ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.1923

# Overview of Particle Accelerator Physics in South America: A Systematic Review of Regional Contribution and Collaboration Networks

Sánchez Rosas, Luis Junior[1], Díaz Desposorio, Félix Napoleón[2], Gaytan Rodriguez, Mathias Leandro[3], and López Córdova, Juan Andre[3]
[1]*Universidad Privada del Norte, Peru,* jusa295@gmail.com
[2]*Universidad Autónoma del Perú, Peru,* fisicadiaz@gmail.com
[3]*Universidad Tecnológica del Perú, Peru,* U22200510@utp.edu.pe, U22227040 @utp.edu.pe

***Abstract*– The landscape of particle accelerator physics in South America has been the subject of a systematic review that analyses the regional contribution and collaborative networks in this field. The research focuses on the role South American countries play in the development and research of particle accelerators, highlighting both the achievements and challenges facing the region. The review highlights the importance of international collaboration in particle accelerator physics, evidencing how South American scientists and institutions have established connections and alliances with research centers around the world. These collaborations have not only enabled access to advanced technologies and knowledge but have also contributed to the exchange of ideas and the development of scientific capacities in the region. This systematic review comprehensively examines the state of particle accelerator physics in South America, assessing regional contributions, collaborations, and challenges through the analysis of 797 articles collected from the Scopus (716 articles) and Web of Science (230 articles) databases. The study highlights the leadership of Brazil and Argentina as major players in the region, emphasizing their significant contributions to advancement and research in this field. The research reveals how international collaboration has been instrumental, in allowing South American scientists and institutions to forge strategic alliances with global research centers. These synergies have facilitated access to cutting-edge technologies and the exchange of knowledge, significantly boosting regional scientific development. Emblematic projects and key technological advances are highlighted, underscoring South America's potential in particle physics. Finally, critical challenges are identified, such as the need to increase investment in infrastructure and talent training. The study suggests strengthening intra-regional and international collaboration networks to overcome these barriers. In conclusion, this review provides a comprehensive perspective on particle accelerator physics in South America, highlighting the achievements, challenges, and the vital importance of international collaboration in advancing this essential scientific field.***

***Keywords*-- Particle Physics, Particle Accelerator, South America, High Energy Physics and Brazil**

**Digital Object Identifier:** (only for full papers, inserted by LACCEI).
**ISSN, ISBN:** (to be inserted by LACCEI).
**DO NOT REMOVE**

## I. Introduction

Particle accelerator physics has emerged as one of the most fascinating and dynamic scientific fields of the 21st century, driving human knowledge about the fundamental particles that make up our universe and the forces that govern them [1, 2, 3]. In the South American context, this scientific landscape takes on a particular relevance, marked by growing international collaboration and a shared commitment to borderless research [4-11].

South America is emerging as a vibrant scene in the study of particle physics, characterized by a network of research institutions and universities that have consolidated their presence in the global scientific community [4, 11-17]. It began in the 1960s with the first linear accelerators brought to Brazil for the CBPF (Centro Brasileiro de Pesquisas Físicas), which led to the modest goals of research with accelerated particles taking off in the region from that point on [18-21]. Through the construction and operation of state-of-the-art particle accelerators, significant strides have been made toward understanding fundamental phenomena, from the structure of the atomic nucleus to the nature of dark matter and dark energy that make up the cosmos [12, 22-27].

From the construction of the first particle accelerator to the more ambitious projects underway, South America has emerged as a major player in high-energy physics, contributing significantly to advancing human knowledge in this crucial area of science [12, 28-31]. This overview provides a panoramic view of this exciting scientific field in the South American region, highlighting its importance in the global context of particle physics research [5, 17, 31, 32].

This diverse and ever-evolving landscape encompasses a wide range of projects and facilities, from the legendary Synchrotron Electron Accelerator (UVX) in Brazil to the Pierre Auger Project in Argentina, which investigates ultra-high-energy cosmic rays [4, 10-12, 19, 33, 34]. In addition, the region has been a place of international collaboration, where scientists from different countries and continents come together to carry out borderless research and innovative projects [11, 31, 35].

The need to carry out a bibliometric review focuses on the state of knowledge looking at the advances and active fields of research [36, 37], as well as the areas little explored; identifying emerging trends and issues within the region, collaborations, and research networks, analyzing scientific production to observe patterns of collaboration between institutions in the region; identify available resources and existing capacities to strengthen research in the region; global impact and increase the visibility of research in the region [38, 39]. This will contribute to advancing scientific and technological knowledge in this important and constantly evolving field.

For this bibliometric analysis, bibliographic databases such as Scopus and WoS will be used, as well as the tools VOSviewer [40-42] and Bibliometrix (in R) [43-45], the R software and RStudio [46, 47]. All these tools allow us to perform an exhaustive bibliometric analysis that leads us to identify research trends, evaluate scientific productivity, identify leading institutions, analyze scientific collaboration, explore emerging research areas, evaluate impact and visibility, identify challenges facing particle accelerator physics research in South America, and opportunities for the future development of physics in the region.

In this bibliometric analysis, we explore the rich scientific fabric that defines the landscape of particle accelerator physics in South America, highlighting the outstanding achievements, current challenges, and promising prospects that shape the advancement of this exciting field in the region.

## II. METHODOLOGY

The strategies used to perform a bibliometric analysis on particle accelerator physics in South America are based on statistical techniques. This analysis seeks to evaluate scientific contributions and the scope of publications in various research areas. Documents were gathered from recognized databases such as SCOPUS and WoS, which were subjected to detailed analysis and graphically represented through tables, charts, and figures to understand the intellectual and conceptual evolution in this field. This process involved studying elements such as citations, keywords, and authorship [48]. Additionally, metrics such as citations per article, author, and/or institution contributions by country were used to determine the influence of published literature on research, as well as to evaluate the specific impact of authors, journals, and institutions within each study area [49-51].

Considering the remarkable scientific and technological advancements of the 21st century, particularly in the field of particle accelerator physics, we have chosen to restrict our focus to publications between the years 1969 and 2023 [52]. This period was selected due to its historical relevance and statistical significance, encompassing the most contemporary and relevant trends in this study. Regarding exclusion criteria, works in languages other than those specified for inclusion were discarded, as well as publications predating 1969, as detailed in Figure 1 and Table 1.

Figure 1 represents the research plan of this study, which involves a search strategy in Scopus and WoS, incorporating the keywords mentioned in Table 1. A search comprising titles, abstracts, and keywords was conducted to identify relevant articles. This search yielded 716 articles published in Scopus-indexed journals and 230 in WoS. A manual verification of the relevance of each article was performed, resulting in the exclusion of 149 duplicate articles, leaving a total of 797 articles for bibliometric analysis.

The analysis was carried out in two main phases: in the first phase, contributions were identified using the Scopus and WoS databases, while in the second phase, a bibliometric analysis was conducted using bibliometric software in RStudio, and the tools Biblioshiny and VOSviewer.

TABLE I
SEARCH STRATEGY COMPONENTS FOR BIBLIOMETRIC ANALYSIS

| Component | Description | Terms / Operators |
|---|---|---|
| Keywords Group 1 | Terms relates to Different Detectors and Other Detectors in South America | "Particle Accelerator", "Particle Detector", "Particle Collider", "Particle Physics", "High Energy Physics", "Linac", "Linear Accelerator", "Cyclotron", "Sirius", "Hadron Collider", "Synchrotron", "Electron Accelerator", "Proton Accelerator", "Atom Smasher" |
| Keywords Group 2 | Terms relates to South America and its Countries | "South America", "Brazil", "Peru", "Argentina", "Chile", "Ecuador", "Bolivia", "Uruguay", "Paraguay", "Venezuela", "Colombia" |
| Excluded Keywords | Terms to Excluded | "Other Languages", "Other Years" |
| Boolean Operators | Connectors for combining terms | OR (within each group), AND (between groups), AND NOT (to exclude terms) |
| Search Fields | Specific areas of the database | Title, Abstract, Keywords (TITLE-ABS-KEY) |

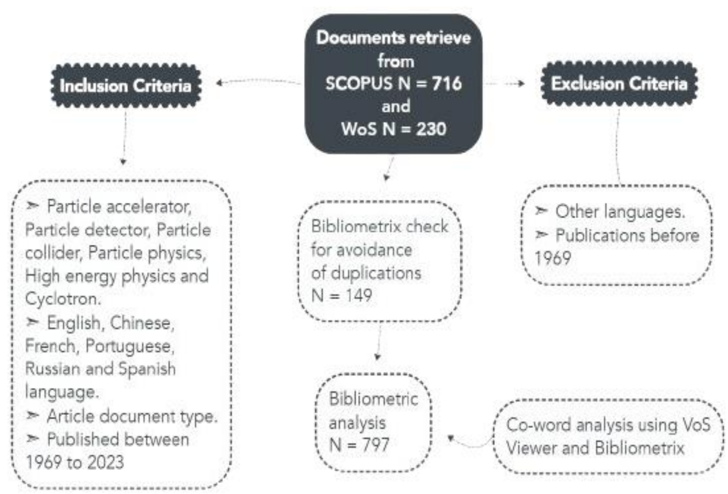

**Fig. 1** - Search Process flowchart for the Bibliometric Review.

## III. ANALYSIS AND DISCUSSION

### *A. Annual scientific production*

Figure 2 presents an analysis of the annual production in the field of particle physics in South America, which allows us to have a detailed view of the number of articles published in each year starting from 1969 and extending until 2023. The graph shows an initial pattern of relatively stationary or non-existent research activity, with a marginal number of articles up to the 1990s. This period could represent the dawn of the countryside in the region, marked by an incipient infrastructure and research capacity. There is a piece of information that marks the beginning of this study in 1969 when only one article was produced by the United States, this work had to do with two projects carried out in Bolivia, when a set of particle detectors was operated for studies of "Atmospheric Čerenkov Light (CL)" and "Bolivian Air Shower Joint Experiment (BASJE)", allowing Bolivia to be seen as one of the first South American countries to be linked to this field.

The figure also shows us a production drought for more than 10 years in the region, this does not mean that particle accelerator physics stagnated, the large scientific communities were in a period of construction and research and emerging countries such as South America countries were waiting for them to give continuity and collaboration in this field. Let's keep in mind that in 1983 the TEVATRON accelerator at FERMILAB had just been built and the construction of the LEP accelerator at CERN had just begun, the largest particle accelerator in the world.

A notable change occurred in the mid-1990s, where an upward trend in scientific production was observed, reaching what seems to be the first phase of significant growth around the turn of the millennium. This growth could be attributed to the consolidation of research in the region, an increase in institutional and financial support, or the maturation of scientific collaboration within the South American accelerator physics community. Observing that since 1985 there has been an increase in the production of articles as can be seen in Figure 2, this boom goes hand in hand with the great discoveries that were due to particle accelerators in the world, one of these is the discovery of the famous "Higgs boson" in 2013, responding to the great theories about the universe and South American countries were getting more and more involved, mainly Brazil and Argentina, who extended their collaborative networks for their high scientific production. Scientific production reached its peak in the period between 2010 and 2015, with a maximum of approximately 50 articles published annually, reflecting a stage of maturity and high activity in research. However, this peak is followed by a noticeable fluctuation indicating periods of increase and decrease in the production of items. These fluctuations could be due to funding cycles, the impact of large-scale research projects coming to an end, or changes in policy and scientific priorities at the regional or global level.

Since 2020 this production has been declining as can be seen in the graph, in recent years it has become worrying. While caution should be exercised when interpreting the past few years due to the provisional nature of the most recent data, this decline could be influenced by factors such as the COVID-19 pandemic, which began in 2020, and had a significant impact on scientific research worldwide. Many laboratories and research centers temporarily closed or reduced their operational capacity, which affected the conduct of experiments and the progress of research projects in particle physics, including those related to particle accelerators, as well as the decrease in research funding, economic challenges, or the evolution of scientific interests towards other emerging fields.

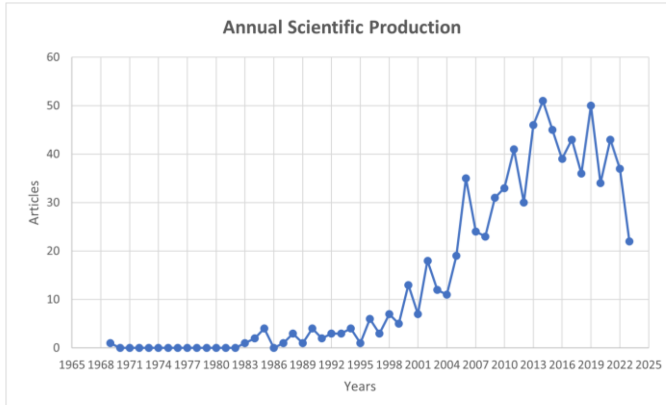


**Fig. 2** - Annual production of articles.

### *B. Countries with the highest scientific production.*

Figure 3 displays a bar graph illustrating the distribution of scientific publications according to the countries of corresponding authors, distinguishing between single-country publications (SCP) and multiple-country publications (MCP), representing international collaborations. As observed in Figure 3, Brazil significantly leads in the number of published documents, with a notable quantity of SCPs and a minimal proportion of MCPs. This indicates a strong national research production in Brazil, as well as active international collaboration. Argentina and the United States follow, exhibiting a balance between the number of SCPs and MCPs compared to Brazil, indicating research activities at both national and international levels for each of these countries. On the other hand, Colombia, Chile, and Ecuador contribute fewer documents, with a tendency towards SCPs, suggesting that these countries are still largely focused on national contribution and present limited participation at the international level.

Figure 3 also presents a comparison with nations from other continents, such as Germany, Italy, and France, which exhibit prominent scientific production, with more SCP publications than MCP. On the other hand, Australia shows a more balanced distribution between SCP and MCP, as well as South Africa and Austria, albeit with relatively low figures. This phenomenon could indicate different research focuses or the dynamics of international collaborations in these countries. These variations could be due to various factors, such as the global nature of certain research topics or the pursuit of knowledge and resources among multiple nations. Spain and the United Kingdom present a mix of SCP and MCP, with a greater presence of SCP, suggesting strong national collaboration.

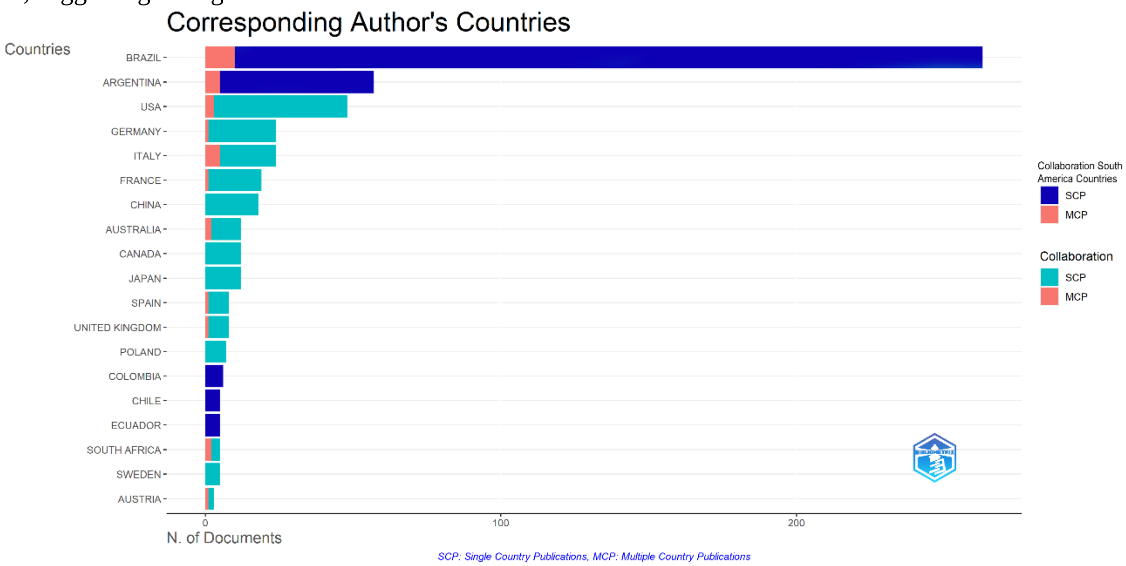


**Fig. 3** - Distribution of scientific publications by country.

Conversely, China, Canada, Japan, Poland, and Sweden contribute fewer documents, with a bias towards SCP, indicating that these countries still primarily focus on national contributions and have limited international involvement.

Figure 3 shows the different quantities of scientific production and collaboration trends among countries in the field of particle accelerator physics in South America. By analyzing how scientific production and collaborations among multiple countries are distributed, we can obtain information about collaboration dynamics and the research capacity of each country in this scientific field.

The data presented in Figure 4 reveal a notable concentration of research production in certain areas, especially in Brazil, identifiable by darker shades. This country leads in the number of contributions, reflecting a solid national research infrastructure and significant investment in the scientific study of particle accelerator physics in South America. Additionally, North America and Argentina show considerable scientific production, suggesting active research communities and financial support for these efforts. In contrast, countries represented by lighter shades, including various countries from the continent and other regions such as much of Europe, Africa, and Asia, show lower levels of scientific production. This distribution may be attributed to differences in resource allocation, research priorities, or the availability of advanced technological infrastructure necessary to conduct high-level research in particle accelerator physics in South America.

Additionally, this map suggests an inclination towards collaboration at the national level. However, South American nations still exhibit a relatively modest level of scientific production, limiting their capacity to play a prominent role in promoting research partnerships and, consequently, in the potential advancement of the field through the exchange of knowledge and resources. On the other hand, Brazil stands out for its dynamic research activity, positioning it as a potential facilitator of these collaborative efforts. As a result, there is the possibility of enhancing the scientific contribution of other nations and their integration into the global research community through this connection.

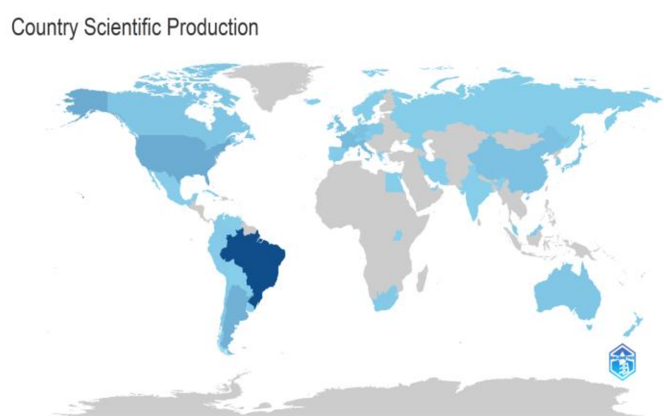


**Fig. 4** - Country scientific production.

### C. *Most frequent keyword.*

The graphical representation of the network in Figure 5 offers an abstract view of the analyzed literature. This visualization highlights the main discoveries through interconnected nodes and connections, providing insights into the primary and secondary themes and the overall evolution within the considered time. One of the notable findings is the predominance of the theme of "synchrotron radiation", which stands out as the main node on the network map. Additionally, related nodes such as "X-ray fluorescence", "synchrotron", "X-ray diffraction", and "trace elements" are identified, underscoring the significant application of particle accelerators in particle physics and high-energy physics. Particle physics

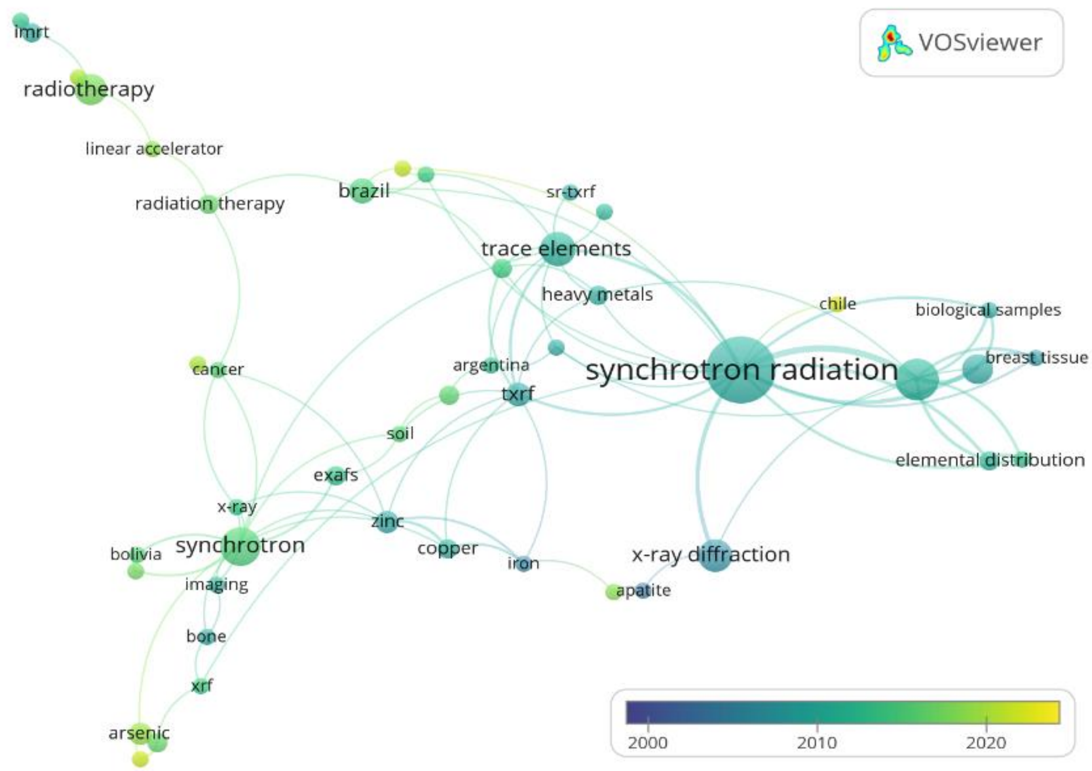


**Fig. 5** - Thematic network visualization of keywords

and particle accelerators find various applications in X-ray studies, imaging, radiotherapy, biological samples, cancer, and minerals, among others. "Synchrotron radiation" represents a specialized application of particle accelerators, offering a technological pathway for the study of charged particles and emitted radiation.

Considering that the color scale represents the period of highest occurrence of the keywords, the keyword "synchrotron radiation" is the most significant among all, connecting with 16 other words in its network, and this pattern was notably prominent mainly during the period from 2007 to 2012. Another relevant keyword is "synchrotron," which is associated with 12 words in its network and is prominent in the period from 2010 to 2020. This finding indicates that among the various applications of particle accelerators is the synchrotron accelerator, used to investigate a variety of topics.

Additionally, geographical nuances can be observed by including nodes such as "Brazil", "Argentina", "Chile" and "Bolivia" on the map. The appearance of these terms suggests localized research efforts or significant contributions from these regions, which may influence the direction or focus of the field. These geographical references among emerging terms indicate specific research in a particular region, suggesting unique challenges related to the study or construction of accelerators in these places, as well as the evolution of specialized applications to meet local or regional needs.

Figure 5 also reveals a temporal color gradient on the network map, indicating the evolution of research focus over time. Although a precise temporal delineation for each color is not provided, the spectrum of colors reflects changes in research concentration from 2000 to 2023. This visual feature illustrates the progression of the field, the potential emergence of new trends, or the decline in previous areas of interest. The strength of the links within the network indicates the intensity of association between thematic terms. Thicker lines suggest terms that frequently appear together, highlighting well-established connections in the research corpus, especially about the "synchrotron accelerator." These strong associations imply a cohesive research dialogue within the field.

### *D. Authors and their collaborative networks.*

The visual representation of collaborative networks within the research community is illustrated in Figure 6. This authorship network graph provides clarity on collaborations and publication output among scholars in this field. The nodes in the figure, varying in size, represent individual researchers and their scientific contributions. Larger nodes, such as those associated with 'Lopes, R. T.' and 'Anjos, M. J.', both of Brazilian origin and collaborating with over 20 authors each on this map, suggest that these authors exert considerable influence in the field, either through a higher number of publications or their central roles in collaborative research networks. Their prominence on the map indicates a strong presence in the literature related to particle accelerator physics in South America. Followed in size by nodes associated with 'Moreira, S.', 'De Jesus, E. F. O.', 'Barroso, R. C.', and 'Pereira, G. R.', these researchers demonstrate significant influence in this domain, collaborating with around 10 authors each.

The density and breadth of the lines connecting these nodes provide insight into the strength and frequency of collaborative links between researchers. A highly interconnected group centered on 'Lopes, R. T.' and 'Anjos, M. J.' signals a strong collaborative network, underscoring the importance of these authors in promoting collaborative research efforts. The various groups identified in the network map reveal sets of authors who are frequent co-authors of articles or share thematic research

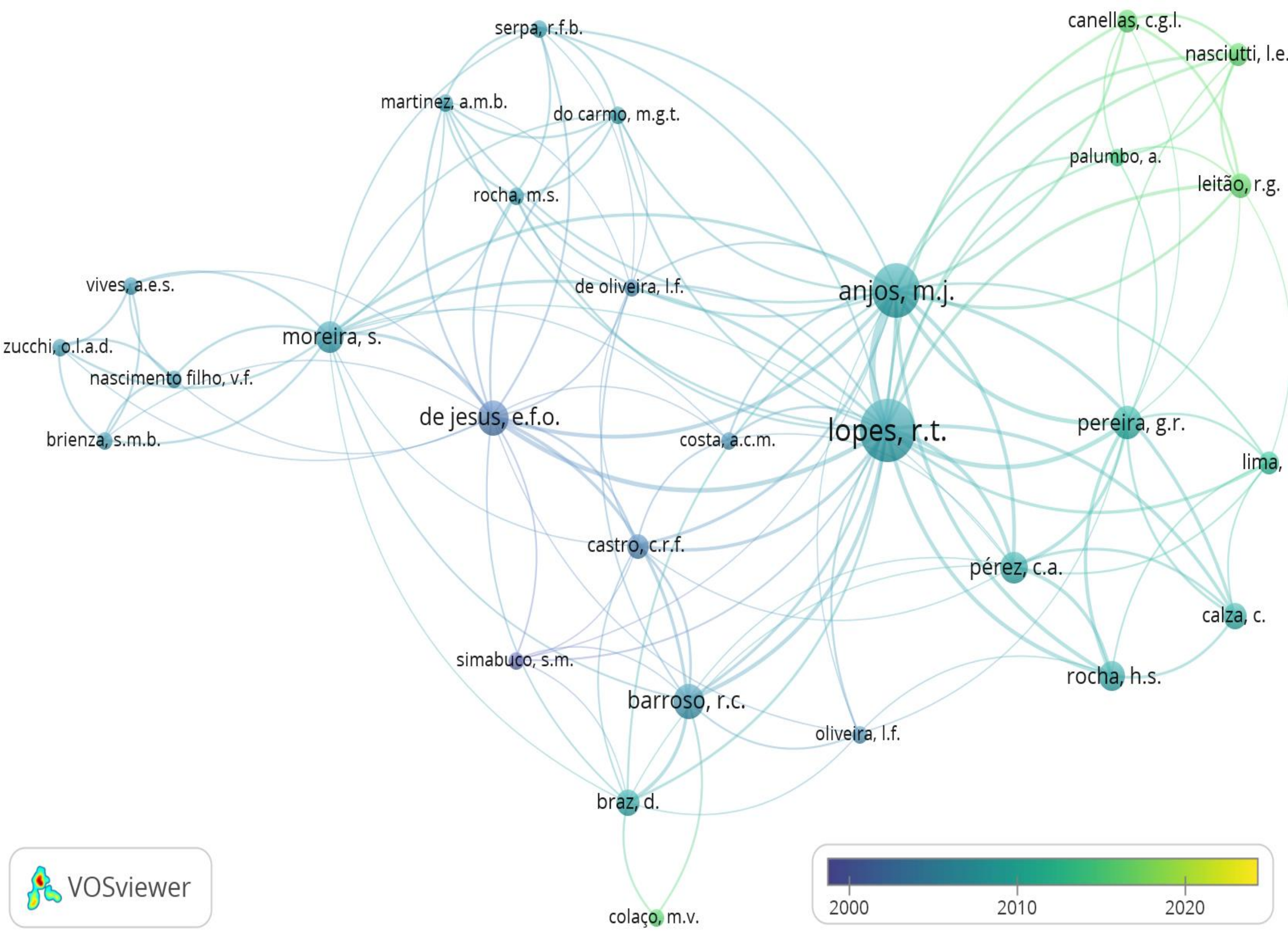


**Fig. 6** - Map of authors with the greatest scientific production and their collaborative networks.

interests. These groups, represented by authors such as 'Moreira, S.', 'De Jesus, E. F. O.', 'Barroso, R. C.' and 'Pereira, G. R.', denote a cohesive research community, with shared methodologies or convergent approaches in similar thematic areas within the vast field of particle accelerator physics in South America.

Figure 6 also incorporates a temporal dimension into the visual representation using a color gradient applied to the nodes, indicating the periods of activity of the authors from 2000 to 2023. These colors tell us that these authors were active during that period. Nodes with cooler or lighter shades denote years with higher frequencies of author appearances, such as

"Canellas, C.G.L.", "Nasciutti, I.", "Palumbo, A.", and "Leitao, R.G.", denote more recent activity in the timeline.

### E. Thematic map.

Figure 7 illustrates a strategy diagram that categorizes various research topics according to their importance in the field and the impact of their progress. This analytical approach helps to identify mature, emerging, and fundamental areas in particle accelerator physics in South America. The colors in the topics provide a visual way to understand the spatial distribution, characteristics, etc., which allows us to identify important patterns or trends in this study, such as the relevance of these topics in the last 20 years.

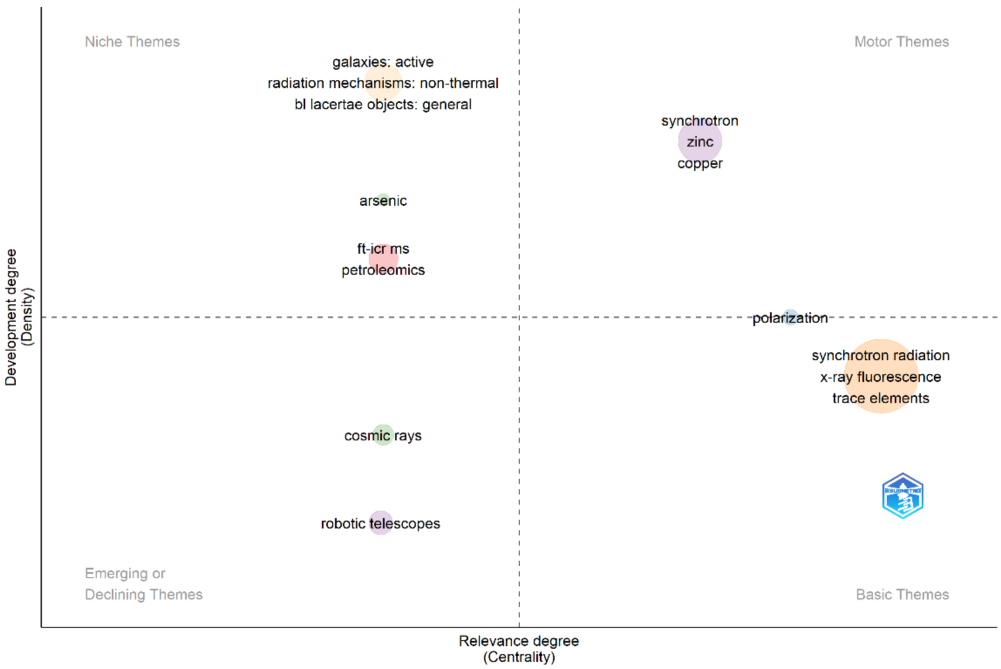


**Fig. 7** - Strategic diagram of research theme

The diagram is divided into four quadrants, each representing a distinct typology of research topics. The vertical axis assesses the density or degree of progress of the topics, signaling the depth of research and the interconnectedness of studies within each area. While the horizontal axis considers centrality, indicating the prominence and influence of topics within the wider research network.

Specialized topics in the upper left quadrant, such as "Galaxies: Active", "Radiation Mechanisms: Non-Thermal" and "BL Lacertae Objects: General", among others, show a high degree of development. Despite their active research, these topics have less centrality in the big picture, indicating that they are highly specialized areas that may be of interest to specific segments within the scientific community. In contrast, the key topics in the upper right quadrant, such as "Synchrotron," "Zinc," and "Copper," represent central and well-developed areas of research. These topics are essential as they often drive the field forward and point to areas of significant scholarly engagement and interdisciplinary relevance. Of equal importance to the field are the fundamental topics, such as "Synchrotron Radiation", "X-ray Fluorescence" and "Trace Elements", located in the lower right quadrant. Despite their fundamental importance and high centrality, these areas have yet to reach the same degree of thematic development as the key themes, suggesting potential for further exploration and expansion.

Emerging or declining topics are found in the lower left quadrant, such as "Cosmic Rays" and "Robotic Telescopes", both of which are characterized by less centrality and development. In the case of "Cosmic Rays", it is an emerging topic because it is gaining relevance in the study while "Robotic Telescopes" is in decline because it is losing interest compared to previous years. These areas represent nascent domains that are ripe for growth or that are experiencing a decline in interest within the current research landscape.

## IV. Conclusions

The systematic review of the regional contribution and collaborative networks in the field of particle accelerator physics in South America has revealed a significant international effort in scientific production. Brazil and Argentina have emerged as leaders in this field in the region, showing strong research output both nationally and through international collaborations. The balanced mix of individual and collaborative publications across multiple countries is an additional indicator of this global effort. The analysis of scientific production by country has revealed a geographical distribution of scientific production and different levels of collaboration trends. Countries with significant scientific output, such as Brazil, have established strong international collaboration links, while others, such as Argentina and the United States, are actively seeking international research partnerships. The analysis of the most recurrent keywords and themes has revealed that "Synchrotron Radiation", "Synchrotron", "Radiotherapy", "X-ray Diffraction" and "X-ray Fluorescence" are central elements in the literature. These keywords encapsulate the core of the field's focus areas and the integration of various focus areas in which particle accelerator physics is applied. The analysis of authors and collaborative networks has highlighted the presence of influential researchers and the relevance of scholarly communication for progress in the field. This analysis has revealed a landscape characterized by nodes of various sizes, which represent the magnitude of the contributions of individual authors and their importance within the collaborative network. The strategic thematic map classifies research topics into consolidated, emerging, and specialized areas. Fundamental topics such as "Synchrotron Radiation", "X-ray Fluorescence" and "Trace Elements" show high centrality but a variable level of development, suggesting areas ripe for further exploration. Ultimately, we conclude that the field of particle accelerator physics in South America is characterized by dynamic research activity, innovative methodological approaches, and a clear trend toward international collaboration. These findings provide a solid foundation to guide future research directions and promote an inclusive global research community for the advancement of high-energy physics in this region of the continent.

## References


[1] P. A. Phi Nghiem, La física de los aceleradores...: ...a través de la física de la vida cotidiana y el universo. Acentoline Comunicación Editoria SL, 2021. [En línea]. Disponible en: https://irfu.cea.fr/dacm/public/Libro_acelerador_phiNghiem_VE_2021.pdf

[2] "La física de altas energías, un paso al entendimiento de los procesos físicos del Universo." https://www.dgcs.unam.mx/boletin/bdboletin/2013_101.html

[3] S. A. Gourlay, T. O. Raubenheimer, and V. Shiltsev, "Challenges of future accelerators for particle physics Research," Frontiers in Physics, vol. 10, Jun. 2022, doi: 10.3389/fphy.2022.920520.

[4] L. Borgnino, "El Señor de los Anillos: El poder de la luz de Sincrotrón," Jul. 29, 2021. https://revistas.unc.edu.ar/index.php/cicterranea/article/view/34152

[5] "Nueva estrategia para la física latinoamericana," Symmetry Magazine, Feb. 16, 2021. https://www.symmetrymagazine.org/article/new-strategy-for-latin-american-physics?language_content_entity=es

[6] Graciella, W & Kawamura, R. "A divulgação científica e os físicos de partículas: a construção social de sentidos e objetivos" Ciência & Educação (Bauru), vol. 23, núm. 2, Abril-Junho, 2017, pp. 303-320

[7] Urrutia, G, Prado, L, and Bietenholz, W , "Theoretical high energy physcis in Latin America from 1990 to 2012: a statistical study," Scientometrics, vol. 116, no. 1, pp. 125–146, May 2018, doi: 10.1007/s11192-018-2739-1.

[8] Peña, J & Núñez, L , "LA-CoNGA physics: an open science collaboration in advanced physics between Latin-America and Europe" Proceedings of Science, Vol 398, n 907, 2021 ISSN 18248039

[9] Nakamori, T et al., "Collaboration between high schools in Japan and Argentina for cosmic-ray research using CosmicWatches", en Proc. Sci., Sissa Medialab Srl, 2022. [En línea]. Disponible en: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85143747838&partnerID=40&md5=32fbe8b16d6ebf5f7aa267d82aee96e9

[10] The Pierre Auger Collaboration. (2015). "The Pierre Auger Cosmic Ray Observatory" . Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 798, 172-213. DOI https://doi.org/10.1016/j.nima.2015.06.058

[11] Nakamori, T & et al . "Collaboration between high schools in Japan and Argentina for cosmic-ray research using CosmicWatches". Proceedings of Science, Vol 395, n 1365. ISSN 18248039

[12] Aco, "Brasil y Argentina desarrollarán en conjunto acelerador de partículas - CNPEM," CNPEM, Jan. 21, 2022. https://cnpem.br/brasil-y-argentina-desarrollaran-en-conjunto-acelerador-de-particulas/

[13] Da Cunha, T & Dorsh G (2023) . " Particle Physics in high school Part II: Nuclear Physics" Revista Brasileira de Ensino de Física, Vol 45, n e20230067. DOI 10.1590/1806-9126-RBEF-2023-0067

[14] Da Cunha, T & Dorsh G (2021) . " Particle Physics in high school Part I: Quantum Electrodynamics" Revista Brasileira de Ensino de Física, Vol 43, pp 1-32. DOI 10.1590/1806-9126-RBEF-2021-0083

[15] Urrutia, S. Pradro, L. & Bietenholz, W (2018) "Theoretical high energy physics in Latin America from 1990 to 2012: a statistical study" Scientometrics. Vol 116, pp 125-145. DOI 10.1007/s11192-018-2739-1

[16] Alvares, G. Vanz, S. & Barbosa, M. (2017) "Scientometric indicators for Brazilian research on High Energy Physics, 1983-2013" Anais da Academia Brasileira de Ciencias. Vol 89, pp 2525-2543. DOI 10.1590/0001-3765201720160620

[17] Shibuya, E. (2010) "High energy interactions" Proceedings of Science. Vol 118, n 044. ISSN 18248039

[18] Ribeiro, A. de Andrade y Moura, A. Gonçalves, «Os aceleradores lineares do General Argus e a sua rede tecnocientífica», Revista Brasileira de História Da Ciência (RBHC), vol. 14, pp. 3-16, 1995, [En línea]. Disponible en: https://www.sbhc.org.br/arquivo/download?ID_ARQUIVO=224

[19] Moreno, B. G. "Aceleradores para Colombia," Revista De La Academia Colombiana De Ciencias Exactas, Físicas Y Naturales, vol. 38, no. 0, p. 71, Nov. 2014, doi: 10.18257/raccefyn.155.

[20] Graievich, A (2020) "Synchrotron radiation in Brazil. Past, present and future". Radiation Physics and Chemistry, Vol 167, n 108253. DOI 10.1016/j.radphyschem.2019.04.003

[21] De Andrade, A & Muniz, R. "The quest for the Brazilian synchrocyclotron" Historical Studies in the Physical and Biological Sciences. Vol 36, pp 311-327. DOI 10.1525/hsps.2006.36.2.311

[22] "¿Qué es el Gran Colisionador de Hadrones y por qué cambió la historia de la física?," IBERO. https://ibero.mx/prensa/que-es-el-gran-colisionador-de-hadrones-y-por-que-cambio-la-historia-de-la-fisica

[23] Dib C. "Experimental facilities in Latin America" CERN Yellow Reports: School Proceedings, Vol 2, pp 193-219, May 2021. DOI 10.23730/CYRSP-2021-002.193

[24] Giambici, J. J. . “La física en América Latina”. *Revista de* REVISTA DE LA ENSEÑANZA DE LA FÍSICA, pp 74-80, Vol.3 n 1, Feb 1990.

[25] Ramirez, D. and Violini, G. “About the possibility of an international ground-based Very High Energy particle detector experiment in Ecuador,” Journal of Instrumentation, vol. 14, no. 09, p. C09038, Sep. 2019, doi: 10.1088/1748-0221/14/09/c09038.

[26] Velho, L & Pessoa Jr, O (1998) "The decision-making process in the construction of the synchrotron light national laboratory in Brazil" Social Studies of Science. Vol 28, pp 195-219. DOI 10.1177/030631298028002001

[27] Goncalves Da Silva, C. Rodriguez, A. & Cralevich, A (1988) "The National Laboratory for Synchrotron Light of Brazil" Synchrotron Radiation News. Vol 1, pp 28-32. DOI 10.1080/08940888808602489

[28] Bastianin, A. & Florio, M. “Social Cost Benefit Analysis of HL-LHC” . CERN-ACC-2018-0014 May, 2018 https://cds.cern.ch/record/2319300 (accessed Feb. 02, 2024)

[29] Martins, M & Silva, T , "Electron accelerators: History, applications, and perspectives" , Radiation Physics and Chemistry, DOI 10.1016/j.radphyschem.2012.12.008

[30] C. O. Dib, “ANDES: an underground laboratory in South America,” Physics Procedia, vol. 61, pp. 534–541, Jan. 2015, doi: 10.1016/j.phpro.2014.12.118.

[31] Lederman, L. M. “Fermilab and Latin America,” AIP Conference Proceedings, Jan. 2006, doi: 10.1063/1.2359388.

[32] Taylor, L & Gottschalk, E. (2009) "CMS centres worldwide: A new collaborative infrastructure" Journal of Physics: Conference Series. Vol 219, n 082005. DOI 10.1088/1742-6596/219/8/082005

[33] Aab, A & et al. (2015) "The Pierre Auger Cosmic Ray Observatory" Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. Vol 798, pp 172-213. DOI 10.1016/j.nima.2015.06.058

[34] Brum, J & Tavares, P (2007) "The Brazilian synchrotron light source" AIP Conference Proceedings, Vol 879, pp 196-201. DOI 10.1063/1.2436039

[35] De Mendoza, H & Vara, M. "Winding roads to big science: Experimental physics in Argentina and Brazil", Science, Technology and Soclety, Vol 12, pp 27-48, Mar 2007 DOI 10.1177/097172180601200103

[36] Li, Y., Xu, Z. A bibliometric analysis and basic model introduction of opinion dynamics. *Appl Intell* **53**, 16540–16559 (2023). https://doi.org/10.1007/s10489-022-04368-5c

[37] Agarwal, Ashok1,; et. all. Bibliometrics: tracking research impact by selecting the appropriate metrics. Asian Journal of Andrology 18(2):p 296-309, Mar–Apr 2016. | DOI: https://doi.org/10.4103/1008-682X.171582

[38] Shenwen Chen, Yisen Wang, Ziquan Liu, Wenbo Du, Lei Zheng, Runran Liu, Analysing educational scientific collaboration through multilayer networks: patterns, impact and network generation model, *Journal of Complex Networks*, Volume 11, Issue 5, October 2023, cnad033, https://doi.org/10.1093/comnet/cnad033

[39] Dag Aksnes, W. Fredrik Niclas Piro, Lone Wanderås Fossum; Citation metrics covary with researchers’ assessments of the quality of their works. *Quantitative Science Studies* 2023; 4 (1): 105–126. doi: https://doi.org/10.1162/qss_a_00241

[40] Van Eck, N.J., Waltman, L. (2007). VOS: A New Method for Visualizing Similarities Between Objects. In: Decker, R., Lenz, H.J. (eds) Advances in Data Analysis. Studies in Classification, Data Analysis, and Knowledge Organization. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-70981-7_34

[41] Smyrnova-Trybulska, E., Morze, N., Kuzminska, O. and Kommers, P. (2018), "Mapping and visualization: selected examples of international research networks", *Journal of Information, Communication and Ethics in Society*, Vol. 16 No. 4, pp. 381-400. https://doi.org/10.1108/JICES-03-2018-0028

[42] VOSviewer user manual. access to https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.20.pdf

[43] Massimo Aria, Corrado Cuccurullo. Bibliometrix: An R-tool for comprehensive science mapping analysis, Journal of Informetrics, Volume 11, Issue 4, 2017, Pages 959-975, ISSN 1751-1577, https://doi.org/10.1016/j.joi.2017.08.007.

[44] Büyükkıdık, Serap. (2022). A Bibliometric Analysis: A Tutorial for the Bibliometrix Package in R Using IRT Literature. Eğitimde ve Psikolojide Ölçme ve Değerlendirme Dergisi. 13. https://doi.org/10.21031/epod.1069307

[45] Daneshvar Ghorbani, Babak. (2024). Bibliometrix: Science Mapping Analysis with R Biblioshiny Based on Web of Science in Applied Linguistics. https://doi.org/10.1007/978-3-031-51726-6_8.

[46] R Core Team (2021) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.https://www.R-project.org

[47] RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

[48] Helena, A. and Araújo, Wagner Junqueira, “Prospective scenarios: systematic review at Lisa, Emerald, Scopus and Web of Science,” La Referencia.info, 2020. https://www.lareferencia.info/vufind/Record/BR_9b7afa48e19ba6a31973df6a7ebb8491 (accessed Feb. 02, 2024)

[49] Moral, J. Herrera, E. Santisteban, A. and Cobo, M. “Software tools for conducting bibliometric analysis in science: An up-to-date review,” Profesional De La Informacion, vol. 29, no. 1, Jan. 2020, doi: https://doi.org/10.3145/epi.2020.ene.03.

[50] Naveen Donthu, S. Kumar, D. Mukherjee, N. Pandey, and Weng Marc Lim, “How to conduct a bibliometric analysis: An overview and guidelines,” Journal of Business Research, vol. 133, pp. 285–296, Sep. 2021, doi: https://doi.org/10.1016/j.jbusres.2021.04.070

[51] Tandon, A. Kaur, P Matti Mäntymäki, and Dhir, A. “Blockchain applications in management: A bibliometric analysis and literature review,” Technological Forecasting and Social Change, vol. 166, pp. 120649–120649, May 2021, doi: https://doi.org/10.1016/j.techfore.2021.120649

[52] Goyal, K, and Kumar, S., “Financial literacy: A systematic review and bibliometric analysis,” International Journal of Consumer Studies, vol. 45, no. 1, pp. 80–105, Aug. 2020, doi: https://doi.org/10.1111/ijcs.12605