Monitoring and Controlling Particle Collisions at Nanometer Scale and with Picosecond Duration

Application Note

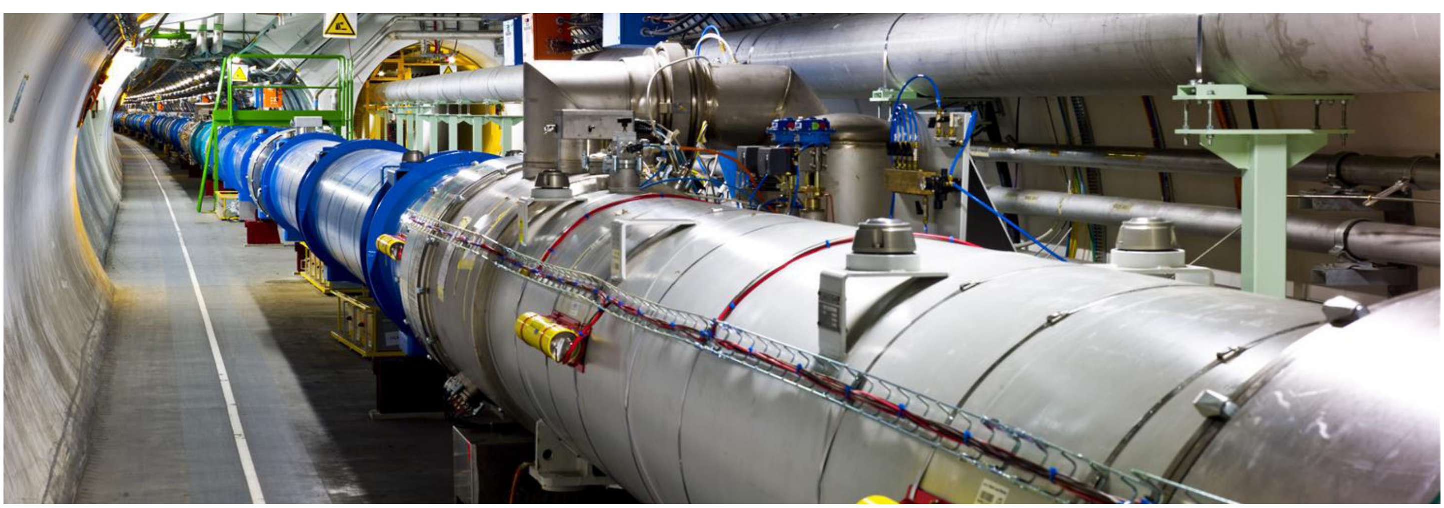
Overview

For the past 50 years, high-energy particle accelerators have been helping researchers investigate big questions about the nature of matter and the origins of the universe. Typical experiments involve carefully controlled collisions between either intersecting particle beams or a particle beam and an atomic-scale target. The results have gradually filled in the Standard Model of physics—and the recent discovery of the Higgs boson is a landmark event in this field of research.

Creating collisions at nanometer scale with picoseconds of duration requires extreme precision in spatial and temporal control. At facilities such as the European Organization for Nuclear Research, more commonly known as CERN, high-performance Agilent Acqiris digitizers are helping researchers achieve the precision and control needed to perform more and better experiments in less time. In this type of application, digitizers must provide fast measurement throughput, very short "dead time" between measurements and excellent measurement fidelity.

The Large Hadron Collider (LHC) at CERN is the world's most powerful particle accelerator, capable of producing 7 TeV. The CERN Control Centre (CCC) manages the LHC and the chain of accelerators that feed it. Along the injector chain, the Open Analogue Signal Information System (OASIS) can acquire and display more than 2,000 individual analog signals.

In such situations, high-speed data acquisition requires maximum throughput. Agilent Acqiris digitizers implement innovative techniques that maximize data bandwidth and ensure rapid measurements.



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Problem

There are two types of accelerators: linear accelerators ("linacs") and synchrotrons. Linacs operate in a straight line and, due to size constraints, have limited power. Synchrotrons are circular and have multiple stages, enabling them to produce much higher power levels than linacs.

To illustrate the structure of a synchrotron, Figure 1 shows a simplified diagram of the LHC. Listed in order of operation, here is a summary of the acronyms in the figure:

- **Linac 2:** Linear accelerator for protons
- **PSB:** Proton Synchrotron Booster•
- **PS:** Proton Synchrotron
- **SPS:** Super Proton Synchrotron
- **LHC:** Large Hadron Collider

The process starts in Linac 2, which generates 50-MeV protons that are fed into the PSB. It boosts the protons to 1.7 GeV before they are injected into the PS, which raises the energy to 26 GeV. Next, the SPS raises the energy level to 450 GeV. Over a period of about 20 minutes the protons are injected into the LHC's main ring. In this final stage, protons accelerate to 7 TeV and circulate as two separate beams traveling in opposite directions. Collisions can be created at four intersections located around the LHC. (1)

The term "beam" is a misnomer: Rather than a continuous stream, hadrons (protons or neutrons) are formed into "bunches" that have durations (or "widths") measured in picoseconds. Bunching is intrinsic to the physics of using RF fields to achieve high gradients of acceleration within the synchrotron. Bunches, which may contain several billion protons, travel at velocities approaching the speed of light. Depending on the accelerator's circumference, transit time ranges from a few hundred nanoseconds to tens of microseconds.

Thinking broadly, a particle accelerator is a giant scientific instrument. It includes numerous subsystems, ranging from interconnected arrays of accelerators to tiny photo-detector diodes. Clusters of traditional test equipment are used to measure, monitor and control the quality of particle beams. One key measure of beam quality is focus: Tightly focused beams help ensure high rates of particle collisions and interactions.

Within a typical accelerator, essential monitoring equipment includes detectors and digitizers. Detectors sense attributes such as the light intensity or energy level produced by individual bunches. Digitizers convert a detector's analog output into a digital representation that can be quantified, analyzed and used for beam control. In some cases a PC mounted in the instrument chassis performs initial data reduction and sends the preprocessed results across the local area network (LAN).

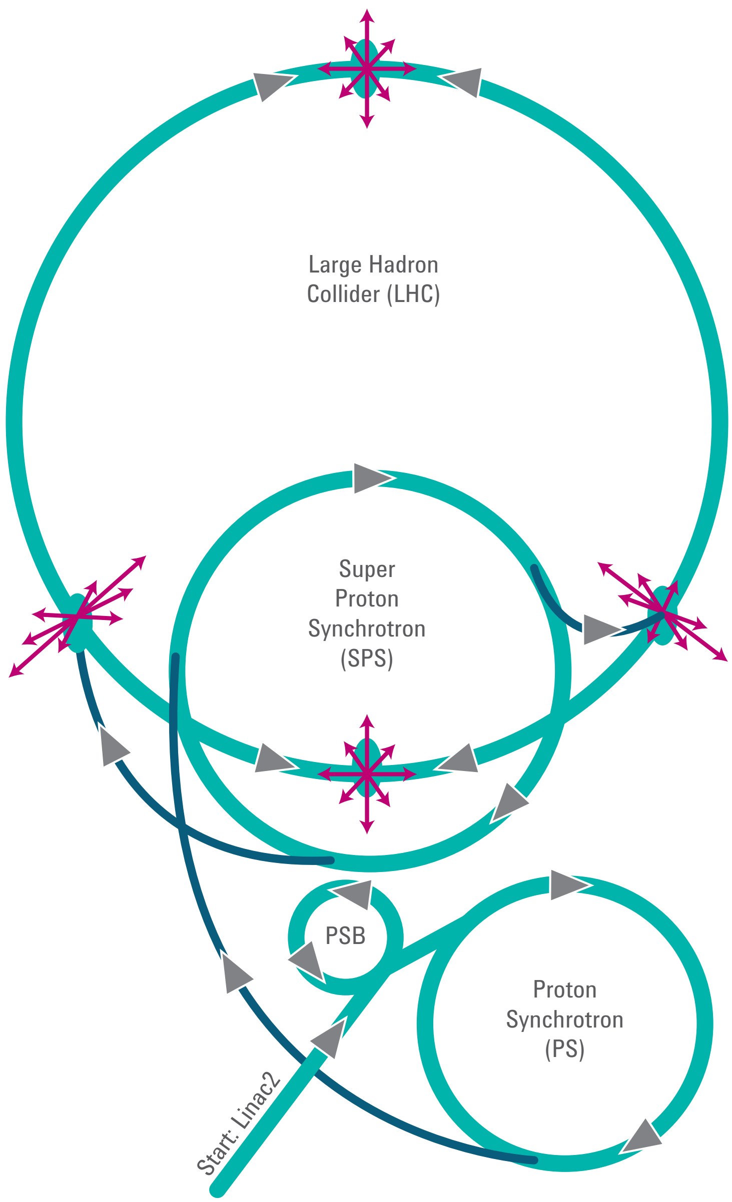

FIGURE 1. Simplified diagram of the LHC multi-stage synchrotron that accelerates protons to nearly light speed

Solution

The CERN Control Centre (CCC) manages the LHC and oversees operation of the laboratory's eight accelerators, consolidating all control rooms under one roof. It also manages the lab's technical and cryogenic infrastructures, which controls the cooling of 1,600 superconducting magnets spaced throughout the LHC.

Within the LHC, each counter-circulating beam consists of about 2,808 bunches, each of which contains up to 100 billion protons. The bunches travel at 99.9999991% of the speed of light—and at that rate one transit of the 27-km LHC takes about 90 µs.

The performance of the LHC depends on its injector chain. Along that chain, the Open Analogue Signal Information System (OASIS) acquires and displays analog signals in the acceleration domain. The signals come from every CERN accelerator and are sampled using various types of high-performance digitizers. (2)

More than 2,000 individual signals are available to the operators and physicists who use OASIS. They are looking for a variety of indicators from the LHC and its injector chain: instabilities in proton bunches, currents in fast-pulsing magnets ("kickers"), phase relationships between kickers, and the state of RF signals in the accelerating cavities. These characteristics help determine if conditions are right for the experiments scheduled during any given shift, day or night.

With proton bunches traveling near the speed of light, fast measurements are essential and digitizers must have very short dead time between measurements. This is one of the key reasons CERN is using Agilent Acqiris digitizers in the "control and diagnostics" sections of the LHC and the accelerators it feeds.

More than 100 Agilent modules are currently installed, providing sample rates that range from 500 MSa/s to 8 GSa/s with resolution of 8 or 10 bits on one, two or four channels (Figure 2). The digitizers are used to perform wideband beam monitoring and to monitor forward and reverse RF signals in the accelerator cavities. In a literal sense, the beam-monitoring measurements are made possible by Agilent digitizers that provide sufficient speed and bandwidth to capture the signals of interest. (3)

Summary of Results

In laboratories around the world, Agilent instrumentation has become an integral part of advanced experimental systems. Our instruments are used in two major areas that require high-speed measurements: real-time applications and single-shot or event-based applications. We provide the extreme speed and precision needed for system monitoring and control, and for capturing data from the interactions and events in the experiments themselves.

Agilent's measurement solutions for advanced research can integrate directly into your experiment. Our range of instruments includes oscilloscopes, power supplies and high-speed data converters. Agilent digitizers offer distinct advantages when you need a large number of synchronized acquisition channels: high speed, low-power operation, high channel density and excellent accuracy.

The LHC installation is just one example of what's possible with Agilent instrumentation. We've worked closely with research teams around the world—and we're ready to help you create the right solution for your most challenging projects.

FIGURE 2. U1065A Acqiris 10-bit high-speed cPCI digitizers can be configured with one, two or four input channels and sampling rates of 2 to 8 GSa/s.

References

1. Large Hadron Collider information in English: public.web.cern.ch/public/en/LHC/LHC-en.html
2. Project OASIS: project-oasis.web.cern.ch/project-oasis
3. Agilent application note *Monitoring and Controlling Particle Beams in Real Time*, publication 5990-5154EN available from www.agilent.com

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