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Particle Physics Facing a Pandemic

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Particle physics facing a pandemic

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Our ordinary life changed quite a bit in March of 2020 due to the global Covid-19 pandemic. While spring time in general well awaited and regarded as a synonym for rejuvenation the spring of 2020 brought lock-down, curfew, home office and digital education to the lives of many. The particle physics community was not an exception: research institutes and universities introduced home office and digital lecturing and all workshops, conferences and summer schools were canceled, got postponed or took place online. Using publicly available data from the INSPIRE and arXiv databases we investigate the effects of this dramatic change of life to the publishing trends of the high-energy physics community with an emphasis on particle phenomenology and theory. To get insights we gather information about publishing trends in the last 20 years, and analyse it in detail.

I. INTRODUCTION

In January of 2020 the high-energy phenomenology community was looking forward to another busy year full of workshops, schools and conferences. The situation dramatically worsened by the end of February and the final and lethal blow to all these live events happened in the middle of March. The quick escalation of the situation was personally experienced by the authors during the organization of the *PRecision Effective FIeld Theory School (PREFIT20)* from 2nd to 13th of March [1] and during a short-term scientific mission to Hamburg. The *PREFIT20* school had to be switched from lecturers being on-site to online presentations on the fly and turned out to be the last major live event in our field. The short-term scientific mission looked like an ordinary trip during the out-bound journey (9th of March), but one and a half weeks later (18th of March) almost all flights got canceled and the airport at Frankfurt (an always busy bee hive full of people) became completely deserted, with all the shops closed and reeking from disinfectant.

By the end of March lock-down, home office and digital education became the standard. This also meant all conferences and workshops got canceled or postponed until the end of summer. Within a couple of weeks the dominant platform to interact with colleagues became Zoom. The system got so wide-spread that "zoom meeting" became the 15th most frequently used words in 2020 [4]. In the particle physics community collaborations spanning over several countries or continents are not seldom hence people were more-or-less familiar with virtual meeting platforms and the technical transition was free from major difficulties and problems.

Although distant collaborations had been set up and were working flawlessly well before the pandemic the situation changed because traveling restrictions completely prohibited short visits and brain-storming sessions during conference coffee breaks. Also, it is very common that new collaborations form spontaneously, a process for which in-person meetings, workshops and structured programs at centers for scientific exchange like those offered by Aspen, GGI, INT, KITP, MIAPP, MITP, etc. play an important role. [2] During a pandemic virtual presence and online platforms can keep going an already working collaboration, but new collaborations become much harder to start due to the lack of personal contacts between potential members.

The pandemic not only changed the professional life of researchers but their personal ones were affected as well. This can also have consequences to scientific output and should not be disregarded. With lock-down and digital education introduced in schools researchers not only had to cope with new ways to keep their current collaborations going and to establish new ones despite the lack of all personal contacts but also had to prepare for lecturing using virtual class rooms. The latter aspect is of particular significance as the community generally regards chalk and black board lectures as the best way to convey course material and scientific ideas. All of these factors have an effect on scientific research and it is not at all clear how the community could adopt to new circumstances.

In this paper we analyze the scientific outcome of the high-energy particle physics phenomenology community by using various open search engines to retrieve data on published papers during the pandemic and in the past twenty years to get a better understanding of the true effects of this pandemic and to see what kind of changes it induced in the community. To have a broader

[1] The *PREFIT20* school [1] was organized as a joint event of the COST actions *PARTICLEFACE* [2] and *VBSCan* [3] at DESY in Hamburg.

[2] Aspen Center for Physics [5], Galileo Galilei Institute (GGI) for Theoretical Physics [6], Institute for Nuclear Theory (INT) [7], Kavli Institute for Theoretical Physics (KITP) [8], Munich Institute for Astro- and Particle Physics (MIAPP) [9], Mainz Institute for Theoretical Physics (MITP) [10].

perspective we also collected data related to the two major experiments, ATLAS and CMS, conducted at CERN at the Large Hadron Collider (LHC) and the high-energy particle physics theory community as well.

II. DATA EXTRACTION METHODS

In order to extract publication data we used the search engines of two databases, which cover basically all scientific publications in the field of high-energy physics: INSPIRE [11] and arXiv [12]. These engines allow for sophisticated searches by restricting hits through the use of many criteria, like paper categories (hep-ph, hep-th, hep-ex, etc.), by requiring papers to have a certain number of authors or by listing papers published or uploaded within a given period of time. As these highly specialized tools have become quite mature it is possible to perform automatic queries by invoking the site's search engine directly with an API (Application Programming Interface). By using a special URL the search engine can be instructed to perform a search according to the parameters specified through the URL and to return the result in some machine readable format. For example, if the number of publications which appeared in 2021 and are categorized as hep-ph papers is extracted from INSPIRE the following URL should be invoked from the browser:

```
https://inspirehep.net/api/literature?fields=hits.total&format=json&q=
  publication_info.year:2021%20AND%20arxiv_eprints.categories:hep-ph
```

The result is delivered in the `JSON` format, which is tolerably readable by the human eye but easily digestible by the many commonly available interpreting languages, like `Python`. In our case only the total number of papers fulfilling certain criteria was needed, hence the method we have employed is:

1. URL is constructed with all needed keywords.

2. URL is invoked from `Python`.

3. Result is delivered in `JSON` format.

4. Total number of papers is extracted and written into data file.

5. Histograms are created with `GNUplot`.

In case of the arXiv database we did not use the arXiv API. Instead, by selecting the advanced search option, the total number of records fulfilling the search criteria were gathered manually.

In recent times a strong proliferation of proceedings can be seen in all the categories we have investigated. In order to avoid this proliferation as much as possible and to get a clearer view of publishing trends we have filtered out all records without a DOI number. This method does not fully eliminate proceedings from the search results but restricts their number to a subset which is indeed published in one form or another. The filtering according to the DOI number was only possible with the INSPIRE API. Hence, we have validated our arXiv results by taking a look at the annual statistics reported from both search engines to see if the presence of proceedings in the arXiv search results affects the trends obtained with the INSPIRE API.

With the INSPIRE API we have collected annual statistics starting in the year 2001 and up to 2021. To get the annual number of papers we have requested that the field `publication_info.year` includes the year for which total number of publications are collected.

Moreover, the document type had to be `article`, all the records were supposed to have a DOI number and to belong to the target category (hep-ph, hep-th or hep-ex) for which we collected the data. In case of the hep-ex category we have only accepted papers by the ATLAS and CMS collaborations and, hence, rejected any other. By varying the number of authors we were able to get statistics data for various collaboration sizes.

In case of the arXiv search engine our set of selection criteria was very modest. We have performed searches in the same three categories as in case of the INSPIRE API, filtered records according to their submission year and, for a finer resolution, the month in which the submission happened.

III. ANNUAL STATISTICS USING INSPIRE API

For the long-term annual trend in publishing the INSPIRE API was used in the three different categories: particle phenomenology (hep-ph), theory (hep-th) and experiment (hep-ex), the latter being restricted to the ATLAS and CMS collaborations only, and the results were filtered by requiring a valid DOI number attached to each record in order to minimize bias due to the proliferation of proceedings. Specifically we are interested in the total number of papers on an annual basis and in the number of authors.

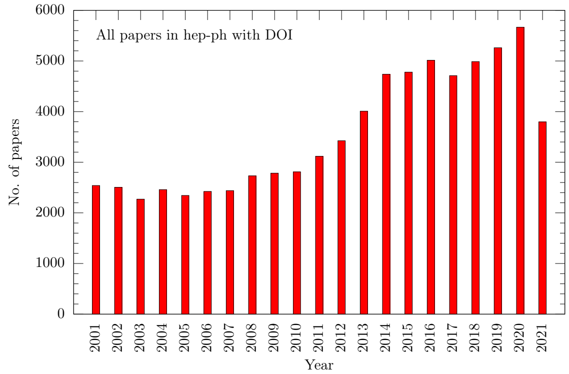
For the interpretation of the data collected in this way, it is also important to identify scientific events with potential impact on the publishing behavior of the high-energy physics community, such as new discoveries, the schedule of LHC operations, or other important developments. For the categories we have analyzed potential events are listed in Tab. I.

Event	Date
LHC Run I	late 2009 - early 2013
OPERA announcement of measurement of superluminal neutrinos [13]	23 September 2011
CERN announcement of Higgs boson discovery [14]	04 July 2012
ATLAS and CMS presentation of diphoton excess at 750 GeV [15, 16]	15 December 2015
LIGO announcement of first measurement of gravitational waves [17]	11 February 2016
LHC Run II	2016 - 2018

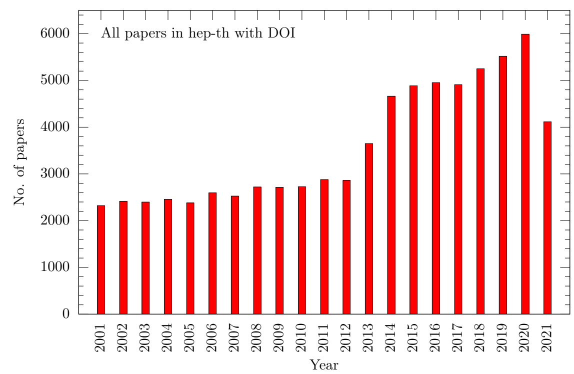
TABLE I: Noteworthy events with impact on publishing trends and tendencies in the high-energy physics community since the start of LHC operations.

A. Total number of papers

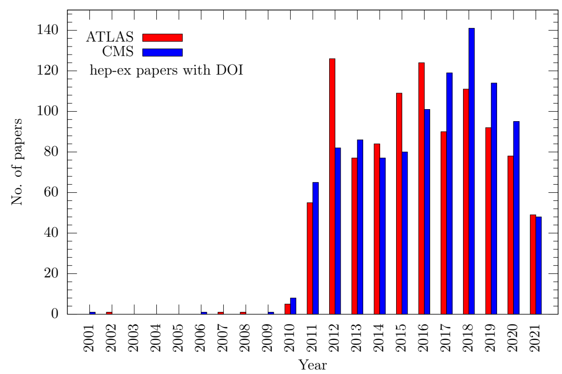
The total number of published papers in the period 2001 to 2021 are depicted in Fig. 1 and it is evident that the start of LHC operations with Run I had a tremendous effect on publication activity in high-energy physics. As it can be seen in Fig. 1a before 2010 the number of papers produced in the phenomenology community remained at a steady level with a slight increase hardly discernable due to fluctuations. However, as first LHC results started to pour in the number of papers increased rapidly. A certain fraction of the increasing number of papers in 2011 can be also attributed to the



(a) All papers published with hep-ph category label.



(b) Same as Fig. 1a for hep-th.



(c) Same as Fig. 1a for hep-ex with separately listing papers contributed by ATLAS and CMS.

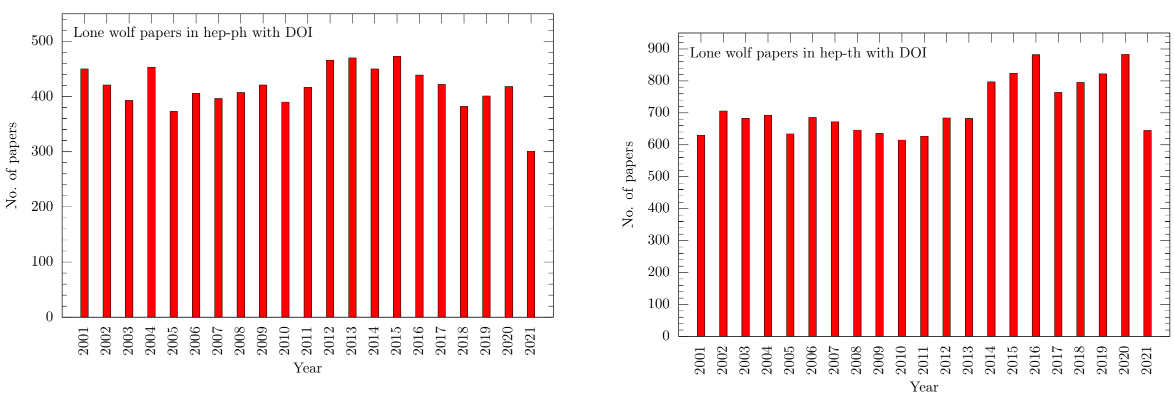
FIG. 1: Total number of published papers according to INSPIRE filtered using various arXiv category labels and requesting a valid DOI number.

OPERA announcement on the measurement of superluminal neutrinos [13]. In 2014 and with the end of Run I the increase flattens out, the annual publication rate becomes roughly constant but with a different normalization, roughly factor of two compared to pre-LHC days. A small peak can be seen in Fig. 1a in 2016, which can be attributed to the 750 GeV diphoton excess [15, 16]. The Run II of LHC has a less dramatic effect on the number of phenomenology papers and it is also shifted by a year or so starting to ramp up only in 2018. The increase in the number of publications at the end of the LHC Run II did not finish in 2019, instead it is still visible in data taken for 2020. Knowing that the Covid-19 pandemic had its first real effects in March 2020 this is a remarkable observation. The publishing trend did not change by the measures enforced on the phenomenology community but on the contrary even with all difficulties induced by the pandemic the community was able to flourish. The total number of published papers in 2021 is still not complete hence it is harder to see the long-time trend of the pandemic. But the number of papers published by the end of the summer of 2021 is roughly three-forth of the total number of papers of 2020, so we can envisage a slight decrease or a stagnation in the publishing trends.

A look at the high-energy theory category in Fig. 1b shows that the number of papers published grows only moderately until the year 2013, where a sudden increase happened in the normalization. This change of normalization coincides with new achievements in multi-loop amplitude calculations where the first publications appeared on arXiv in 2013 and completely changed the way loop integrals are being calculated nowadays. The real change in the trend appeared after the Run I starting in 2015 and 2016. Then, a second, less dramatic increase starts in 2018, a trend in agreement with the previous LHC related ramp-up. The number of theory papers increases not during but just after the end of the LHC run.

This could be a consequence of lack of new physics found in both runs, leading the community to speculate about the lack of new signals. In 2021 the number of papers is lacking behind previous years with only two-third of previous year's papers produced so far. Assuming a uniform distribution of paper publications throughout a year the slight increasing trend can be held even this year, even during the pandemic.

The annual number of published papers produced by the ATLAS and CMS collaborations are shown in Fig. 1c and it is evident that the publication activity really started around 2011 and 2012 once real data was taken and subsequently analyzed. As for Run I ATLAS outnumbered CMS which started to catch up during Run II later on. Also between the two runs the continuous analysis of recorded data produced a steady flow of published papers. As more and more data has been analyzed the rate of papers decreases, which is already visible in the numbers recorded in 2019 and 2020. Those numbers coming from 2021 (although partial) completely fit into the general trend of recent years. Taking into account that the number of publications for 2021 is partially incomplete the trend seems to be completely unaffected by the pandemic.



(a) All papers published with a hep-ph category label and by a single author.

(b) Same as Fig. 2a for hep-th.

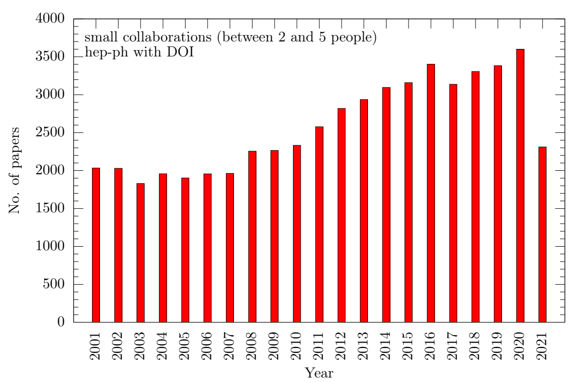
FIG. 2: Total number of published papers according to INSPIRE filtered using hep-ph (left) and hep-th (right) arXiv category labels, requesting a valid DOI number and with a single author.

B. Number of authors

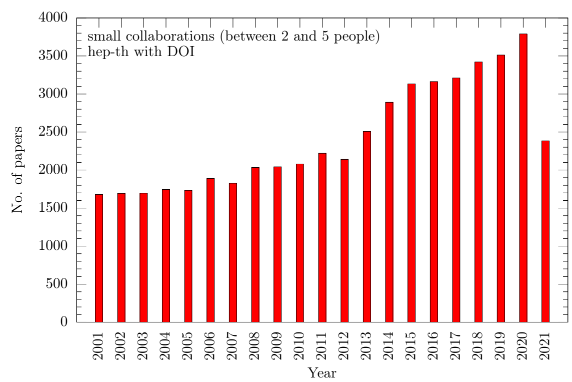
In high-energy physics collaborations of many sizes exist. A pandemic can have different effect on different collaboration sizes hence it is very informative to dissect the annual number of papers according to different collaboration size ranges. This partitioning can only affect phenomenology and theory papers because in the hep-ex category we only consider ATLAS and CMS publications. The latter two collaborations have constant size since the start of LHC operations in 2009 with approximately 3.000 authors in case of ATLAS and around 2.500 authors in case of CMS.

For the hep-ph and hep-th categories, the annual statistics for single-author papers is shown in Fig. 2. Restricting ourselves to the phenomenology papers only in Fig. 2a it can be seen that the number of papers displays a rather steady trend with somewhat larger fluctuations due to the smaller amount of papers produced on an annual basis. Due to higher fluctuations possible trends are harder to identify but a slight increase can be observed at the start of LHC Run I in 2010 and ending in 2012. Recent years starting with 2016 brought a steady decrease of number of papers with a slight increase starting in 2018 in accord with the end of LHC Run II. This slight increase did not stop in the year 2020 but considering the partial number for 2021 a stagnation is probable.

In Fig. 2b single-author hep-th papers are listed as a function of publication year. Before LHC Run I it follows a more-or-less constant trend with some fluctuations, even some decrease can be seen ending in 2010. A ramp-up period can be identified starting in 2010 in line with the start of LHC operations resulting in a peak in 2016, part of which can be attributed to the diphoton excess announcement in December 2015 and the LIGO announcement of first measurement of gravitational waves in February 2016 [17]. Another period of increasing publication activity started in 2017 in line with the end of the LHC Run II. If a uniform publication tendency is assumed this trend can still be maintained this year. The year 2020 witnessed a still increasing publication activity for single-author papers in hep-th so it seems that the pandemic was not a significant factor in this respect.



(a) Number of papers published by small-size collaborations (two to five people) in the hep-ph category.

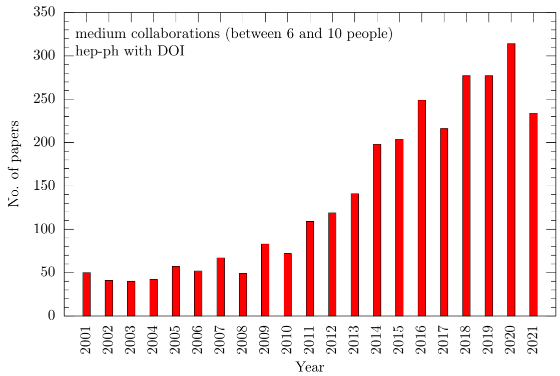


(b) Same as Fig. 3a for hep-th.

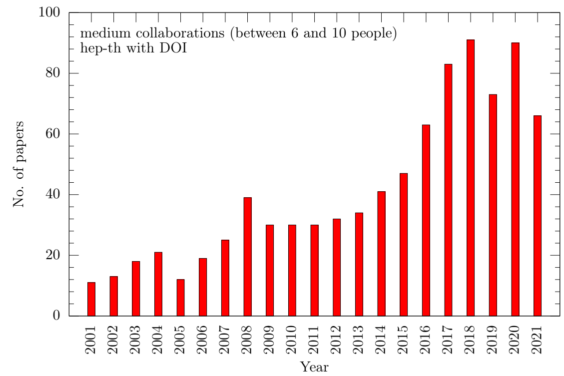
FIG. 3: Total number of published papers according to INSPIRE filtered using hep-ph (left) and hep-th (right) arXiv category labels, requesting a valid DOI number and by collaborations with between two and five authors.

For small-size collaborations, which we define to consist of two to five people, the number of published papers on an annual basis is plotted in Fig. 3 for both communities, phenomenology and theory. In Fig. 3a it is visible that before the LHC Run I the phenomenology community more-or-less followed a steady publishing tendency with the same amount of papers produced annually with some fluctuations. The start of Run I resulted in a steady increase in published papers with a slight slow-down tendency as nearing the Run II. The year of 2016 witnessed a remarkably good year for publishing most probably by the diphoton anomaly announced in late 2015. Run II ignited one more increase which seems to be stopped this year considering that in the first three quarters of the year the collaborations only were able to produce less than two-third of previous year's publications.

On the right hand side of Fig. 3 publishing trends of small hep-th collaborations can be seen with a very similar behavior as in hep-ph, although with a slightly elongated slow increase. The big jump in publishing happens not through the Run I period but slightly after with no clear sign of superluminal neutrino or the diphoton excess announcements. The same trend is visible in recent years, as the numbers of publications grow again with the end of Run II. The partial results for 2021 indicate that this increasing tendency most probably cannot be maintained.



(a) Number of papers published by medium-sized collaborations (six to ten authors) in the hep-ph category.



(b) Same as Fig. 4a for hep-th.

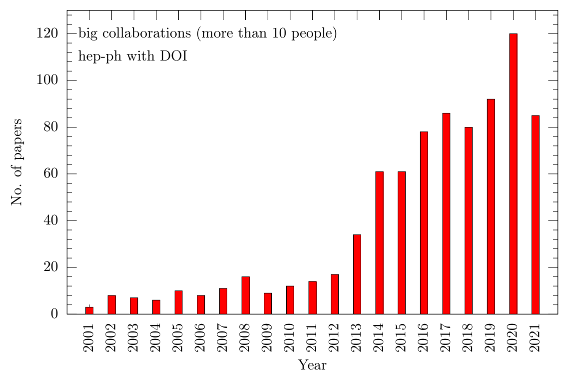
FIG. 4: Total number of published papers according to INSPIRE filtered using hep-ph (left) and hep-th (right) arXiv category labels, requesting a valid DOI number assigned and by collaborations with between six to ten authors.

Medium-size collaborations [3] are neither very common in phenomenology nor in theory as can be seen from the annual statistics in Fig. 4. It seems evident that the start of LHC operations during its Run I was a crucial factor in forging collaborations of this size since both in phenomenology and in theory the number of papers published drastically increased throughout and after this period. In the phenomenology statistics a clear peak is visible in 2016, correlated in time with the diphoton excess. In recent years the trends seem to stabilize with large fluctuations. Considering the partial number of papers produced in 2021 it seems that these collaborations are again not affected by the pandemic since the remaining couple of months can easily result in such an amount of papers to allow this year to maintain the overall trend.

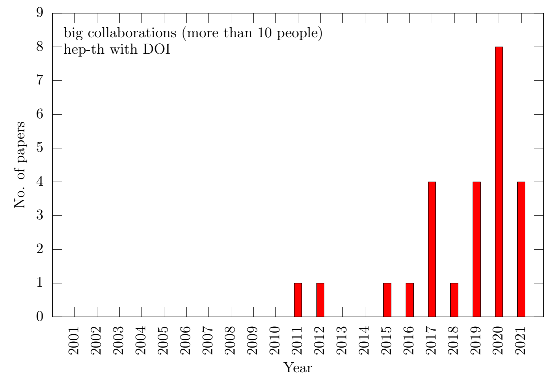
Large-size collaborations [4] (more than ten people involved) do not have a long history in the analyzed two communities as can be seen in Fig. 5. In the theory community even nowadays these can be regarded as scarce with less than a dozen papers produced annually. As Fig. 5a shows the advent of LHC physics and the first results from LHC Run I catalyzed the formation of these kind of collaborations. In comparison less than twenty such papers were published on an annual basis before the LHC-era. The past recent years however do witness a rising trend of publications from large-size collaborations in the hep-ph category, culminating in an enormous peak in 2020 (more than 20% increase compared to 2019). This dramatic increase in the number of publications by

[3] There is no solid definition what collaboration size can be considered medium-sized. In this paper drawing from our experience have settled for the number of authors in the range of six to ten in order to fit into this category.

[4] As with medium-size collaborations there is no firm definition of what could be considered a large-size collaboration in these areas of academic research. Hence the lower bound for these collaborations of more than ten people reflects the authors' judgment of what can be regarded as big in our communities.



(a) Number of papers published by large-sized collaborations (more than ten authors) in the hep-ph category.



(b) Same as Fig. 5a for hep-th.

FIG. 5: Total number of published papers according to INSPIRE filtered using hep-ph (left) and hep-th (right) arXiv category labels, requesting a valid DOI number by collaborations with more than ten authors.

large-size collaborations in phenomenology can be explained by the extraordinary performance of LHC during and since Run I. The high quality data created a strong driving force for precise predictions, which, on the other hand, require a significant amount of manpower. In consequence, the demand for state-of-the-art predictions can often only be fulfilled within a reasonable time-frame by joined efforts, hence large(r) collaborations have been and are being formed. The peaking behavior can also be seen in the publication trend in the hep-th community but since the number of publications there is smaller by a factor of two the increase in 2020 compared to 2019 can be partially attributed to fluctuations. However, it is clear from the trend (at least for the hep-ph community) that the pandemic did not have any effect on the publishing trend. On the contrary, the past one and a half years were fruitful for producing papers for this size of collaborations.

Judging from these annual statistics, it seems that the effect of the pandemic on the three communities in high-energy particle physics (hep-ph, hep-th and ATLAS, CMS in hep-ex) is at most moderate and in the worst case resulted in a stagnation in the publishing trends or a very slight decrease. Collaborations of larger sizes seem to be immune to the Covid-19 restrictions, being able to publish with the same or even higher frequency. In the case of the ATLAS and CMS collaborations the overall trend for the recent years shows a decreasing rate of publications and the data for 2020 and the extrapolated data for 2021 mirror also this well-established trend.

IV. MONTHLY STATISTICS USING ARXIV

The search engine of arXiv allows to extract also data not only on an annual but on a monthly basis. The engine does not allow to restrict the search to published papers only, but even with proceedings contained in the collected samples, it is interesting to look at publication and arXiv submission trends at a finer resolution. In order to convince ourselves that statistics gathered on a monthly basis including proceedings still contain valuable information the total annual statistics collected via arXiv can be compared with the histograms in the previous Section based on the data of the INSPIRE API. As an example for this cross-check annual submission statistics was collected

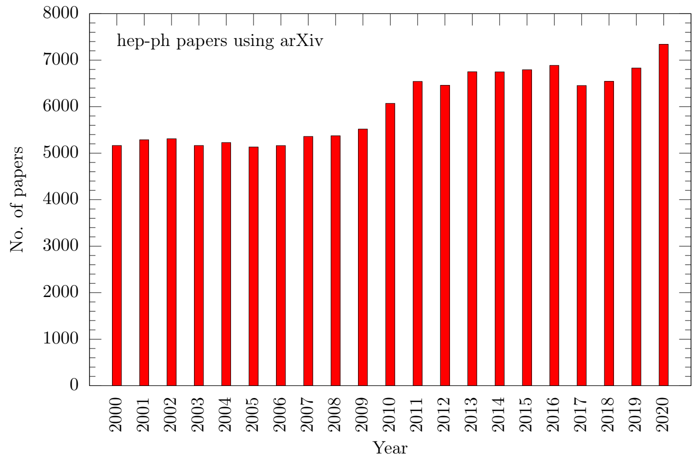
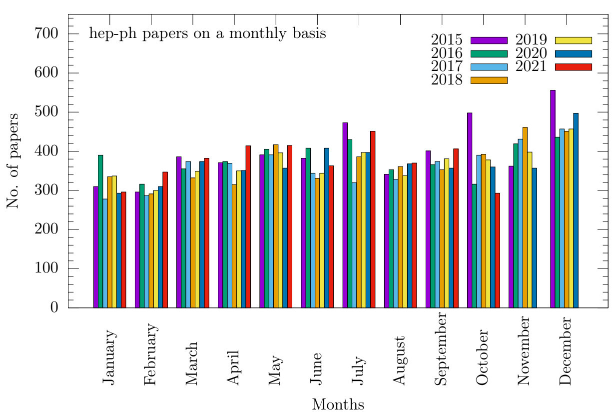
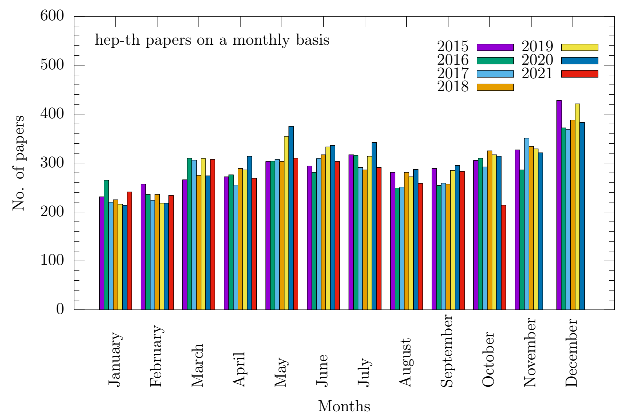


FIG. 6: Annual submission statistics in the hep-ph category using the arXiv search engine.



(a) Number of papers uploaded to arXiv on a monthly basis in the hep-ph category.



(b) Same as Fig. 7a for hep-th.

FIG. 7: Number of papers submitted to arXiv in the hep-ph (left) and hep-th (right) categories between 2015 and 2021 for further details see the main text.

in the hep-ph category on arXiv and the resulting histogram is plotted in Fig. 6. Comparing Fig. 6 to Fig. 1a shows that the trends are the same, although the overall normalization is different. Before the LHC Run I period both statistics follow a more-or-less constant trend with an increase in the number of publications due to LHC Run I. Even the publishing peak in 2016 is visible with arXiv results and the increasing frequency of recent years can be identified. These findings give us enough confidence to take a look at the monthly charts obtained from arXiv and to search for tendencies in them.

In Fig. 7 we have plotted the monthly statistics for seven consecutive years for both hep-ph and hep-th. As it can be seen from both plots the publishing trend is relatively constant for phenomenology papers but for theory papers a clear pattern emerges. The publishing frequency is systematically lower in the first two months of the year and increases to a local maximum in the summer but just to turn back and reach a second minimum in august and september and then it ramps up to reach the maximum frequency as the year ends. The histograms contain both 2020 and partial 2021 results and these data fit perfectly well into the general trend of recent years with a somewhat lower yield this year (the data from october 2021 only shows partial results). In order to create these histograms we have used the original submission date for the records to filter results. In this way it is easy to see for example that the 750 GeV diphoton excess really created a swell of publications [5] both in phenomenology and theory papers resulting in an excess of 15-20 % of publishing in 2015 December with a significant surplus carried over to January 2016 (more than 30% for phenomenology and 17% for theory compared to same period of previous year).

From these statistics it seems that the pandemic did not change too much the already settled publishing trends and sometimes it even overshoots the same month from previous years. We cannot see any dramatic increase nor dramatic decrease in the publication rates.

V. CONCLUSION AND OUTLOOK

Sir Isaac Newton was just a student at the University of Cambridge in 1665 when the bubonic plague broke out and forced the university to close down for two years. These two years were extremely successful for the young Newton, 23 years of age then, who was able to work out his theory of gravitation in that period. Newton's achievements serve as an example how the focus on a specific scientific problem during a pandemic and eventually a lock-down can bear fruitful results. Also, taking a look back at the history of the human kind it always encountered some pandemic of some kind, like typhus, Spanish flu, etc., not to mention that science had to learn how to flourish during war, depression and in lack of proper funding. This resilience and adaptation to new circumstances is clearly visible in the documented publishing trends, which seem to have been affected only in minor ways. For the high-energy physics community it was not only possible to stay alive but even to somewhat increase their numbers of publications. For this year 2021 the tendency seems to stabilize or at most decrease slightly.

At the same time the in-person interaction is a vital component in the process of exchanging scientific ideas, for work in existing collaborations and for the start of new ones. Here, workshops, conferences and topical programs at centers for scientific exchange play an important role by creating suitable environments and atmospheres. The complete lack of such interactions can have a negative impact on the community. While the various virtual presence platforms seem suitable and efficient for administrative purposes and supersede in-person meetings, they cannot serve as a substitute for the true melting pots of new ideas during social events. Travel and workshop attendance can also help to focus on research in the absence of the usual other errands, lectures and administrative burdens.

In summary the community was able to tackle the Covid-19 pandemic and the associated restrictions for the time being but to avoid complete stagnation and to really progress towards a bright future the high-energy physics community has to restart in-person events, scientific visits and black board discussions.

VI. ACKNOWLEDGEMENTS

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[5] In the community this effect is sometimes referred to as“chasing the ambulance”.

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[1] *PREFIT20: PRecision Effective FIeld Theory School*, https://indico.cern.ch/event/817757.
[2] COST Action CA16201, *PARTICLEFACE - Unraveling new physics at the LHC through the precision frontier*, https://particleface.eu.
[3] COST Action CA16108, *VBSCan - Vector Boson Scattering Coordination and Action Network*, https://vbscanaction.web.cern.ch.
[4] Irish Times, *What's the top word of 2020? Oh, you guessed that one easily*, https://www.irishtimes.com/culture/what-s-the-top-word-of-2020-oh-you-guessed-that-one-easily-1.4298315.
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