
Symmetriā
PariO
Russell Ward
executive producer
ANDELAIN
A YARLUNG RECORDS COMPANY

Symmetriā Pario

1	Kaija Saariaho, *Sept Papillons* Mov 1	1:09
2	CERN Sweep ttH Tracks	0:12
3	Steven Stucky, *Musicas Dormidas* from *Tres Pinturas*	4:38
4	CERN Event Monitor part 1	0:34
5	Steven Stucky, *Amigos de los Pajaros*, from *Tres Pinturas*	2:59
6	CERN Top Quark Jet, fast	0:30
7	Maurice Ravel, Sonata for Violin and Piano in G Major Mov 3, *Perpetuum Mobile*	4:16
8	CERN Higgs Jet 2	0:37
9	Max Grafe, *Obsidian Liturgy*	10:18
10	CERN Higgs Jet 1	1:38
11	Claude Debussy, *La Plus que Lente*, arr. Leon Roques	4:27
12	CERN Top Quark Jet, slow	0:41
13	Igor Stravinsky, *Firebird* exerpt arr. Stravinsky & Dushkin, Scherzo	2:38
14	CERN Inner Detector Layers part 1	0:52
15	Sergei Prokofiev, Sonata for solo violin in D Major, Opus 115, Mov 1, *Moderato*	4:57
16	CERN Event Monitor part 2	1:17
17	J S Bach, Partita No.1 in B Minor, BWV 1002, arr. Schumann, *Sarabande et Double*	3:25
18	CERN Sweep ttH Clusters	0:10
19	J S Bach, Partita No.1 in B Minor, BWV 1002, arr. Schumann, *Tempo di Bourree et Double*	4:13
20	CERN Inner Detector Layers part 2	1:08
21	Kaija Saariaho, *Sept Papillons* Mov 4	2:04

Symmetriā Pario

I listen to music every day; it is great medicine for me, and for many people. It is clear that music came early to human experience, as evidenced by the bone flutes in our fossil record. At some unknown time music emerged paired with African dance forms. But what is music exactly, and what might be its fundamental form? First we must ask: does what we perceive as music exist in some form independent of human experience - perhaps in bird song - and at levels that we don't ordinarily experience. Specifically in this project, we want to know how the definition of music might extend to the realm of quantum mechanics.

I follow the progress made by CERN, the European Organization for Nuclear Research, founded in Geneva in 1954. CERN takes its name from its French description, *Conseil européen pour la recherché nucléaire.* CERN's website: home.cern offers updates on current investigations into the building blocks of the material universe and includes detailed information on the Large Hadron Collider (LHC), the world's largest particle accelerator used in this research. CERN's director, Dr. Fabiola Gianotti, is not only one of the world's leading experimental physicists, but she trained as a classical pianist. She has spoken about the link between music and particle physics that exists in terms of their shared, fundamental properties of harmony and symmetry. Fabiola Gianotti gave us generous permission to use CERN music files and CERN photographs in this album. Professor Gianotti, please accept our heartfelt thanks.
It must be noted, however, that *Symmetriā Pario* is not a CERN album, nor are the recordings a CERN project. CERN posts music files synthesized by Professor Lily Asquith and others at http://lhcsound.hep.ucl.ac.uk/page_library/SoundsLibrary.html

The purpose of this album is to explore the relationship that exists between the CERN LHC data and music, without incorporating the LHC sound files into a more elaborate musical score. The CERN sound files function here as *intermezzi*.

For each of these "*intermezzi*" I have converted the most basic "sonified" files in the Sounds Library to midi piano and violin tracks using the native instruments in Apple's LogicProX. I intend the paired piano-violin tones to represent particle-antiparticle pairs typically produced in the LHC collisions. I have set the key and tempo globally for each track, in order to better match the music performance movements. I have not altered the relative arrangement of tones within the tracks, meaning that I preserved the original structure of the data.

Tracks on the album alternate between recordings made and previously released by Yarlung Records with the midi tracks, which my friend Brian L. Ruhe and I recorded from a high-resolution audiophile playback system I designed and built for projects like this. Special thanks to Yarlung's Martin Chalifour (violin), Joanne Pearce Martin and Bryan Pezzone (piano), Mika Sasaki (piano) and Elinor Frey (cello). I hope that the patterns in the music you hear performed by these outstanding musicians connect in your mind with the patterns generated by the most elementary known particles in our universe, as captured in their ephemeral dance in CERN's accelerator complex in Switzerland.

For listeners who find this connection intriguing, I want to offer more details and more perspective on the relationship that is envisioned between these two types of music. This relationship arises, as previously noted, from mathematical principles of periodicity, harmony, and symmetry. These are underlying themes in this album, and perhaps underlying structures in any collection

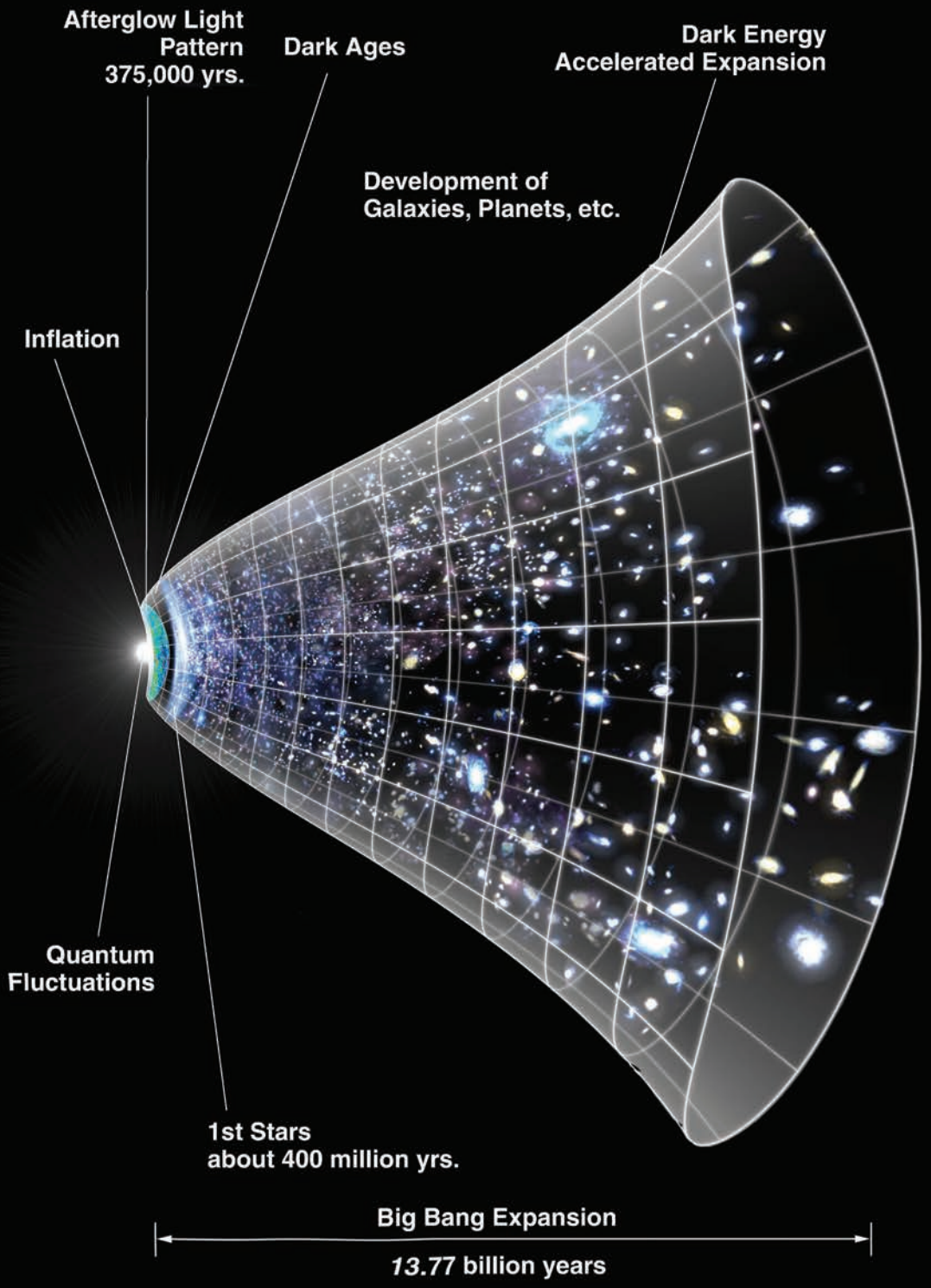
of works which we perceive as music. In a more rigorous way, these principles are also fundamental to quantum physics. Musicians and composers create symmetry and harmony out of physical matter. The alchemy of music emerges from the wood body and metal strings of violins and pianos and from the blood, sinews and muscles in human beings. Like the metaphoric music emerging from CERN's particle detectors, music originating in our great concert halls comes from matter also. The five-story Atlas Detector surrounds violinist Martin Chalifour like a concert hall on our album cover.

We titled our album *Symmetriā Pario*. The title references the birth of the universe and the birth of particles within the Atlas detector, as well as the creation of music by musicians and physicists alike. In our definition of the Latin, "Symmetriā Pario" literally means "I give birth to symmetry."

Professor Gianotti adds a note of whimsy: "Art is based on very clear, mathematical principles like proportion and harmony. At the same time, physicists need to be inventive, to have ideas, to have some fantasy." With these principles and freedom to interpret in mind, let us enjoy this exploration.

According to current evidence and models of the universe, time itself began with the Big Bang. However, as conditions approximating the Big Bang are recreated in the LHC experiments, specifically the high energy of the interactions, multiple events must occur prior to the collisions.

image on following page: NASA / Wikimedia Commons. The expanding universe depicted on a timeline beginning with the quantum field fluctuations that the Standard Model does not include. This is followed by the inflationary period, starting at the limit of the model,10-36 sec after the Big Bang. As space expands, the energy density contained in particles diminishes; as the inflationary period ends and reheating begins, energy transforms (decays) to particles. These particles ultimately combine to form the composite particles forming atoms, molecules, gasses, and stars of the early universe. Expanding universe image is in public domain, attributed to NASA, located in Wikimedia Commons as CMB Universe Expansion.png

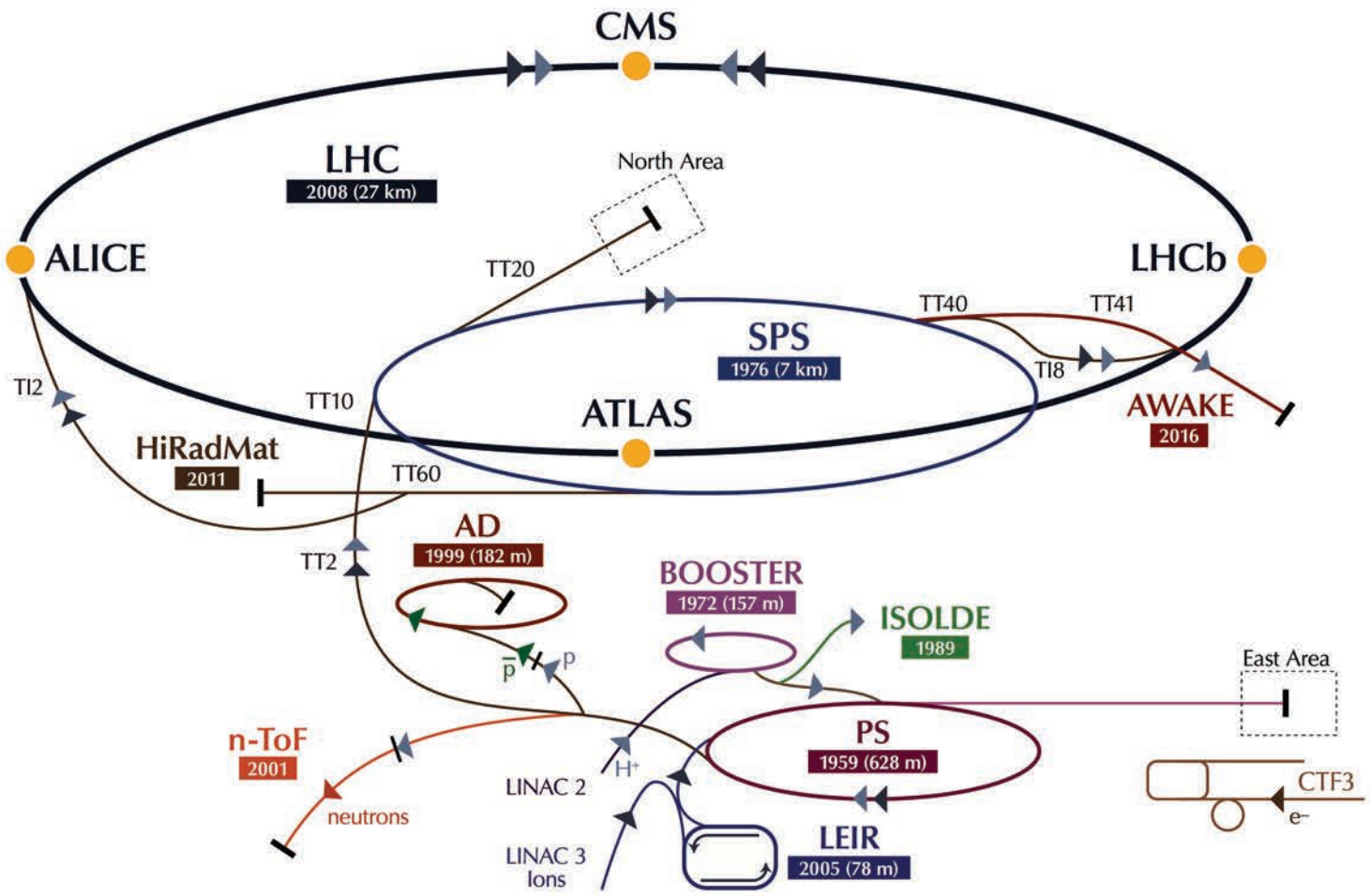

Afterglow Light Pattern 375,000 yrs.
Dark Ages
Dark Energy Accelerated Expansion
Development of Galaxies, Planets, etc.
Inflation
Quantum Fluctuations
1st Stars about 400 million yrs.
Big Bang Expansion
13.77 billion years

This sequence of accelerations, the increasing resonator and beam circuit frequencies, the collisions, and the ultimate decay and/or dispersion of particles into separate patterns, form the (adopted) subject of the music chosen for this album. The music (if we may call it that) derived from data reflects physical properties of the particles produced from the collisions; the result is a tonal pattern representing particles undergoing decay, as in the early universe. These two types of patterns are now juxtaposed.

In each case, we offer an interpretation of the music composed and performed by human beings that fits the sequence of events surrounding the generation of particles in high-energy collision experiments, and, later, the formation of particles in the early universe. We then juxtapose those pieces with transposed sound files representative of actual collision events.

image on following page: CERN, License: CC-BY-4.0, CERN particle accelerator complex. A beam of protons from hydrogen atoms stripped of electrons undergoes a series of accelerations up to nearly the speed of light, first in a 50 MeV linear accelerator, then in a series of circular ones, separated by transitions between accelerators. Each acceleration becomes the precursor to a larger circuit and further acceleration, up to energies at which new particles can be created. The beams are guided in their circular pipes by strong magnetic fields generated by electromagnets, and accelerated by radio-frequency oscillating electric fields generated in RF cavities. Radio-frequency oscillations are at 200MHz for the 1.4 GeV SPS; In the LHC, two counterrotating beams produced from SPS, traveling in separate beam pipes, guided by magnetic fields from superconducting electromagnets, and accelerated in superconducting 400MHz RF resonators, are then brought together at each of the experiment sites, resulting in high-energy (13 TeV) particle-generating collisions.
http://cds.cern.ch/images/OPEN-PHO-ACCEL-2013-056-1

CERN's Accelerator Complex



▶ p (proton) ▶ ion ▶ neutrons ▶ p̄ (antiproton) ▶ electron ⟶⟵ proton/antiproton conversion

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility AWAKE Advanced WAKefield Experiment ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

The first sound that we hear on this album comes from cellist Elinor Frey playing *Sept Papillons* Mov 1 by Kaija Saariaho from Yarlung's album *Dialoghi*. This is a piece that might well portray the quantum field fluctuations that hypothetically preceded the inflationary period of the early universe. It is a sound of emergence, that also reflects the first generation of protons emerging from their hydrogen atom "cocoons" as the electrons are stripped away. These bare protons are then accelerated in the first of a chain of accelerators, Linac 2.

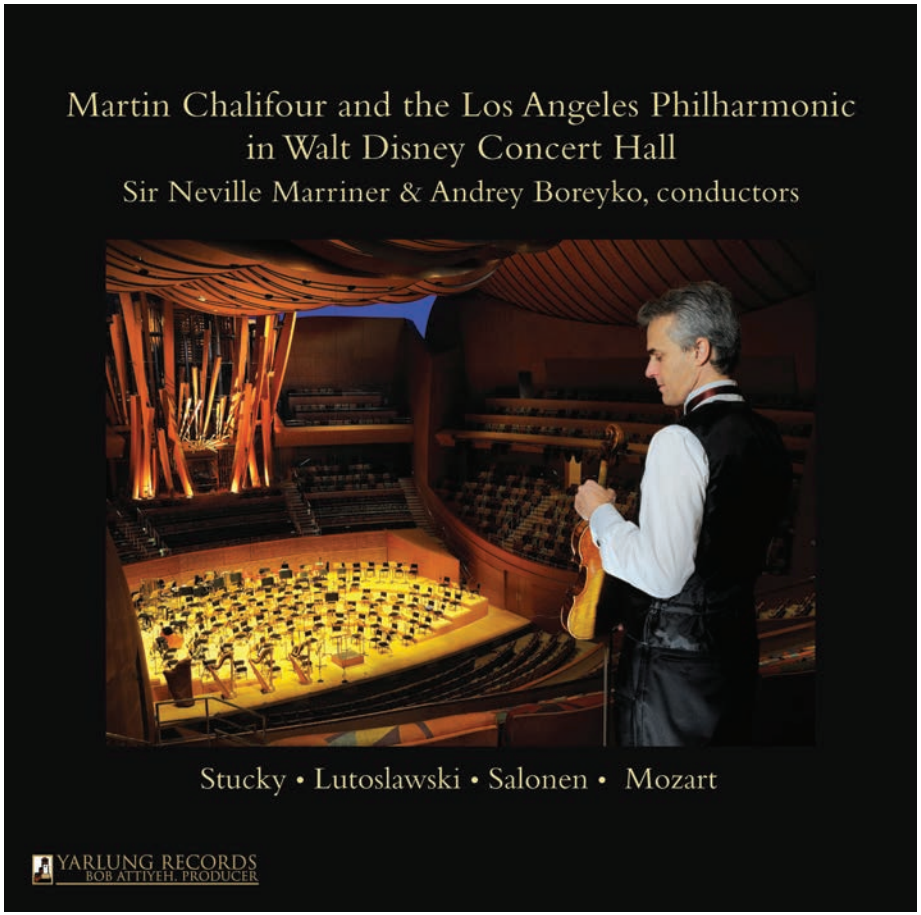
We follow this piece with a CERN sound file of a sweep detector searching for simulated particle "hits" in a CERN experiment. This sound file is an example of simulated top quark data that should be associated with either normal background particle decay, or with decay of a Higgs boson, the strange, elusive particle that has avoided detection, until recently.

Let us be clear about the music in our two first tracks. *Sept Papillons* by Saariaho represents a human musician playing a musical instrument, and is open to broad interpretation. Track 2, "CERN Sweep ttH Tracks," represents the data from an experiment, transposed to a virtual instrument, played and recorded from a custom, high-resolution sound system, representing a specific, physical event. We propose that these two pieces may each be heard as music.

Injection and transfer lines of the LHC Synchrotron Booster.

In the foreground is the vacuum chamber for the 50MeV proton beam coming from the Linac. The tank in the white frame contains the "vertical distributor", which deflects the beam to the four levels of the booster. The "Recombination Line", intersecting the Injection Line, crosses the picture diagonally from left to right.
https://cds.cern.ch/record/615853

Next comes music from Martin Chalifour's second Yarlung album, *Martin Chalifour and the Los Angeles Philharmonic*. Joanne Pearce Martin accompanies Chalifour's violin on piano. The "sleeping musicians" in composer Steven Stucky's *Musicas Dormidas* from *Tres Pinturas* might represent the bare nuclear protons as they "awaken" during their transition to the Synchrotron Booster. This is followed by the sound file "CERN Event Monitor part 1," in which actual data from CERN's Atlas calorimeter is represented as audible tones. Here the relative pitch of each note is determined by the number of particle trails in the event. This is a low number of actual particle trails, at a base luminosity (interaction) level, at the start of detection.



In Stucky's *Amigos de los Pajaros*, also from *Tres Pinturas*, the music represents the circling "birds" of particles in the Proton Synchrotron. As one moves to track 6, "CERN Top Quark Jet, fast," one hears the reference to top quark jets, again possible decay products of a Higgs boson. Next comes a gently frantic piece, Ravel's *Perpetuum Mobile* (Maurice Ravel, Sonata for Violin and Piano in G Major Mov 3, also performed by Martin Chalifour and Joanne Pearce Martin, from Martin's first recording, *Martin Chalifour in Walt Disney Concert Hall*) interpreting the increasing acceleration and driving frequency taking place in the Super Proton Synchrotron.

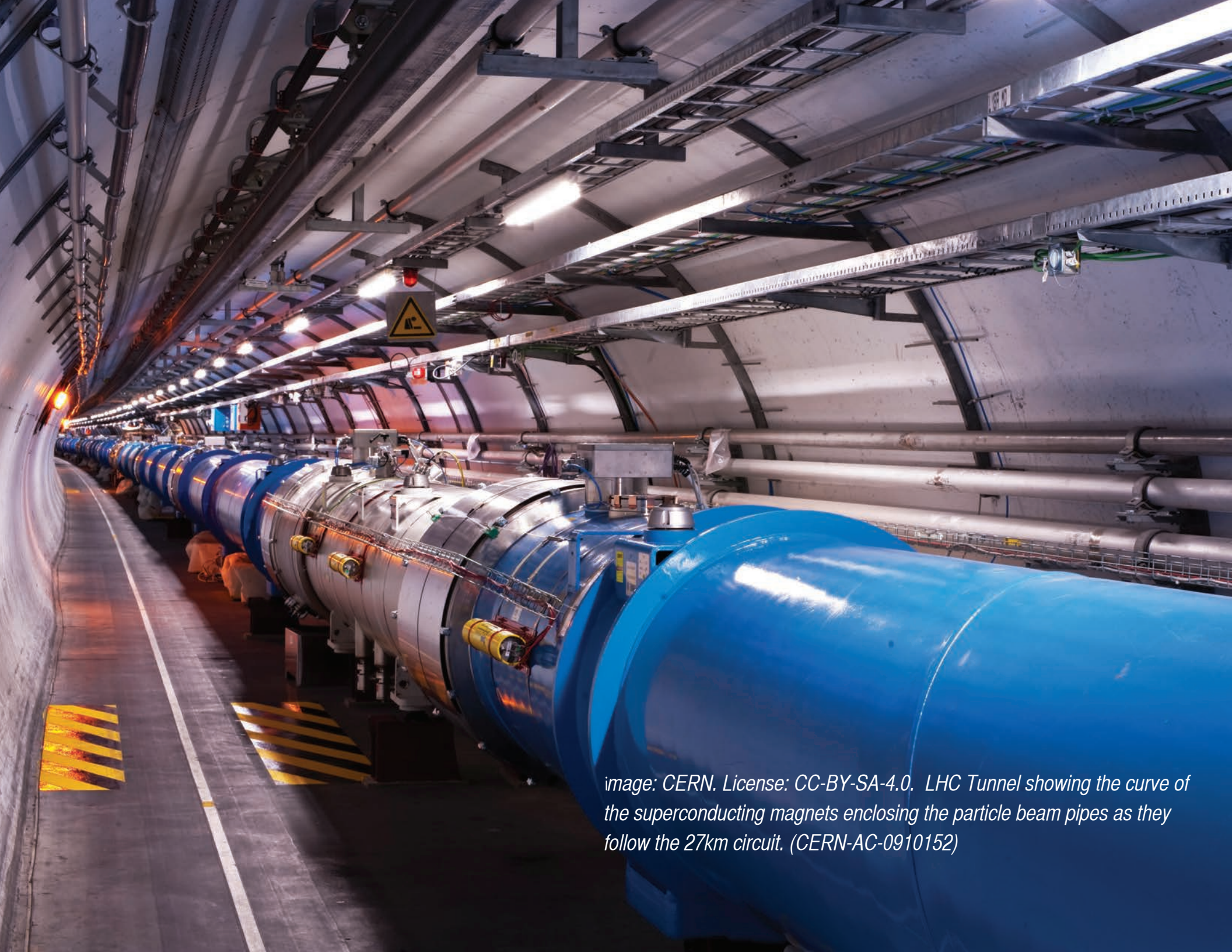


image: CERN. License: CC-BY-SA-4.0. LHC Tunnel showing the curve of the superconducting magnets enclosing the particle beam pipes as they follow the 27km circuit. (CERN-AC-0910152)

In our next track, we hear another strong indicator of the presence of the Higgs field in "CERN Higgs Jet 2." Jets are groups of decay particles emerging from particle-to-particle interaction such as a scattering or collision event. The decay particles all travel in roughly the same direction as the particle from which they originated. This may be generally, or at least partly, transverse to the original particle beam. They tend to stay fairly close together, forming a cone (the jet), which contains most of the momentum and energy of the original particle. The particles in this cone or spray then leave energy deposits in the detector, which can be measured, to reconstruct the jet.

At this point the particle beam, which is about the diameter of a human hair, has been split into two oppositely-directed halves, each held together by the intense magnetic fields of the superconducting quadrupole and octupole magnets within the LHC. In the upcoming collisions, some of the particles are generated within jets of multiple particles, whose distances from the collision point determine their relative positions in the musical bar or measure. The further they travel within the detector cells, the later they are heard in the measure. Distance from the axis of the jet is represented as frequency; energy, equivalent to mass, is represented as amplitude. The free-travel distance of particles is inversely related to their mass, which is acquired in their "symmetry-breaking" interaction with the Higgs field.

We might imagine the vacuum surrounding the beams prior to collisions as represented by the opening of composer Max Grafe's *Obsidian Liturgy*, played by pianist Mika Sasaki on her debut album *Obsidian.* A few minutes later in the piece, we hear what might be interpreted as a "sonification" of the collisions between protons in the two counterrotating beams. The cascades of notes symbolize the formation of new particles from energy released in the collisions.

Following these opening moments in *Obsidian Liturgy*, we hear Ms. Sasaki's conjuring portrayal of what might be associated with the near-silence of the unknown, the first instants of the formation of the universe, not included in the "Standard Model."[1] Then begins the inflationary period of the early universe, as the quantum fluctuations expand, and fields differentiate. *Obsidian Liturgy* becomes expansive. The tolling of bells refers to the passage of time. The following measures invoke the first particles, excitations in newly-formed fields occupying spacetime.

Our next track, "CERN Higgs Jet 1," reminds us that the Higgs boson is one of the short-lived heavy particles that we don't hear (observe) directly; we only hear the sound of the decay products, the top quark-antiquark pair, and its decay jets. However, the music again reflects the sound of other particles gaining mass as they interact with the Higgs field. Pairs of oppositely-charged, "discordant" particles are generated from single excitations.

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[1] The Standard Model is a theory describing fundamental particles and how they interact with one another. For more information please visit https://home.cern/science/physics/standard-model

Debussy's *La Plus que Lente* (Martin Chalifour and Joanne Pearce Martin) represents the first in a series of dances, in which – in this interpretation - certain decay products (quarks) begin to organize into composite particles composed of the more elementary quarks. This process continues with "CERN Top Quark Jet, slow." Again the detectors register the "hits" of the decay products, now many more particles that result from the collisions represented in *Obsidian Liturgy*. As space expands, long wavelengths of sound, symbolizing the red shift of the expanding universe, begin to enter the soundscape. At the same time, a still small percentage of energy becomes concentrated into more localized patterns, becoming our solar systems, star systems and galaxies.

But we ultimately arrive at a surprising realization: from the earlier upheaval, through *Firebird* (Martin Chalifour and Brian Pezzone, piano), through the transitional movement of Prokofiev's Sonata for solo violin D Major, Opus 111, Mov 1, *Moderato,*[2] and the CERN Event Monitor track which follows it, we detect increasing organization.

As music theorist John Rahn notes, "It is hard to write a beautiful song. It is harder to write several beautiful songs that, when sung simultaneously, sound as a more beautiful polyphonic whole. The internal structures that create each of the voices separately must contribute to the emergent structure of the polyphony, which in turn must reinforce and comment on the structures of those individual voices. The way that is accomplished is... 'counterpoint.'"

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[2] *I am grateful to Martin Chalifour, who kindly recorded this movement of the Prokofiev sonata for us while sequestered at home during the Covid-19 pandemic. He plays his Josef Filius Andrea Guarneri violin, from circa 1720.*

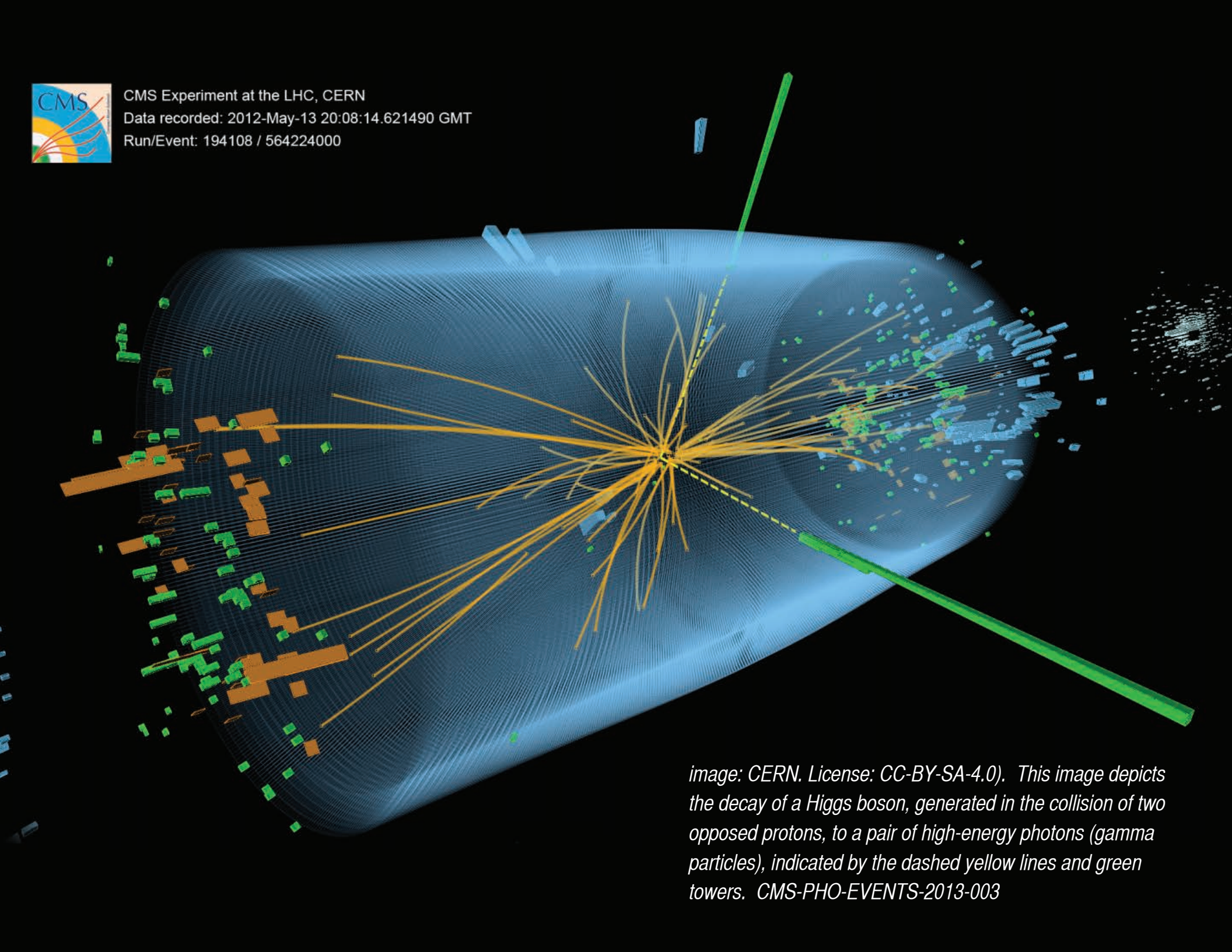

image: CERN. License: CC-BY-SA-4.0). This image depicts the decay of a Higgs boson, generated in the collision of two opposed protons, to a pair of high-energy photons (gamma particles), indicated by the dashed yellow lines and green towers. CMS-PHO-EVENTS-2013-003

This increasing organization is represented beautifully by Martin and Joanne in their recording of the *Sarabande* and *Bourree* from Bach's, Partita No. 1 in B Minor, BWV 1002, as arranged by Robert Schumann. These two movements, divided by the brief "CERN Sweep ttH Clusters," herald the advent of order, harmony and counterpoint. This order, this *Symmetriā*, has been present throughout our album and throughout our universe, but has been increasing, not decreasing, since the Big Bang. We might expect that all of the early-formed particles would annihilate, or that those left would simply degenerate into heat, but this has not been the case. Our universe continues to incorporate a significant amount of order, balanced by increasing entropy, as absolute temperature decreases with the expansion of space.

The track "CERN Sweep ttH Clusters" is another simulation of a decay of a Higgs boson into a top quark – antiquark pair; the progeny perform a final dance for the physics. In this case the relative pitch of the note corresponds to the energy deposited in the detector cell.

This relationship between waveform frequency and energy lies at the core of quantum mechanics.

Physicists theorize that the essential structure of the universe took shape from the quantum field fluctuations that these physicists postulate existed at the origin of the universe. But the field responsible for the expansion of these fluctuations has not yet been detected. Scientists have not yet explained the asymmetry existing today between matter and antimatter. Dark energy, which is thought to be responsible for the increasing rate of expansion of space, has not been isolated. None of the data resulting from the

CERN experiments has yet provided satisfactory answers to these mysteries. The data itself represents an unfinished symphony of sound. But have we heard, in these simply converted sound files, evidence that interactions occurring at the most fundamental level of physics incorporate a structure recognizable as music? We might consider this question as we listen to the final two tracks on our album.

In closing, I wish to thank Professor Fabiola Gianotti, director-general of CERN, for her inspirational leadership and for the multicultural and multidisciplinary environment she has fostered in and around CERN during her tenure. Though I am not affiliated with CERN, I join many who benefit from its publications. I also want to thank Professor Lily Asquith for establishing the LHC Sounds Library. I am grateful to Bob Attiyeh who put this album together for me and for the collection of albums he has produced at Yarlung Records. We appreciate Martin Chalifour, Joanne Pearce Martin, Elinor Frey, and Mika Sasaki for their contributions to the classical genre. Thanks also to my friend and colleague Brian L. Ruhe for his patience and technical skills in recording and production of the CERN tracks, as well as text edits. Much appreciation to Teresa Nemeth for her crucial suggestions and edits. Thanks as well to the folks at Pass Labs in California, Chris VenHaus of VH Audio, and Gilmer Wood in Oregon for their unique products. Finally I want to thank family and friends for their many combined hours of listening and helpful comments. I anticipate that *Symmetriā Pario* is only the first of my several projects enjoying the links between human-composed and quantum-composed music.

--Russell Ward, executive producer

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Symmetriā Pario

J. S. Bach
CERN
Debussy
Grafe
Prokofiev
Ravel
Saariaho
Stravinsky
Stucky

image: the ALICE Inner Tracking System during its transport in the experimental cavern and its insertion into the Time Projection Chamber.

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