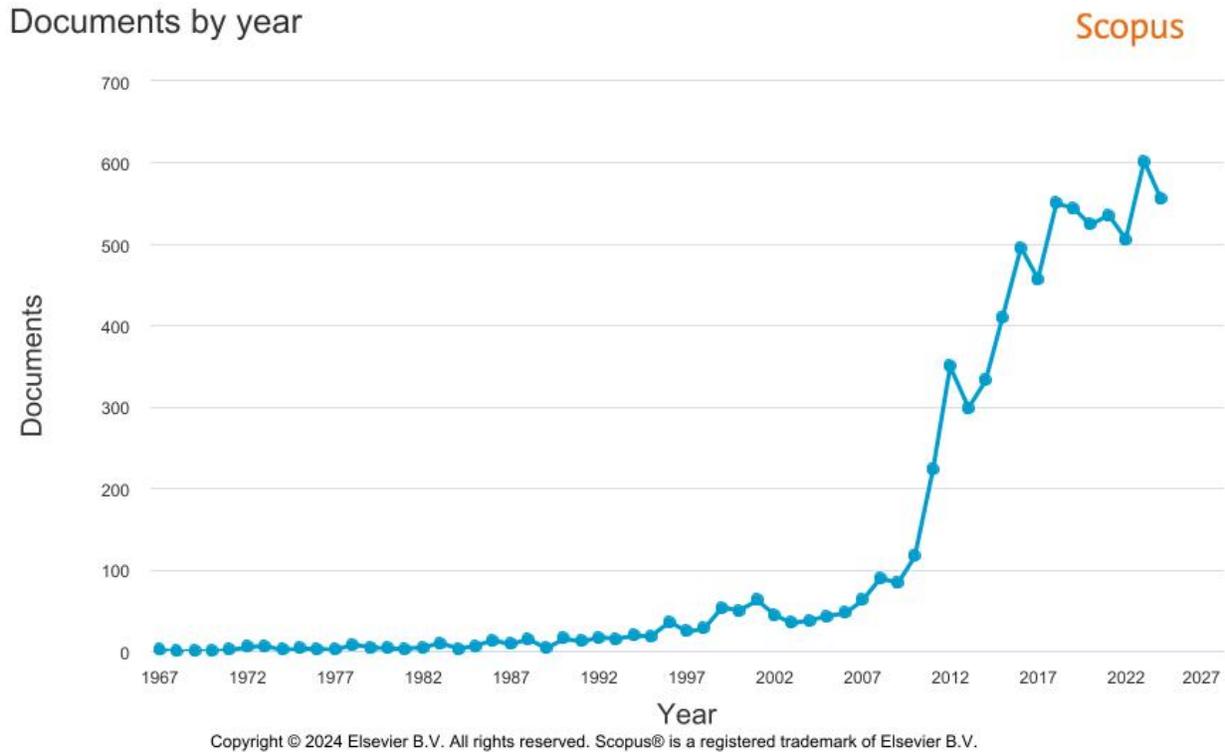


Figure 3-2: Annual Research Output in Particle Accelerator Physics in Africa (1967–2024) (Source: Scopus [6])

610 3.2 Accelerator Physics Capacity in Africa

611 Within the realm of accelerator physics in Africa, a spectrum of scientific activities unfolds, reflecting a
 612 diverse range of research endeavors. Countries such as South Africa, Nigeria, and Egypt, among others,
 613 have emerged as focal points for accelerator-based investigations. These endeavors encompass fundamental
 614 studies in nuclear and particle physics, exploring the fundamental building blocks of matter, and unraveling
 615 the mysteries of the universe.

616 One notable example is the iThemba LABS facility in South Africa, a prominent accelerator center that
 617 serves as a hub for nuclear and particle physics research. Researchers at iThemba LABS are engaged in
 618 investigations spanning nuclear structure, astrophysics, and materials science, contributing valuable insights
 619 to both fundamental science and applied technologies.

620 Collaborative efforts are a hallmark of the accelerator physics landscape in Africa. Initiatives like the African
 621 School of Fundamental Physics and Applications (ASP) bring together physicists from across the continent
 622 to share expertise, foster collaborations, and train the next generation of scientists. ASP not only facilitates
 623 knowledge exchange but also strengthens the scientific network within Africa, positioning the continent as
 624 an active participant in the global scientific community. Moreover, accelerator applications extend beyond
 625 theoretical explorations to practical solutions for societal challenges. Medical physics research, utilizing
 626 accelerators for cancer treatment and diagnostic imaging, is gaining momentum in several African countries.

627 These initiatives aim to enhance healthcare infrastructure and address pressing medical needs, showcasing
628 the tangible impact of accelerator physics on improving lives.

629 In energy research, accelerator-driven systems are explored as potential solutions for sustainable power
630 generation. African researchers are actively involved in studying accelerator-driven subcritical systems for
631 nuclear energy applications, contributing to the quest for cleaner and more efficient energy sources.

632 As we delve into the scientific activities of accelerator physics in Africa, this section will provide a compre-
633 hensive overview of key projects, collaborative initiatives, and advancements that underscore the vibrant
634 and dynamic landscape of accelerator research on the continent.

635 3.2.1 The iThemba LABS

636 The main facility for accelerator physics research and facilities in Africa is iThemba Laboratories for
637 Accelerator Based Sciences (LABS), which is a business unit of the National Research Foundation (NRF)
638 in South Africa. iThemba LABS operates one of the most significant and advanced cyclotron facilities in
639 the African continent and the separated sector cyclotron is the largest accelerator facility in the Southern
640 Hemisphere. The k-200 separated sector cyclotron can accelerate protons to energies of 200 MeV, and heavier
641 particles to much higher energies. iThemba LABS provides access to state-of-the-art research infrastructure,
642 both locally and globally, to facilitate activities that probe the nature, structure and properties of matter
643 and materials, and to produce radioisotopes that can be used for diagnostics, imaging and therapy in nuclear
644 medicine applications.

645 iThemba LABS has embarked on a recapitalization program, the overall objective of which is to safeguard
646 the long-term sustainability of Africa's most unique Accelerator Based research facility. The first pillar of
647 this program is the South African Isotope Facility (SAIF) [22], which is dedicated to research infrastructure
648 renewal whose accomplishment is geared to achieve the twin objectives of increase in radioisotope production
649 and research on the one hand, and the freeing up (on the other hand) of beamtime from the 200 MeV
650 Separated Sector Cyclotron which will be dedicated for sub-atomic physics research and applications [8].
651 The first phase of SAIF is centred around the acquisition of a 70 MeV Cyclotron to enhance research and
652 production of radioisotopes for nuclear medicine. In addition, iThemba LABS has two laboratories dedicated
653 to research at the atomic scale using particle beams from a 3-MV Tandetron and a 6-MV Tandem accelerator
654 [10]. These laboratories offer various techniques for ion beam analysis, ion implantation, subatomic physics,
655 and environmental isotopes. iThemba LABS also collaborates with other international facilities and networks,
656 such as the African light Source (AfLS), which is an initiative to build a synchrotron light source on the
657 African continent [9, 11].

658 3.2.2 CERD Nigeria

659 The Particle Accelerator Facility located at the Centre for Energy Research and Development (CERD)
660 within Obafemi Awolowo University, Ile-Ife, Nigeria, was inaugurated on September 28, 2008, primarily for
661 Ion Beam experiments utilizing a single beam line [12, 13]. The establishment of this facility was made
662 possible through the collaborative efforts of the Federal Government of Nigeria and the International Atomic
663 Energy Agency Technical Cooperation (IAEA TC) Project NIR 1010. The accelerator itself is a NEC
664 5SDH 1.7MV Pelletron Accelerator, a product of the National Electrostatics Corporation (NEC) based in
665 Middleton, WI, USA. Notably, in 2016, a significant enhancement was made to the facility by introducing

666 a second beam line, complete with an NEC RC43 end-station, thus further augmenting its capabilities and
667 research potential.

668 The Ion Beam Analysis (IBA) facility at CERD revolves around the utilization of a NEC 5SDH 1.7 MV
669 Pelletron Accelerator, incorporating an RF charge exchange ion source capable of generating both proton
670 and helium beams [4]. Although the accelerator can accommodate up to five beam lines, our current
671 configuration focuses on maintaining two operational beam lines. One of these lines is furnished with a
672 versatile End Station designed for four distinct analytical techniques: Particle Induced X-ray Emission
673 (PIXE), Rutherford Backscattering (RBS), Elastic Recoil Detection Analysis (ERDA), and Particle Induced
674 Gamma-ray Emission (PIGE). Meanwhile, the second beam line houses an NEC RC 43 End Station, similarly
675 equipped with these four techniques, with added capabilities for conducting grazing experiments on thin
676 samples, thereby enhancing our capacity for material studies. The application spectrum of our facility spans
677 across a multitude of fields, encompassing mineralogy, geological analysis, agricultural assessments of soil
678 and plant samples (including leaves, fruits, and seeds), biomedical and biological research, environmental
679 pollution monitoring, air quality assessments, materials science investigations, thin film studies, as well as
680 archaeological and cultural heritage analyses.

681 3.2.3 PELLETRON Accelerator in GHANA

682 The Ghana National Accelerator Project, initiated in 2008, aimed to acquire and install a 1.7MV Pelletron
683 Accelerator in Ghana, facilitated through cost-sharing with the International Atomic Energy Agency (IAEA)
684 [14, 15, 16]. This endeavor saw the generous donation of the accelerator, complete with Ion Source and high-
685 energy end components, from the Government of the Netherlands. The refurbishment of the accelerator
686 and the procurement of a complete beamline, as well as its subsequent installation, were financed by the
687 IAEA. In turn, Ghana contributed by providing essential local infrastructure, including the construction
688 of the facility building, electrical installations, air conditioning, and water and compressed air systems.
689 Furthermore, the project prioritized human capacity building, with support from the IAEA. This included
690 sponsorship for staff training in accelerator technology and applications, such as through the IAEA sandwich
691 PhD program in advanced accelerator laboratories. Additionally, technicians received specialized training
692 in accelerator systems maintenance, fostering local expertise in maintaining and operating the facility. Staff
693 members also actively participated in the refurbishment of the accelerator in Groningen and were involved in
694 the installation process alongside NEC Technicians, culminating in an Acceptance Test conducted by IAEA
695 experts. This concerted effort not only realized the establishment of the Pelletron Accelerator in Ghana but
696 also empowered local personnel with the necessary skills and knowledge to effectively utilize and maintain
697 this advanced scientific infrastructure.

698 The accelerator was commissioned on March 2016, while its performance since its installation has been
699 generally satisfactory, there have been some challenges and breakdowns encountered along the way. However,
700 most of these issues have been successfully resolved, in some cases with or without the assistance from the
701 NEC supporting Team. This collective effort not only ensured the establishment of advanced scientific
702 infrastructure in Ghana but also facilitated the development of local expertise in accelerator technology
703 and operations. Through continuous maintenance and improvement efforts, the accelerator continues to
704 contribute significantly to scientific research and educational initiatives in the region, further solidifying
705 Ghana's position in the field of accelerator physics and related disciplines.

3.3 Instrumentation and Control Systems Capacity in Africa

South Africa leads the continent in instrumentation and control systems with several institutions and initiatives driving advancements in this field. iThemba LABS, SARAO (South African Radio Astronomy Observatory), SKA (Square Kilometer Array), Necsa (Nuclear Energy Corporation of South Africa), and St. James Software are key players, each contributing expertise and infrastructure to various scientific endeavors. iThemba LABS, for instance, not only houses advanced accelerators but also excels in instrumentation and control systems crucial for monitoring and managing these facilities. It has advanced control systems for its cyclotrons and Tandetron accelerators, employing frameworks like EPICS (Experimental Physics and Industrial Control System). Recent developments include integrating EtherCAT-based hardware for distributed control and developing advanced user interfaces using tools like CS-Studio and React Automation Studio. These systems ensure real-time monitoring and high-performance operation across its facilities. SARAO and SKA are at the forefront of radio astronomy, deploying cutting-edge instrumentation and control systems to operate telescopes and process vast amounts of astronomical data [31]. Necsa, South Africa's Nuclear Energy Corporation, focuses on instrumentation and control systems for nuclear applications, ensuring safety and efficiency in nuclear facilities and research. Moreover, entities like St. James Software provide innovative solutions such as the JlogBook e-log-book, enhancing data management and collaboration across scientific disciplines. Furthermore, African countries actively participate in international collaborations like CERN, where they engage in technology transfer, operations, upgrades, and instrumentation development, using advancements in areas such as artificial intelligence to drive scientific progress and innovation both locally and globally. These efforts collectively demonstrate Africa's growing expertise and capacity in instrumentation and control systems, essential for driving scientific research and technological innovation across various disciplines.

3.4 Diverse Applications of Accelerator Physics Across Various Fields

More than 50,000 accelerators are used in a wide range of applications that span various scientific disciplines and industrial sectors [21, 23, 24]. From fundamental research in nuclear physics to practical applications in medicine, materials science, and beyond, accelerator-based techniques play a pivotal role in the advancement of scientific knowledge, technological innovation, and social progress. In this section, we explore the diverse array of applications enabled by accelerator physics.

- **Nuclear Physics:** Nuclear physics research facilities often have multiple accelerators for various purposes, including particle physics experiments and nuclear research. Large research institutions like iThemba LABS in South Africa [20, 10], CERN in Switzerland, Fermilab in the United States, and KEK in Japan host numerous accelerators, including cyclotrons, synchrotrons, and linear accelerators. The number of accelerators dedicated specifically to nuclear physics worldwide is estimated to be from 500 to 1000. The Egyptian Atomic Energy Authority (EAEA) operates several facilities equipped with accelerators for nuclear physics research [25]. These facilities include cyclotrons and linear accelerators used for nuclear research, medical isotope production, and radiopharmaceutical development. EAEA also collaborates with international institutions on nuclear research projects.
- **Medical Physics:** Accelerators in the medical field are primarily used for radiation therapy in cancer treatment. Thousands of medical linear accelerators (LINACs) are installed in hospitals and clinics worldwide for delivering external beam radiation therapy. More details about the ones in Africa can

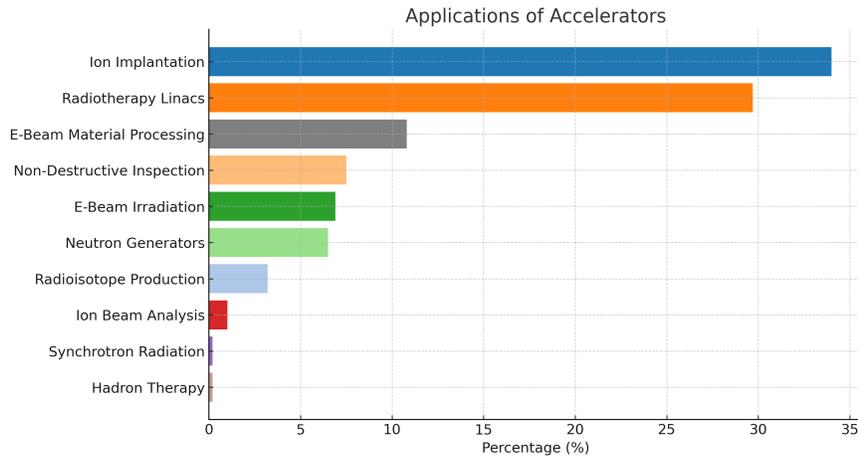


Figure 3-3: Distribution of accelerators worldwide by common applications. Data sourced from [21]

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be found in Section 3.8. In addition to LINACs, advanced treatment techniques such as hadron therapy, which utilizes protons or heavier ions, are being increasingly adopted to target tumors with greater precision, though it currently represents a smaller share of applications. iThemba LABS uses its accelerators for proton therapy which makes it one of the few centers in Africa offering advanced radiation therapy using proton beams, in addition to its standard radiotherapy treatments.

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- **Materials Science:** Synchrotron radiation facilities are widely used for materials science research. Major synchrotron facilities, such as the Advanced Photon Source (APS) in the United States, the European Synchrotron Radiation Facility (ESRF) in France, and the Diamond Light Source in the United Kingdom, host thousands of researchers annually conducting experiments on materials properties, crystallography, and structural biology. Moreover, ion implantation, which accounts for 34% of accelerator use, is a crucial technique in the semiconductor industry for doping materials, essential for manufacturing integrated circuits. Researchers use the accelerators at iThemba LABS to modify and analyze materials at the atomic level, contributing to the development of new materials and the improvement of existing ones.

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- **Energy:** Accelerators are utilized in environmental and energy research for various purposes, including nuclear waste management, environmental monitoring, and alternative energy research. Facilities such as the European Spallation Source (ESS) in Sweden, which is under construction, aim to advance research in areas like nuclear energy, materials for energy storage, and environmental science. Beyond research, accelerators are used in non-destructive inspection (7.5%) and neutron generation (6.5%), critical in energy applications for ensuring the integrity and safety of materials and systems. The EAEA in Egypt operates several research centers that use accelerators for energy research. Their work includes studying materials for nuclear reactors, improving the efficiency of energy production from nuclear sources, and exploring alternative energy solutions. The EAEA also focuses on research to advance nuclear energy technology and its applications in Egypt and the broader region. NCERD in Nigeria also focuses on energy research [26]. The center conducts studies on nuclear energy, including the development of nuclear reactors and the application of nuclear techniques in energy production. NCERD’s work is essential for advancing nuclear energy technology in Nigeria and supporting the country’s energy needs.

775 Accelerators are versatile tools with applications extending beyond these traditional areas (see Fig. 3-3). For
776 example, ion beam analysis (1.0%) and E-beam material processing (10.8 %) play important roles in quality
777 control and material modification in various industries. Radioisotope production (3.2%) supports medical
778 diagnostics and treatments, contributing to advancements in nuclear medicine, while synchrotron radiation
779 (0.2 %) continues to drive forward cutting-edge research in structural biology and materials science. These
780 diverse applications highlight the critical role accelerators play in both industrial and medical advancements.

781 3.5 Building a Pan-African Accelerator Network: Bridging Inno- 782 vation, Collaboration, and Scientific Growth

783 The motivation for establishing dedicated accelerator divisions across African countries stems from the
784 transformative potential these facilities hold for science, technology, and sustainable development. A pan-
785 African vision for accelerator technology would involve strategic placement of accelerator divisions in different
786 regions, bolstering local capacity and fostering regional collaboration. This network would not only elevate
787 Africa’s research capabilities but also create a platform for shared expertise, enabling scientists from across
788 the continent to collaborate and push forward high-impact projects like the development of African light
789 sources.

790 Morocco’s strategic geographic position offers significant advantages for establishing an accelerator division
791 that could lead to deeper collaboration with European research centers like ALBA (Spanish 3rd generation
792 synchrotron light source) in Spain [36] and the STAR (Southern European Thomson back-scattering source
793 for Applied Research) facility in southern Italy [35]. The proximity to these centers allows for easier exchange
794 of expertise, joint projects, and access to advanced infrastructure. Such collaboration would contribute
795 to a robust ecosystem where Moroccan researchers can engage in international partnerships, leveraging
796 the experience of these established projects to develop new capabilities in accelerator technology and light
797 sources. The broader context includes existing strong trade and scientific ties between Morocco, Spain, and
798 Italy, as shown by Morocco’s position as a significant partner in EU trade and research agreements. This
799 mutual relationship underlines the potential for beneficial scientific exchanges and infrastructure projects in
800 fields such as accelerator physics and light source development. Collaborative efforts would help establish
801 the foundations for a comprehensive Pan-African network of research facilities, reversing the brain drain by
802 providing African scientists with the necessary tools and resources at home. Such initiatives could pave the
803 way for the future development of larger, more advanced light source projects across Africa, including in
804 South Africa and Morocco, building on initial steps with compact light sources.

805 Currently, South Africa’s iThemba LABS stands as a strong research facility in the field of nuclear physics
806 and accelerator-based sciences. However, creating a specialized accelerator division within iThemba LABS
807 and replicating similar divisions in north countries like Morocco and other African nations would significantly
808 strengthen the continent’s research infrastructure. Such divisions would serve as hubs for training, innovation,
809 and collaborative research in accelerator physics and related disciplines.

810 The establishment of multiple accelerator divisions would accelerate the continent’s progress toward building
811 compact light sources. These sources are feasible starting points due to their relative simplicity and lower
812 costs compared to large-scale synchrotrons or colliders. Compact light sources can still deliver impactful
813 results in applications ranging from medical imaging and materials analysis to cultural heritage conservation
814 and environmental studies. This vision aligns with reversing the brain drain that has historically affected
815 Africa’s scientific community. By providing advanced research facilities and opportunities, African accelerator
816 physicists and engineers who work abroad could be motivated to return, bringing their skills and experiences
817 to bolster the development of domestic research ecosystems. Such initiatives could lead to the eventual

818 establishment of full-scale light source facilities—potentially one in South Africa and another in North
819 Africa, such as Morocco. These facilities would create a robust research network that promotes scientific
820 excellence and positions Africa as a leader in the global research landscape.

821 Furthermore, the creation of accelerator divisions supports economic development, as it attracts investments
822 and partnerships with international research organizations. By investing in accelerator technology, African
823 countries can foster local innovation, build highly skilled workforces, and strengthen regional and interna-
824 tional scientific collaborations, laying the groundwork for long-term development and scientific leadership.

825 3.6 High-priority future needs

826 • **Infrastructure Development:** Accelerator physics in Africa faces a crucial need for the development
827 and enhancement of research infrastructure. Investing in state-of-the-art accelerator facilities, upgrad-
828 ing existing ones, and establishing new centers will be pivotal for conducting cutting-edge experiments
829 and staying at the forefront of global scientific advancements.

830 • **Human Capital Development:** The shortage of skilled personnel poses a significant challenge. Ini-
831 tiatives for training and capacity building in accelerator physics are essential. Collaborative programs,
832 workshops, and educational partnerships can play a vital role in nurturing the next generation of
833 African physicists, engineers, and technicians.

834 • **International Collaboration:** Strengthening collaboration with international partners is a high-
835 priority need. This involves fostering partnerships with established accelerator centers worldwide, par-
836 ticipating in joint research projects, and facilitating knowledge exchange. International collaborations
837 with organizations like CERN, Fermilab, and SESAME (in Jordan) can accelerate progress, including
838 funding Support from governments, private sector, and international agencies that should invest in
839 accelerator research for African scientists to contribute meaningfully to global scientific endeavors.

840 • **Outreach Programs** Increasing outreach programs to introduce accelerator physics to students is
841 critical for fostering interest and cultivating talent in this field. Organizing workshops, seminars, and
842 summer schools targeted at high school and undergraduate students can raise awareness about accel-
843 erator physics and its applications. Additionally, mentorship programs and internships at accelerator
844 facilities can provide hands-on experience and inspire students to pursue careers in this specialized area
845 of science. As an exemplar, the ASP Outreach Program, which took place in Marrakech, Morocco,
846 from April 15th to 19th, 2024. This initiative was meticulously designed to ignite and sustain learners'
847 interests in Physics and its diverse applications. A significant segment of the program was exclusively
848 dedicated to Accelerator Physics, aimed at acquainting students with its fundamental principles and
849 cutting-edge technologies. Under the guidance of esteemed experts, Dr. Sanae Samsam from INFN
850 (Istituto Nazionale di Fisica Nucleare) and Dr. Christine Darve from ESS (European Spallation
851 Source), the program unfolded with a blend of comprehensive lectures and engaging practical sessions.
852 These sessions were meticulously curated to provide participants with a holistic understanding of
853 accelerator physics, ranging from its theoretical underpinnings to its real-world applications. Through
854 interactive discussions and hands-on activities, students were not only introduced to the intricacies of
855 particle acceleration but were also inspired to explore its interdisciplinary connections and potential
856 for scientific innovation. The report which resume all the activity can be found in this Ref. [7].

857 In summary, Africa has immense potential to develop accelerator physics for scientific research, medical
858 applications, and socioeconomic growth. By investing in education, infrastructure, and collaborations,
859 African nations can contribute significantly to this field.

3.7 Synergies with neighbouring fields

Accelerator technologies play a pivotal role in medical physics and healthcare, contributing to cancer treatment through radiation therapy and medical imaging. Moreover, accelerator-based techniques in materials science and nanotechnology significantly impact research and development, offering powerful tools for ion-beam analysis and materials characterization. Environmental science and geophysics benefit from accelerator applications, particularly in studies related to archaeology, climate change, and geological processes. The intersection of accelerator physics with nuclear physics and astrophysics is evident in research exploring nuclear structure, reactions, and astrophysical phenomena. Accelerator technologies also drive technological innovation and industry applications, influencing semiconductor manufacturing, ion implantation, and non-destructive testing. Furthermore, accelerator initiatives contribute to education and capacity building, offering training programs and workshops that empower the next generation of scientists and technologists. Collaborations with international research institutions underscore Africa's role in global scientific endeavors, fostering knowledge exchange and joint projects. Through these synergies, accelerator physics emerges as a catalyst for holistic scientific progress, bridging diverse fields and expanding the frontiers of knowledge in the African context.

3.8 Clinical Linacs Driving Cancer Treatment Across Africa

Clinical Linacs, short for Clinical Linear Accelerators, are sophisticated medical devices primarily used in the treatment of cancer through a process called radiation therapy. These machines generate high-energy X-rays or electrons, which are directed towards the patient's tumor to destroy cancerous cells while minimizing damage to surrounding healthy tissues.

The proliferation of clinical Linacs across Africa marks a significant advancement in the region's capacity to provide essential cancer treatment services. According to the IAEA DIRAC (Directory of Radiotherapy Centres), there are approximately 432 Linacs dedicated to MV Therapy spread across the continent [5]. Notably, North Africa boasts the largest share with 237 Linacs, followed by 107 in the southern region and 88 in the central part of the continent (see Fig. 3-4).

This distribution underscores the commitment of African nations to improve access to radiotherapy services, addressing the pressing healthcare needs of their populations. With Linac technology widely available in different regions of Africa, more patients can receive timely and effective treatment, contributing to better cancer outcomes and improved healthcare infrastructure throughout the continent.

Country	RT Centers	MV Therapy	Light Ion Therapy	kv Therapy	Brachytherapy
Algeria	16	37	0	0	13
Egypt	75	124	0	1	23
Libya	5	8	0	0	0
Morocco	30	48	0	0	10
Tunisia	15	27	0	1	4

Table 3-1: Clinical Linacs in North Africa

Tab. 3-1 provides an overview of the distribution of clinical linear accelerators across North Africa, highlighting the infrastructure for cancer treatment in the region. Egypt emerges as a leader in this regard,

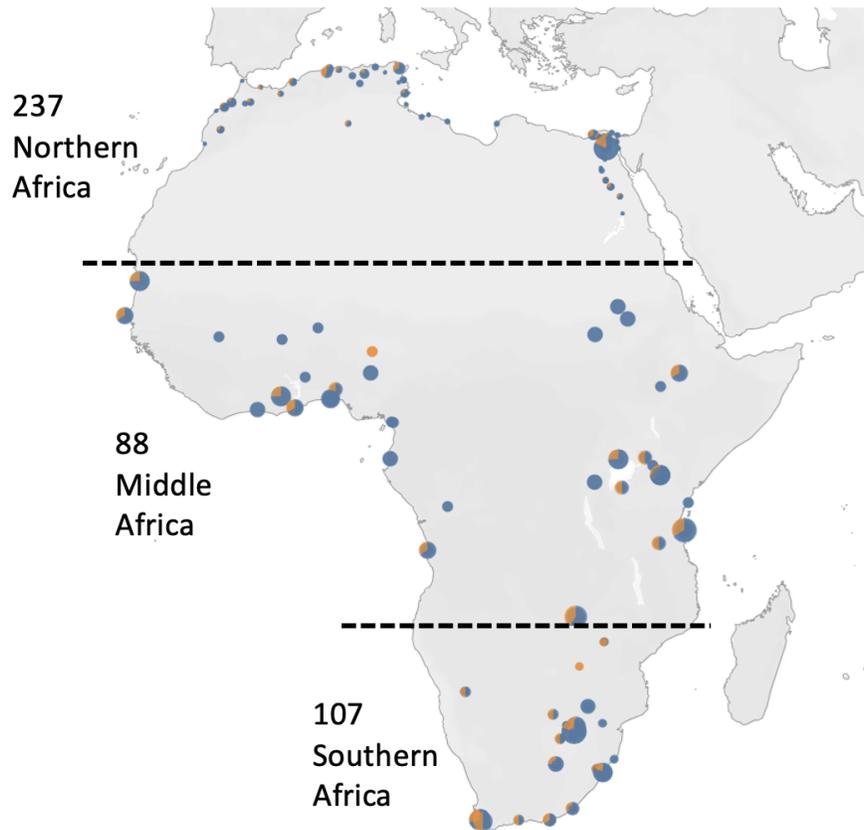


Figure 3-4: Status of Radiation Therapy Equipment in Africa

891 boasting the highest number of Linac centers (75) and offering the most diverse range of treatment modalities,
 892 including megavoltage (MV) therapy and kilovoltage (kV) therapy. Additionally, Egypt stands out as the
 893 sole provider of light ion therapy among the countries surveyed, indicating a more advanced level of radiation
 894 oncology infrastructure.

895 Following Egypt, Morocco demonstrates a significant presence in Linac facilities with 30 centers, although its
 896 range of treatment modalities is slightly more limited compared to Egypt. Algeria and Tunisia also exhibit
 897 substantial Linac infrastructure, albeit with fewer centers. Algeria notably has a considerable number of
 898 brachytherapy facilities (13), indicating a focus on this targeted treatment method.

899 Conversely, Libya appears to have the most limited infrastructure among the surveyed countries, with only
 900 five Linac centers and minimal representation in other treatment modalities.

901 In Middle Africa (see Tab. 3-2), several countries demonstrate modest but emerging capabilities in cancer
 902 care. Kenya is distinguished with a notable presence of 10 Linac centers, indicative of its commitment to
 903 expand the accessibility to cancer treatment. Nigeria follows closely with seven Linac centers, reinforcing its
 904 position as a regional hub for healthcare services.

Country	RT Centers	MV Therapy	Light Ion Therapy	kv Therapy	Brachytherapy
Angola	2	3	0	0	1
Burkina Faso	1	2	0	0	0
Cote D'Ivoire	1	2	0	0	0
Cameroon	3	2	0	0	0
Congo	1	1	0	0	0
Ethiopia	3	3	0	0	1
Gabon	1	2	0	0	0
Ghana	3	6	0	0	3
Kenya	10	16	0	0	5
Madagascar	2	3	0	0	1
Mali	1	1	0	0	0
Mozambique	1	1	0	0	0
Mauritania	1	4	0	0	1
Mauritius	1	3	0	0	1
Malawi	1	1	0	0	0
Niger	1	1	0	0	0
Nigeria	7	9	0	0	2
Reunion (France)	1	5	0	0	0
Rwanda	1	2	0	0	0
Sudan	4	6	0	0	0
Senegal	4	4	0	0	1
Togo	1	1	0	0	0
Tanzania	4	8	0	0	4
Uganda	1	3	0	0	1
Zambia	1	3	0	0	2

Table 3-2: Clinical Linacs in Middle Africa

905 Ghana, Tanzania, Sudan, and Senegal also show significant progress in Linac installations, reflecting efforts
 906 to enhance cancer treatment capacities. These countries not only possess multiple Linac centers but also
 907 offer various treatment modalities, including megavoltage (MV) therapy and brachytherapy.

908 In contrast, several countries in the region have limited Linac infrastructure, with only one or a few centers.
 909 Despite this, there is potential for growth and collaboration to address the gaps in cancer care accessibility.

910 In South Africa, as shown in Tab.3-3, South Africa emerges as a prominent player in cancer care, boasting
 911 a substantial number of Linac centers (62) and offering a wide range of treatment modalities. With more
 912 than 100 units of MV therapy and significant representation in brachytherapy.

913 Botswana and Namibia show promising developments in cancer treatment infrastructure, with two Linac
 914 centers each. These countries also provide brachytherapy services, indicating efforts to diversify treatment

options. Zimbabwe, while having a more limited number of Linac centers, still contributes to the regional landscape of cancer care with three facilities. The presence of brachytherapy services underscores efforts to provide holistic cancer treatment approaches.

Country	RT Centers	MV Therapy	Light Ion Therapy	kv Therapy	Brachytherapy
Botswana	2	2	0	0	1
Namibia	2	2	0	0	1
South Africa	62	102	0	8	23
Zimbabwe	3	1	0	0	2

Table 3-3: Clinical Linacs in Southern Africa

The distribution of clinical Linacs facilities in Africa reveals varying levels of cancer treatment infrastructure. While Egypt leads in North Africa and South Africa in the south with substantial Linac centers and diverse treatment modalities, Kenya emerges as a notable player in Middle Africa. These findings underscore the imperative for continued investment and collaboration to strengthen cancer care infrastructure across the continent and ensure equitable access to quality treatment options.

Overall, the data underscores the need for continued investment and collaboration to strengthen cancer treatment infrastructure across Middle Africa, ensuring that all individuals have access to quality care regardless of geographic location.

3.9 Cyclotrons Capacities for Medical and Reserach applications

3.9.1 Current Landscape of Cyclotron Facilities in Africa

While accelerators are primarily known for their large-scale applications in research facilities like iThemba LABS, cyclotrons play an essential role in various sectors across Africa, particularly in nuclear medicine and medical isotope production. Several African countries (as shown in Fig.3-5), including Egypt, Morocco, Algeria, South Africa, Kenya and Tunisia, host cyclotron facilities, which are pivotal for the local production of medical isotopes used in diagnostics, imaging, and radiation therapy [27, 28]. These isotopes, such as fluorine-18 used in PET scans, are critical for early disease detection and treatment planning.

In addition to their medical uses, cyclotrons in Africa are also utilized for fundamental research. iThemba LABS, in South Africa, operates one of the largest cyclotron facilities on the continent, producing isotopes for medical and industrial applications. The facility’s separated sector cyclotron, which accelerates protons to energies of up to 200 MeV, serves as a cornerstone for both regional research and medical applications. Other countries, such as Egypt and Tunisia, utilize their cyclotrons for nuclear physics research, where they contribute to scientific advancements in areas such as material science and radiation physics.

These smaller, standalone cyclotrons are not only crucial for local healthcare advancements but also represent a growing infrastructure that supports collaborative scientific efforts across the continent. Their expansion in Africa reflects the increasing importance of accelerator-based technologies in improving public health, advancing scientific research, and contributing to technological innovation.

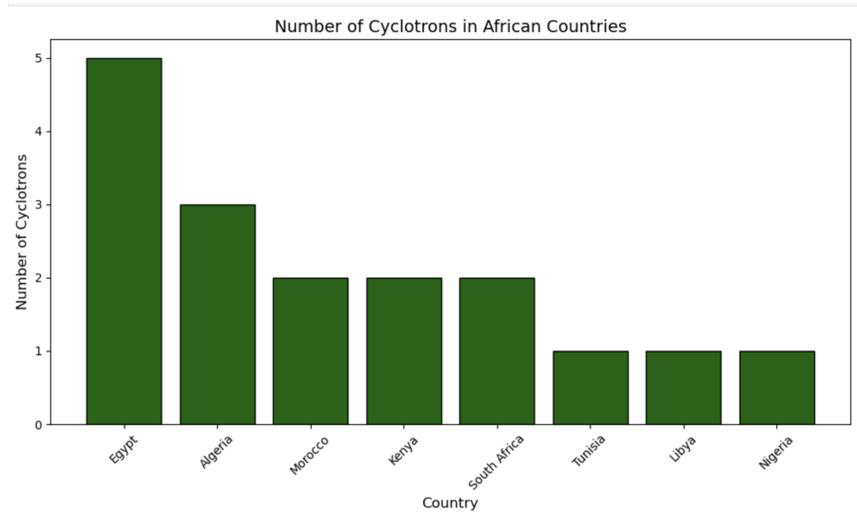


Figure 3-5: Database of the Cyclotrons used for radionuclide production in Africa[28]

944 3.9.2 Challenges in Cyclotron Access and Usage

945 Despite their importance, many African nations still face challenges in expanding their cyclotron facilities.
946 Key barriers include:

- 947 • High initial costs: The infrastructure for cyclotron facilities is expensive, and many countries lack the
948 financial resources or investment mechanisms to develop them.
- 949 • Limited technical expertise: Cyclotron operation and maintenance require highly specialized technical
950 skills. There is a need for training programs and capacity-building efforts in this area.
- 951 • Geographic concentration: Cyclotron facilities are currently concentrated in a few countries, creating
952 disparities in access to these critical technologies across the continent.

953 3.9.3 Strategic Recommendations for Enhancing Cyclotron Use in Africa

954 To address these challenges and expand the role of cyclotrons in Africa, the following strategies are recom-
955 mended:

- 956 • Establishing Collaborative Networks: Strengthening regional collaboration between countries with
957 existing cyclotron facilities (such as South Africa, Egypt, and Tunisia) can help share knowledge,
958 resources, and best practices. Regional hubs could be developed to provide services to neighboring
959 countries with limited access to such facilities.
- 960 • Increasing Investment in Cyclotron Infrastructure: Governments and international organizations should
961 consider allocating more funds to the establishment of cyclotron facilities in countries that do not yet

962 have them. Public-private partnerships could be explored to reduce the financial burden on national
963 governments.

964 • Building Local Expertise and Training Programs: Developing specialized training programs in accel-
965 erator physics, cyclotron operation, and medical isotope production is critical. This could involve
966 collaborations with existing facilities like iThemba LABS, as well as international training programs
967 offered by institutions such as the IAEA.

968 • Expanding Medical Applications: There is an opportunity to scale up the production of medical
969 isotopes for both domestic use and export. This would involve improving the production capabilities
970 of existing cyclotron facilities and expanding their medical isotope portfolios to include isotopes for
971 cancer therapy, diagnostic imaging, and radiopharmaceuticals.

972 • Promoting Research and Development: Encouraging the use of cyclotrons for both medical and
973 scientific research in Africa is essential for advancing fields such as nuclear physics, materials science,
974 and environmental research. Collaborative international research projects could boost the scientific
975 capabilities of African cyclotron facilities, making them more attractive for global research initiatives.

976 3.10 Energy Recovery Linacs: A Pathway for Sustainable Particle 977 Accelerators in Africa

978 3.10.1 Introduction and Motivation

979 Energy Recovery Linacs (ERLs) represent a transformative technology in the field of accelerator science,
980 offering unparalleled energy efficiency, high beam quality, and the potential for sustainable operation.
981 Globally, ERLs have demonstrated their ability to address diverse challenges in particle physics, materials
982 science, and medical applications [29]. However, their adoption remains limited in regions lacking the
983 infrastructure and expertise needed to develop advanced accelerator facilities.

984 Africa, despite its growing contributions to global science, faces significant barriers to building a robust
985 accelerator science ecosystem. The absence of dedicated accelerator divisions and research facilities has
986 hindered the development of cutting-edge technologies such as ERLs. Yet, this challenge presents an
987 opportunity: by leveraging international collaborations and focusing on sustainable technologies like ERLs,
988 Africa can lay the foundation for a future of self-sufficient and impactful accelerator research.

989 This section explores the motivation for pursuing ERL technologies in Africa. It highlights their potential to
990 address pressing regional needs such as advancing healthcare diagnostics, supporting industrial innovation,
991 and fostering scientific collaboration while providing a pathway for building capacity and expertise in
992 accelerator science. By integrating ERLs into Africa’s scientific roadmap, the region can align with global
993 trends, contributing to and benefiting from advancements in accelerator technology.

994 3.10.2 History

995 The concept of an energy-recovery linac (ERL) was first proposed by Maury Tigner in 1965 , as a way to
996 enhance the current in a collider for high-energy physics [30]. Traditional methods, where two beams are
997 accelerated, collided, and then discarded, were highly inefficient. Tigner suggested recovering the energy

998 of the beams using the same cavities that accelerated them, significantly improving machine efficiency and
999 simplifying the design of the beam dump. However, implementing this idea required the development of
1000 reliable superconducting RF (SRF) accelerating cavities, which advanced over the following decade. The
1001 first major application of SRF cavities occurred at the High Energy Physics Lab at Stanford University,
1002 where researchers introduced a recirculation loop capable of varying the path length. This allowed electrons to
1003 either be accelerated or decelerated during a second pass through the cavities both processes were successfully
1004 demonstrated [32]. This marked the first ERL with SRF cavities, referred to as "same-cell energy recovery".
1005 Although the beam was neither used for experiments nor operated in continuous mode, energy recovery was
1006 clearly observed in the RF power requirements during the beam pulses.

1007 3.10.3 The Role of ERLs in Africa's Research Landscape

1008 Energy Recovery Linacs (ERLs) offer a transformative opportunity to address Africa's research challenges
1009 by providing energy-efficient, compact accelerator systems suited for diverse applications. These systems
1010 can drive advancements in synchrotron-based research for materials science, drug development, and energy
1011 technologies, while also enabling medical imaging and nondestructive testing in industrial applications. The
1012 sustainability and cost-efficiency of ERLs make them a practical choice for regions with limited resources, of-
1013 fering a pathway to align with global trends in environmentally conscious scientific infrastructure. Moreover,
1014 integrating ERLs into Africa's research landscape can foster capacity-building through training programs
1015 and collaborations with global institutions, such as CERN or Cornell University, creating a new generation
1016 of accelerator physicists and engineers. This development can bridge the gap between fundamental and
1017 applied sciences, enabling Africa to contribute to global accelerator projects and establish a leadership role
1018 in sustainable accelerator technology. By prioritizing ERLs, Africa can simultaneously address pressing
1019 regional needs and lay the groundwork for a self-sufficient and impactful research ecosystem.

1020 3.10.4 Challenges and Opportunities in Adopting ERLs

1021 The adoption of Energy Recovery Linacs (ERLs) in Africa presents both significant challenges and exciting
1022 opportunities. One of the primary challenges is the lack of existing infrastructure and technical expertise in
1023 accelerator science. Building ERL facilities requires specialized knowledge in superconducting technology,
1024 high-gradient RF structures, and beam dynamics, which are currently limited in many African countries.
1025 Additionally, the high initial costs of setting up such advanced technologies, along with the need for
1026 ongoing operational support, pose financial barriers. Moreover, there is a need for specialized facilities
1027 and laboratories, which require substantial investment in research and development (R&D), as well as in
1028 training personnel capable of designing, operating, and maintaining ERL systems.

1029 However, these challenges also create significant opportunities for Africa. The development of ERLs offers
1030 the potential for leapfrogging traditional accelerator technologies, providing a more energy-efficient and cost-
1031 effective solution for scientific research and applications. By starting with compact ERL systems, Africa can
1032 focus on smaller, more manageable projects that can serve as a foundation for future growth. The long-
1033 term benefits of adopting ERLs include reduced energy consumption, the ability to support a wide range of
1034 scientific applications, and the creation of high-tech job opportunities in accelerator physics and engineering.
1035 Furthermore, international collaboration with established ERL research centers could facilitate technology
1036 transfer and knowledge sharing, helping to overcome the resource and expertise gaps. As the global demand
1037 for sustainable accelerator technologies increases, Africa's involvement in ERL development could position

1038 the continent as a key player in the future of accelerator science, with the potential for both local impact
1039 and global collaboration.

1040 **3.10.5 R&D Objectives and Capacity Building**

1041 To successfully adopt Energy Recovery Linac (ERL) technology in Africa, focused research and development
1042 (R&D) objectives must be established alongside capacity-building initiatives. The primary R&D objectives
1043 for ERL adoption include developing cost-effective, energy-efficient accelerator systems tailored to Africa's
1044 specific scientific and technological needs. These systems should prioritize sustainability, with a focus on
1045 reducing operational energy consumption and integrating renewable energy sources, making ERLs ideal for
1046 the continent's infrastructure challenges. Additionally, advancing key areas such as high-gradient RF struc-
1047 tures, superconducting materials, and beam dynamics will be critical to ensuring the long-term performance
1048 and reliability of ERLs in diverse applications.

1049 Simultaneously, capacity building must be at the core of ERL adoption in Africa. This includes training
1050 the next generation of accelerator physicists and engineers through specialized programs, workshops, and
1051 collaborations with established global ERL research centers. Building local expertise will not only support
1052 the development and operation of ERLs but also foster innovation in accelerator science. Partnerships
1053 with institutions like CERN, Jefferson Lab, and Cornell University could play a vital role in facilitating
1054 knowledge transfer, providing hands-on training, and supporting the establishment of research hubs in
1055 Africa. Furthermore, creating educational pathways, such as graduate programs and internships focused on
1056 accelerator physics, will be essential in developing a skilled workforce capable of supporting ERL projects.
1057 The R&D efforts should also involve collaborative projects with industry to ensure that the technologies
1058 developed are commercially viable and can be scaled to meet local needs. Through these initiatives, Africa
1059 can create a robust scientific and technical foundation for the successful integration of ERLs, driving both
1060 regional and global advancements in accelerator technology.

1061 **3.10.6 Potential Applications of ERLs in Africa**

1062 Energy Recovery Linacs (ERLs) offer a wide range of potential applications that could significantly impact
1063 various sectors in Africa, driving both scientific progress and socio-economic development. One of the
1064 most promising applications is in medical imaging and radiotherapy. ERLs can provide high-quality electron
1065 beams for advanced imaging techniques such as X-ray and CT scans, potentially improving healthcare access
1066 and diagnostics in underserved regions. The high beam quality of ERLs also makes them ideal for precise
1067 cancer treatments, offering a non-invasive, highly effective method for radiation therapy, which could enhance
1068 medical capabilities across Africa's growing healthcare sector.

1069 In materials science, ERLs could enable the development of advanced synchrotron light sources. These light
1070 sources are crucial for the analysis of materials at the atomic level, supporting innovations in industries
1071 such as energy storage, nanotechnology, and environmental science. By establishing regional synchrotron
1072 facilities powered by ERLs, African researchers could contribute to the global effort to develop more efficient
1073 batteries, renewable energy technologies, and environmentally friendly materials, fostering economic growth
1074 and technological independence.

1075 ERLs could also play a significant role in industrial applications, such as non-destructive testing of materials,
1076 which is essential for sectors like mining, construction, and manufacturing. The precision of ERL-driven

1077 electron beams can be used to detect structural weaknesses and improve quality control without damaging
1078 the materials. This application is particularly valuable in Africa, where industries such as mining and in-
1079 frastructure development are rapidly growing, and where cost-effective, reliable testing methods are essential
1080 for ensuring safety and durability.

1081 Finally, ERLs could serve as a foundation for training and education in accelerator physics, enabling the
1082 development of a highly skilled workforce. Establishing ERL facilities could serve as a hub for knowledge
1083 exchange, attracting students and researchers from across Africa and beyond. These facilities would not only
1084 enhance scientific capacity but also create opportunities for international collaboration, positioning Africa
1085 as a key player in the global accelerator science community. Through these diverse applications, ERLs can
1086 drive innovation, improve public health, and support sustainable economic development across the continent.

1087 3.10.7 Collaboration and Implementation Roadmap

1088 The successful adoption and implementation of Energy Recovery Linacs (ERLs) in Africa will require a
1089 coordinated approach that integrates local, regional, and international efforts. A robust collaboration
1090 framework is essential to overcome the challenges of limited infrastructure and expertise, while also ensuring
1091 that the benefits of ERL technology are realized across multiple sectors. This roadmap outlines key steps for
1092 fostering partnerships, guiding the phased implementation of ERL projects, and ensuring sustainable growth
1093 in Africa's accelerator research landscape.

- 1094 • **Building International Partnerships:** Collaboration with established global ERL research centers,
1095 such as CERN, the Thomas Jefferson National Accelerator Facility (TJNAF), and Cornell University,
1096 will be pivotal for technology transfer and knowledge sharing. These institutions can offer both
1097 technical expertise and training programs, facilitating the development of local competencies in ac-
1098 celerator science. International partnerships will also enable access to shared resources, joint research
1099 projects, and participation in global accelerator initiatives. Strategic alliances with countries that
1100 have successfully developed ERLs will provide critical insights and guidance, ensuring that Africa can
1101 leapfrog some of the early-stage challenges faced by other regions.
- 1102 • **Developing Local Collaborations:** Collaboration among African nations will be key to maximizing
1103 the impact of ERL technology. The establishment of regional research consortia, involving universities,
1104 national laboratories, and industrial partners, will allow for pooling of resources, talent, and expertise.
1105 These consortia can spearhead the design, development, and operation of small-scale ERL demonstra-
1106 tors, serving as training hubs and pilot projects for larger facilities in the future. Additionally, local
1107 industries and stakeholders, such as those in the healthcare, energy, and materials sectors, should be
1108 engaged early in the process to identify specific applications for ERL technology and ensure that the
1109 resulting infrastructure meets regional needs.
- 1110 • **Phased Implementation Approach:** The roadmap for ERL implementation in Africa should follow
1111 a phased approach, starting with the establishment of small-scale ERL prototypes and progressing
1112 towards larger, more complex facilities. In the initial phase, the focus should be on building the tech-
1113 nical capacity needed to design and operate ERLs, including the development of laboratory space, the
1114 acquisition of key components, and the training of local staff. This phase could also involve establishing
1115 collaborations with international partners to create a knowledge-sharing platform, such as workshops
1116 and joint research projects, aimed at building a sustainable ERL ecosystem in Africa. The next phase
1117 should focus on scaling up to pilot facilities capable of supporting applications in materials science,
1118 medical imaging, and industrial testing. These facilities would serve as a demonstration of ERL's

1119 potential impact and would help attract further investment and collaboration. The final phase would
1120 involve the establishment of full-scale ERL-based research centers with broader applications, including
1121 synchrotron light sources, particle physics research, and advanced medical facilities. These centers
1122 would be integrated into the global scientific community, contributing to collaborative international
1123 research and ensuring long-term sustainability.

- 1124 • **Resource Mobilization and Funding:** Securing adequate funding for the development and oper-
1125 ation of ERL facilities will require a combination of national, regional, and international investment.
1126 Governments should recognize the long-term value of ERL technology for scientific and economic
1127 development, and prioritize funding for accelerator research as part of broader science and technology
1128 initiatives. International funding agencies, such as the African Union, the United Nations, and the
1129 European Union, can play an important role in supporting the establishment of ERL infrastructure
1130 through collaborative research grants and joint programs. Additionally, private sector involvement,
1131 particularly from industries that would benefit from ERL technology, should be explored to ensure a
1132 diverse and sustainable funding base.

1133 Through strategic collaboration, phased implementation, and resource mobilization, Africa can overcome
1134 existing barriers and lay the groundwork for a thriving accelerator research ecosystem powered by ERLs.
1135 This roadmap will enable the continent to not only benefit from the global advancements in accelerator
1136 technology but also contribute meaningfully to the future of sustainable science and technology.

1137 3.10.8 Towards a Sustainable Future

1138 The development and adoption of Energy Recovery Linacs (ERLs) in Africa represents a significant step
1139 toward building a sustainable and self-sufficient research infrastructure. As the global scientific community
1140 increasingly prioritizes sustainability, ERLs offer a promising pathway for Africa to address its unique
1141 challenges while contributing to international efforts to reduce the environmental impact of large-scale
1142 research facilities. By leveraging the inherent energy efficiency of ERLs, Africa can establish accelerator-
1143 based technologies that not only drive scientific progress but also align with global sustainability goals.

1144 ERLs are particularly well-suited for Africa's needs due to their energy-efficient design, which recycles the
1145 energy from electron beams, significantly reducing operational energy consumption compared to traditional
1146 linear accelerators. This characteristic makes ERLs an ideal technology for regions with limited energy
1147 resources or those seeking to minimize the environmental footprint of scientific infrastructure. By integrating
1148 renewable energy sources into ERL operations, such as solar or wind power, Africa can further enhance the
1149 sustainability of these systems, making them resilient to energy supply challenges.

1150 In addition to their energy efficiency, ERLs can contribute to Africa's sustainable development by supporting
1151 applications that address critical regional needs. For example, ERL-driven synchrotron light sources can aid
1152 in the development of cleaner energy technologies, such as more efficient solar cells or advanced materials
1153 for energy storage, directly contributing to Africa's transition to renewable energy. Similarly, ERLs used
1154 in medical imaging and radiation therapy can improve healthcare outcomes across the continent, providing
1155 access to state-of-the-art technologies without the high operational costs typically associated with traditional
1156 accelerators.

1157 The sustainable impact of ERLs in Africa will also extend beyond energy and health. By fostering local
1158 expertise in accelerator technology and creating a skilled workforce, ERL projects will generate long-
1159 term educational and economic opportunities, helping to build a knowledge-based economy. International

1160 collaborations, knowledge-sharing platforms, and the establishment of regional research hubs will ensure that
1161 ERLs serve as a catalyst for broader innovation and scientific advancement across the continent.

1162 Ultimately, the adoption of ERLs in Africa has the potential to create a sustainable and forward-looking
1163 accelerator science ecosystem that addresses both local and global challenges. By embracing this technology,
1164 Africa can contribute to the global pursuit of sustainable, energy-efficient research infrastructure while
1165 building a foundation for scientific and technological leadership in the 21st century.

1166 3.11 Recommendations

1167 To ensure sustainable progress in accelerator physics in Africa, we propose the following key recommenda-
1168 tions:

- 1169 • **Strengthening Research Networks and Consortia:** It is crucial to establish pan-African research
1170 consortia dedicated to accelerator physics (see Section 3.5). These networks should facilitate collabora-
1171 tion between African institutions, pooling resources, expertise, and infrastructure. Such consortia
1172 can also act as a platform for engaging with global partners, securing funding, and coordinating large-
1173 scale research initiatives. By including Africa’s needs in international conferences, we can amplify
1174 the importance of developing accelerator physics on the continent. For instance, during the recent
1175 EuPRAXiA PP Annual Meeting in Italy, the mission of the African School of Physics was presented,
1176 followed by a roundtable discussion pointing out that the number of accelerator physicists in Africa is
1177 critically low, stressing the urgent need to train more in order to benefit from their expertise in the
1178 future [33]. The mission had also been presented earlier in April 2024 during the 3rd Accelerator Days
1179 (TERZA Giornata Acceleratori) at the Frascati National Labs of INFN [34], which inspired the idea
1180 of including more outreach activities in conferences like EuPRAXiA and inviting members of the IOC
1181 to strengthen the relationship between INFN and ASP.
- 1182 • **Creating Structured Training Programs:** Governments, universities, and research centers should
1183 prioritize the creation of structured educational programs like Ph.D positions focused on accelerator
1184 physics. This includes developing graduate programs, certification courses, and specialized training
1185 sessions. Additionally, expanding opportunities for African students and professionals to receive
1186 training abroad, through scholarships and exchange programs, will help in skill-building and knowledge
1187 transfer.
- 1188 • **Expanding Public and Private Sector Funding:** A strong push for increasing financial support
1189 from both the public and private sectors is needed. Governments should recognize the strategic
1190 importance of accelerator physics in driving scientific and technological innovation, and allocate more
1191 resources to research and development in this field. Partnerships with industry could also be leveraged
1192 to attract private investments in accelerator-related technologies, particularly those with commercial
1193 potential, such as medical accelerators or renewable energy applications.
- 1194 • **Enhancing Digital Infrastructure and Access to Computational Tools:** With many accelerator
1195 physics experiments requiring advanced simulation software and computational tools, it is important
1196 to ensure that African institutions have access to the necessary digital infrastructure. This includes
1197 high-performance computing facilities and access to software platforms such as CAIN, WHIZARD, and
1198 others. Support for training researchers in using these tools effectively should also be prioritized.
- 1199 • **Encouraging Knowledge Dissemination and Scientific Publications:** It is essential to promote
1200 knowledge sharing within the African accelerator physics community and beyond. Initiatives should

1201 be developed to encourage researchers to publish their work in peer-reviewed journals, participate in
1202 international conferences, and contribute to open-access platforms. Creating an African accelerator
1203 physics journal or repository could further enhance visibility and collaboration in this field.

- 1204 • **Long-term Strategic Planning:** Governments and research institutions should formulate long-term
1205 strategic plans to guide the growth of accelerator physics in Africa. This could include roadmaps
1206 for infrastructure development, timelines for achieving specific research goals, and frameworks for
1207 integrating accelerator technologies into national priorities, such as healthcare, energy, and education.
- 1208 • **Encourage Policy Support for Accelerator Research:** Policy frameworks that support the
1209 growth of accelerator science and technology in Africa should be established at the national and regional
1210 levels. Governments should create policies that promote investment in R&D, facilitate international
1211 partnerships, and provide incentives for private sector involvement. By recognizing the strategic
1212 importance of accelerators in advancing science and technology, policymakers can create an enabling
1213 environment for innovation and ensure the long-term success of ERL projects. Furthermore, policies
1214 that encourage the use of ERLs in various sectors, including healthcare, materials science, and industrial
1215 applications, will ensure that the technology has a broad and lasting impact.
- 1216 • **Promote Sustainability in ERL Design and Operation:** Given Africa's unique environmental
1217 and energy challenges, sustainability should be a central consideration in the design and operation of
1218 ERL facilities. The integration of renewable energy sources, such as solar and wind, should be explored
1219 to power ERL operations, reducing their environmental footprint and enhancing their resilience to
1220 energy shortages. Additionally, energy-efficient technologies, including those for cooling, power supply,
1221 and waste heat recovery, should be prioritized in the development of ERL systems. By focusing
1222 on sustainability, Africa can position itself as a leader in environmentally responsible accelerator
1223 technology and contribute to global efforts to reduce the carbon footprint of scientific infrastructure.

1224 By following these recommendations, African nations can build the necessary infrastructure, expertise, and
1225 partnerships to harness the full potential of an accelerator division, advancing not only scientific research
1226 but also economic and social development. With careful planning, international collaboration, and a focus
1227 on sustainability, ERLs can become a cornerstone of Africa's future in science and technology.

1228 3.12 Preliminary Results of the ASFAP Survey on Accelerator 1229 Physics

1230 3.12.1 Educational Background and Awareness

1231 The survey revealed significant gaps in the educational exposure of African students and researchers to
1232 accelerator physics. in Fig.3-6, only 46.3% of respondents had accelerator physics or technology included
1233 in their academic curriculum, and 53.7% were unfamiliar with fundamental accelerator concepts. These
1234 results highlight the urgent need for integrating accelerator-related topics into undergraduate and graduate
1235 programs across Africa.

1236 Moreover, 57.1% of respondents were unaware of existing accelerator facilities in Africa. Among those
1237 familiar, 69% cited iThemba LABS in South Africa, indicating the limited recognition of existing resources.
1238 These findings point to the need for awareness campaigns to showcase the relevance of accelerators and their
1239 applications in various fields.

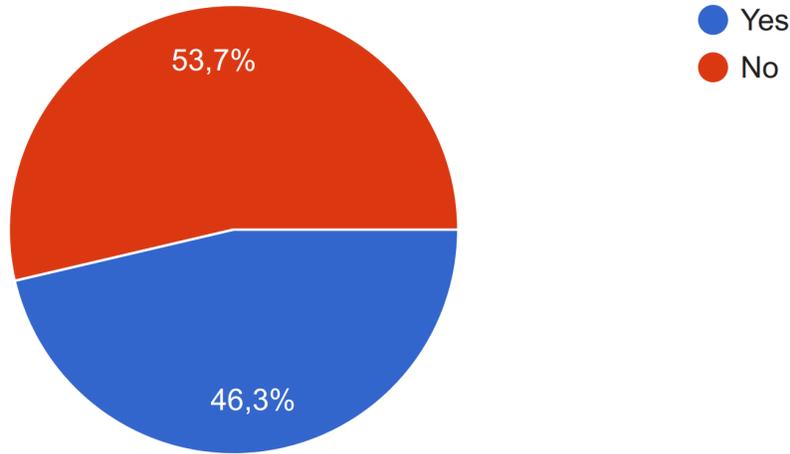


Figure 3-6: Inclusion of Accelerator Physics or Technology in Academic Curricula

1240 3.12.2 Aspirations for Accelerator Physics Development

1241 The survey highlighted widespread support for developing accelerator divisions in Africa, with 88.1% of
 1242 respondents expressing the belief that such divisions are necessary (see Fig. 3-7). Furthermore, Fig. 3-8
 1243 shows that 77.4% strongly agreed that the establishment of accelerator facilities would significantly enhance
 1244 research opportunities on the continent.

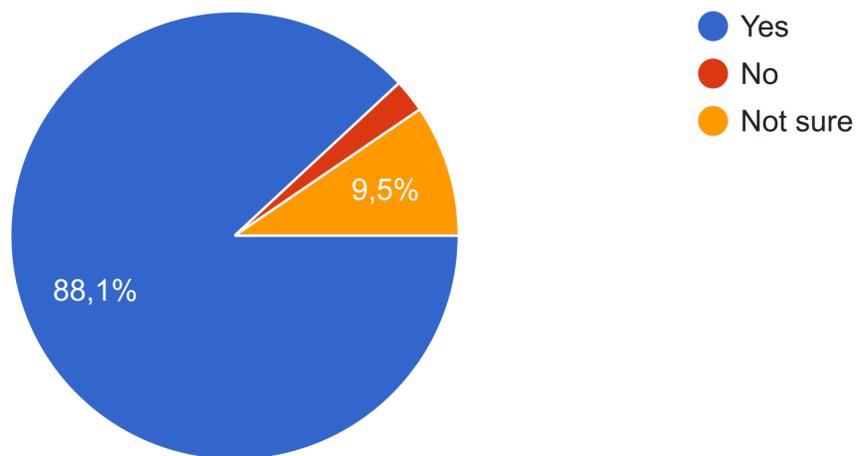


Figure 3-7: Perception of the Need for Accelerator Divisions in Africa

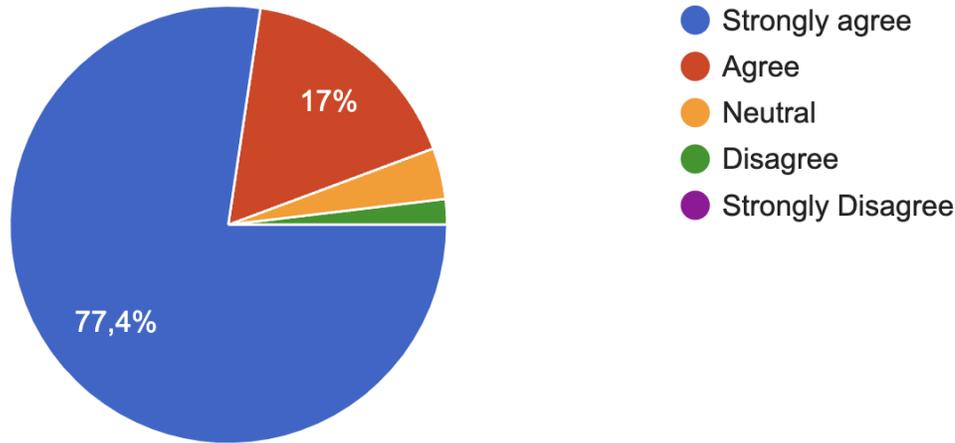


Figure 3-8: Impact of Accelerator Facilities on Scientific Research Opportunities in Africa

1245 Respondents also identified compact accelerator technologies as a promising starting point for Africa. 92.3%
 1246 viewed compact accelerators favorably, emphasizing their cost-effectiveness and accessibility compared to
 1247 larger facilities. These preliminary results suggest a clear interest and readiness within the African scientific
 1248 community to embrace accelerator technology.

1249 3.12.3 Barriers to Progress

1250 Respondents identified several key challenges to establishing accelerator divisions in Africa:

- 1251 • Lack of funding: Identified by 64.3%, this was the most significant barrier.
- 1252 • Insufficient expertise: Highlighted by 57.1%, this reflects the need for more trained professionals.
- 1253 • Limited education and training opportunities: Reported by 57.1% of participants.
- 1254 • Political and logistical obstacles: A lack of political will and infrastructural support further compounds
 1255 the difficulty of establishing such facilities.

1256 These barriers underscore the need for focused strategies to address funding, skills development, and infras-
 1257 tructure deficits.

1258 3.12.4 Potential Solutions and Strategies

1259 Participants proposed several actionable strategies to overcome these challenges:

- 1260 • Increasing funding through international partnerships: Supported by 78.6% of the respondents.
- 1261 • Strengthening regional and global collaborations: Highlighted by 57.1%.
- 1262 • Developing smaller, cost-effective facilities (e.g., compact light sources (CLS): Suggested by 54.8% as
1263 a practical entry point for Africa.

1264 Respondents also emphasized the importance of capacity building through training programs and the in-
1265 volvement of the African diaspora. In particular, 57.5% expressed willingness to return to Africa to work
1266 in accelerator divisions if opportunities arise, providing a strong basis for diaspora participation initiatives.

1267 3.13 Conclusion and perspectives

1268 Although accelerator physics in Africa may not be as developed as in some other regions, there is a growing
1269 recognition of its importance for scientific research and technological advancement, leading to increased
1270 investment and collaboration in this field across the continent. Africa's accelerating interest stems from a
1271 collective understanding of the transformative potential that accelerator-based facilities offer across diverse
1272 scientific domains. This burgeoning acknowledgment has spurred a notable uptick in investment and
1273 collaboration within the accelerator physics realm throughout Africa.

1274 This momentum is not merely confined to the establishment of accelerator facilities but encompasses a
1275 broader spectrum of initiatives aimed at nurturing indigenous expertise, fostering collaborative networks, and
1276 leveraging international partnerships. Through strategic capacity-building programs, educational outreach
1277 endeavors, and knowledge exchange platforms, African countries are actively cultivating a skilled workforce
1278 capable of driving accelerator-based research forward.

1279 Moreover, the increasing integration of accelerator physics into national scientific agendas reflects a broader
1280 commitment to harnessing science and technology for sustainable development objectives. By leveraging
1281 accelerator-based tools, such as synchrotron radiation facilities and particle accelerators, African nations are
1282 poised to address pressing societal challenges, ranging from healthcare and materials science to environmental
1283 conservation and renewable energy.

1284 In essence, while accelerator physics in Africa may currently be in a nascent stage compared to its counter-
1285 parts in more developed regions, the trajectory is undeniably upward. As investment and collaboration
1286 continue to amplify, Africa's accelerator physics community is poised to make increasingly substantial
1287 contributions to global scientific discourse, innovation, and societal well-being, solidifying its place on the
1288 international stage of scientific endeavor.

Bibliography

- 1289
- 1290 [1] Accelerator Knowledge Portal, <https://nucleus.iaea.org/sites/accelerators/Pages/default.aspx>
- 1291
- 1292 [2] Touchrift. B, Salah. H, Benouali. N, Ziane. A, Non Rutherford elastic scattering to measure energy loss of
- 1293 H2 ions in aluminium, NUCL INSTRUM METH B, <https://doi.org/10.1016/j.nimb.2018.12.004>.
- 1294 [3] The South African Isotope Facility (SAIF), <https://tlabs.ac.za/saif/>
- 1295 [4] I. Obiajunwa and G.A. Osinkolu and F.I. Ibitoye and D.A. Pelemo, Ion beam analysis facility at the
- 1296 centre for energy research and development at Ile-Ife Nigeria and its applications in research, NUCL
- 1297 INSTRUM METH B, <https://doi.org/10.1016/j.nimb.2019.07.034>
- 1298 [5] Status of Radiation Therapy Equipment, <https://dirac.iaea.org/Query/Map2?mapId=2>
- 1299 [6] Scopus, <https://www.scopus.com>
- 1300 [7] K. A. Assamagan, A. Boskri, K. Cecire, M. Chabab, C. Darve, F. Fassi, M. Laassiri, S. Samsam, J.
- 1301 Vischer, Summary Report on the ASP2024 Learners Program. <https://arxiv.org/abs/2408.01464>
- 1302 [8] Bark, R., Cornell, J., Lawrie, J., Vilakazi, Z. (2013). Activities at iThemba LABS Cyclotron Facilities.
- 1303 In: Greiner, W. (eds) Exciting Interdisciplinary Physics. FIAS Interdisciplinary Science Series. Springer,
- 1304 Heidelberg. https://doi.org/10.1007/978-3-319-00047-3_15
- 1305 [9] The African Light Source. <https://www.africanlightsource.org/>
- 1306 [10] Chamunorwa Oscar, ENERGY CALIBRATION OF THE 6 MV EN TANDEM ACCEL-
- 1307 ERATOR OF iThemba LABS, <https://wiredspace.wits.ac.za/server/api/core/bitstreams/0ee0dfa0-3383-4f53-8942-cb8584fc5172/content>
- 1308
- 1309 [11] Mtingwa S, Comments on the Geopolitical Conceptual Design Report for an African Light Source.
- 1310 <https://events.saip.org.za/event/249/contributions/9843/>
- 1311 [12] Centre for Energy Research and Development (CERD) <https://cerd.oauife.edu.ng/>
- 1312 [13] IAEA Supports Upgrade and Use of a CERD Accelerator in Nigeria. <https://www.iaea.org/newscenter/news/iaea-supports-upgrade-and-use-of-a-cerd-accelerator-in-nigeria>
- 1313
- 1314 [14] CHRISTIAN NUVIADENU, PELLETRON ACCELERATOR IN GHANA. https://www.afcone.org/wp-content/uploads/2021/11/4.Ghana_Presentation_Ghana.pdf
- 1315
- 1316 [15] Amos Forson, Ghana's 1.7MV Pelletron Accelerator Post-Installation Operations. https://nucleus.iaea.org/sites/nuclear-instrumentation/OM_2021/IAEA_%20VIRTUAL%20PRESENTATION_%20Amos%20Forson_%20Ghana.pdf
- 1317
- 1318
- 1319 [16] Ghana - International Atomic Energy Agency. <https://www.iaea.org/sites/default/files/20/07/tc-ghana.pdf>
- 1320
- 1321 [17] CNSTN - Centre National des Sciences et Technologies Nucleaires. <http://www.cnstn.rnrt.tn/>
- 1322 [18] Adib M, Habib N, Bashter II, El-Mesiry MS, Mansy MS. Simulation study of accelerator based quasi-
- 1323 mono-energetic epithermal neutron beams for BNCT. Appl Radiat Isot. 2016 Jan;107:98-102. doi:
- 1324 10.1016/j.apradiso.2015.10.003. Epub 2015 Oct 9. PMID: 26474209.

- 1325 [19] Accelerators Around the World: [https://www.pelletron.com/library/](https://www.pelletron.com/library/accelerators-around-the-world/)
1326 [accelerators-around-the-world/](https://www.pelletron.com/library/accelerators-around-the-world/)
- 1327 [20] International Nuclear Physics Conference in SA. [https://www.iol.co.za/capetimes/news/](https://www.iol.co.za/capetimes/news/south-africa-hosts-international-nuclear-physics-conference-cd9a881f-4d1d-4675-a702-880d14b836ed)
1328 [south-africa-hosts-international-nuclear-physics-conference-cd9a881f-4d1d-4675-a702-880d14b836ed](https://www.iol.co.za/capetimes/news/south-africa-hosts-international-nuclear-physics-conference-cd9a881f-4d1d-4675-a702-880d14b836ed)
- 1329 [21] Sheehy. S, Applications of Particle Accelerators, arXiv:2407.10216v1 [physics.acc-ph] Jul2024, <https://arxiv.org/html/2407.10216v1>.
1330
- 1331 [22] The South African Isotope Facility (SAIF), <https://tlabs.ac.za/saif/>
- 1332 [23] Accelerate Your Teaching MOOC. <https://www.europeanschoolnetacademy.eu/dashboard>
- 1333 [24] Particle Accelerators and Radiation Research. [https://www.epa.gov/radtown/](https://www.epa.gov/radtown/particle-accelerators-and-radiation-research#:~:text=According%20to%20the%20International%20Atomic,Learn%20more%20about%20Radiation%20Therapy)
1334 [particle-accelerators-and-radiation-research#:~:text=According%20to%20the%](https://www.epa.gov/radtown/particle-accelerators-and-radiation-research#:~:text=According%20to%20the%20International%20Atomic,Learn%20more%20about%20Radiation%20Therapy)
1335 [20International%20Atomic,Learn%20more%20about%20Radiation%20Therapy](https://www.epa.gov/radtown/particle-accelerators-and-radiation-research#:~:text=According%20to%20the%20International%20Atomic,Learn%20more%20about%20Radiation%20Therapy)
- 1336 [25] El Sarraf M, El-Sayed A, Evaluation of gamma-ray buildup factors for some waste paper and natural
1337 rubber composites, Nucl. Phys. At. Energy 2022, volume 23, issue 4, pages 280-287. [https://jnpae.](https://jnpae.kinr.kyiv.ua/23.4/Articles_PDF/jnpae-2022-23-0280-El-Sarraf.pdf)
1338 [kinr.kyiv.ua/23.4/Articles_PDF/jnpae-2022-23-0280-El-Sarraf.pdf](https://jnpae.kinr.kyiv.ua/23.4/Articles_PDF/jnpae-2022-23-0280-El-Sarraf.pdf)
- 1339 [26] Adedayo H, Adio S, Oboiren B, Energy research in Nigeria: A bibliometric analysis, Energy Strategy
1340 Reviews Volume 34, March 2021, 100629. <https://doi.org/10.1016/j.esr.2021.100629>
- 1341 [27] Anna Grigoryan et al, Development of nuclear medicine in Africa, October 2021 Clinical and Transla-
1342 tional Imaging 10(4). DOI:10.1007/s40336-021-00468-3
- 1343 [28] Database for cyclotron facilities. [https://nucleus.iaea.org/sites/accelerators/Pages/](https://nucleus.iaea.org/sites/accelerators/Pages/Cyclotron.aspx)
1344 [Cyclotron.aspx](https://nucleus.iaea.org/sites/accelerators/Pages/Cyclotron.aspx)
- 1345 [29] Adolphsen C et al, European Strategy for Particle Physics Accelerator R&D Roadmap. [https://doi.](https://doi.org/10.23731/CYRM-2022-001)
1346 [org/10.23731/CYRM-2022-001](https://doi.org/10.23731/CYRM-2022-001)
- 1347 [30] M. Tigner. A possible apparatus for electron clashing-beam experiments. Nuovo Cim.,37:1228-1231,
1348 1965. <http://doi.org/10.1007/BF02773204>.
- 1349 [31] Abraham J. Accelerator Control Development at iThemba LABS: Road to EPICS and beyond. [https://](https://conference.sns.gov/event/258/contributions/607/)
1350 conference.sns.gov/event/258/contributions/607/
- 1351 [32] Smith T, Schwettman H, Rohatgi R, Lapierre Y, and Edighoffer J. Development of the SCA/FEL
1352 for use in biomedical and materials science experiments. Nucl. Instrum. Meth. A, 259(1):1-7, 1987.
1353 [https://doi.org/10.1016/0168-9002\(87\)90421-9](https://doi.org/10.1016/0168-9002(87)90421-9).
- 1354 [33] Laassiri M, African School of Physics for the Outreach session of the EuPRAXIA PP Annual meeting,
1355 Isola d'Elba, Italy. <https://agenda.infn.it/event/41613/timetable/#20240927>
- 1356 [34] Samsam S, African School of Physics for the Outreach session of the 3rd accelerator days, Fras-
1357 cati, Italy. [https://agenda.infn.it/event/38953/timetable/?view=standard_inline_minutes#](https://agenda.infn.it/event/38953/timetable/?view=standard_inline_minutes#day-2024-04-057)
1358 [day-2024-04-057](https://agenda.infn.it/event/38953/timetable/?view=standard_inline_minutes#day-2024-04-057)
- 1359 [35] Bacci A et al., STAR HE-Linac Complete Detailed Design Report, arXiv:2109.10351. DOI:10.48550/
1360 [arXiv.2109.10351](https://arxiv.org/abs/2109.10351)
- 1361 [36] ALBA Synchrotron. <https://www.cells.es/en>

Computing Working Group

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2363 7.1 Introduction and Motivation

2364 Research nowadays needs strong computing services to analyze big data, extract results, make discoveries,
2365 and improve the lives of citizens.

2366 What we define as a computing service is comprised of many layers, ranging from the underlying hardware
2367 including network resources, computer systems, and storage, to the applications and software implemented
2368 on the hardware. For decades, we have observed the advent of new computing fields such as Artificial
2369 Intelligence and Deep Learning that have revolutionized data processing.

2370 Even though computing is itself a science and a field of research and technology, we consider here the
2371 application of informatics to other science research fields. We should also not forget Quantum Computing,
2372 which will give a major advantage to countries and organizations that master this field.

2373 A large fraction of the information collected in this report is based on a survey launched in March 2022,
2374 including ASFAP participants and attendees of the 2nd African Conference of Fundamental and Applied
2375 Physics ACP2021 [1] held in March 2022 in Casablanca, Morocco. More details can be found in ref. [19]. This
2376 survey was launched to evaluate the status of computing resources in the field of African Physics Research.
2377 The panel was mainly composed of participants working and living in Africa (more than 82%); the rest
2378 being largely what we call Africans from the diaspora. 26 countries were represented in the panel.

7.2 Computing Challenges for Scientific Activities in Africa

Scientific fields that rely on data processing to extract knowledge are numerous. They span various fields including Physics, Astrophysics, Biomedical and Environmental research, etc. The survey cited above has gathered participants belonging to more than 30 different fields. Most of them highlighted the scarcity of computing infrastructure and often the lack of stakeholder understanding about the extent of the need for computing in their field.

In recent decades, the importance of providing robust computing resources and services has become increasingly evident. For instance, the discovery of the Higgs Boson at the Large Hadron Collider (LHC) at CERN [4, 5] would not have been possible without such resources. To put this in perspective, the CRAY X-MP/48 computer, used at CERN around 1985, would take approximately 3.5 million years to process just one year's worth of data from the LHC today. Even the high-performance computing infrastructure from around 1995 would still require 11,000 years to achieve the same task [6].

The sheer size and complexity of the LHC's data, the stringent selection process required to find the "needle in a haystack," and the necessity of generating billions of simulated events to compare against theoretical models required an unprecedented level of computing power. This example underscores the need for computing resources that are not only vast, but also shared, distributed, and interoperable across a global community of scientists.

Another computational challenge is the need to simulate increasingly more complex physical phenomena that require different heterogeneous architectures and a level of coding that allows better exploitation of new architectures such as GPUs (Graphical Processing Units). Active research, in particular using Deep Learning, Natural Language Processing, Graphical Networks and other AI-related techniques is ongoing to produce code that would be optimized for specific infrastructures. Simulations require substantial processing power for computational physics, and other research applications in Physics involving large datasets require high computational power to produce precise and timely results (Navaux, et al.,2023 [8]). To process large datasets and perform complex calculations, researchers can use High Performance Computing (HPC) resources. The main challenge in Africa is the limited availability of HPC facilities for researchers, hindering research in the African region.

Not all fields demand such a large amount of computing resources; but as modest as the data sample may be, it may need complex processing that cannot anymore be done by hand.

If we focus on the Africa region, lack of commitment from African governments toward advancing scientific and technological innovation is also a key challenge to the scientific research in the region. The ASFAP community report (2020-2024) reveals that African countries have been spending less than 1% of their gross domestic product (GDP) on research despite the increase in the number of scientists in the past five years. South Africa and Egypt allocate the highest budgets for scientific research which are respectively 0.83% and 0.72% of their GDP [7].

More so, the significant costs associated with acquiring, operating, and maintaining higher-performance computing systems could be overwhelming and challenging in the regions with the poorest economy.

Another challenge would be the insufficient number of skilled computational scientists and engineers to support and operate the computing resources. This may hamper the effective and efficient use of computing resources in the region.

2419 7.3 Synergies with neighboring fields

2420 The need for more computational performance in many fields of science is driving the search for more powerful
2421 architectures and applications. We have seen above that very close neighboring fields can and will develop
2422 with the need for powerful computing for Physics. The most obvious ones are the fields related to Artificial
2423 Intelligence and Quantum Computing. These two fields are providing and will provide an unprecedented
2424 boost in the power of computing for any research thematic.

2425 7.3.1 Artificial Intelligence

2426 Artificial Intelligence (AI) is already widely used in many domains in industry, research, communications,
2427 etc., and it is difficult to fully capture and describe the role it has taken on in our every day life.

2428 Particle physics was one of the first fields of science in the late 1960s to study and use AI, in particular
2429 Neural Networks, to discriminate more accurately between signal and background, and also Deep Learning
2430 to increase analysis performance of the immense amount of data delivered by powerful colliders.

2431 It is used in many other fields, some of them being security, machine control, work in extreme environments,
2432 and in particular in medical sciences: early diagnostics of pathology, second opinion for doctors, drug
2433 discovery and personalized treatment. Accordingly, the broader adoption of AI in healthcare systems in
2434 Africa would be of significant benefit for the continent.

2435 Although AI techniques are still in their early stages, they have accelerated the progress in research,
2436 penetrated all facets of our life, and they contribute to considerable resource savings.

2437 The 2024 Nobel Prize in Physics Went to AI Research and recognized John Hopfield and Geoffrey Hinton
2438 for foundation research in neural networks. The Nobel Prize Committee has awarded the 2024 Nobel Prize
2439 in physics for their fundamental discoveries in machine learning, which is key to artificial intelligence as it
2440 develops how a computer can train itself to generate information (Matthew S. Smith, 2024. IEEE Spectrum
2441 [9]).

2442 7.3.2 Quantum Computing

2443 Quantum computing is one of the most trending and promising chapters of all quantum technologies. The
2444 basic idea behind its development is the possibility to rely on the quantum properties of matter at the
2445 microscopic scale, mainly quantum superposition and quantum entanglement, in order to build up computing
2446 hardware (quantum circuits) and software (quantum algorithms), that can handle complex problems which
2447 are out of reach of conventional computing resources, in a reasonable amount of time.

2448 Quantum superposition has been demonstrated a long time ago and routinely used in several applications
2449 such as atomic clocks and interferometry, using inter alia the basic Rabi oscillations phenomenon. However,
2450 quantum entanglement was by far a more elusive phenomenon that has required significantly more effort from
2451 the physics community to provide fully accepted evidence of it. This field was triggered by the groundbreaking
2452 experimental work of A. Aspect in the 1980's, which demonstrated the violation of Bell's inequalities and
2453 proved the existence of quantum entanglement. Further research conducted by A. Zeilinger and others was

2454 able to implement quantum teleportation, based on quantum entanglement, opening up the possibility to
2455 effectively consider technological applications of these quantum properties.

2456 Quantum Computing uses qubits, similar to the bits in classical computing, but offering the advantage
2457 of multiple outputs, as opposed to just 2 outputs, 0 and 1, for the standard electronic bit. This quantum
2458 quantum property, if embedded in a quantum computer, would enable the resolution of complex problems
2459 in an exponentially faster time than with a classical computer. In 2019, Google claimed that it solved a
2460 sampling problem in 200 seconds which would have taken 10,000 years on a classical computer. Notably, the
2461 engineering of qubits has proven to be very challenging, and many governments and private corporations
2462 worldwide are heavily investing in this research. Not only is it very difficult to build a processor based on
2463 qubits, but another related challenge is to build software and algorithms to exploit its capabilities. Progress
2464 in AI, Quantum Computing, and in general in Computing Sciences is one of the most important approaches
2465 to deal with the avalanche of data in all fields of science, and to speed up the process of discoveries that
2466 impact our everyday lives. Synergy between the work of research scientists and computing experts is essential
2467 to explore the quantum world. The rapidly growing field of quantum information and quantum engineering
2468 will require quantum-aware engineers [3].

2469 In Africa, Quantum technologies, and especially quantum computing, have been recognized by the physics
2470 community as important fields, and several teams across the continent engaged significant efforts and means
2471 for research and capacity building accordingly. It is important to mention the pioneering role of South Africa
2472 in this field. The country has several universities working on quantum computing and related topics, and
2473 has already endorsed a national quantum road map, on the same footing as most of the developed countries
2474 in the world. Several other countries are following this path, including Morocco, Egypt and Tunisia.

2475 Numerous initiatives have been implemented to foster collaborations across Africa. It is worth citing the
2476 series of Quantum Africa Conferences, initiated in 2010 in South Africa and held every two years. A number
2477 of other informal networks, either national, regional or continental, are actively organizing on-line events in
2478 the field of quantum computing, in addition to training schools and workshops.

2479 The African School of Physics (ASP) has included Quantum computing as part of its training program
2480 regularly and the lectures are appreciated by the young attendees, showing their interest in this field. It is
2481 highly recommended to keep the momentum on this topic and to continue the efforts for capacity building
2482 and stronger involvement of African physicists in this emerging and trending discipline.

2483 7.4 High priority Future Needs from Scientific Community Con- 2484 sultations

2485 We have consulted a scientific community belonging to more than 15 research fields about their experience
2486 accessing computing facilities and their training and education in computing sciences. Parts of the answers
2487 are summarized in figure 7-1: the largest number of responses stress the lack of budget for computing, the
2488 lack of technical support, and the fact that the management does not understand the need of computing for
2489 research.

2490 On computing resources available to achieve their work, the largest number of responses – more than 50% –
2491 find the computing resources to be highly insufficient and the percentage goes up to 66% when counting only
2492 scientists using their local resources. They point at the lack of budget for computing, the lack of technical
2493 support and the fact that the management does not understand the need of computing for research.

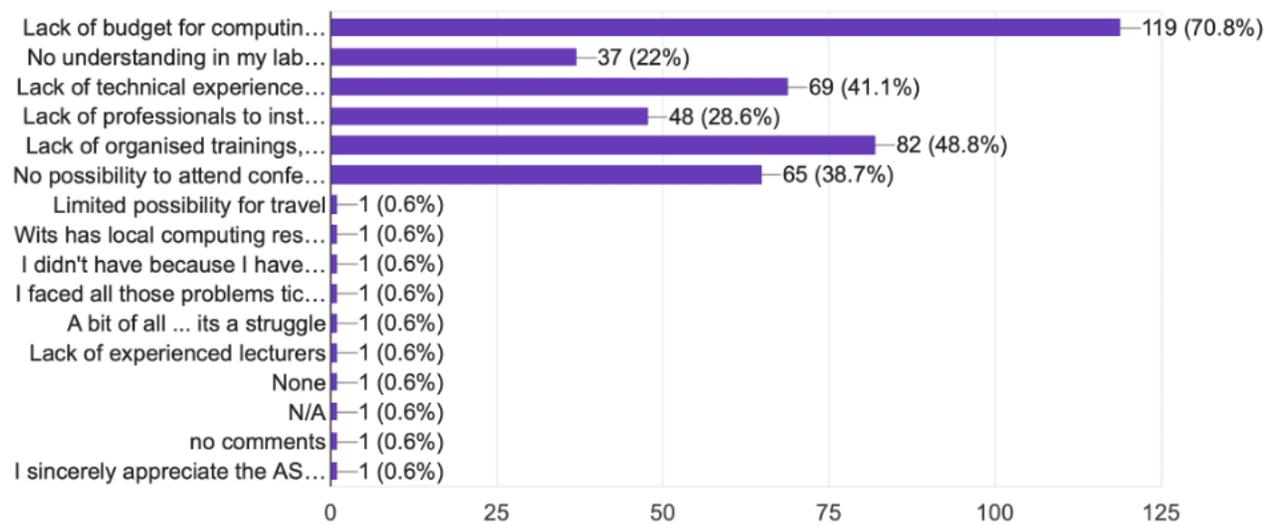


Figure 7-1: Main obstacles to the use of computing by scientists: the largest bottleneck is the lack of budget for computing in physical sciences. The problem might arise from the lack of funding as well as from the wide spread opinion that scientists do not need computers and computing infrastructures to perform their research. This last point is also raised as we see in the graph that 22% of the answers highlight a "No understanding in their lab" of the necessity of computing.

2494 On Education and Training, the participants stress the lack of organized training and workshops and
 2495 the difficulty to attend those meetings organized abroad. Concerning this specific point, more detailed
 2496 information is found in figure 7-2: 74.4% of the scientists are not provided with courses and lectures, or an
 2497 insufficient level thereof. Comprehensive analysis of the survey from which the statistics are extracted can
 2498 be found in [19].

2499 7.5 Recommendations and perspectives

2500 Considering the answers provided by the survey cited above and to improve the situation and boost the
 2501 scientific research in Africa, we draw the following guidelines:

- 2502 • **Develop computing infrastructure and build a knowledgebase:** Infrastructure should be made
 2503 available and, if already existing, improved by a significant level in order to provide easy access to
 2504 data and enough computing performance to process the massive and/or complex data samples. Major
 2505 components of the underlying infrastructure are:
 - 2506 – **Network:** Since networks are vital for the access to data and information, an essential part of
 2507 Computing services is the access, availability and performance of the network, i.e., Academic
 2508 and Research Network in Africa. This is not only true at the local level in universities and
 2509 research centers, but even more so at the national and international level with connections to other
 2510 countries. Most of the countries have, at scientific level, a poor network and slow connections to
 2511 each other: one needs to get a global picture of the existing situation and compile the needs of all

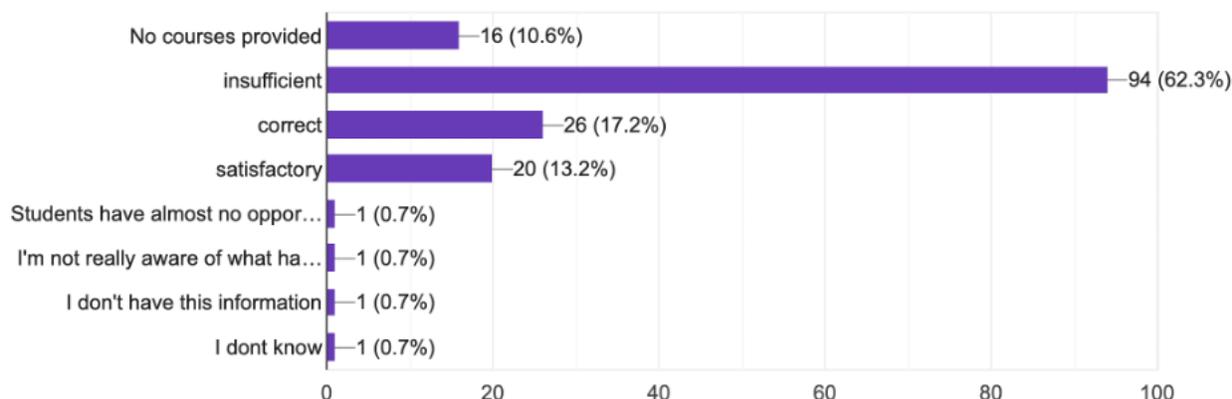


Figure 7-2: Teaching and Training: details are provided about the status of the computing know-how: more than 70% of the answers point to a nonexistent or insufficient level of courses and training.

constituents in order to draw up a strategy for improvement. It is imperative for all countries to share their knowledge. An African coordinated initiative would be a real asset to the continent.

- **Storage and Computing Power:** these are necessary to store and process the data, which is the only way to produce results and advance science. The computing needed is more and more sophisticated now that Artificial Intelligence and Deep Learning have entered the game in all fields of science. As suggested by some of the participants, large data centers shared within a country or with other countries within Africa would certainly be a solution that would federate the resources, and decrease the costs and disparities between universities and countries.

- **Qualified technical staff** is necessary to deploy and run these computing resources and make them available to the physics research scientists that would not be able to deal with Cloud deployment or computer storage access by themselves. Here a collaboration between different countries (within Africa and beyond) could be a fruitful initiative to share IT technicians, setup a few test sites, and start setting up an infrastructure on site.

- **Build Knowledge and include computing in Education:** The poll has highlighted the insufficient level of education in computing. Many solutions should be envisaged simultaneously:

- **Increase the number of computing courses** in the courses of physics and other science students.

- **Train IT professionals** to prepare and operate the infrastructure. These professionals are an important piece of the game as they are the ones that can deploy the complex infrastructure and follow up on the progress in the field.

- **Organize regular workshops and trainings.** This would be highly beneficial for knowledge sharing and to stay at the forefront in computing where evolution is very fast. But this also would have an important positive side effect: Researchers have highlighted the fact that they quite often work isolated. These workshops are the best place to meet their peers and initiate collaborations that would be very beneficial to raise research productivity.

- **Establish Communities of Practice.** Many research computing facilities in Africa face the common problems of isolation and staff retention. Most groups operate in relative isolation and struggle to engage with peers. This is largely owing to the lack of financial resources to facilitate in-person engagements since the vast majority of scientific computing workshops occur outside

2541 of Africa. Another contributing factor towards isolation is simply the lack of awareness of any
2542 accessible broader communities in Africa.

- 2543 – **Establish sustainable workforce development pipelines.** While there is an identified
2544 need to train and upskill the technical workforce in Africa to operate and maintain advanced
2545 research computing resources, any workforce development pipelines must be sustainable. Research
2546 institutes that manage to upskill their technical staff face a subsequent challenge of retaining the
2547 newly-skilled staff who now have opportunities to migrate to higher-paying industries with more
2548 attractive resources.
- 2549 – Last but not least, **national and international collaboration** with peers more experienced in
2550 these fields would provide accelerated knowledge transfer and build mutually beneficial collabo-
2551 ration.

- 2552 • **Harnessing Cloud Computing for Africa’s Scientific Research Infrastructure:** The rapid evo-
2553 lution of computing capabilities to meet the growing demand for data processing presents a significant
2554 challenge to Africa’s scientific research infrastructure. To keep pace with the computing requirements
2555 for today’s vast amounts of data, there is a critical need for constant optimization of computing
2556 resources. Cloud computing offers a cost-effective solution to this challenge. While traditional High-
2557 Performance Computing (HPC) systems require substantial investment in acquisition, operation, and
2558 maintenance, cloud computing provides a viable, lower-cost alternative. Although cloud computing has
2559 its limitations, its adoption by African researchers and institutions could bridge the gap in accessing
2560 essential computing resources for high-quality research. Additionally, embracing this technology has
2561 the potential to stimulate further research and advancements in cloud computing and data center
2562 management, fostering innovation in these fields.

- 2563 • **Prioritizing Sustainable Investments in HPC Centers for Africa’s Development:** Instead
2564 of providing financial aid or loans to African nations, developed countries should prioritize direct
2565 investments in sustainable projects, such as the establishment of HPC centers within the region. These
2566 efforts should include the training of personnel to operate and manage such centers, ensuring long-term
2567 success. This approach would contribute to achieving the Sustainable Development Goal 9 (Industry,
2568 Innovation and Infrastructure) included in the 2030 Agenda for Global Education of the UNESCO
2569 (ref. to be added here) and significantly enhance the region’s computing capabilities to meet present
2570 and future demands.

- 2571 • An example of an initiative to address a sustainable HPC development pipeline is South Africa’s HPC
2572 Ecosystems Project [?]- A project that oversees a now ten-year partnership between Southern African
2573 countries and international computing facilities which has led to the establishment of more than thirty-
2574 five HPC systems in eleven African countries and provided technical training to over 700 participants.
2575 Through the Project’s engagements, a virtual community of practice for emerging HPC Administrators
2576 has grown to incorporate more than 350 members from five continents, which prioritises sustainable
2577 workforce development and adoption of advanced research computing best practices.

2578 7.6 Conclusion

2579 The unavoidable and exponential increase of computing in all science fields including fundamental and
2580 applied sciences necessitates the availability of computing resources, the growth of computing awareness in
2581 the scientific communities and the inclusion of computing in education. Although certainly not extensive
2582 and complete, some key recommendations are drawn in the section above that might fill the gap that is
2583 visibly present when one compares African research with that of other continents. Investing in computing

2584 is one of the highest return on investment that a country can expect. It would provide to the youth of all
2585 countries an opportunity at the level of their hopes and ambitions.

The top priority is raising the awareness of governing bodies and stakeholders at each level; continent, state, university, and research centers about the crucial role of computing in research and sciences. But beyond sciences, it would have a large societal impact and would keep Africa in the race for knowledge, better living and peace.

Global and long scale planning is necessary as this evolution needs building networks, facilities and educating new generations of women and men to adopt the rapidly evolving computing landscape. Budget should be expressly dedicated to computing: it would include all equipment needed for scientists, students and technicians for education, research, and R&D (Research and Development) and the budget to build, connect and run large-scale facilities to host and access the exponentially increasing volume of data.

As the demand for computing capacity is growing enormously, close collaboration between countries is the most efficient way to provide the needed resources. None of the main discoveries of the last decade would have been made possible without the collaborative work effort and the setup of closely connected powerful data centers distributed all over the world.

2586

Bibliography

2587

[1] <https://www.africanschoolofphysics.org/acp2020/>

2588

[2] G. Rahal, "Status of the Computing for Research in Africa <https://arxiv.org/abs/2206.05306>", 2022.

2589

[3] Abraham Asfaw et al., "Building a Quantum Engineering Undergraduate Program <https://arxiv.org/pdf/2108.01311.pdf>", 2021.

2590

2591

[4] ATLAS Collaboration, "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC Phys. Lett. B716 1."

2592

2593

[5] ATLAS Collaboration, "Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC, Phys. Lett. B716 (2012) 30".

2594

2595

[6] COMPUTER EVOLUTION: Time to process LHC Data (2014). <https://videos.cern.ch/record/1958239>

2596

[7] University Worldnews - African Edition: <https://www.universityworldnews.com/post.php?story=20210616151534847>

2597

2598

[8] Navaux, P. O. A., Lorenzon, A. F., & Serpa, M. da S. (2023). Challenges in High-Performance Computing. Journal of the Brazilian Computer Society, 29(1), 51–62. <https://doi.org/10.5753/jbcs.2023.2219>

2599

2600

[9] Matthew S. Smith, 2024. IEEE Spectrum, https://spectrum.ieee.org/nobel-prize-in-physics?mkt_tok=NzU2LUdQSC04OTkAAAGWPZ2vjDBUyO5NhTrJB044SVKy3GRP5lygH6POJJX-FCU18hlxI8S5TJAPhVFidsRTKhtYktWECQ27IcwdaO0_BTmrLkPRvC_kB6gTFUxYIIr

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Instrumentation and Detectors Working Group

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11.1 Introduction and Motivation

By construction, this working group is transversal and multidisciplinary, and its activities are related to all other physics groups. The Instrumentation and Detectors Working Group aims to identify existing or new initiatives and projects within a wide range of instrumentation, which should be further developed in order to become valid proposals to provide access and/or create new facilities across Africa. The role of this WG is to coordinate and encourage such initiatives and to provide assistance in the process of writing concrete proposals toward the so-called 'White papers' [Ref].

11.2 Major challenges for scientific activities

In the early phase of the WG, a small and probably insufficient attempt was made to generate an approximate overview of existing (active) facilities in Africa by scanning through web pages, conference proceedings and other miscellaneous sources of information. This process turned out to be fairly difficult, especially in the physics domains outside of the competences of the WG conveners. However, the prejudice that most of the instrumental centers are concentrated in very specific regions on the continent, e.g., South Africa, Namibia and in the Northern part of Africa, seemed to be confirmed, while very few are located in the sub-Saharan countries of central Africa.

Some of the large research activities are also described in chapter 4 on various instrumentation used in astronomy and cosmology across the whole continent, in chapter 3 on accelerator technologies and in chapter 16 with respect to the participation of several research groups in particle physics experiments, especially at CERN[1] in Geneva, Switzerland: Researchers from universities and laboratories in Morocco, Egypt, and South Africa are members of these large international collaborations like ATLAS, ALICE, and CMS and are contributing to High Energy Physics Experiments. Recently, physicists from Nigeria, Algeria, and Tunisia have joined these collaborations.

3095 In the U.S., the university of Antananarivo has joined the DUNE[11] long base line neutrino experiment and
 3096 the new facility of an electron ion collider[12] at Brookhaven National Laboratory in New York has attracted
 3097 researchers from Egypt, Tunisia, and Zambia. Lastly, Senegal is involved at the Thomas Jefferson National
 3098 Accelerator Facility in Virginia[24] and the Facility for Rare Isotope Beams in Michigan[25].

3099 African countries can contribute to the field of experimental physics, thanks to the international character of
 3100 this field of physics. In the development of these collaborations, African laboratories profit from knowledge
 3101 transfer and the installation of new facilities, which opens up further possibilities for future activities.

3102 Examples of relatively large centers with an important activity in instrumentation are the nuclear facilities
 3103 with accelerators at iThemba Labs[2] and several astrophysics observatories such as the South African
 3104 Astronomical Observatory (SAAO)[3] and Square Kilometer Array (SKA)[4] in South Africa, the High
 3105 Energy Stereoscopic System (HESS)[5] in Namibia, and larger research centers such as the Center National
 3106 de l'Énergie, des Sciences et des Techniques Nucléaires (CNESTEN)[6] in Morocco and the Center for
 3107 Development of Advanced Technologies (CDTA)[7] in Algeria. Other smaller instrumentation-focused centers
 3108 exist also in other countries, that includes the Lasers Atoms Laboratory at Cheikh Anta Diop University
 3109 and the Radiocarbon Laboratory of the Institut Fondamentale d'Afrique Noire (IFAN)[8] in Senegal, the
 3110 Atomic Molecular Spectroscopy and Applications Laboratory at the University of Tunis El Manar in Tunisia,
 3111 and the Center for Energy Research and Development (CERD)[9] in Nigeria, among others. Various small
 3112 research groups established a multi-country collaboration to establish a larger network of complementary
 3113 scientific capabilities like the African Laser Center[26]. There are many other laboratories on the continent
 3114 with various instruments to conduct research, however, not only a large fraction are known to be inactive
 3115 due to lack of resources to repair some key components, albeit with some needed minor repairs, but also the
 3116 large majority being unknown to the African scientific community.

3117 A first meeting of the WG took place in November 2021, with the principal goal of helping in the submission
 3118 of Letters of Intent (LoIs) designed to be a call to the African scientific community to obtain inputs for
 3119 the African Strategy for Fundamental and Applied Physics (ASFAP). These LOIs were further analyzed by
 3120 structuring the collected information on existing facilities. This initial survey was complemented with other
 3121 information collected from presentations at various scientific meetings, conferences, and workshops such as
 3122 ACP2021[10] and others. Two main issues were raised repeatedly:

- 3123 • There is a strong consensus that the main problem researchers face is the need and easy accessibility
 3124 of experimental facilities to conduct their research; and
- 3125 • The second essential need is to overcome the lack of educational training centers in instrumentation
 3126 for basic and advanced experimental physics.

3127 11.3 Analysis of submitted Letters of Intent (LoIs) related to 3128 instrumentation

3129 After the first set of submitted LoIs, several were identified that possibly relate to instrumentation needs.
 3130 These LOIs were grouped in three categories as listed below (the numbers in the brackets refer to the
 3131 submission identification of the LoI). A graphical representation is provided by Fig.11-1:

- 3132 1. Extensions of existing facilities:
 - 3133 • (Radio)-Astronomy (51, 54, 56, 67)

- 3134 • Accelerator centres (17, 24)
- 3135 2. New facilities
- 3136 • Astronomy: local observatories for North Africa (14)
- 3137 • Astroparticle underground (15)
- 3138 • African millimetre telescope (33)
- 3139 • Am-Be neutron source (39)
- 3140 • AfLS (not a special LoI)
- 3141 • Instrumentation for AfLS (58, 59, 61,66)
- 3142 3. Centers of Excellence (within which the instrumentation part was not always explicit or clear)
- 3143 • Graphen Flagship (4)
- 3144 • Energy centre of excellence (5)
- 3145 • NANOAFNET(10)
- 3146 • Quantum physics and biology (19, 23, 27, 49)
- 3147 • Education, ICEPA (68), Internet of Things

3148 Three types of LoIs spanning over many fields of physics emerged, some proposing extensions of already
 3149 existing facilities, others the creation of new facilities. A third category of LoIs concentrated on centers of
 3150 excellence to address specific topics, emphasizing collaboration between African countries.

3151 In the spring 2022 the conveners of the WG started to approach the authors of the existing LoIs directly
 3152 with two goals: (1) to compile more details pertaining to instrumentation and (2) to encourage a plan for
 3153 the organization of a global collaborative effort; the latter aiming to coordinate concrete action items and
 3154 to assist in instrumentation needs. However only two meetings could be held, on May 5th and June 9th,
 3155 gathering a total of 21 and 14 participants, respectively. Further meetings were planned but canceled due
 3156 to problems identifying dates accommodating the speakers and conveners' availability. The beginning of the
 3157 summer 2022 break put an end to that round of meetings.

3158 On May 5th three LoIs were discussed, namely letter #39 (Am-Be neutron source), #54(Low Frequency(<
 3159 1 GHz) RadioInterferometric Arrays), and #33 (The first millimeter-wave radio telescope). The following
 3160 meeting on June 9th centered on two existing facilities at iThemba Labs (#17, #24) and #10, UNESCO-
 3161 UNISA[22] and NANOAFNET[23]. Brief summaries for the former are listed below.

3162 **LoI #39: Am-Be neutron source** proposes to extend the use of Am-Be neutron sources for teaching
 3163 and applied research beyond Nigeria to other African countries. Transferring this technology will
 3164 stimulate new collaborations. Neutron sources are technically much easier than research reactors to
 3165 probe materials with thermal neutron reflection technique or neutron activation analysis. Only 8
 3166 African countries have research reactors: Algeria(2), DR Congo (2), Egypt (2), Ghana (1), Libya (1),
 3167 Morocco (1), Nigeria (1), and South Africa (1).

3168 **LOI #54: Low Frequency(< 1 GHz) RadioInterferometric Arrays** which is an already growing in-
 3169 ternational collaboration between Gabon, New Zealand, and South Africa that explores the time
 3170 dependent density of the ionosphere, which has a large impact on many communication channels
 3171 with satellites but also on radio-astronomy. Arrays of GPS stations can monitor the Total Electron
 3172 Content (TEC) of the ionosphere. Transient Array Radio Telescopes (TART) or a scaled-down version
 3173 of The Long Wavelength Array (SDLWA) address astrophysical topics.

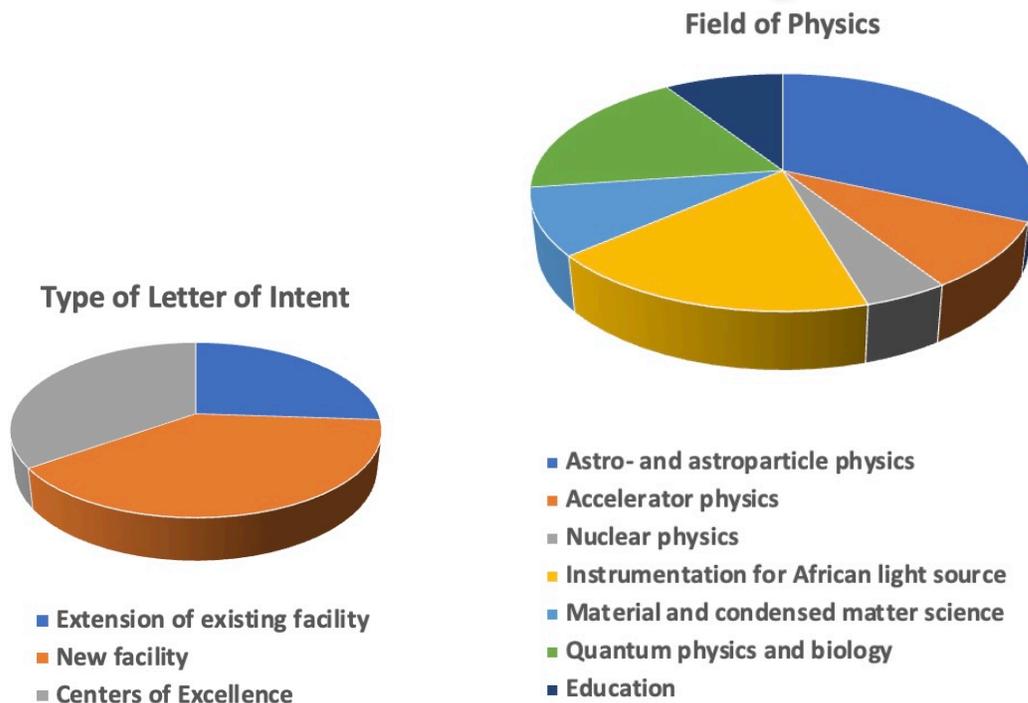


Figure 11-1: The Letter of Intents submitted by the African scientific community grouped by type (left) and sub-field of physics (right).

3174 **LOI #33: The first millimeter-wave radio telescope** which is a “single dish” radio telescope cur-
 3175 rently being built in Namibia. It will open new perspectives for astrophysics in Africa as well as
 3176 new international collaborations, especially if the telescope is incorporated in the world wide Event
 3177 horizon telescope[27].

3178 All the above mentioned projects are built on some already existing experimental activities and have the
 3179 potential for the future to create African-wide collaborations. The existing facilities at iThemba Labs do
 3180 already attract scientists from other countries like Algeria, Senegal, Burkina Faso, and Nigeria; however,
 3181 there is quite some room to further increase such collaborations.

3182 In the discussions following the presentations, it became evident that one of the most important short-
 3183 comings was in fact the problem of finding enough person power to widen the scope of these projects beyond
 3184 the country where these activities are located presently. Especially for the astrophysical related projects this
 3185 is a bit surprising because Africa has a fairly large astronomy community, particularly in East Africa.

3186 One of the projects, namely the proposal for an underground laboratory in a tunnel in South Africa (LoI #15)
 3187 took a very positive development during the last years into a strong collaboration now called PAUL (for Paarl
 3188 Africa Underground Laboratory) and is described in more detail in chapter 17. It has been published[14]
 3189 and presented at several conferences[13]. Unfortunately, because of difficulties to find a convenient time slot,
 3190 this project could not be reviewed by the Instrumentation and Detector Group. The proposal consists in
 3191 the creation of a new underground facility in the existing Huguenot tunnel similar to existing underground
 3192 laboratories in the world. If realized in the future, it will create unique research possibilities in many fields

3193 of physics for the African continent. It is a prime example of successful collaboration building between many
3194 African and international scientists.

3195 Unfortunately, the start of the LoI-review could not be continued after the summer break, for various reasons,
3196 mainly manpower, and the lack of participation and resonance within the community.

3197 11.4 High priorities

3198 Several ideas of how to improve the lack of know-how in instrumentation and experimental facilities were
3199 discussed in many meetings. The existence of more such facilities would certainly also increase the number
3200 of people interested to extend their experimental research activities. As mentioned already in the previous
3201 section, difficult communication between the researchers and engineers over the vast African continent is a
3202 further obstacle to progress in the fields. While it is difficult to prioritize any of the ideas presented in the
3203 LOIs, the Instrumentation and Detector Working Group identified three areas that could serve as a basis for
3204 improving the state of scientific excellence in Africa.

3205 11.4.1 A proposal for an International Center for Experimental Physics in 3206 Africa (ICEPA)

3207 Within the Instrumentation and Detector working group a proposal for an “International Center for Ex-
3208 perimental Physics in Africa (ICEPA)” was discussed in order to address the lack of experimental training
3209 facilities in Africa. Some ideas were sketched and then submitted as a LoI (#68). The LoI was also presented
3210 at a meeting of the Physics Education working group. The idea for such a school was born from the apparent
3211 lack, but high need for experimental education and know-how in most African countries. The concept is
3212 very much inspired by the African Institute for Mathematical Sciences (AIMS[15]) and the US Particle
3213 Accelerator School[28], as well as other educational centres like the Southern African Institute for Nuclear
3214 Technology and Sciences (SAINT[16]) or the Sèmè City[17] in Benin.

3215 The proposed center would consist of a master-like curriculum of typically one and a half year, including
3216 a 6-month research project and would include high-level lectures with a major component on hands-on
3217 experiences. A final examination and a recognised diploma (the association to a university will be required
3218 in such case) would conclude the cursus. While the proposed training centre is conceptually very similar to
3219 AIMS, it focuses on experimental techniques used in physics and is strongly oriented towards instrumentation.
3220 For the latter, the idea is to build experimental installations and facilities at strategic locations on the African
3221 continent. The instrumentation could partially be contributed or donated by international collaborators and
3222 universities. These donors ideally should also take the responsibility to maintain the equipment, at least for
3223 the first years, until a local staff has been trained and qualified.

3224 11.4.2 Small physics experimentation and the Internet of Things

3225 Another very interesting and potentially powerful possibility with the goal to foster experience in instrumen-
3226 tation, is the intense use of micro processors and controllers for education. Furthermore, it is much easier
3227 to establish.

3228 Most of today's physics experiments use sensors converting measured physical quantities into electronic
3229 signals, which are finally acquired and treated with computers. This means that skills in electronics,
3230 computer interfacing and programming are essential for an experimental physicist. Micro-controllers are
3231 mass produced[19] and for this reason they have become extremely cheap. This is a major advantage for
3232 countries with small budgets. On the other hand, these micro-controllers have become very powerful with
3233 many low-cost standardized interfaces like GPIO, I2C, I2S, Can bus etc.[20], but still with high precision.
3234 Examples of sensors easy to implement are:

- 3235 • sht30: temperature and humidity sensor
- 3236 • PlanTower pms5003 (sensor with laser technology measuring light deflection through dust particles)
- 3237 • Analog devices MAX 2769 GPS receiver
- 3238 • MPU6050 accelerometer and gyroscope
- 3239 • and many, many more

3240 Very divers experiments can be made for a few dollars using these devices such as:

- 3241 • Medical measurements like ECG, heart rate, oxygen content in the blood etc.
- 3242 • Environmental measurements like air or water quality
- 3243 • Meteorologic measurements of air temperature and humidity, soil moisture, wind speed etc.
- 3244 • Smart farming experiments
- 3245 • and many more.

3246 Some of the micro-controllers integrate network interfaces (Ethernet or WiFi, BlueTooth or GSM) allowing
3247 them to be connected to the Internet. Measured data can be transferred to servers and further analyzed and
3248 displayed there. These servers can give world-wide access to the measurement results. These are systems of
3249 type "Internet of Things"[18]. It is easily possible to provide documentation of experiments on the Internet
3250 using Wiki pages. The software needed for data readout, readout, analysis and communication with the
3251 Internet can be made available through github[21], allowing easy collaboration between groups of physicists
3252 working on similar subjects across borders. Unfortunately there are very few universities in Africa providing
3253 courses on the Internet of Things, despite the very limited budget needed to set up such a course and the
3254 great potential for the students they would have. Teaching digital electronics, data analysis, micro-controller
3255 programming of WEB programming would give the student chances in a wide range of industries also outside
3256 of physics.

3257 11.4.3 Regional instrumental conferences

3258 Regional conferences focused on instrumentation and detectors across different fields could be one way
3259 of enhancing the exchange of knowledge and expertise between scientists of neighboring countries and to
3260 stimulate new collaborations.

3261 11.5 Conclusion, synergies with other fields and perspectives

3262 After an enthusiastic start in 2021/2022 in the context of the ASFAP townhall meeting in the Spring 2022, the
3263 activities of the Instrumentation and Detector working group came to an apparent hold during the Summer
3264 2022. Therefore the group could not guide the proponents of LoIs to generate White Papers. The activities
3265 also suffered from a lack of interaction with the other working groups, whose input is urgently required
3266 because instrumentation can only be developed in a global context of physics and education. Examples
3267 for the latter are the proposed instrumentation school (ICEPA) and the implementation of "The Internet
3268 of Things" into universities curricula. The mobilization of the African scientific community itself is still
3269 insufficient to develop a strategy and the proposed projects and to find African leaders as spokespeople for
3270 these.

Bibliography

- 3271
- 3272 [1] <https://home.web.cern.ch/>
- 3273 [2] <https://tlabs.ac.za/>
- 3274 [3] <https://www.sao.ac.za/>
- 3275 [4] <https://www.skao.int/>
- 3276 [5] <https://www.mpi-hd.mpg.de/hfm/HESS/>
- 3277 [6] <https://www.cnesten.org.ma/>
- 3278 [7] <https://www.cdta.dz/>
- 3279 [8] <https://ifan.ucad.sn/>
- 3280 [9] <https://www.unn.edu.ng/academics/centres/centre-for-energy-research-and-development/>
- 3281 [10] <https://indico.cern.ch/event/1060503/timetable/?view=standard>
- 3282 [11] <https://www.dunescience.org/>
- 3283 [12] <https://www.bnl.gov/eic/>
- 3284 [13] <https://twiki.cern.ch/twiki/bin/view/PaulLab/ScienCe>
- 3285 [14] <https://arxiv.org/abs/2306.12083>
- 3286 [15] <https://aims.ac.za/>
- 3287 [16] <https://tlabs.ac.za/saints/>
- 3288 [17] <https://semecity.bj/>
- 3289 [18] <https://en.wikipedia.org/wiki/Internet-of-things>
- 3290 [19] https://www.espressif.com/en/news/1_Billion_Chip_Sales.
- 3291 [20] Commonly used interfaces:
- 3292 gpio: https://en.wikipedia.org/wiki/General-purpose_input/output
- 3293 i2c specs: <https://www.nxp.com/docs/en/user-guide/UM10204.pdf>
- 3294 spi: <https://www.analog.com/en/resources/analog-dialogue/articles/introduction-to-spi-interface.html>
- 3295 i2s: <https://www.nxp.com/docs/en/user-manual/UM11732.pdf>
- 3296 can bus: <https://www.ti.com/lit/an/sloa101b/sloa101b.pdf>
- 3297 [21] Example of a lecture at the African School of Physics 2024: <https://github.com/uraich/ASP2024>,
- 3298 with the documentation at
- 3299 <https://github.com/uraich/ASP2024/wiki>
- 3300 [22] <https://www.unisa.ac.za/sites/corporate/default/Colleges/College-of-Graduate-Studies/>
- 3301 [23] <https://nanoafnet.tlabs.ac.za/>
- 3302 [24] <https://www.jlab.org>
- 3303 [25] <https://www.frib.msu.edu>

- 3304 [26] <https://africanlasercenter.org>
- 3305 [27] <https://eventhorizontelescope.org>
- 3306 [28] <https://uspas.fnal.gov>