

Preprint version 1, March 2016. Currently under review for publication.

Beams of Particles and Papers.

The Role of Preprint Archives in High Energy Physics.

Alessandro Delfanti
University of Toronto
a.delfanti@utoronto.ca

Abstract: In high energy physics scholarly papers circulate primarily through online preprint archives based on a centralized repository, arXiv.org, that physicists simply refer to as “the archive.” This is not a tool for preservation and memory, but rather a space of flows where written objects are detected and then disappear, and their authors made available for scrutiny. In this work I analyse the reading and publishing practices of two subsets of particle physicists, theorists and experimentalists. In order to be recognized as legitimate and productive members of their community, physicists need to abide by the temporalities and authorial practices structured by the archive. Theorists live in a state of accelerated time that shapes their reading and publishing practices around a 24 hour cycle. Experimentalists resolve to tactics that allow them to circumvent the slowed-down time and invisibility they experience as members of large collaborations. As digital archives for the exchange of preprint articles emerge in other scientific fields, physics could help shed light on general transformations of contemporary scholarly communication systems.

Keywords: scholarly communication; particle physics; archives; temporalities; open access; authoriality

1. Introduction

In high energy physics the spheres in which information circulates and credit is attributed are partially separated from the ones formally used to evaluate research output. Scholarly papers circulate primarily in venues outside the traditional peer-reviewed scholarly journals. The community exchanges, retrieves, and evaluates papers almost exclusively through online “preprint” archives that publish research manuscripts that have not yet been subject to a formal peer review and editorial process. These archives are based on a centralized repository, arXiv.org, that physicists simply refer to as “the archive.” In a nutshell: physicists do not read journals. Furthermore, epistolary and face-to-face communication are key in processes of information exchange and individual evaluation. However, physicists do publish their work in journals and spend considerable money and

effort in sustaining them. This separation between what is read and formal peer-reviewed publications makes high energy physics an ideal case for investigating the relation between the scholarly communication system and the dynamics of scientific credit and attribution. In this work I propose that physicists' practices could be of interest for an analysis of more general transformations of scholarly communication systems.

Indeed, in the last decade open access archives for the publication of preprints have been proliferating, and by now they are available in many sectors of research, although in different forms. Some are public, some are private, others are relatively low-tech, whereas others have adopted technologies that are typical of the most recent social media. Created in 2013, biorXiv.org is establishing itself in the field of life sciences, whereas in fields such as social sciences a commercial service such as academia.edu has been proving able to supersede institutional and public archives and has attracted increasing volumes of preprints (Hall 2015). However, disciplines in which researchers have been using open archives as the main infrastructures to exchange their own papers for decades — such as particle physics — provide a telling example showing that this instrument is connected to specific ways of circulating scientific writing and structuring the scientific community. In short, open access archives are closely connected to the existence of what has been called a “preprint culture” (Mele et al. 2006) developed and settled over the 20th century. Other disciplines either not having developed this culture or having institutional or social structures different from physics have been facing specific issues and may struggle to adopt preprint archives as the central place in which knowledge is shared and debated.

In addition, preprint archives in physics are not mere instruments for a faster and more effective communication, and are arguably not about access either. High energy physics is often used an example of the evolution of open access in the era of digital scholarly communication. For example, Kathleen Fitzpatrick points at this platform as having “in effect replaced journal publication as the primary mode of scholarly communication” within some scientific fields (2011, p. 23, see also Borgman 2007). Yet there seems to be a confusion about the role and significance of archives. Are they tools for access, preservation, discussion, curation, or peer review? Media scholars have coined the term “zombie media” (Garnet and Parikka 2012) to describe media whose death or disappearance has been announced several times as inevitable and yet insist on existing. Examples would include the book (or printed media tout court) or television. arXiv has been described as one of the pieces of evidence that point to a future death of the peer reviewed paper, while at the same time underpinning knowledge circulation, review and preservation. Yet a closer look at the role of preprints in particle physics allows for a rethinking of such claims. Indeed, as I point out below, in particle physics both preprint archives and open access communication predate the digitization of its communication system. Furthermore, rather than being tools

for access or preservation, archives are the spaces where the community is continuously created and maintained, and where physicists publicly affirm their existence as individuals within their community.

But are scholarly articles important at all for physicists? In what is arguably one of the most important works on particle physics culture, Sharon Traweek discarded the importance of publications (1988). Indeed Traweek stated that what has been written and published is uninteresting to physicists: published work is uncontested and does not get read. Physicists, according to Traweek, rarely read journals or visit the library but “do scan preprints in order to know who is writing about what,” (1988, p. 121). Also in order to achieve this goal they rely on what Traweek called “gossip” (word of mouth communication) as physicists want to know what is going on before a piece of research is published. Oral communication conveys restricted information while written works contain public information, which is made accessible to the whole community but might be old, incomplete or unimportant. In Traweek’s work articles and preprints assumed the role of commodities exchanged among physicists in order to claim ownership and “pay royalties” to colleagues in form of citations. Written articles and preprints are thus record-keeping devices that are merely a trace of something happening elsewhere—Traweek used the metaphor of the traces left by particles in a bubble chamber, a technology based on liquid hydrogen invented in the 1950s and used in modern physics to detect electrically charged particles moving through it (p. 122). Yet while gossip might still be one of the main communication practices of the physics community, the digitization of the archives has brought about a change in physicists’ relation to written communication. I believe that archives are crucial spaces, spaces that are central to the physicists’ community - they keep on referring to them alternatively as “the archive” or “the archives,” depending on whether they refer to the centralized arxiv.org that contains almost the totality of new works, or to other archives that are overlays built on top of it and use its information to provide metadata and other services. Beware: I do not believe that the *content* of physicists’ papers has acquired importance because of the transposition of archives onto digital technologies. Communication on “physics,” as physicists would describe the kind of scientific knowledge they see as appropriate for discussion amongst whoever is part of their community, might still happen in face-to-face communication for example in conferences or at the chalkboard, and epistolary or personal interactions. Today, this is often mediated by the Internet and thus takes the form of webinars, Skype calls or emails. But in my view, what happens on digital archives is a different kind of communication that requires a rather radical change of perspective.

Thus although in particle physics preprint circulation predates the digitization of scholarly communication, the latter phenomenon has crucial implications for the cultural significance

of archives within this scholarly community. In particle physics, archives apparently meet a demand for internal cohesion and competition. Indeed in this paper I argue that preprint archives are not used merely for building a public record of scholarly activity. Rather they are spaces of flow that shape the role and meaning of authorship by structuring the temporalities of scholarly publishing, and by allowing a renegotiation of the nature of the objects that come to constitute a publication. With Foucault, I wonder which kind of “author function” particle physicists construct or lose while publishing their papers on preprint archives (1999). As the “solid and fundamental unit of the author and the work” constitutes one of the core bases upon which modern knowledge is built and sedimented, particle physics makes both the concept of *work* (oeuvre) and the status of the author highly problematic (p. 205). They are of course the result of transformations and clashes, and thus are historically and culturally (and perhaps technologically, we may add) situated. Building on the metaphor proposed by Traweek and based on the technologies used in particle physics, that is articles being traces left by subatomic particles, I propose that the archive has assumed the role of the core *detector* used by the community to make written objects noticed and their authors available for scrutiny. Detectors are huge machines that can identify and make visible subatomic particles coming either from the environment or from an accelerator. Within this metaphor, in this paper I analyze how two different subsets of particle physicists, theorists and experimentalists, shoot--or indeed refuse to shoot--their manuscripts through the archive as beams of particles produced by an accelerator. They do so in the hope of being detected as authors, as well as legitimate and productive members of their community. In order to achieve this they need to abide by the way the archive structures the condition of being an author.

2. Digitized archives

The dynamics of particle physics authorship and publishing systems have been analyzed from different viewpoints along the lines of authorship and credit attribution (Galison 2003, Birnholtz 2006). Most accounts fail to focus on preprint archives as the core venue for credit accumulation and negotiation over one’s position within the physics community. If preprint archives enter the picture they do so merely as tools for fostering open access to scholarly articles. I suggest that preprint archives are the core spaces where community bonds are created through the publication and exchange of written documents. This is not new, as the genealogy of archives emerging from a digitization of physics media reveals a strong continuity with Gutenberg-era publication formats. First of all we should consider that regardless of hegemonic descriptions of digital scholarly communication as “revolutionary,” change in media (and thus in publishing systems) often maintains a balance between continuity and discontinuity (Borgman 2007). Through cycles of re-mediation, new media

technologies evolve out of older media while preserving underlying communication formats and practices. Not surprisingly, old practices seem to fold into new technologies and shape them continuously (Bolter and Grusin 2000).

For decades, long before the rise of digital media, physicists have been using preprints as their medium of choice. Epistolary communication has always been one of the pillars of modern science. Yet since the end of World War II and the subsequent growth of the field of physics the practice of exchanging preprints by post, irrespective of the distribution of the same papers via science journals, has been institutionalized (Gentil-Beccot et al 2010). When they thought that an article was ready to be read by colleagues, physicists would take it to their laboratory's library. The libraries of departments or laboratories used to keep an archive of preprints that used to be sent in by other schools or laboratories around the world. Once received, preprints were posted on a bulletin board, often positioned at the entrance of the library, where researchers could read the titles, the authors list, and if they were interested in a paper, request a copy. This was an expensive practice, and the wealth of a department or laboratory used to influence the quantity of preprints it was able to send out, whereas its reputation influenced the quantity of incoming preprints. The ability to send and receive a high volume of preprints meant that a physicist was positioned within a core area of the discipline, such as an important laboratory or department. For example, the drawers of CERN's archive occupied a full hallway. A physicist's place in one of the core networks that cross the community--a position that is possibly more important than one's record of peer-reviewed publications--was thus crucially expressed by her ability to send and receive preprints. In fact, in a Gutenberg era, that is, before the emergence of digital media, the role of journals was already peripheral. Physicists did not read journals and rather relied on archives to exchange and retrieve information. Furthermore, formal peer review processes did not occupy a central place in the journal-based publishing system. Studies of the review systems of different physics journals in the 1920s revealed that consensus on formal peer review as the best practice was never reached (Clarke 2015). Peer review was an option at hand rather than a formalized requirement. Evaluation was clearly happening through strict rings of support and hierarchy. Personal relations with the most important figures in the field would ensure a speedy and smooth publication process.

Finally, physics gets old quite quickly. This epistemic characteristic means that a piece of work can be forgotten as fast as in a few months (Traweek 1988, p. 86): thus the need to rely on oral communication and to publish preprints in order to avoid the long gap between submission to a journal and publication, when an article might have already become less interesting. This has been transposed almost perfectly to the current system, where digital archives are a faster, centralized, more convenient and reliable way of exchanging papers. Since the 1970s, preprint exchange has moved to emails and online newsletter first, and

eventually to website-based repositories. ArXiv.org, born in 1991 as the aggregation of a number of previously existing online archives such as Babbage (hosted by SISSA in Trieste, Italy), represents the core publishing venue for particle physics. It is based at Cornell University and operated by a relatively small group of editors financed through grants. Since 1991, arXiv.org has grown to comprise a vast majority (99%) of particle physics' written output. It has also become the standard for the publication of research results in other sectors of physics, mathematics, computational biology and other disciplines.

As soon as a paper is thought to be ready to be made public, its authors submit it to arXiv. Physicists submit their preprints to the clearly separated and specific sub-section that reflects their disciplinary position, for example HEP-TH for theoretical high-energy physics and HEP-EX for experimental high-energy physics. The paper is then subjected to a fast review process that may only last for few hours. This includes institutional limitations, as the paper must be sent from a recognized institutional email account and a new author must be endorsed by a recognized user; automated textual analysis screens the content for plagiarism; and finally human moderation. Once published, articles are included in a daily digest that aggregates them in a strict chronological order. Only at a later time, in many cases a few weeks after its appearance on arXiv, the same paper is submitted to a journal to go through peer review, a process that can last several months. Physics journals seem to have a very high acceptance rate. According to recent estimates, 10,000 papers a year are published by particle physicists on the archive, and 5,000 formal publications appear in peer-reviewed journals. I will discuss this discrepancy later. Furthermore, each sub-discipline only has a handful of journals. For example, in theory (HEP-TH in the archive) the core journals seem to be *Physical Review Letters*, *Physical Review D*, *Journal of High Energy Physics*, and *Nuclear Physics B*. Physicists' papers rarely get rejected and are published roughly by the same few journals. It is unclear how useful journals are for recognition and credit attribution in high-energy physics. When the paper is accepted and published by the journal, often the authors replace the file existing on arXiv with the most updated version, especially if the manuscript has undergone substantial amendments or improvements. As a physicist put it, "diligent people will publish a final version on the archive." In some cases, authors even publish *post-print* versions of a paper, meaning that they update the final, accepted journal paper with a newer and better version: in such cases, the version available on the journal website becomes outdated.

Notwithstanding their genealogy and even the visual similarities with pre-digital era archives, the concept of remediation falls short of fully describing the transformation fostered by digitization and other processes that have changed physicists' publishing practices and assumed new cultural significance. Focusing on platforms for knowledge exchange, some scholars have been interrogating the concept of a moral economy in order to

understand which social norms underlie exchanges in open science models of scientific production. Digitization creates spaces of knowledge exchange and circulation that can be seen as either analogous (based on common cultural characteristics that make them similar to older media) or homologous (representing a direct evolution of previous technologies) of previous practices. Science historian Bruno Strasser (2011) has proposed that a moral economy of sharing specimens in natural history museums has shaped the foundation of GenBank as an open access database for sharing sequences. Similarly, Christopher Kelty has proposed that the emergence of open source synthetic biology mirrors older model organisms newsletters, which were exchanged by biologists in order to share knowledge about the common basic tools of research, such as *arabidopsis* or *drosophila* (2012).

Physics digital preprint archives can thus be seen as homologous to previous print-based archives managed by libraries before the rise of digital media. Included in this homology is the core characteristic that I highlight in this paper. Archives are made of flows and populated by things-in-motion rather than functioning as record-keeping devices: beams of papers flow through them and hopefully get detected. It is this circulation in different regimes of value in space and time (Appadurai 1988, Daston 2000) that needs to be followed in order to grasp their cultural and community-structuring significance. These flows exist in older scholarly media too: libraries send out newsletters informing about their latest acquisitions, and bookstores show new arrivals on a dedicated table; also, paper-based preprint archives used billboards to post the latest received articles. Yet two dimensions, one temporal and the other organizational, have modified the role of scholarly object circulation in particle physics. While I acknowledge that the archive is nothing but a transposition of older practices and technologies onto a new medium, I want to show that its organization of time and its contribution to negotiations about authorship claims have made it central to the community itself. First, the digitization of scholarly communication has contributed to an acceleration of time within the community. Some physicists now live in a state of digital immediacy in which the production, circulation and usage of scholarly communication is both accelerated and more central. Media technologies play of course an important role in the changing speed of community life (Tomlinson 2007, Virilio 2006) and can thus structure the actors tempos of work (Munn 1992). Second, the growth of transnational collaborations that operate particle accelerators and detectors and include hundreds, or even thousands, of physicists, has both slowed down time and created serious problems of authorship. Collaborations list articles' authors in alphabetic order, making individual physicists completely invisible (Galison 2003). The archive provides physicists with a space for claiming their role within the community through a redefinition of what the objects of scholarly communication are.

This work is based on archival research and semi-structured interviews conducted in 2015 with twenty high energy physicists in Italy and California. The sample includes physicist at every stage of their career: advanced PhD students and postdoctoral scholars, faculty members at various stages, as well as retired physicists. The research was aimed at understanding the history and daily use of a wide set of media, including arXiv and other preprint repositories and the *Journal of High Energy Physics*, one of the core publications in the field. In this paper I will focus on material linked to writing, publishing and reading habits in the two main sub-groups within particle physics: *theorists* write the equations used to predict and interpret what *experimentalists* find when they run their accelerators and detectors. Both groups use preprint archives as their main communication platforms, but have different writing, publishing, authoring and reading patterns, which in turn lead to different needs and strategies. While contra Traweek I intend to insist on the idea that written scholarly communication is at the core of practices of community building and functioning, I also believe that the everyday practices of high energy physicists challenge the assumption, so deeply entrenched in the contemporary neoliberal university, that journals are the only venue for both information circulation and academic credit.

3. Theorists: living in times of flow

In the course of their PhDs young theorists are socialized to the community's communication systems. First, they learn to rely on oral and face-to-face rather than written communication for the discussion of knowledge (Traweek 1988). At the same time though they learn to use the archive as readers first, and as authors later. In this process, they need to learn how to deal with and command three different temporal scales: the minute, the day, and the year. In fact, as part of the learning process that introduces physicists to the shape and dynamics of their community, students are trained on the functioning of the archive and gradually learn to look at it on a daily basis, as well as to become part of its flow as authors. Preprints submitted to and accepted by arXiv are published every weekday at 8 PM EST in order of submission and can amount to about one to three dozen a day. There are several tools that physicists use to tap into this daily flow. One can open the main website, arXiv.org, or use other technologies that provide the day's list of preprints every morning, such as RSS feed, an email alerting service and a smartphone app called "arXiv mobile." Not surprisingly, the latter is especially used by younger physicists such as advanced graduate students, who might use it to browse the daily flow of articles while on their way to school. These different interfaces allow physicists to browse through the list of the papers published day by day in the HEP-TH (High Energy Physics - Theory) subcategory. Students and postdoctoral fellows, who play a fundamental

transitional role in physics, must be ready to discuss who published what on that specific day, possibly at the department cafeteria during lunch break.

Physicists at more advanced stages of their career tend to be less rigorous in checking archives on a daily basis: they seem to become less obsessed with this flow of papers, at least as readers, and rather tend to use other archives to browse for useful papers and perhaps check someone's citation record if they are evaluating aspiring postdoc fellows or researchers in the screening steps before hiring a new colleague. As fast as it has become, the digital archive still seems to be slower than other communication practices like word of mouth, in a world in which "most people know most other people," as a theorist noted. If a physicist is centrally positioned within the community he or she will be able to rely on oral communication. Indeed, even though they rely on arXiv for the daily flow of preprints, physicists use a different archive for searching articles that they need to use in their work. inSPIRE [1] (an evolution of SPIRES, or Stanford Physics Information Retrieval System) is a website that provides an overlay to arXiv: it uses information contained on arXiv, such as the unique numeric identifier that is associated to each and every published article, in order to provide metadata. On inSPIRE, physicists can easily retrieve old articles as well as access data about citations, co-authorship, articles published in peer reviewed journals vis-a-vis preprints. Yet understanding how physicists interact with the daily flux on the main archive is crucial for grasping the digital immediacy of physics' scholarly communication system. This digital immediacy prevents physicists from analyzing the content of preprints that appear as parts of the flow on the archive. The sheer number of papers published every day (a few dozen for each major sub-discipline) makes it impossible to read the content unless one limits its attention to their specific field of study, such as supersymmetry or topological string theory, for example. In the daily flow of articles on arXiv reading is thus limited to the titles, the authors, in a few cases the abstracts, and much more rarely an entire article in case one downloads a copy for future reading. Checking the archive on a daily basis teaches what the subjects of the moment are, and being able to discuss the relevant ones proves one's belonging to the particle physics community.

If for readers the times of browsing the daily flow of preprints are so accelerated, becoming an author is a matter of timing too. Theorists need to keep a strict control over two further temporalities fostered by the archive: publishing frequency and instantaneous submission. Publishing frequency means that theoretical physicists need to make their name appear in the archive a certain suitable number of times per year. This frequency guarantees a visibility that is used to claim their role within the community: the archive does not only inform about the content of a research project, but also about one's productivity, as well as about who is working on what and collaborating with whom, thus making public the kinship relationships that are so crucial within the community (Traweek 1988). This is

especially true for advanced graduate students and postdoctoral scholars, who might identify a specific target frequency even though this is not related to the perceived quality of their work: “you need a certain number of papers a year to stay in the game. But how many papers you need to find a truth, that’s up to you,” a postdoc told me, adding that “five is a good number, but you can get away with four or even three papers if they’re really good.” While the content of their scholarly output might have been discussed at conferences and chalkboards within their department, they shoot their own papers in the beam in the hope that they will be detected by the community. After all, as another postdoc told me, “in theory, time is cheap:” it only take a few weeks or months to write up a theoretical paper with a handful of colleagues. Finally, whereas the majority of the preprints published on arXiv turn into papers published by peer reviewed journals, it is not completely clear how this transition is evaluated. In a quite small and cohesive sector as particle physics is, the publication process concerns a very limited number of journals that, with very few exceptions, struggle to differentiate from one another in terms of prestige. After its publication on the archive, theoretical physicists expect to receive comments from colleagues. In most cases this form of open peer review boils down to a small number of emails with requests for citations or minor comments. Yet it appears that the peer review process carried out by the journal that receives a manuscript is likely to be even shallower, and in fact the most prestigious journals tend to have a very low rejection rate. Indeed, physicists are much more excited and nervous about the appearance of one of their papers on the archive than about its submission to a peer reviewed journal. The journal publication, as a theorist put it, “is the dessert.” Also, negotiations around the appropriate journal to send an article to are minimal. Theorists only acknowledge the superior prestige of *Physical Review Letters*, a journal that publishes short papers of general interest, as substantially higher than other publications.

The last temporality has to do with the functioning of arXiv’s submission system. Papers are posted daily and, as stated on arXiv.org, they “will be entered in the listings in order of receipt on an impartial basis” [2]. Furthermore, physicists know that papers in the top or bottom tier of the day’s listing receive more hits and are more likely to be detected. Thus they need to pay attention to the archive’s daily deadline: submissions gathered every day before 4 PM EST are made publicly available on that evening and then appear in the RSS or mailing list the next morning. Submitting a paper at 4:01 PM indeed ensures that it will be amongst the first ones in the next group of articles. Physicists race to submit their most important papers at the right moment in order to meet the need for increased visibility, for example when they are submitting a crucial piece of work or an article emerging from an important collaboration. They wait for this internal deadline, “ready to push the button at the right moment,” in the hope that their work will benefit from additional visibility.

Theorists thus deal with three temporalities structured by the archive and learn to shoot their beams of papers accordingly. Digital immediacy is at play for the temporalities of reading and discussing, which revolve around a 24 hour scale, and submitting, where the very minute at which one submits a paper to arXiv.org may influence the number of people who detect it. Finally, a year-long scale is what shapes their publishing practices, based on assumptions about the appropriate publishing frequency. By hitting the archive at the right moment and frequency with their beams of papers, theorists claim their role within their peers.

4. Experimentalists: beams of unknown particles

Experimentalists who build and operate particle accelerators and detectors have little control over the timing of their publications, which is slowed down by the bureaucracy that manages publishing practices, or over individual authorship claims. They work in large-scale transnational collaborations that design, build, maintain and operate particle accelerators and detectors. These machines, such as the Large Hadron Collider (LHC) at CERN, are the largest scientific instruments ever built. Each article produced by the collaboration lists as authors all the hundreds or even thousands of researchers, PhD students, and even technicians that contribute to the building of a detector and operate it, for example the ALICE experiment at CERN (“A Large Ion Collider Experiment”), that analyzes quark–gluon plasma. Furthermore, in most collaborations names are listed in strict alphabetic order, irrespective of their actual contribution. At the same time the research, data collection, or analysis that lead to an article have been carried out by one specific group of physicists, whose names are diluted in the collaboration list and become absolutely invisible. This collectivist practice has been called “hyperauthorship” (Cronin 2001). An experimentalist might be listed as author in hundreds of publications, of which she has directly contributed to a handful, and has read only a minority. A second year postdoc from the ALICE collaboration that I interviewed told me he had “written two articles, published one hundred and thirteen,” and has already gotten to the point where he can not list his articles in his CV anymore. While other scholars have discussed the changes that this organizational form brings about in the definition of physicists as “epistemic subjects” (Birnholtz 2006, Knorr-Cetina 1999), here I am concerned with the role of scholarly communication, and of preprint archives in particular, for individual physicists as authors. Articles produced by the collaboration do not allow for the attribution of credit related to a physicist’s individual contribution to an experiment or measurement, yet single authors must find alternative strategies to communicate their direct contribution to a research project or what subjects they are personally working on.

Forms of credit attribution based on peer reviewed, or preprint, individual articles are excluded for two classes of reasons. First, the temporalities at play in high energy physics experiments exceed a single physicist's career, as experiments are conducted within multi-decade long temporal frameworks that are beyond the control of any individual physicist. "Experiments can take five years to complete, so experimentalists have to choose which problems they work on: five years is a significant fraction of one's lifetime," as noted by an experimentalist. Second, individual physicists affiliated with a collaboration do not have the authority to submit their articles for publication. Collective authorship is mediated by complex political and bureaucratic arrangements over the publishing process. Once physicists have collected data from an experiment they present their results in internal seminars. Once they have drafted a manuscript they must circulate it via internal mailing lists, present it in internal seminars, and then eventually submit it to an internal editorial committee. If the committee approves the manuscript, it will also be in charge of deciding where and when to submit. Usually, on arXiv and contextually to a journal. The final article will list as authors all members of the collaboration in alphabetical order. These processes are governed by internal rules that are based on forms of liberal democracy adapted to the regulation of matters of publishing and authorship. Often these rules are called "constitutions," such as in case of the ALICE experiment and its more than 1,300 members (ALICE 2014). Authorship rights are typically attributed based on a labor model: a physicist who joins the collaboration must work on its detector for six months or a year before gaining the right of being listed in each article produced by the collective, and maintains this right for the same amount of time after leaving. Furthermore, individual physicists do not sign or author a paper published by the collaboration, but rather "endorse" it.

According to Foucault, with modernity we came to accept scientific texts as the product of anonymity: the scientific author is diluted within the membership in a collective effort--science--while her individual name does not stand as the guarantee of truth. According to this view, in modern science the author function fades away as the credibility of claims about Nature is provided by the scientific method of knowledge production rather than by the person who makes them (1999, p. 213). Furthermore, STS scholars specifically working on particle physics have maintained that in this field the author function fades away even in relation to credit attribution (Biagioli 2003, Traweek 1988). Individual experimental physicists accumulate symbolic capital through face-to-face communication activities, for example at the chalkboard during internal seminars, where they literally show their peers they can "get the sums right." Conference presentations, internal memos, letters of recommendation, and gossip are crucial forms of communicating individual credit over a certain measurement or piece of equipment (Galison 2003). I argue that whereas traditional ways of constructing an author function are occupied by collectivist arrangements that

obscure individual contributions, physicists do not accept the dilution of the author function and struggle to produce and circulate claims related to their individual stance within the field. How is credit attributed then besides oral and informal communication?

Experimental physicists need to master a number of strategies for establishing their individual contributions to an experiment and role within the community. These physicists use what appear to be liminal but can actually be quite central objects within the archive. They shoot out beams of objects that exceed formal articles produced by the collaboration and are not destined for peer review, but that reinstate their individual identities as authors. These objects take the form of conference proceedings, technical reports, data, white papers, or presentations from conferences. This so-called “grey literature” (Banks 2006) accounts for part of the missing 5,000 objects that appear on the archive under the banner of high energy physics and are never published in peer-reviewed journals. It is through these objects that would be considered irrelevant in other disciplines that experimentalists publicly claim credit over their own measurement or over the piece of hardware they have personally built. For experimental physicists, the archive is the space that allows the detection of these objects within its daily flux.

As members of such a collectivist organization, experimental physicists also need to find ways of expressing dissent. A parallel could be drawn to signal similarities with the governance of free software communities (see for example Kelty 2008). But physicists are arguably quite different from software developers. Physicists also work in geographically dispersed collaborations organized through complex bureaucracies complete with subcommittees and working groups; each team or individual is in charge of modular contributions that are aggregated within a more complex product such as a detector; decisions on when to publish a new dataset or paper is bestowed upon editorial committees that supersede individual contributors. Yet crucially, physicists can not fork a project,[1] as the sheer materiality of a particle detector can not be replicated by anything smaller than a transnational, multi-billion dollar collaboration. Dissent is thus articulated through non-authorship. In the democratic model that underpins their constitutions, collaborations create space for expressing dissent in a number of different forms. Although originally developed in relation to consumer choices, a reference to Albert Hirschman’s theorization of exit, voice and loyalty might be of interest here (1970). Members of a collaboration can have their *voice* heard in internal meeting and boards and thus modify the trajectory of a piece of research they disagree with. They can show *loyalty* by abiding by the authoriality roles and endorse a colleague’s manuscript. Or they can temporarily *exit* the collaboration by withdrawing their endorsement and thus becoming non-authors of a particular article that is to be published on arXiv. This form of subtraction is rare, heavily moralized and in some cases explicitly discouraged, as it undermines the force of the argument made in a

publication as well as the consensus within the collaboration (Galison 2003). Non-authorship can also take the form of outspoken dissent, even though it does not mean that dissenting physicists will be expelled from the collaboration. It may also not be noticeable in the archive and often needs to be brought to light by more public forms of action.

Experimentalists thus need to master different objects and forms of dissent in order to publicly re-establish their role as members of the community. Grey literature becomes central as it can be detected in the archive as the product of individuals or small groups in which the author function is reinstated. It also allows physicists to overcome the slowed-down time of arXiv publishing by large-scale collaborations. Finally, non-authorship becomes crucial as a way of expressing dissent over collective choices without breaking the collaboration. By publishing grey literature on the archive, and at times by denying their participation in publications that they can not control, experimentalist use archives to reclaim their individuality.

5. Conclusions

Particle physics might still be based on an oral culture of face to face communication, as well as on kinship relationships that are only partially captured within its formal communication system. Yet the features which I have outlined force us to wonder whether preprint archives may have assumed a central role within the field as the spaces where belonging and credit are constructed and confirmed. In a culture where preprint archives are pervasive and dominant, practices to affirm one's recognition can vary greatly, but often seem to have to do with a continuous flow of papers that pass through the main preprint archive used by physicists, arXiv.org. This seems to be an ephemeral space whose main purpose is not the preservation of a record of scholarly publications. I use a metaphor borrowed from particle physics itself when I argue that the archive is a *detector* that physicists need to hit with their beams of papers at the right time and with the right objects in order to signal their existence and claim credit for what they have done.

The role of preprint archives is also highlighted by the existence of viXra.org, arXiv's evil twin. This dissenting and independent archive, that mimics the appearance and functioning of the original one, is aimed at overcoming the forms of policing that keep undesired papers outside of arXiv. ViXra claims to be "*truly* open" and to serve "the *whole* scientific community." In fact, the review processes enforced by arXiv are seen as failing to meet the standards of openness preprint archives are supposed to live up to. This clash reinforces the idea that archives are the sites where traditional efforts to negotiate and define the boundaries of science ("the community") are situated in particle physics.

This leads to a number of further questions. First, as many open access advocates think that high energy physics is a good model for the scholarly communication system of the future, what would it mean for other disciplines or scholarly subcultures to embrace preprint archives as their core communication infrastructure? How are the tempos and authorship practices of social science or biology shaped by the adoption of archives such as academia.edu or biorXiv, with their constraints and affordances, as hegemonic venues for scholarly communication? Second, the growth of massive collaborative research in other disciplines, for example in “omic” sciences such as genomics or proteomics, will push other scientists to figure out ways of claiming individual authorship over snippets of their collaboration’s output. The role that archives will assume in these fields will depend on the different disciplinary cultures, local and epistemic, as well as different social and institutional arrangements at play. Finally, how is scientific dissent expressed through non-authorship? Democratic theory suggests that forms of collective authorship may sanction and at the same time foster forms of withdrawal and non-participation, and an exploration of the significance of these practices might be overdue (Casemajor et al. 2015). Studying particle physics might change the way we think about the role of archives in science, as well as transform the meaning of concepts such as publication, author, or access.

NOTES

[1] <http://inspirehep.net>

[2] <http://arxiv.org/help/general>

[3] In software development, forking is a process in which some developers take a piece of software or package and start to develop it independent of the original product or community. This gives birth to a distinct piece of software. One example is Linux Mint, an operating system forked from Ubuntu, which in turn derives from Debian. The right to fork a product is explicitly allowed by free software licenses such as GPL, or General Public License.

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