CULTURAL ANTHROPOLOGY

ETHNOGRAPHY AND THEORY OF THE SIGNATURE IN PHYSICS

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> The Lord whose oracle is at Delphi neither reveals nor conceals, simply announces by a sign.
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> —Heraclitus

Ending a decades-long search for the elusive Higgs particle, physicists at the Conseil Européen pour la Recherche Nucléaire, or CERN, in Switzerland, announced the news of its historic discovery on July 4, 2012. After analyzing trillions of proton-to-proton collisions in experiments conducted at CERN's Large Hadron Collider (LHC), the world's most powerful particle accelerator, two independent teams of physicists confirmed spotting the Higgs, a particle postulated back in 1964 as a possible explanation for one of the most fundamental questions in physics: What is the origin of mass, or matter, in the universe? This extraordinary confirmation demonstrates the prerequisite and ultimate measure of a physical science in the inescapable givenness of things. As César Gómez, a string theorist and one of my more reflexive informants, once remarked, "physicists are Platonist only in credo. In actuality, they hold an absolute trust in the reality of things."[1] Under what conditions does an experiment disclose the reality of things?

I examine this question by way of the commonly used term *signature* in experimental physics. Characteristic patterns of decay formed by particles subsequent to collisions, such as a Higgs boson decaying into two energetic photons,

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are termed signatures and constitute the chief unit of discovery in particle physics. This is a preliminary definition whose detailed exposition I will take up later. For now my concern is to introduce the notion of a signature and how it anchors the indisputable reality of things in science. But to begin with, is it not a little paradoxical to approach things through signs, or the material through the mental? In positivistic thought, nothing is more radical than the opposition of things to signs. Things are concrete, exemplified by a materiality—or to use Hegel's expression, immediacy—whereas signs are pure values, arbitrarily generated and differentially interpreted (Cassirer 1957).

The paradox of the physics signature is that it is at once a thing and a sign, or a fact and a value. The LHC sees roughly 600 million proton-to-proton collisions per second. But the bare fact of a collision tells us nothing because it means nothing. It is the attribution of meaning—as a signal—to the fact of a collision that makes it decisive. Here meaning is not an outward garb subsequently added to a bare fact. Rather, in the very identification of a collision (fact) there lies suppressed an evaluation that inflects it with purpose and significance (value). To regard a pair of photons as a conclusive signal of a Higgs particle, or high-energy muons as a signature for dark matter, constitutes a mode of recognition involving two elements—thing and sign—that are so completely taken up into each other that although they can be identified as different in reflection, they participate intrinsically together. Not like anything that science can describe, the signature of physics revels both in being itself (thing) and something other than itself (sign), and this bipolar orientation shifts modern metaphysics into a completely new light.

Underlying the investigation is an attempt to raise the signature from the interstices of the dichotomy of thing and sign to an existence as an autonomous and subversive element in a semiotic triad. At a time when we are revisiting perplexing questions and envisioning new elements of a postconstructivist anthropology (Kirksey and Helmreich 2010), we may confidently give form to a nondualistic mode of inquiry that regards the universe not from the standpoint of things or signs but from that of relations. Subordinate to no other aim save mediation, the postulate of relations expresses a powerful intellectual orientation. As numerous contemporary works attest, the overwhelming need to find relations between humans and nonhumans has led to the creation of novel non-dichotomous concepts such as cyborgs, hybrids, or assemblages in rethinking much of the work accomplished in the natural sciences (Haraway 1991; Latour 1993; Rabinow 2003). In the dispensation of emerging new sciences, the inquiries are distinguished for dispelling the illusion of pure categories like the biological, the social, the material, and so forth (Franklin 2003). Varied in their focus, these approaches hold in common an emphasis on the emergence of objects, on how these take on fluid avatars and enter new configurations (Fischer 2003).

The path here takes me slightly away from these recent developments. For in this rapid survey, I should like to point out one force that decisively governs the trajectory of relations. The links connecting heterogeneous objects, events, or practices are principally observed to follow a logic of instrumentality and contingency. Paul Rabinow and Gaymon Bennett (2012, 7) note, "The dominant mode of rationality and purpose guiding the life sciences today is instrumental." Moving away from "the imaginary desire of historical narration for coherence, integrity, totality, and closure, . . . we are currently witnessing a lively debate concerning the contingent, contaminated, local and situated making of science" (Rheinberger 1997, 140). Donna Haraway (1997, 113) has suggested that the commitment "after the implosions of technoscience requires immersion in the work of materializing new tropes in an always contingent practice of grounding or worlding."

A critical evaluation of contemporary technoscience, however, remains incomplete if we grasp the element of correspondence of nature and culture, or human and nonhuman, only in contingent practices or instrumental action. It remains one-sided because the strength of the relation derives not from within, but must be sought from the outside—the context—of motivations, which makes it provisional or partial (Strathern 1991). The problem most intriguing to me are the questions found in Émile Durkheim's (1965) framework, namely, (1) how *concepts* are forms of symbolic classification, and (2) what gives them their *necessary* or compulsory character. Durkheim clarifies that the importance of conceptual associations is "not to facilitate action, but to advance understanding. . . . The Australian does not divide the universe between the totems of his tribe with a view to regulating his conduct or even to justify his practice, it is because, the idea of the totem being cardinal for him, he is under a necessity to place everything that he knows in relation to it" (Durkheim and Mauss 1963, 81–82).

The evaluation of the physics signature is a foil for considering in a comprehensive way Durkheim's insistence on concepts as instruments of knowledge that reveal necessary interconnections of mind and nature. Based on two and a half years of fieldwork at the LHC particle accelerator complex at CERN and building off a rich ethnographic data set comprising close interactions with more than a hundred physicists and engineers, the present essay probes the indissoluble coalescence of fact and value in the notion of the physics signature. This unity will be approached first in the material culture of the laboratory to elaborate key elements of instrumentation in relation to the production of signatures. The second section, with its emphasis on interpretation and analysis, will outline how signs provide a way of determining the factual in experimental physics. The chief contribution of the following section is to make explicit the kinds of reasoning and negotiations through which the form of a signature manifests. At this juncture I arrive at the core of what I seek to inquire: dissecting the internal unity of the signature from the point of view of its adequacy or efficacy and examining the relevance of formal theories by Ferdinand de Saussure or Charles S. Peirce in considering "natural signs." The essay ends with an appeal to the realm of relations, which serves to distinguish the activity of meaning and form—as much as mass or momentum—intrinsic to physics, as well as the more provocative problem of how necessary consequences follow from contextual signs.

My ethnographic attention dovetails with Rabinow's (2003) "concept-centered" approach. The physics community routinely uses the term *signature* to identify events of importance, such as the recent discovery of the Higgs particle. Still lacking, however, is an analytical discussion of what the general concept entails. The demand for such a discussion involving a leading physical science becomes especially alluring when we learn that "the concept of signature disappears from Western science with the advent of the Enlightenment" (Agamben 2009, 68). Re-emerging in the most exact of all post-Enlightenment sciences, this remarkable concept provides, as I aim to show, the means and material by which an experimental science gives expression to the secrets of the physical world, where it shows a universal splendor and simultaneously exhibits a concrete and fastidious logic when its source is disclosed in human thought. To get to both these aspects, the material culture of the laboratory forms the indispensable starting point for our discussion.

MATERIAL CULTURE OF THE LABORATORY

Amid much fanfare and publicity, the first beam of protons went into circulation in the Large Hadron Collider on September 10, 2008, at 10:28 a.m. It was a singular beam sent at injection energy of 450 Gigaelectron Volt (GeV), steered around the full twenty-seven kilometers of the accelerator. Although there were no collisions at the time, the event of the first beam generated considerable excitement at CERN. Crowds of physicists stood glued to the monitors watching the first operational LHC beam go around the accelerator. A little later, at lunch, I ran into Michael Doser, an antimatter experimentalist and then deputy director of the CERN Physics Division. He asked me rather sarcastically, "So how does the first step in the social construction of the Higgs appear?"

Doser's provocative comment meant to indicate the spuriousness of the claim of the social construction of nature when faced with its tangible materiality. Like most particle physicists, he was aware of Andrew Pickering's (1984) book, or certainly of its title, *Constructing Quarks*. Doser's remark that theories of physics, which may well be social constructions, are materially constraining (and Pickering's work hardly ignores materiality or experimental reality) serves as a reminder of the tension between the physical and the human sciences that continues to exert an uneasy pressure (Weinberg 2001). The tension becomes clear when we examine how the physical component, like that of beams or collisions, is connected to the human element, of computations or calculations, say, and how the two simultaneously remain distinct.

In the physical register, the instrument looms large. Built at a staggering cost of 3.5 billion Swiss francs, spread over fifteen years, the LHC is the highest-energy particle accelerator in the world. At a record energy of 14 trillion electron volts, two counter-rotating proton beams are made to collide head-on with each other every twenty-five nanoseconds (ns). At four specified points of collision, detectors record the "data," or the product ensuing from the collisions. The site of each detector forms a distinct experiment pursuing specific physics goals. The two large experiments, based on general-purpose detectors, are ATLAS and CMS, designed to investigate the widest range of physics discoveries, whereas LHCb and ALICE are specialized experiments that delve closely into the areas of flavor physics and heavy ions, respectively.

On the human side reside two elements of utmost importance: trigger and analysis. To obtain maximally "interesting" or atypical physics interactions, special parameters are used to make a selection. This selection is called a "trigger," which assorts events with a bias, for example, a muon trigger would select events from collisions containing muons. This element of selection is vitally important because most of the particle interactions are considered "junk," since physicists have viewed these millions of times in previous experiments. Here they are focusing on atypical ones produced in the LHC, since it is geared to unprecedentedly high levels of energy and luminosity. After the selection of data, or the trigger, the complex electronics of readout channels integrate millions of segmented data into a coherent description called an "event" and transmit the data to the computing grid for physicists across the globe to process and analyze. Analysis, then, con-

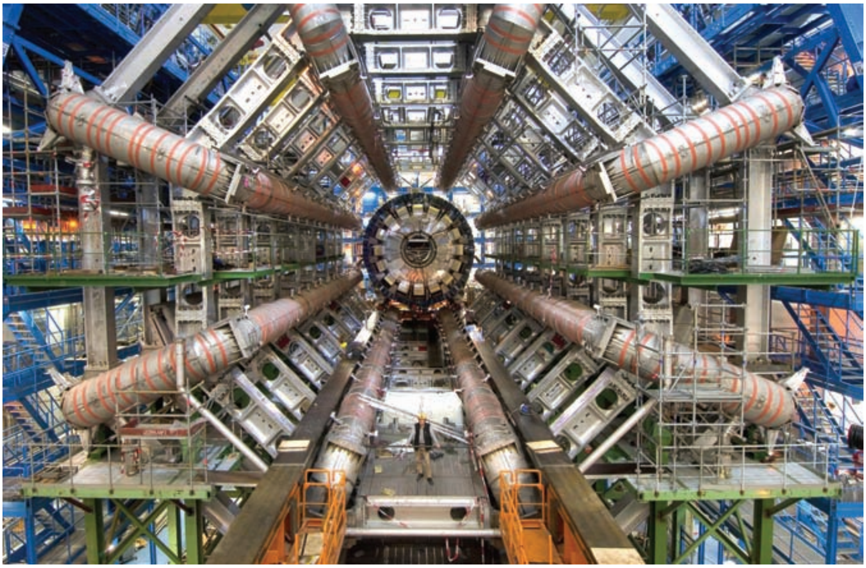

Figure 1. ATLAS is the largest-volume particle detector in the world, weighing over seven-thousand tons. (Image by Maximilien Brice, CERN)

stitutes the final stage of the combination and reconstruction of key events, and one where the prospects of a discovery become distinctly conspicuous. It is not surprising to learn, therefore, that the analysis of data, or physics analysis, forms the most distinguished stage in experimental physics.

I started fieldwork at CERN in August 2007 in standard participant-observer mode in the ATLAS Control Room, tagging the T/DAQ (Trigger and Data Acquisition) Group headed by Livio Mapelli and later by David Francis. Within a few months, well-meaning informants impressed on me that trigger and data acquisition was simply a preparatory stage. The "real action" would begin, they said, after the data started emerging and people who did analysis would be at the forefront of the game, which is where I should be if I wanted my research to capture the front-line excitement. After some deliberation, I followed their advice and shifted my attention from trigger and data acquisition to event reconstruction and analysis. It was during the time spent with teams in physics analysis in the ATLAS experiment that I first encountered the term *signatures*, which suggested a unique intellectual orientation in the world of matter. Before I explicate this uniqueness, a feature of instrumentation claims our attention.

To maximize the probability of collisions, the countercirculating LHC proton beams are divided into so-called bunches. Each bunch contains 1.1x1011 protons, and there are in all 2,808 bunches per beam. Every twenty-five nanoseconds, the proton bunches cross, resulting in about 600 million collisions per second. An undeniable materiality or facticity clearly underlies experimental physics. But the assumption so often set forth by naive realism as self-evident—that materiality explains itself—is an exaggeration (Cassirer 1957). In the consideration of every single material fact lies concealed a prerequisite for its existence. This prerequisite is the gradation of purpose or significance. How is beam dynamics affected by collimation or why is the superconducting magnet placed in front of the electromagnetic calorimeter? The characterization of purpose and significance built into such questions indicates that a perspective has been imposed on matters of fact. In mentioning this, I am trying to highlight the intellectual character of physics.

But do bear in mind that gradation of purpose or relevance is merely a conditioning mechanism. That is, in the functioning of technology, facticity and significance come together—or go apart—in accordance with exigency. Let me clarify: I am not arguing that operations involving beams and collisions do not require engineering skill or administrative decisions, factors that clearly suggest human intervention. For sure, an engineer is needed to turn on the beams or to design the beam pipe. But when the beam is running, no reference to a human observer is needed. That is, once a technology is instituted, it *functions* independently of the scientist or the engineer, whose presence becomes extraneous and is required simply for maintenance, safety, and repairs.

On the other hand, in the case of a signature, fact and significance are intrinsically bound together as a *unity at all stages and modes of operation*. The relation to the human subject cannot be eliminated at any stage without losing the whole concept. What Peirce said for signs—they "address somebody"—holds true of the physics signature. The signal is real, and this is absolutely crucial, not because it is materially present in a collision. No, it is real because the physicist recognizes or receives it. The signature of physics compels our attention to the human subject. And as the element of human recognition gains in strength, it does not abolish the relevance of the material, but rather makes use of it to forge a unity. This coalescence of the human and the material and its anchoring in the conception of a signature is what I lay out in the next section.

HIGGS → γγ SIGNATURE

It is easier to illustrate what a signature is in experimental physics than to define it. Consider a statement: "A two-body mass peak in the region of hundred

GeV and above is the most robust signature one can hope for" (Mangano 2008, 3). The application of this statement finds its most conspicuous expression in the decay of a Higgs boson into two photons (γγ) of definite mass. As an analogy, let me ask the reader to imagine a ball, whose material composition is not known a priori, getting hit and subsequently smashing to pieces. Now *if* the ball were made of crystal glass weighing, say, a hundred pounds, then according to the principle of the conservation of mass or momentum, we should expect to find in the debris two conspicuous glass pieces of roughly fifty pounds each. Once we detect these two distinct pieces in the debris, we deduce that the original object in the collision was most likely a crystal object with a mass of more than one hundred pounds. Likewise, a particle collision, if it succeeds in producing a Higgs boson in a certain mass range, say, between 100 and 120 GeV, would most likely decay into two energetic photons of roughly 50 or 60 GeV each, owing to the principle of the conservation of mass.

The analogy is useful but must not be pressed to an extreme. For in relativistic quantum physics, decays are processes in which particles (such as a Higgs particle) *spontaneously transform* into other particles (like two photons), instead of decomposing or dissolving into constituent particles. New particles are really produced under the effect of field interactions based on the principle of the conversion of energy into mass ($E = mc^2$). That is, when fast-moving or energetic particles collide with each other, some of their energy is converted into the creation of completely new particles. Yet due to the relatively short-range quantum nature of interactions, physicists cannot directly observe the new particles. Instead, their evidence has to be sought in the decay products, and the term *signature* is used to characterize the decay products by which physicists identify the source particles. This should make clear how the beginning of a signature lies in the reverse deduction through which physicists draw inferences about unknown particle states from observed final states.

The task of deduction that a signature demands, however, is not an easy one. It is not easy simply because the signature has to be extracted from the background. *Background* refers to identical and competing processes that often fake a signal process. A potential source of background, as in this particular illustration of the Higgs decaying into two photons, are photons produced by bremsstrahlung, or electromagnetic radiation given off by accelerated particles. The photons from bremsstrahlung form the "irreducible background" and create a massive problem for physicists (ATLAS 1994, 217). The problem is to figure out, on a statistical basis, which photons are emerging as a consequence of bremsstrahlung, the irreducible background, and which ones are decaying from a possible Higgs source, the signal.

While speaking to the convener of the Higgs search on the ATLAS experiment, Andreas Hoecker, I asked him how he deals with the high photon background in the analysis of the Higgs signature. He replied rather nonchalantly that he did not believe in the concept of an irreducible background. Hoecker is a highly regarded figure in physics analysis, but soon I heard a few friendly murmurs of criticism in the community of his approach to background. If he does not believe in the background, how can he discern a signal? Skeptics were quick to point out that on a hadron collider especially, an experimentalist must have a complete understanding of the irreducible background to obtain a relevant signal, because hadrons are composite particles. Collisions involving hadrons are therefore rather messy, generating a lot of debris, that is, background.

I went back to Hoecker and posed to him the same concern on the extraction of a Higgs signal from the heap of photons, the background, generated in the LHC. He confidently replied that he was aware of the "conservative view in the community," but argued that while statistically plotting the decays, if a clear peak starts emerging from the "invariant masses of the energetic photons," it forms the "signal that these are from a Higgs." On the other hand, the photons from bremsstrahlung with differing masses, the irreducible background, would be all over the graph, falling in the "tail regions" of a quintessential Gaussian distribution. The peak formed by the invariant masses of the two isolated photons in the final state against the overall shape of the distribution would give Hoecker and his team a clear signature of the Higgs boson.

I confess that I listened to Hoecker's explanation attentively but that it took me almost a year to understand, and not without the aid of other physicists at CERN. In fact, listening to his and others' expositions on the way they extract signals from collision data—as they filled my field notebooks with rough, sketchy histograms and plots—I was struck by how materiality turns away from itself while seeking itself. The task of probing matter is foisted on a vast semiotic terrain that involves recognizing signals, tracing them to initial conditions, measuring background, and so on. It follows that the case of a material discovery, like that of a Higgs particle, can be settled only after isolating the photons emerging from random bremsstrahlung (the background) against those issuing from a genuine Higgs particle (the signal). This, however, is an act of discrimination or judgment, which presupposes a subject, or more appropriately, a community of subjects.

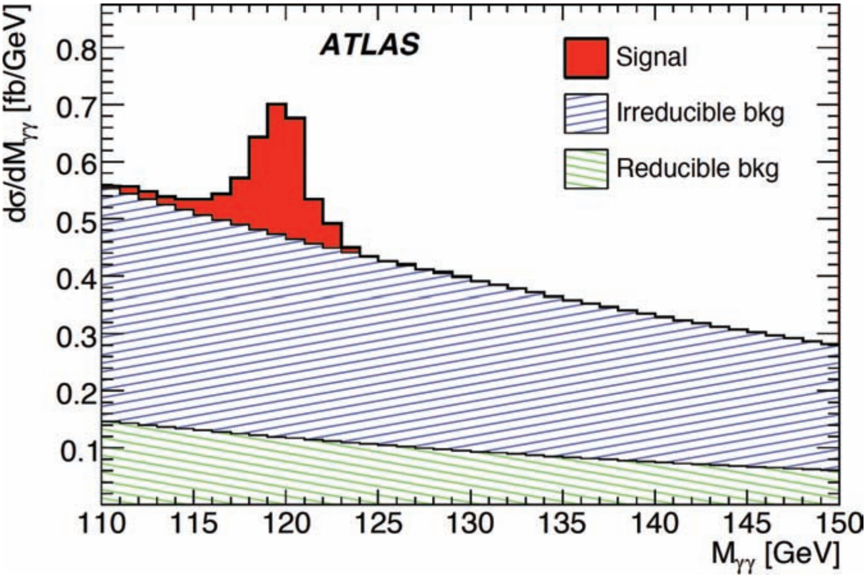

Figure 2. Signal of a possible Higgs boson obtained from di-photon invariant mass spectrum. (Image from "Higgs Boson," CERN, 2008. Figure 8, page 1228. Available at http://cds.cern.ch/record/1159618/)

Without the recognition of a scientist immanent to it, nothing answers to the notion of a signature.

Here we face a decisive turning point in the appraisal of modern science. The signature of physics presents us with an unmistakable case of non-dualism between human and nonhuman, and it places before us a new angle of inquiry into science. As is well known, several studies have called our attention to the entanglement of material-semiotic intermediaries in experimentation, emergent "inter-actions" of nature and culture, or the use of analogies and metaphors in the sciences (Barad 2006; Galison 1997; Knorr-Cetina 1999). In my view, this distinguished catalogue of studies manifests, however, a lacuna in that exigency or contingency is seen as providing the impetus to the play of associations and the meaning of science is divined in the extrinsic rhapsody of assemblages and fractures, which are themselves understood in an unending logic of means and ends (Haraway 1997; Rabinow 2003; Strathern 1991).

As it stands, this account is inadequate. To criticize science from the standpoint of contingency or exigency alone is to leave it half unread, because there remains the possibility of "necessary relations" (Durkheim 1965, 41) obtaining between concept and object in the interpretation of nature. This question of necessary relations or the conditions under which science creates "its special universe of efficacious principles" (Douglas 1999, 252) has received little clarification. This is where I wish to advance current understanding. I argue here that the signature of physics betrays a *necessary* unity of conception. The relation of sign and thing is not extraneously forged through metaphors or analogies. A heterogeneous mix of elements is not lumped together under the rubric of a signature. Operating by means of conceptual interrelations (ATLAS 1994; Mangano 2008), the signature synthesizes individual features under a form, a form held together with a perspective. As outlined above, without the perspective that recognizes in tracks of photons a signature of a Higgs boson, we cannot grasp how a collision provides the starting point of a new order of things in the precise moment of its decay. This perspectivization of nature, which the signature embodies, closes the gap of fact and value in a single stroke.

Here we confront the full significance of my insistence on the signature exemplifying a unity as opposed to an assemblage or a hybrid. Haraway frequently tells us that science is given to divergent influences, partial viewpoints, and fragmentary connections that have no necessary or essential relation to the world. The ground of its activity is purely exigent or external. The signature repudiates this approach. Instead of confusing diverse realms, it introduces distinctness into a confused obscurity. Instead of soliciting connections in the flux of material activity, it favors the concomitance that subtends and awakens human interest, which comes not by dint of (external) activity, but by (inner) judgment and form. To ask if events are bound by connections is a concern of mechanism (Descartes or Locke), while our interest is in the principle (Leibniz or Kant). The signature forms the inner reason by virtue of which a discovery is what it is, thus affording an opportunity to grasp the source of scientific activity. The value of such an instructive opportunity reposes not only on the inner structure of a signature but also on the community and its thought, as well as on the wider experimental tradition, which I shall now take up for elaboration.

DIFFERENTIATION AND SINGULARITY

The chief difficulty in the way of recognizing a signal event, as previously stated, is the background. The difficulty consists in how to isolate and evaluate the strength, or significance, of a signal for which no strict rule exists. There is no foolproof method "that works under all circumstances that can be picked out from a textbook," as Malcolm John, from the LHCb experiment, explained. "It is mostly a judgment call" on what procedures to follow for what data set. The judgment, which establishes this significance, is not a sum or an aggregate of particular instances, but a form of thought at once logical and mathematical, which works in a kind of a double movement: a movement from confused data to a suggested meaning and from the meaning back to observational facts to which the suggestion had originally directed attention. This movement explains why problems at any level—be they hardware issues of alignment or calibration, or software concerns of timing, trigger, or analysis—can seriously affect the assessment of a signature.

The physics community considers the observation of a signature valid if a statistical significance of "5-σ standard deviations" can be obtained. The 5-σ level is simply another way of saying that a model or a theory has a 0.00003 percent chance of being false. Claims and counterclaims establishing a 5-σ discovery level are rampant as these are debated or dissolved in talks and publications. At seminars and conferences, I heard over and over again questions like: "How well have you estimated the errors from systematics?" "Are you basing your evidence solely against Monte Carlo simulations?" "To what degree can you distinguish a Standard Model Higgs from look-alikes?" In addition to background, informants explained, they have to take care against the so-called noise generated by electronics such as the amplification of small electrical signals, against statistical errors from limited event samples, detector effects like limited acceptance and the resolution of measurements, and so on. While there operates a clear chain of tasks, specification of procedures, and recognition of skills, the ultimate extraction of a signature makes for a delicate and drawn-out process, much like finding a needle in a haystack.

A lot can be written to describe in detail the methods and procedures employed by experimental physicists in extracting signatures from the bulk of the background (Collins 2004; Galison 1997; Knorr-Cetina 1999). My aim here is more ascetic: to inquire into the *conditions* under which the significance (of a signature) is gauged. Jacques Derrida (1982) identifies a tension at the heart of the general concept of signature—how to reconcile difference with repetition. In his essay "Signature Event Context," Derrida looks at signatures in the everyday context and ascribes "iterability" as their primary specification. He writes, "In order to function, that is, in order to be legible, a signature must have a repeatable, iterable, imitable form, it must be able to detach itself from the present and singular intention of its production" (Derrida 1982, 328). But equally the signature is a singularity, the bearer of a unique identity, which Derrida recognizes but fails

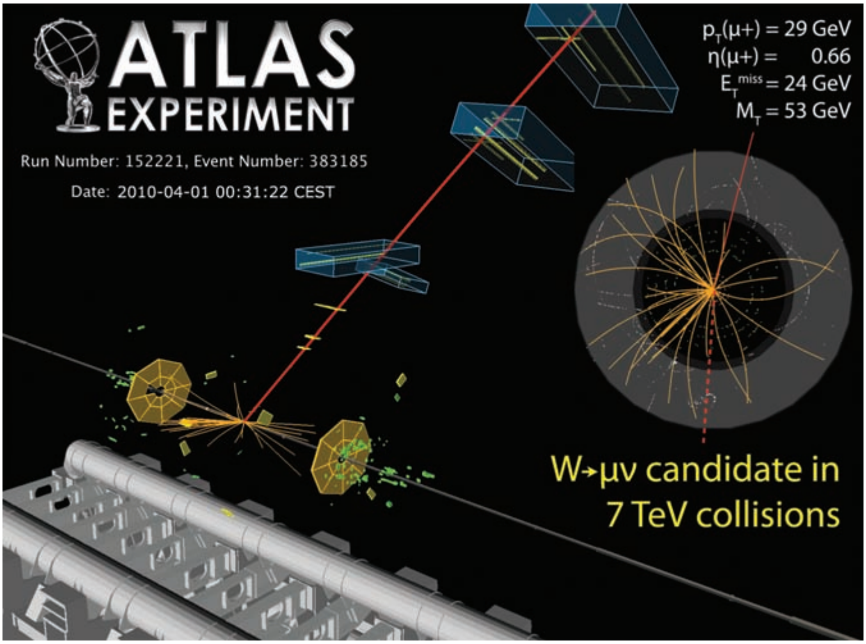

Figure 3. The extraction of a W-boson signature from the decay of two leptons in proton-proton collisions. (Image by CERN, from the *ATLAS Experiment Blog*, http://pdg3.lbl.gov/atlasblog/)

to elaborate on. I wish to pursue this. What is the locus of the signature's singularity?

In the case of the physics signature, to be sure, unless a signal is repeated enough times, it would be difficult to make recognition of it. It is never, properly speaking, one signal or one event that experimentalists invoke. It is the peak around which a cluster of events coheres that gives meaning to a signature in physics. So prominent is this requirement of basing evidence on a collection of cases that statistical inference is treated as one of the yardsticks of experimental confirmation (Galison 1997; Mangano 2008). But while it is true, as Derrida asserts, that without the support of iterability or repeatability a signature would be less credible, recurrence is not a *condition* for its occurrence.

This plain assertion means to put before us the recognition that characterization of singularity arises from differentiation (Saussure 1983, Uberoi 2002). Every experimental physicist attests to the merit of the statistical repeatability of signatures, or the need for counting and collecting like cases. But what they do not utter in words but which constitutes, or consumes, the whole of their professional existence is evincing the signal from its contrast, the background. No-where does the meaning of the factual emerge with as much clarity as in the distinction of signal and background. To return to the example of the Higgs outlined in the previous section, repetition by itself does not explain which ones amid the bulk of photons form the signal of a Higgs particle. How a material fact gains truth value adheres not in the aggregation of events but in their differentiation. As opposed to Derrida's emphasis, I argue that it is not sameness as much as differentiation that explains the singularity and versatility of a signature.

The signature is an exemplification of an indissociable unity whose meaning derives from differentiation: these are the two elements that I have shown so far to be fundamental to the constitution of the signature. Now arises the question: How does the signature come to indicate definite material states of affairs? Here it would be rewarding to consider the input of semiotics (Peirce 1982–2009; Todorov 1982), especially because they proffer the additional advantage of us no longer needing to inquire separately into decay modes, trigger criteria, or statistical significance. Instead, we may focus on the concept of the signal and its probatory force to ascertain if science can be assimilated to a general problematics of the sign, or semiotics.

THE CLASSIFICATION OF SIGNS

In considering the signature semiotically, there are at least three elements involved, which we must examine closely. First, in experimental physics, signs come in the form of things. This feature, of things functioning as signs, explains the specificity of physics as a privileged discourse of matter as well as the tremendous task of experimental physicists in probing the structure of matter. Second, the signature of physics constitutes a relation among three terms: observed events, matter fields, and possible objects. The observed events are the closest to the receiving subject (i.e., the physicist), and their relevance lies in what they make accessible, either particular aspects or suggested meanings, of possible objects. The matter fields play the mediating role in the generation of possible objects from observed events. Third, in this semiotic chain something present leads to some kind of conclusion about the existence of things not immediately given. For instance, final states of hadronically decaying tau leptons in proton-to-proton collisions may indicate the presence of supersymmetry (SUSY). The sign, that is, the final states of tau decay, provide some information on a reality not yet known, like that of SUSY masses.

This complex chain of signification with which experimental physics confronts us can be grasped more comprehensively when we relate it to a basic question: How is it that signs reveal the character of objects? The question has utmost importance in theories of semiotics. In Peirce's (1982–2009) classification, for instance, we find that the relation between signs and objects may be (1) iconic (based on resemblance), such as portraits; (2) indexical (based on contiguity and context), such as weathercocks; or (3) symbolic (based on convention) such as human language. Saussure's (1983) schema, which is dominated by the category of the linguistic sign, lends emphasis to arbitrariness, or conventions, as the principal feature of signs. As is well known, the chief danger in making arbitrary the link joining the signifier and the signified is the exclusion of the referential object from consideration (Benveniste 1971).

More recent efforts by Umberto Eco (1984), Giovanni Manetti (1993), and Tzvetan Todorov (1982) have also brought the arbitrariness of Saussure to grief. Building on classical sources, most notably, Stoic logic, the authors have put forward a conception of sign that relates to its designata not as an equivalence, in the sense that P is identical with Q, or $P \cong Q$, but as an implication, such as if P, then Q, or $P \supset Q$. The move is highly felicitous because the relation of inference or implication (e.g., "if there is a scar, there must have been a wound") works well for the class of natural signs such as indices and symptoms. Yet in some sense we are left with two modes, of equivalence and implication, operating at different levels, and either could be accepted without the other. In their one-sided emphasis, a fundamental problem makes an appearance: a dualism begins to appear between signs considered *natural and necessary*, the reason of signification being contained in their very notion, and signs that are *cultural and arbitrary*, deriving their meaning from social conventions. The dualism of natural impulse and cultural intent, or *phusei* and *thesei*, appears in a number of approaches, including classical sources such as Saint Augustine's or early modern works like Port Royal grammar (Foucault 1970; Todorov 1982).

The chief objections raised against mutually exclusive accounts of sign behavior are that the grounds of division are insufficient or that overlapping criteria are employed, with the consequence that as many typologies as signs arise (Nöth 1990; Sebeok 1976), all of which lead Eco (1976, 217) to rue that "there is a radical fallacy in the project of drawing up a typology of signs." Although these objections are undoubtedly correct in raising our awareness to the complexity of sign behavior and the need for multidimensional typologies, a seductive alternative might be to accept and go beneath the apparent simplicity of the dualism to communicate something concerning the possibility of transcending it. This is what the signature of physics achieves. The signs that disclose the structure of matter are necessary to the extent that there is a prior intrinsic connection between signifier and signified, but they simultaneously require a language for the interpretation of this connection. In this twofold aspect, of the sign as an instance and as an image of material generation, lies the key to understanding how signatures form the thread through which the composition of matter is glimpsed and on which the very possibility of an experimental science depends.

To appreciate this rare semiotic possibility where a sign shares a likeness to a thing and also coincides with it, let us revisit the so-called doctrine of signatures espoused with great rigor by the Paracelsians in the sixteenth century. With an ingenious eye for noncausal explanations, in the treatise "Concerning the Signature of Natural Things," Paracelsus (1967) offers a theory of dynamically related occult sympathies, or signatures, cascading through nature, from worms and plants to minerals and stars, which god has imprinted for man to intercept for his own benefit. Every signature forms an (1) outward vehicle for inner forces and faculties; (2) makes visible what is otherwise invisible and obscure; (3) depends "not only upon the principles of similarity, homogeneity, resemblance, correspondence and sympathy, but also equally upon the contrary principles of difference, separateness, heterogeneity and antipathy" (Uberoi 2002, 14); and (4) "ultimately coincides with the created thing itself, insofar as it is understood as part of the divine plan and purpose of creation" (Weeks 1997, 170).

This vitalistic conception of *signatura rerum*, or of all things bearing signatures that orient them to meaningfulness and efficacy, acquires prominence in the works of later Rhineland thinkers like Valentin Weigel and Jakob Böhme. However, the metaphysics of signatures gradually breaks loose from nature to involve itself exclusively with mystical relations between man and god, which achieves impeccable clarity in the Tridentine dogma of the Eucharist where the flesh and blood of Jesus are held to be "truly, really, and substantially" present under the appearances of bread and wine. While there exist diverse contentions over the issue of the "real presence" of Christ (Agamben 2009; Uberoi 2002), what we attain is the radical ontological possibility of a signature as something that is both itself (thing) and something other than itself (sign). This short summary of the signature's role in alchemy, cosmology, and theology intends to remind us of both its antiquity and continuity. Yet if the signature of physics deserves our attention today, it is not for being mystical, but for once again being the semiotic framework that makes nature expressive and experiment the hunt for these expressive effects.

Two objections to the ongoing account might be raised here. One, that the idea of the extreme proximity of meaning and reference has been developed in the notion of indexicality (Nöth 1990) and that therefore the signature discloses nothing new. The objection is just, and indeed appearances favor the signature manifesting a contextual or part-whole relation. However, I would insist that to understand a signature in the sense of physical proximity is insufficient. To return to the example of the Higgs laid out in the second section of this essay, the context by itself cannot explain which photons, amid the bulk of photons, form the potent signal of the Higgs; a material fact gains truth value not through proximity as such, but through selection and differentiation, which denote a relation of judgment.

The second argument, one favored by Foucault and Agamben, is the recognition that signature is "a form of similitude" that signifies by means of analogical resemblance (Foucault 1970, 25).[2] Furthermore, although "the similarity is metaphorical," the thistle plant with its prickly thorns, for instance, is efficacious as well against sharp and acute pains (Agamben 2009, 36). The question arises: How is a resemblance or a representation able to produce an observable effect? Looking at the issue from the standpoint of experimental physics, I would argue that what distinguishes the signature is not so much the power of representation (*metaphor*) as the power of development of one representation into another (*metamorphosis*). A group of theory fellows at CERN explained to me that signatures of quantum physics make matter intelligible through myriad transformations that affect the values of physical quantities of particles, such as their masses or lifetimes, as a result of their interactions with various fields. These transformations depend on quantum uncertainty and require several different techniques of computation. The computations disclose how the effect of a transformation communicates itself, and if that is within the framework of standard theory or indicative of new physics beyond standard theory. Either way, and regardless of its individual type, every signature is characterized by this force of progressive transformations, which explains the real correlation of sign and effect.

The heuristic value of signatures stands out most sharply when we consider that these are quantum events of discovery. Signatures are annunciations of particle states yet to come. Any overview of scientific semiosis must emphasize two closely related issues, namely, the promise of discovery and the hazard of error. I find that traditional semiotics offers little by way of explanation, except viewing these possibilities as the perfect foil for pragmatics (Eco 1984). The clarification of how the sign prepares the way to those final steps where it purely signifies itself or signifies itself to be an illusion is the final theme of this article. With this I will also conclude the original aim with which the inquiry into signatures began—discerning the methodological import of the signature in the substrate of relations.

DISCOURSE, ERROR, AND POSSIBILITY

In a recent piece, Bruno Latour (2000) revisited the issue of materiality and its relevance for both science and social science. There is much that is interesting and polemical in his essay, but the chief argument is fairly straightforward: restore the rights of the object, recognize its ability to mobilize orders of existence, and reconfigure language and society. The result is "objectivity," which is "not a special quality of the mind, an inner state of justice and fairness," but simply the obduracy of objects, "how they object to what is told about them" (Latour 2000, 115). Latour recognizes the significant contribution of language to the scaffolding of objects, but he decides to place the accent on "the thingness of the thing." Undeniably, things form the substance of any laboratory science. Hits (of particles), jets (of strong interactions), or tracks (of electromagnetic charges) traced on the detectors can force the most recalcitrant or Platonist physicist back to things. To that extent, I hardly disagree with Latour on the pervasive presence of things in science. But I strongly disagree with him concerning their epistemological status in science or the implications for social science.

From my research I wish to underscore that to comprehend scientific objectivity, one needs to take into account not only the presence (or absence) of objects but also the possibilities of thought (Hacking 1999; Weinberg 2001). This central tenet yields the consequence that a doubt can be raised about the objectivity of a scientific fact other than as a doubt about the existence of an object in question. An example may help here. In 1999, the Collider Detector at Fermilab, one of the experimental collaborations on the Tevatron accelerator in Illinois, reported the claim of a discovery of "New Physics" from an event of di-photons with a large amount of missing transverse energy.[3] That is, an event was observed in the detector with two photons and a large amount of missing energy in the final state. According to the rules of statistical significance, the event qualified as evidence for a discovery. But "why do we not consider it as evidence of new physics? Because consensus built up in the community that . . . the evidence is not so compelling" (Mangano 2008, 9). For further clarification I quizzed Albert de Roeck, the deputy spokesperson of the CMS experiment and one of my key informants at CERN. He replied, "Yes, there was a case of di-photons, but what did the event signal? Nothing. Of course, it didn't prevent theorists from going into a frenzy and proposing new models, but no attention was given [to those]."

De Roeck's dismissive response made clear to me that physicists' recognition does not simply convey an *interpretation* of a signal but forms part of the *conception* of a signal. If we take seriously Latour's (2000, 121) proposal to demarcate between a "social sociology," dealing with the "symbolic," and a "physical sociology" that is attentive to "things," the question arises: On which side should the CDF signature of the di-photons with missing energy be placed? The real problem that remains unaddressed in Latour's essay is that if the existence of an object alone were decisive, then science would have no category of "error" (Cassirer 1957). The category of error assumes particular relevance when we regard the process of formation: it holds a mirror to every object that presents itself as self-evident and shows once again that facts are meaningful by virtue of having a logical conception.

Owing to the overwhelming presence of signs in high-energy physics, Karin Knorr-Cetina (1999, 146) describes its epistemic culture as moving "in the shadowland of mechanically, electrically and electronically produced negative images of the world—in a world of signs and often fictional reflections, of echoes, footprints, and the shimmering appearances of bygone events." The decisive importance of her analysis lies in her recognition of the "sign processing machinery" as the distinguishing character of high-energy physics (Knorr-Cetina 1999, 46). Her error lies, if I may put it that way, in consistently viewing signs as "fictions," "phantasms," or "chimeras," from which she deduces the world of high-energy physics to be a "ghostly self-enclosed system" (Knorr-Cetina 1999, 52–53). In my view, the question for anthropology (of science) concerns not so much the ontological status of nature or facts, and to what extent they are to be viewed as constructed or described (Knorr-Cetina 1981), but rather from what perspective and by what logic does an experiment acquire knowledge of physical reality.

In an attempt to address the question, I started my inquiry with the words of César Gómez on the trust scientists place on physical reality. Yet until now I have only stressed the paradoxical character of the physics signature that defies any notion of brute physical reality. The sheer act of identifying a signature includes a change of form, an intellectual transposition that goes beyond physical reality. With this claim, I attempted to undermine Latour's argument on the autonomy of things. On the other hand, signatures are not arbitrary assertions of signs or "fictions," as Knorr-Cetina contends, without an embedding in the order of things. By rejecting the position that physics reposes on the thingness of things, and its alternative that it is laden with arbitrary signs, we seem to have reached a difficult position. We shall meet this difficulty by considering a third option: of relations and their importance.

The argument goes as following: First, we have seen that the ground from which the sign shows the logic of the material world is not a single source, but a Janus-faced relation of signal and background. Rooted in the same system, each shows something specific about the physical world. Second, what distinguishes them is the judgment that experimental physicists bring to bear in their evaluations. This judgment constitutes, as it were, the inner limits of the factual. But this does not suggest that discrimination of a signal is a matter of a few minds agreeing with one another. Third, the act of judging has outer limits marked by the space of possibilities, the configurations linking signatures to specific states of affairs.[4] Since the set of possibilities is internal to the discourse, what it expresses is necessary. Fourth, these two orders, the contextual, where the signature is perceived, and the necessary, which engenders its genesis, form a cross-cutting grid from which experimental physics gives shape to its oracles on matter. Once again appearing paradoxical, we are, nonetheless, faced with the distinct recognition, and to whose substantial prospect the signature is forever alive, that from the syntax of difference arises the semantics of unity (Uberoi 2002).

Ludwig Wittgenstein (1953, §50) makes a puzzling observation in the *Philosophical Investigations*: “There is *one* thing of which can say neither that it is one meter long, nor that it is not one meter long and that is the standard meter in Paris.” The philosophical puzzle gestures at something that is contingent and necessary, commemorative as well as implicative, itself and also something other than itself, which it contains and by virtue of which it signifies. The entire conception of the signature turns on this. While instances of radical discoveries grant it a powerful conviction, negative cases of error are also living witnesses to the fact that when the world of signatures comes undone, the contrast of representation and thing also disintegrates.

CONCLUSION

The articulation of science according to things and signs is by no means self-evident. The recognition of a signature from myriad collisions constitutes an act of meaningful discrimination. To this end, the present essay raises awareness of the signature of physics that bears in itself the germ from which the meaningful apprehension of the physical universe takes place. Physics has systematically obliterated traces of the subject from the process of inquiry, with the exception of models and theories, for which personal credit is duly given, and of the instrument as an engineering feat, where human presence is soundly acknowledged. Yet we find precisely at the juncture where discoveries in nature are claimed the rather subversive concept of the signature, which enjoins on grounds of logical necessity (rather than, say, of ease of manipulation or functional coordination) a subject or, more appropriately, the community of subjects. We are told that the signature, as a general class of signs simultaneously efficacious and expressive, was born in the sixteenth century, in the superposition of semiology, concerned with the constitution of signs, and hermeneutics, involved with the meanings of signs (Foucault 1970, 29), only to rapidly "[disappear] from western science at the end of the eighteenth century" (Agamben 2009, 43). So far only history and philosophy have commented on its extraordinary importance, which I have wished to avail for anthropology from contemporary particle physics.

ABSTRACT

Ending the decades-long search for the elusive Higgs particle, physicists at the Conseil Européen pour la Recherche Nucléaire, or CERN, in Switzerland announced the news of its historic discovery on July 4, 2012. In the wake of the recent discovery of the Higgs particle, the article aims to give a critical account of the concept of signature used in contemporary particle physics. Appearing as interlopers in the material world of science, signatures engender a complex movement between fact and value, thing and sign, or reference and meaning. This movement is instructive in explaining how discoveries are made in an experimental science, and also in the more provocative problem of how necessary consequences follow from contextual signs. Drawing on two and a half years of ethnographic fieldwork carried out at the Large Hadron Collider particle accelerator complex and integrating it with medieval theories of the signature, the essay offers a renewed interrogation into the topic of things, signs, and relations and their relevance for anthropology today. [relations; semiotics; material culture; experimental science]

NOTES

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1. Actual names of informants have been used throughout the text after obtaining their consent as per the protocol of the Committee for Protection of Human Subjects.
2. It is fair to add here that while assimilating the signature to the larger circle of similitude, Michel Foucault (1970, 29) admits that it "forms a second circle" with a "tiny degree of displacement" between the two. But he is largely silent on the source of displacement. Likewise, Giorgio Agamben (2009, 37) imparts to the signature a degree of mystery when he writes that here "*signum* and *signatum* exchange roles and seem to enter into a zone of undecidability."
3. "Missing energy" describes energy in the transverse plane that is not detected by a particle detector but is expected due to principles of the conservation of energy and momentum. Therefore events with missing energy become generic signals of new physics processes, such as "supersymmetry" or "extra dimensions."
4. The role of possibilities becomes more remarkable when we visit the baffling reversal of terms that physics presents in cases of radical novelty. While we usually proceed on the assumption that there are things that are revealed as signs, in cases of radical novelty we have the opposite situation: A sign may stand for a thing that does not exist. The example of missing transverse energy mentioned above forms a very promising signature of physics beyond existing paradigms. Here we see clearly how it is the power of possibilities that persuades scientists to the existence of objects not yet experienced.

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