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Internationalization of Brazil's scientific production in High Energy Physics (1983-2013)

Internacionalização da produção científica do Brasil em física de altas energias (1983-2013)

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RESUMO

Este estudo bibliométrico analisa as dimensões da internacionalização da produção científica brasileira em Física de Altas Energias (HEP) a partir dos artigos publicados em revistas indexadas pela *Web of Science* (WoS) no período de 1983-2013. Com base na classificação proposta pelo Manual de Santiago da *Red de Indicadores de Ciencia y Tecnologia Iberoamericana e Interamericana* (RICYT), a internacionalização do Brasil em HEP é estimada através de Indicadores de Difusão, Colaboração e Impacto Internacional. Os indicadores de Difusão Internacional revelam a preferência pela publicação em periódicos estrangeiros de língua inglesa. A totalidade dos artigos analisados foi veiculada em 35 revistas de 11 países diferentes. Os indicadores de Colaboração Internacional mostram a prevalência da coautoria em HEP visto que 49,07% dos artigos foram assinados por mais de um país. Os indicadores de Impacto Internacional destacam o peso das publicações em periódicos estrangeiros de língua inglesa dentre os citantes. Os documentos citantes internacionais representam 87,78% do total, com destaque para os assinados por autores dos Estados Unidos. Os indicadores de internacionalização utilizados desvelam o perfil científico internacional da HEP no Brasil, acompanhando o padrão característico da área na esfera global.

PALAVRAS-CHAVE: Produção científica. Internacionalização. Bibliometria. Física de Altas Energias.

ABSTRACT

This bibliometric study analyzes the dimensions of internationalization of Brazilian scientific output in the field of High Energy Physics (HEP) from articles published in journals indexed by Web of Science (WoS) from 1983 to 2013. Based on the classification proposed by The Santiago Manual from *Red de Indicadores de Ciencia y Tecnologia Iberoamericana e Interamericana* (RICYT), Brazil's internationalization in HEP is estimated through International Indicators of Diffusion, Collaboration and Impact. International Diffusion indicators show a preference for publishing in foreign, English language journals. All of the analyzed articles were published in 35 journals from 11 different countries. The International Collaboration indicators show the prevalence of co-authorship in HEP, as authors from more than one country signed 49.07 % of the articles. International Impact indicators highlight the weight of citations coming from publications in foreign, English language journals. International citing documents represent 87.7 % of the total, particularly those signed by US authors. Internationalization indicators unveil the international scientific profile of Brazilian HEP, following the worldwide pattern of the field.

KEYWORDS: Scientific output. Internationalization. Bibliometric. High Energy Physics.

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1 INTRODUCTION

The shift in the organization of scientific research from Little Science to Big Science brought new insights into scientific collaboration networks. Since the advent of Big Science, the number of authors per article has increased significantly, especially in High Energy Physics (HEP), where investigations can only be carried out thanks to the work in international collaboration due to the cost and complexity of experiments with particle accelerators (KRETSCHMER and ROUSSEAU, 2001). At present, the teamwork model represents the new paradigm and manifests the change in the mode of knowledge production.

In view of this, internationalization is perceived as a necessary condition for science development, as well as a channel for improving the quality of scientific and technological activities, training human resources, information circulation and the strengthening of links between partners (RED..., 2007). Mele *et al*. (2006) theorize HEP as one of the most internationalized and collaborative scientific disciplines. Since the 1950s, large experimental projects have a participatory character, with hundreds of researchers from several countries. Multinational scientific and technological facilities, such as the European Organization for Nuclear Research (CERN) laboratory, are an important form of internationalization based on collaborative work, especially in fields such as Astronomy, Particle Physics and Nuclear Physics (RED ..., 2007).

The internationalization of science can be contemplated on the basis of different indicators: authorship, diffusion and international impact. Scientific production is an essential element in the evaluation of knowledge by indicators as it provides information on the performance and contribution of aggregates to world production, the intensity of foreign collaboration, the visibility and international influence of subjects/countries' research through the received citations, establishing bases for the elaboration of policies for science internationalization (RED ..., 2007). Some authors such as van Raan (1997) express that a country's process of internationalization must include the publication in English-language international journals with high impact factor and collaborations with foreign authors, since it increases the international impact. Wang, Wang and Weldon (2007) add that citations of all nationalities are also an important aspect to be considered in improving levels of globalization.

In 2008, Brazil began negotiations at CERN to become, under a new participation modality, an Associate Member. Despite not having a formal link with the laboratory, the collaboration of the Brazilian HEP is old and intense. In number of researchers, students and engineers, Brazil is the second largest non-member country, only behind Canada. Equally, Brazilian scientists participate in major international projects involving collaborations in National Laboratories such as Fermi National Accelerator Laboratory (Fermilab) and Brookhaven National Laboratory (BNL), in the United States, and Pierre Auger in Argentina (COORDINATION ..., 2013a), showcasing the Brazilian performance in HEP. In the same year, the Ministry of Science and Technology (MCT) instituted the National Network of High

Energy Physics (RENAFAE), whose main goals are to coordinate activities related to large multinational collaborations and increase the intensity of internationalization in the institutional field (CENTRO..., 2011; SHELLARD, 2011).

Chaves *et al*. (2007) consider that the maturity and quality achieved by the Brazilian HEP are mirrored in the number of international collaborations and co-authored publications. In Brazil, the field is one of the more traditional in experimental research. Its development is proven by the CNPq research groups representativeness and quality graduate programs with HEP research lines, of which 11 of 32 (8 with grade 7, and 3 with grade 6) are considered to have excellence and international profile, according to the CAPES Triennial 2013 Evaluation.

Historically, High-Energy Physics is linked to the foreign scenario, both by the arrival of foreign researchers in Brazil in the early 1930s, and the strong culture of scientific exchange and communicating research results between laboratories in different countries. Previous studies highlight the magnitude of collaboration regarding the number of countries present in the articles and the preference of the HEP scientists worldwide for the publication of the findings in prestigious international journals of high Impact Factor (IF) for Particle Physics (BRAUN et al. 1992, MELE et al., 2006, KRAUSE, LINDQVIST, MELE, 2007, AMAN, 2013). According to Duarte (2008), the intensification of relations between CERN Member States in terms of International Cooperation may represent a window of opportunity for Brazil in the coming years, seeing as the exchange of scientific experiences involving two or more countries adds knowledge for the publication of articles with numerous authors and facilitates the exchange of experiences, methods and processes in large multinational enterprises and structures. Therefore, the importance of this study resides in the possibility to expanding the knowledge on the internationalization of the Brazilian HEP and providing subsidies for the planning of policies and management strategies for the entry of Brazil into CERN under a new participation modality.

This bibliometric research analyzes the dimensions of the internationalization of Brazilian scientific production in HEP from articles published in journals indexed by the Web of Science (WoS) in the period between 1983 and 2013. Based on the classification proposed by the Santiago Manual of *Red de Indicadores de Ciencia y Tecnología Iberoamericana e Interamericana* (RICYT), the internationalization of Brazilian HEP was estimated through International Indicators of Diffusion, Collaboration and Impact.

2 METHODOLOGY

This bibliometric study's corpus of analysis is composed of articles of the Brazilian HEP indexed in the multidisciplinary basis WoS during the period of 1983 to 2013. The collection and download of the records was performed in December 2014, using the Advanced Search option. In the search strategy, the field labels used were CU = Country (Brazil or Brazil) and WC = Web of Science Category (Physics, Particles & Fields). The

results were limited to the document type Article, in all languages, the time stipulated was from 1983 to 2013, and the citation index Science Citation Index (SCI). After the importation of the 6,350 articles to be used for the analyzes of international diffusion and collaboration, the information was organized in a single file (.txt). For standardizing the names of the collaborating/citing institutions and countries, there was the utilization of the List of Authorities of the Scientific Communication Research Group of the Federal University of Rio Grande do Sul (UFRGS) and the CNPq's Lattes Platform. For international impact analysis, the data from 41,152 citing documents were imported from WoS's Create Citation Report option.

The analyzed variables were Publication Year (PY), Journal (SO), Language (LA), Author Address (C1). Based on the classification proposed by RICYT and in agreement with the methodology adopted by Santin, Vanz and Stumpf (2015), in the analysis of the internationalization of the scientific production of Brazilian HEP the indicators used were International Diffusion Indicators (publication in English-language, foreign journals) International Colaboration (co-authoring with authors from other countries), and International Impact (citations in international authors' publications). Regarding data processing, the sotwares in use were Bibexcel (descriptive analysis), Pajek (collaboration network), Philcarto (thematic mapping) and Microsoft Excel 2007. For generating the international indicators of collaboration and impact, this study used the total count, that is, an article for each collaborating/citing country.

3 RESULTS

The ensemble of Brazilian articles represents 3% of the total world scientific production of HEP indexed in WoS in the period of 1983 to 2013, with an annual average growth of 14.27%. Image 1 shows the development of HEP activity throughout the time period. The indexation of new Brazilian journals by WoS in the 2007-2008 biennium and the consequent increase in Brazilian scientific production did not affect the area since a negative growth rate was observed in 2008 (-18.91%). The international dissemination indicators presented below confirm the independence of HEP in relation to national communication vehicles.

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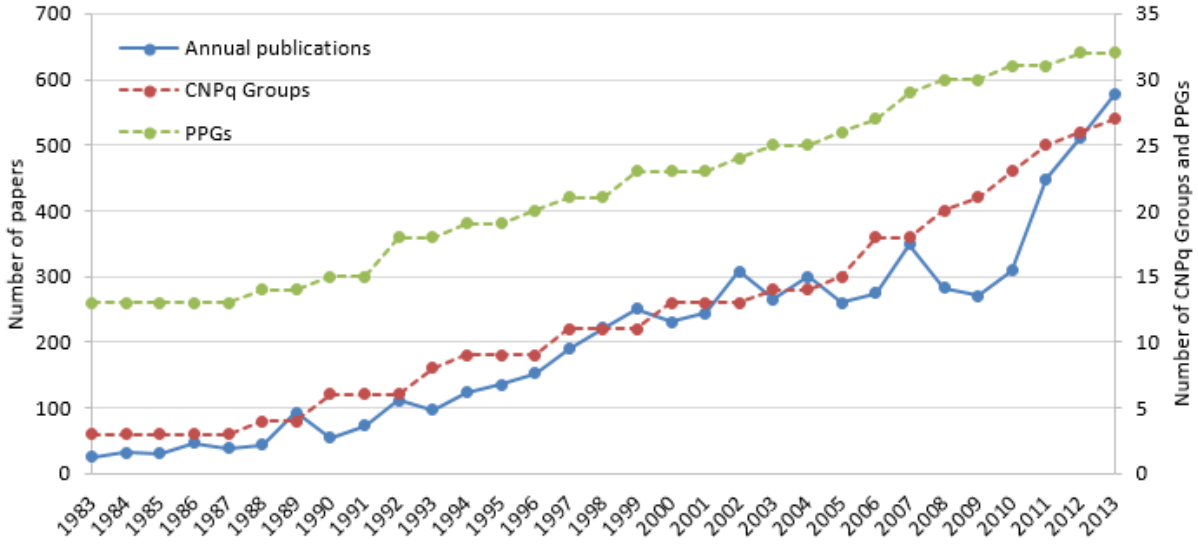

Image 1. Growth dynamics of annual publications, CNPq and PPGs Groups of Brazilian HEP (1983-2013)
Source: research data

The increase in HEP productivity may have been due to the expansion of the research after the creation of new graduate programs and CNPq groups (Image 1). It can be seen that RENAFAE's articulating role was fundamental to the area since the number of publications and CNPq groups increased considerably from 2008. The expansion of graduate and research institutions of the South, Northeast and North regions in the 2000s may also have promoted the increase of Brazil's HEP production.

3.1 International Diffusion

The international diffusion of the Brazilian HEP was analyzed in relation to the percentage of articles in foreign, English-language journals and to the geographic distribution of the scientific production indexed in WoS, as the publishing country of the publications. The 6,350 Brazilian articles were published in 35 journals from 11 different countries. The ensemble of publications is focused on specialized international English-language journals (three multilingual). The titles published in Europe (Germany, England, Holland, Italy, Russia, Switzerland, Ukraine) with 2,963 articles (46,67%) were the most productive. Next, the American journals with 2,515 (39.60%) and the Asians (Singapore, China, Thailand) appear with 872 (13.73%) publications. The geographical distribution of Brazil's HEP research indicates the concentration of publications in a small number of editing countries (Figure 2). The United States with 10 titles (28.58%) is the country with the largest number of journals edited. Then England appears with 5 (14.29%); Germany and the Netherlands with 4 each (11.42%); Singapore with 3 (8.58%); Italy, Russia and China with 2 each (5.71%); Switzerland, Ukraine and Thailand with 1 each (2.86%).

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Leite, Mugnaini and Leta (2011) found that the more experimental and/or technological the subject, the greater the fraction of scientists with a highly international profile. In the analysis, the Exact and Earth Sciences (including HEP), Biology and Engineering were the fields that presented the highest indexes. The authors understand that in order to reach a highly international profile, the areas need to publish between 80% and 100% of the works in foreign English-language journals, behavior observed in Brazilian HEP.

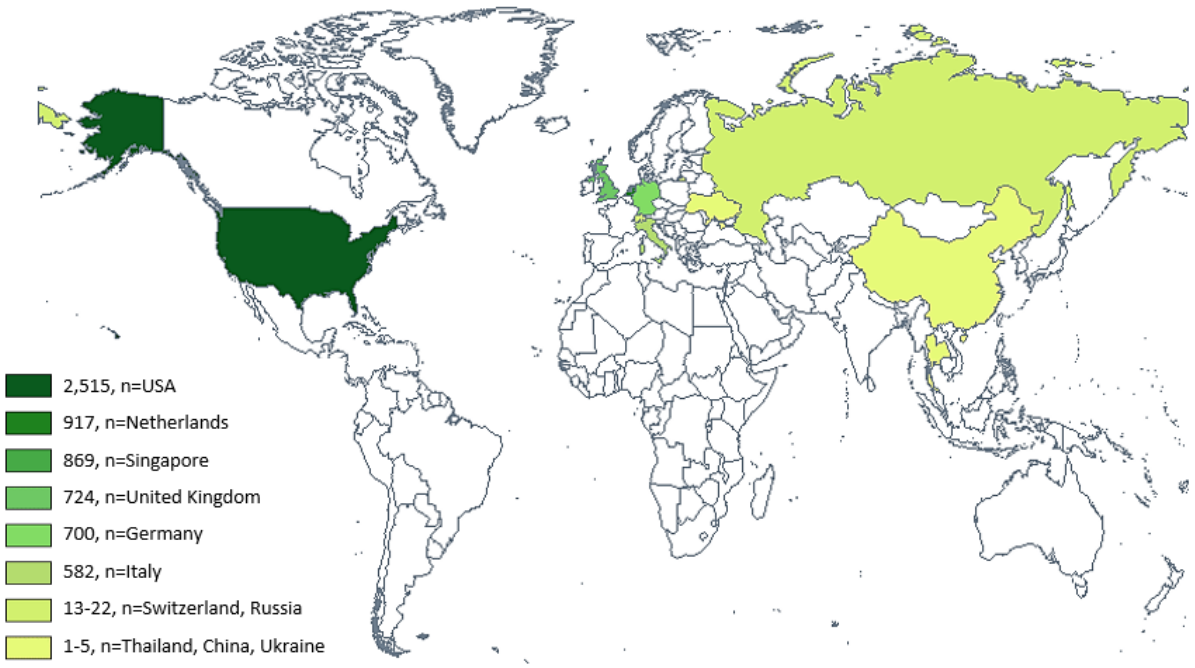

Image 2. Geographical distribution of the scientific production of Brazilian HEP indexed in WoS according to the article's editing country (1983-2013).
Source: research data

The most traditional journals in HEP such as Physical Review D, Journal of High Energy Physics and European Physical Journal C were the preferred choices by Brazilian authors for the publication of scientific results (Table 1). 70% of articles were published in six titles, denoting the high concentration of the research in a few specialized journals. Other authors such as Mele *et. al.* (2006), Calero (2009) and Aman (2013) had previously recognized this particularity of the area.

Table 1. Main journals for publication of Brazilian HEP articles indexed in WoS (1983-2013)

Journal	N. articles	%	Σ %	Country	Language	FI (2014)
Phys. Rev. D	2,259	35.57	35.57	USA	English	4.643
J. High Energy Phys	505	7.95	43.52	Italy	English	6.111
Eur. Phys. J. C	449	7.07	50.59	Germany	English	5.084
Nucl. Instr. Meth. A	435	6.85	57.44	Netherlands	Multilanguage	1.216
Int. J. Mod. Phys. A	382	6.02	63.46	Singapore	English	1.699
Mod. Phys. Lett. A	354	5.57	69.03	Singapore	English	1.198
Class. Quantum Grav.	342	5.39	74.42	U. Kingdom	Multilanguage	3.168

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Nucl. Phys. B	297	4.68	79.10	Netherlands	English	3.929
J. Phys. G	232	3.65	82.75	U. Kingdom	English	2.777
Gen. Relat. Gravit.	187	2.94	85.69	USA	English	1.771

Source: WoS, *Journal Citation Reports* (JCR)

The international diffusion indicators confirmed that the three most productive journals in the studied period are coincidentally those with the highest impact factor, placing it in the quartile 1 of WC Physics, Particles & Fields. In the ranking of journals with the highest IF within the category mentioned in WoS, the three titles appear very well positioned, only behind Living Reviews in Relativity and Annual Review of Nuclear and Particle Science. The level of international excellence reached by the Brazilian graduate programs in HEP with maximum score according to the evaluation of the Coordination... (2013b) manifests itself with the publication in the prestigious journals of the field. In Image 3 it is possible to observe the distribution of the scientific production by periods according to the publication journal.

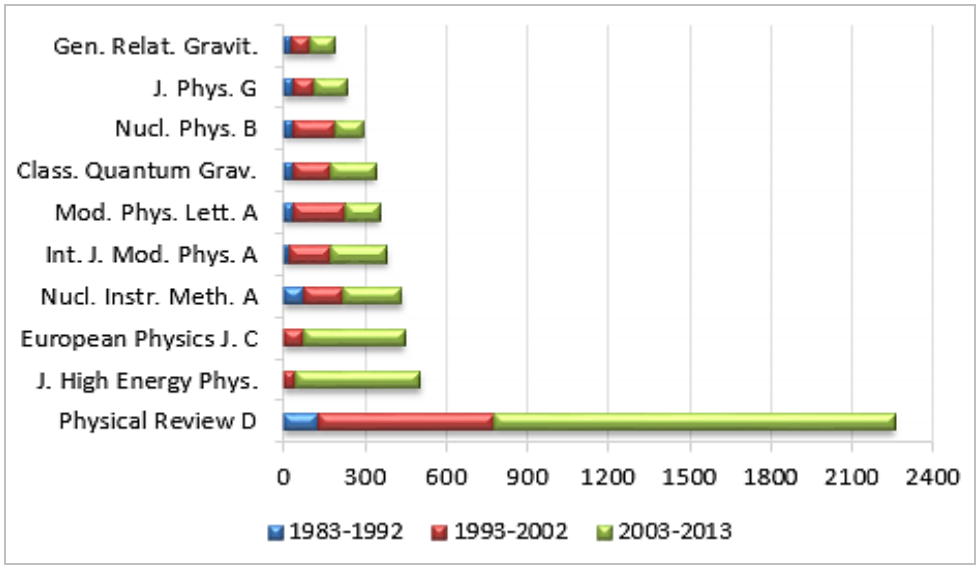

Image 3. Distribution of Brazilian HEP articles by periods according to the publication journal (1983-2013)
Source: research data

When the ensemble of HEP articles was grouped by periods, there was a slight upward trend in the number of publication per journals of Q1 and Q2. The results suggest an initial preference by Brazilian authors for publication in American journals such as the Physical Review D, published since 1970 by the American Physical Society (APS). Also, it is possible to distinguish between 1983 and 1992, another journal with high popularity within the scientific community, the Nuclear Instruments and Methods in Physics Research A. In the period between1993 and 2002, one notices the incipient emergence of the European journals Journal of High Energy Physics (SISSA/IOP) and European Physical Journal C (Springer). The consolidation of these diffusion channels of Brazilian HEP research is clearly perceptible between 2003 and 2013.

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3.2 International Collaboration

Next, the HEP internationalization was analyzed based on the percentage of articles published jointly between Brazil and other countries. The number of documents in international collaboration of Brazilian HEP in Science Information between 1983 and 2013 is 2,888 articles. Considering the extent of co-authorship, publications signed by Brazil and another country (bilateral collaboration) reaches 1,371 articles (47.47%). The ones signed by three countries (trilateral collaboration) reaches 441 articles (15.27%) and those signed by ≥ 4 countries (multilateral collaboration), 1,076 articles (37.26%). When the journals in international collaboration were regrouped, it was observed that articles signed between 2 and 5 countries represent 69.39% of the total. The articles signed by ≥ 6 countries represent 30.61% of the publications, confirming the presence of Brazil in the large co-authoring networks.

The proportion of HEP articles signed by more than one country (49.07%) is vastly higher than the international collaboration rates verified in Brazilian scientific production in recent years, where co-authorship with authors from other countries occurred in approximately 30% of publications (LETA, THIJS, GLÄNZEL, 2013). At the institutional level, it was found that 31.74% of the publications were signed by a single institution, while 19.19% of articles were linked to national collaboration. During the period, there is a greater growth in the number of publications in international collaboration than in national and non-cooperative collaboration, especially since 2008, coinciding with the year of RENAFAE's institution (Image 4).

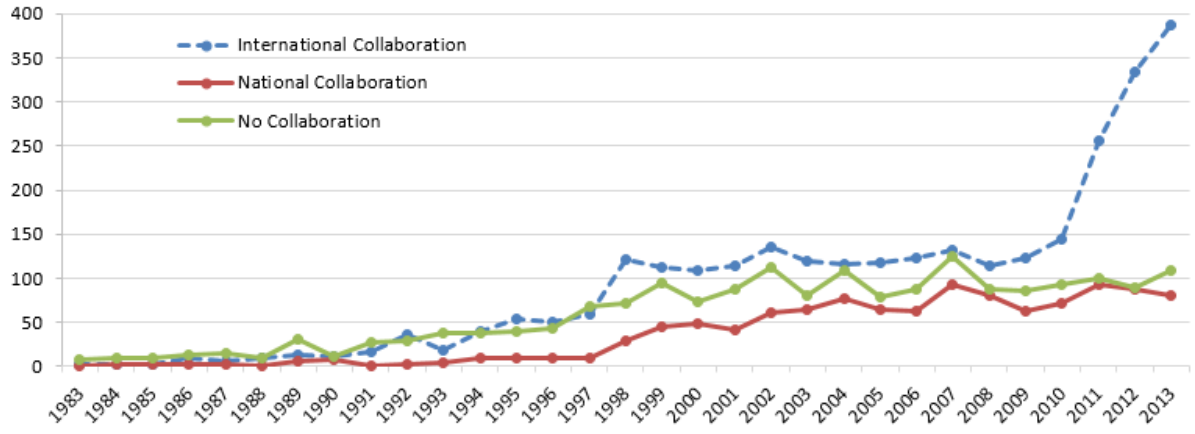

Image 4. Growth dynamics of HEP's scientific production according to the type of collaboration (1983-2013)
Source: research data

In order to enable the experiments related to accelerators and particle detectors, HEP requires the joint use of large facilities and complex instruments, requiring the participation of specialists from different areas and the economic contribution of several countries (VANZ; STUMPF, 2010). According to Leta and Cruz (2003), the reduction of research costs and the multidisciplinarity of some fields are probably the aspects that most stimulate scientific

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collaboration. Braun *et al*. (1992) state that in Space Sciences, HEP, Astrophysics and Nuclear Physics the cost of investigations is higher than most countries' local budget. The articles published in international collaboration were signed by authors from 74 countries, including Brazil. The geographic distribution of HEP's scientific production indexed in WoS according to the collaborating country allows the visualization of partners from different continents and to infer about the internationalization dimension of Brazilian publications (Image 5).

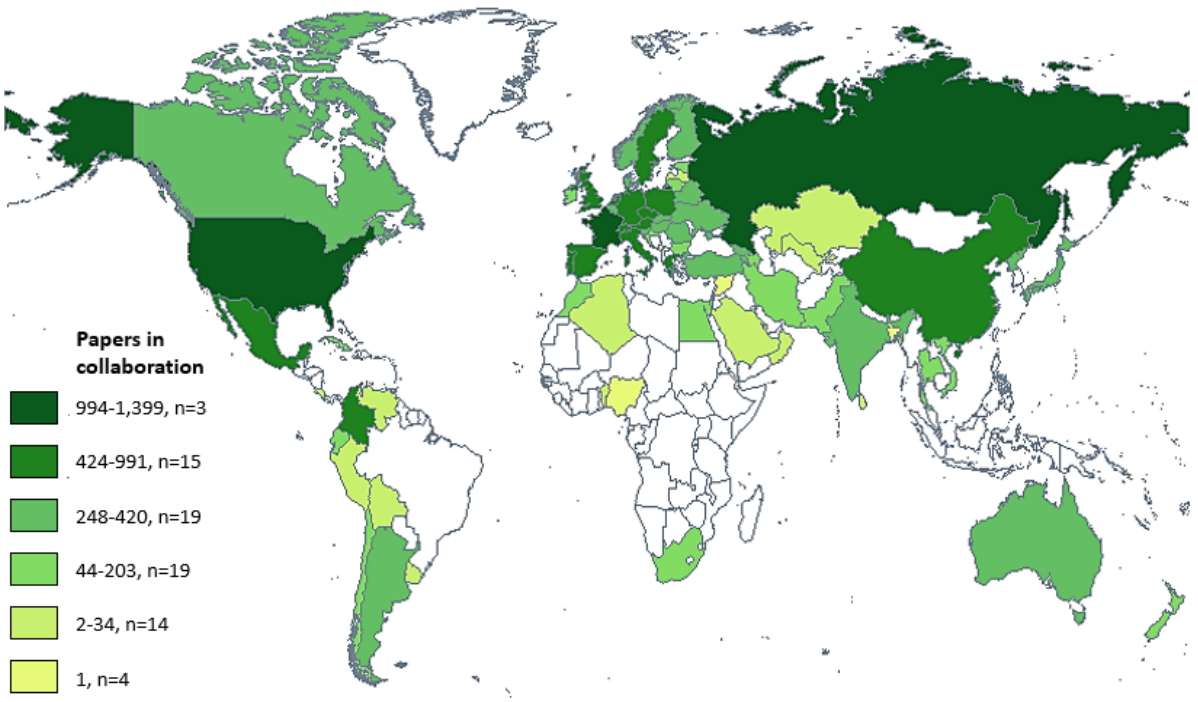

Image 5. Geographic distribution of Brazilian HEP's scientific production indexed in WoS according to the collaborating country (1983-2013)
Source: research data

Among Brazil's co-authors in HEP in the period from 1983 to 2013, we highlight those with the highest tradition of research in the field, the United States (6.10%), Russia (4.56%), France (4,34%), Germany (4.32%), United Kingdom (4.19%) and Italy (4.18%). The intensity of Brazil's collaboration with partner-leaders in terms of world production of High Energy Physics is more noticeable in the period of 2003 to 2013 (Image 6). The main collaborating countries of HEP are basically the same ones that were identified by Vanz (2009) in the coauthories of Brazilian science. The predominance of cooperating relations with the mentioned partners can be explained by the agreements and support programs to international collaborative research that are signed by Brazil. With the United States, collaborative agreements have been maintained since 1950; With Germany since 1964; With France, Portugal and the United Kingdom since 1968; With the Netherlands since 1971; With China since 1982; With Spain since 1992; With Italy since 1998 (AGENCY ..., 2016, online document).

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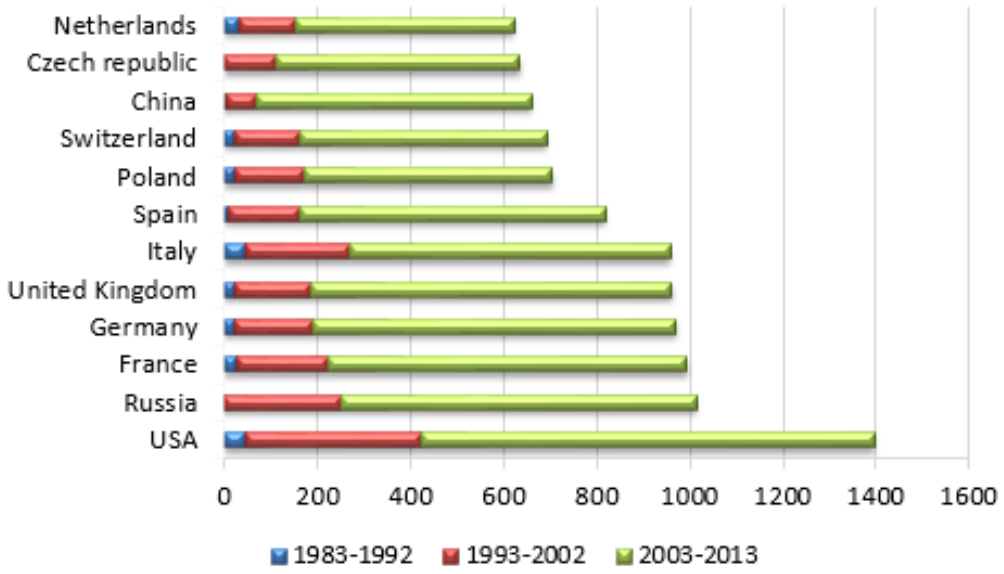

Image 6. Distribution of Brazilian HEP publications by periods according to the collaborating country (1983-2013)
Source: research data

The low participation of the United States perceived in HEP articles implies a reduction of Brazil's scientific dependence of that country and a consolidation of the bonds with partners, for the most part, of Europe. This indicator ratifies the national trend (all fields) observed in the study by Vanz (2009). The great international projects grant to the Brazilian scientific community the opportunity, especially in American and European laboratories, of new investigations in collaboration with several countries in the field of Particle Physics.

3.3 International Impact

Finally, the internationalization of the Brazilian HEP was estimated from the percentage of foreign citing documents. The 6,350 articles of scientific production received 78,812 citations from 41,152 documents, with an average growth rate of 32.17% per year. In terms of impact, it is inferred that the strong internationalization of research in the area contributed to the high percentage of cited articles (87.65%). Lehmann, Laudrup and Jackson (2003) argue that due to the operational cost of the experiments, the strict control of the research and the large number of co-authors, a smaller fraction of the articles mentioned in HEP are expected.

The general characteristics of the citing documents reveal the strong prevalence of journal article (80.48%) among document types and English (99.70%) among the publication languages. The scientific journal was the channel of diffusion most used by the census researchers. In the analysis of the set of 35 titles that published 165 or more articles, it was observed that 97.14% of the published documents are concentrated in international vehicles, especially the journals published in Europe (49.80%) and the United States (41.45%). Only one Brazilian journal was identified among the most productive, the Brazilian Journal of Physics. Physical Review D, Journal of High Energy Physics, Nuclear Physics B, Physics

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Letters B, European Physical Journal C and Physical Review Letters jointly published 44.06% of the documents.

Of all citing documents, 39,555 (96.11%) presented data on the author's affiliation. As for the origin, 34,721 (87.78%) belonged to international citations, being 30,327 (76.67%) without Brazilian authors and 4,394 (11.11%) with Brazilian authors. Likewise, national citations correspond to 4,834 documents (12.22%) between 1983 and 2014. The high number of researchers affiliated to foreign institutions in the citing documents highlights the internationalization of research and low self-motivation in HEP. International citing documents (without Brazilian authors) showed a growth that was noticeably higher than that shown by international citing documents (with Brazilian authors) and national citing documents during the period (Image 7).

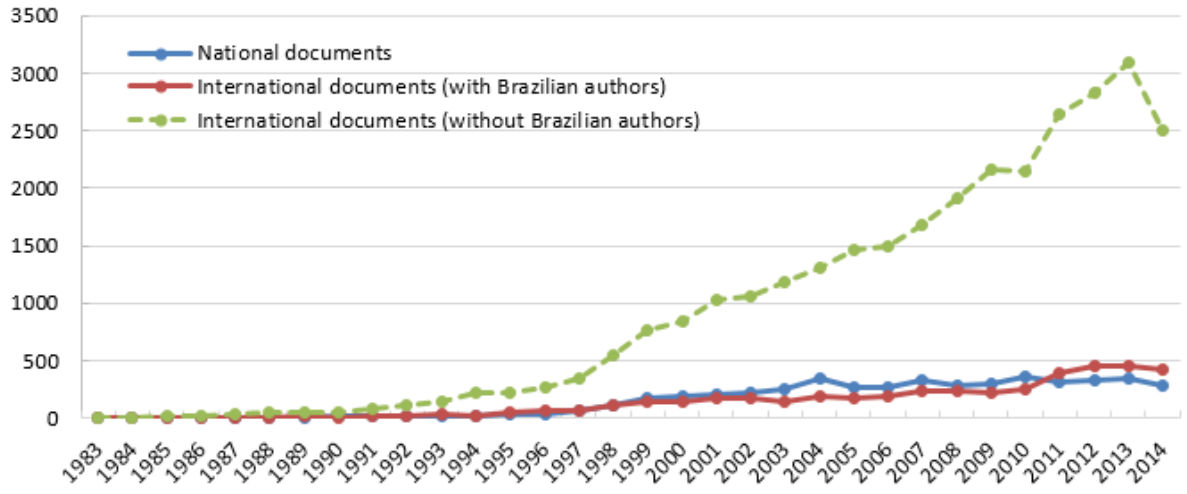

Image 7. Growth dynamics of the citing documents of HEP's scientific production according to provenance (1983-2013)
Source: research data

The five citing countries of the Brazilian HEP scientific production with the highest volume of publications are the United States with 10,554 documents (10.25%), Brazil with 9,309 (9,04%), Germany with 6,322 (6,14%), Italy with 5,139 (4.99%) and the United Kingdom with 4.581 (4.45%). The number of citations from these countries may be associated with the position of privilege they occupy in the international collaboration network of High Energy Physics and in the world ranking of productivity. The study clearly shows how the impact of Brazil's HEP research, measured by the number of citations per document, is more salient between 2004 and 2014, coinciding with the creation of RENAFAE and the increase in Brazilian participation in large international collaborations (Image 8).

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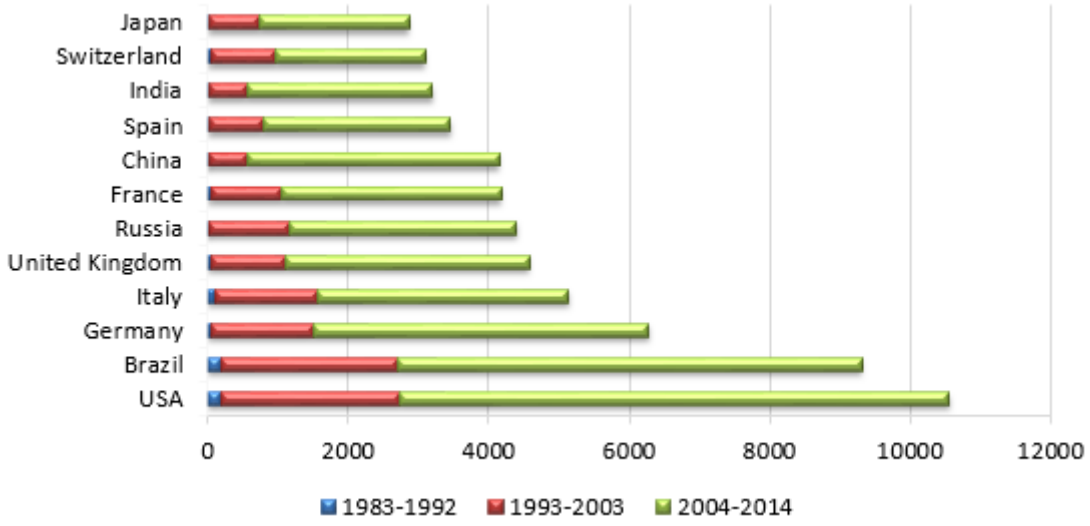

Image 8. Distribution of citations of HEP's scientific production for period according to the citing country (1983-2013)
Source: research data

The Brazilian HEP production was cited by 112 countries (including Brazil), revealing the influence and prestige of Brazilian authors within the international scientific community. Image 9 shows the geographic distribution of the citing documents and the intensity of the impact of Brazilian scientific activity on HEP in the world.

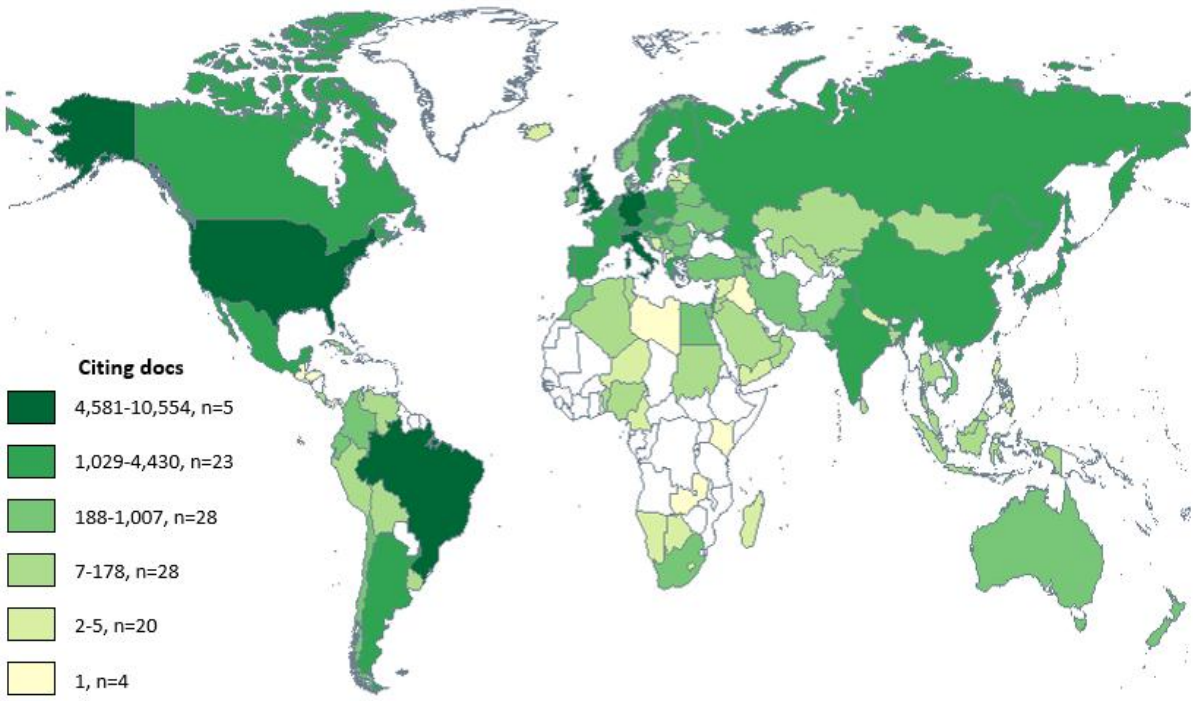

Image 9. Geographical distribution of the citation documents of Brazilian HEP's scientific production according to country of origin (1983-2014)
Source: research data

The examination of the scope of the Brazilian research indexed in WoS was also examined in relation to the continents of the citing documents. Europe, the main co-author of HEP articles in the period between 1983 and 2013, is also the region with the highest number of citations, 55,579 (53.98%). The high number of citations from the European continent is linked to the scientific contribution of the Member States of CERN and to the greater tradition in the experimental research of some countries like Germany and Italy. The United States, with 27,259 citations (26.47%), Asia with 17,604 (17,09%), Africa with 1,421 (1,38%) and Oceania with 1,117 (1,08%).

4 FINAL THOUGHTS

In this research it was possible to infer that the increase in the scientific production of Brazilian HEP indexed in WoS in the period between 1983 to 2013 may have been due to the expansion of the research, due to the increase in the number of graduate programs in Astronomy and Physics with lines of HEP research, CNPq groups, intensification of international collaborations in Brazil and institution of the RENAFAE. The results show a growing presence of Brazilian researchers in the main international journals with a high impact factor of High Energy Physics, in view of the fact that, in terms of the internationalization of scientific activity in HEP through international diffusion, collaboration and impact indicators, in complyance with the model of internationalization and scientific development for countries proposed by van Raan (1997). The proportion of HEP articles written by more than one country is broadly superior to the international collaboration rates verified in Brazilian scientific production in recent years, confirming Brazil's presence in large multinational networks. The analyses show a growing number of international citing documents and a low percentage of self-citation in the period. Both the distribution of the number of co-authoritative and international HEP citations suggest a strong correlation between collaboration and international impact.

The internationalization indicators used in this research revealed the international scientific profile of HEP in Brazil, following the characteristic standard of the subject globally. The results achieved contribute to the knowledge of the international dimensions of Brazilian HEP and provide subsidies for the planning and improvement of policies and strategies linked to negotiation for Brazil's entry into CERN under a new participation modality, the expansion of investments, the creation of national infrastructure, the expansion of international collaboration, expansion of graduate programs and activities of CNPq research groups.

INTERNACIONALIZACIÓN DE LA PRODUCCIÓN CIENTÍFICA DE BRASIL EN FÍSICA DE ALTAS ENERGÍAS (1983-2013)

RESUMEN
Este estudio bibliométrico analiza las dimensiones de la internacionalización de la producción científica brasileña en Física de Altas Energías (HEP) a partir de artículos publicados en revistas indexadas por la *Web of Science* (WoS) en el período de 1983-2013. Con base en la clasificación propuesta por el Manual de Santiago de la Red de Indicadores de Ciencia y Tecnologia Iberoamericana e Interamericana (RICYT), la internacionalización en HEP es estimada a través de Indicadores de Difusión, Colaboración e Impacto Internacional. Los indicadores de Difusión Internacional muestran la preferencia por la publicación en revistas extranjeras de lengua inglesa. La totalidad de los artículos analizados fue publicada en 35 revistas de 11 países diferentes. Los indicadores de Colaboración Internacional muestran la prevalencia de la co-autoría en HEP dado que 49,07% de los artículos fueron firmados por más de un país. Los indicadores de Impacto Internacional destacan el peso de las publicaciones en periódicos extranjeros de lengua inglesa entre los citantes. Los documentos citantes internacionales representan 87,78% del total, destacándose los firmados por autores de los Estados Unidos. Los indicadores de internacionalización utilizados desvelan el perfil científico internacional de la HEP en el Brasil, acompañando el modelo característico del área en la esfera global.

PALABRAS CLAVE: Producción científica. Internacionalización. Bibliometría. Física de Altas Energías.

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