# CERN Scientists Use Virtex-4 FPGAs for Big Bang Research

## How 120 Xilinx FPGAs help scientists understand the big bang and gain insight into the fundamental building blocks of matter.

by Peter Alfke
Distinguished Engineer
Xilinx, Inc.
*peter@xilinx.com*

Volker Lindenstruth
Professor/Chair of Computer Science
Kirchhoff Institute for Physics, University Heidelberg, Germany
*voli@compeng.de*

In a tunnel underneath the French-Swiss border, scientists at CERN, the European laboratory for particle physics, are on the verge of conducting an experiment called ALICE (A Large Ion Collider Experiment).

They will use the world's most powerful particle accelerator to accelerate two streams of heavy lead (Pb) ions very close to the speed of light and make them collide head-on, attempting to recreate conditions believed to exist shortly after the big bang.

CERN scientists expect that each collision will release an enormous amount of energy and create a local temperature of $10^{12}$ °C – a hundred thousand times higher than the core of our sun.

When the heavy ions collide, CERN scientists expect the collision will also generate a vast number of subatomic particles flying in all directions. CERN scientists hope that by tracing the paths of these particles, they can discover answers to many of the deepest questions in physics.

Scheduled to begin in 2008, CERN scientists will observe collisions in the ALICE experiments with the help of Xilinx® FPGAs, which will allow them to map and disentangle the trajectories of the thousands of subatomic particles emerging from the collision. Powerful data-reduction algorithms in the FPGAs eliminate redundant information and send only the important data to the CERN data bank.

In April 2008, Xilinx accepted the ALICE Industrial Collaboration Award for its contributions in support of research into particle physics. Professor Volker Lindenstruth of the University of Heidelberg presented the award on behalf of the ALICE collaboration in recognition of the central role played by Xilinx FPGAs in the core measurement instrumentation (see Figure 1).

*Figure 1 – Pictured from left to right: Marc Defossez, Peter Alfke, Volker Lindenstruth, and Patrick Lysaght*

**The Large Hadron Collider and ALICE**

Considered the "most ambitious scientific undertaking on earth," the Large Hadron Collider (LHC) is the world's largest and most complex scientific instrument. It is housed in a 27-km tunnel 100m below ground, straddling the French-Swiss border near Geneva (Figure 2). It is the latest and most powerful in a series of particle accelerators physicists are using to study quark gluon plasma, the smallest known particles that are the fundamental building blocks of all matter.

The Large Haldron Collider accelerates protons and heavy ions close to the speed of light and smashes them together, thus recreating conditions that existed a fraction of a second after the big bang.

The scientific community generally assumes that the universe has been cooling down ever since the big bang, and that all matter familiar to us evolved out of this event. The particle collisions in the LHC

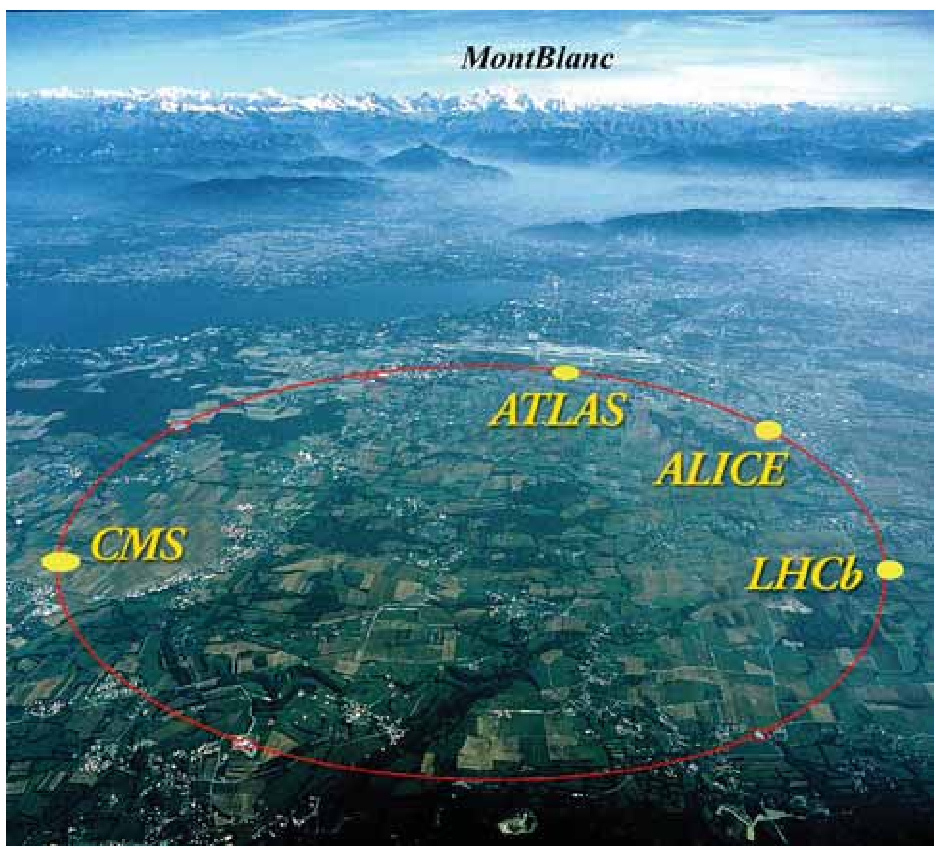


*Figure 2 – The CERN Large Haldron Collider is located underground, straddling the border between France and Switzerland near Geneva.*

**Each XC4VFX100 device performs the first-level data reduction simultaneously and independently, and processes and classifies the trajectory data on the fly. The combined data rate of 2.7 terabits per second is processed by the collection of 120 Xilinx FPGAs...**

will emulate that energy density and thus provide a look at conditions very early in the evolution of the universe. These experiments might uncover new facts about matter, and promise to revolutionize our understanding of the miniscule world deep within atoms to the vastness of the universe.

Two beams of atomic particles called "hadrons" – either protons or lead ions – will travel in opposite directions inside the circular accelerator, gaining energy with every lap. Physicists will then make the beams collide head-on. Teams of scientists from around the world will analyze the particles created in the collisions using special detectors in a number of experiments performed in the LHC.

### The Role of Xilinx Virtex-4 FX FPGAs

When the counter-rotating beams of hadrons collide at extremely high speed they create a storm of subatomic particles. To monitor the particles generated by the collisions, the ALICE experiment uses special photo-detectors that can measure the position of thousands of particle trajectories generated in every collision to a fraction of a millimeter.

The Transition Radiation Detector (TRD) has 1.2 million analog detectors. The system converts each analog signal to a 10-MHz, 10-bit data stream. The 540 individual detectors are combined into 18 super-modules. Their individual analog signals are pre-processed by 67,000 front-end chips. This generates a total

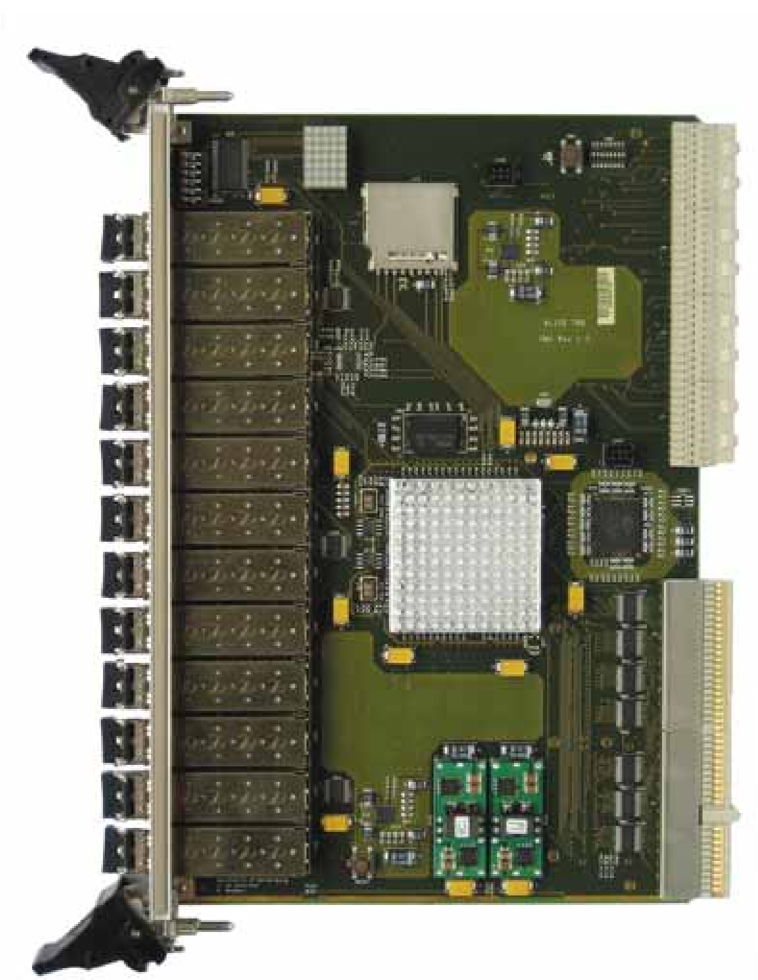

*Figure 3 – A track matching unit card with the Xilinx XC4VFX100 Virtex-4 FPGA*

*Figure 4 – One of many racks containing the TMU cards that filter and track trajectory data from the lead ion collision.*

data stream of 120 terabits per second of raw data.

The system preprocesses and compresses this data locally so that it can be sent out on 1080 optical links, each carrying data at a rate of 2.5 Gbps. These optical cables run to racks filled with 90 Track Matching Unit (TMU) cards. Each of these cards, shown in Figure 3, has 12 optical-to-electrical converters connected to the 12 multi-gigabit transceiver inputs of a single Xilinx Virtex™-4 FPGA.

Each XC4VFX100 device performs the first-level data reduction simultaneously and independently, and processes and classifies the trajectory data on the fly. The combined data rate of 2.7 terabits per second is processed by the collection of 120 Xilinx FPGAs, 90 of them in racks of TMUs (Figure 4).

The ALICE designers connected the remaining 30 FPGAs in a tree structure to higher level modules, where the final trigger decision (capturing the important content and filtering out redundant content) is performed by the FPGA at the top of the tree. With the help of powerful algorithms that eliminate repetitive, redundant, or unimportant data, the complete system is capable of fitting and selecting more than 20,000 track parameters within a microsecond, while preventing information overload in the CERN data processing and storage system.

Each XC4VFX100 FPGA has two embedded IBM PowerPC microprocessors, one of which runs the Linux operating system to perform system verification and housekeeping.

### The Higgs Boson

The ALICE experiment is the most ambitious effort to date from CERN, but it is certainly not the last one they plan to conduct. Indeed, CERN scientists hope that ALICE's sister projects ATLAS and CMS will be able to produce the elusive Higgs boson.

In 1964, physicist Peter Higgs and his colleagues hypothesized the existence of a massive scalar elementary particle, now dubbed the Higgs boson. Physicists have added the Higgs boson to the Standard Model of particle physics, but no experiment to date has been able to confirm its existence.

CERN scientists hope that the Higgs boson particle might explain how elementary particles acquire properties such as mass. This would then be a significant step in the formation of the Grand Unified Theory and research of the nature of dark matter and dark energy.

### CERN and the Six-Billion Dollar Experiment

CERN is the French acronym for the European Organization for Nuclear Research, more appropriately called the European Laboratory for Particle Physics. CERN is the world's largest institution dedicated to high-energy research in subatomic particles.

CERN was founded in 1954 and is located near Geneva, Switzerland. Its annual budget of nearly U.S. $1 billion is provided by 20 European member states plus eight observers, including the U.S. Almost 8,000 scientists and engineers – about half of the world's particle physics community – work on experiments conducted at CERN and analyze the results. Work at CERN was honored twice with Nobel Prizes in Physics in 1984 and 1992.

Most of the activities at CERN are currently directed toward building the Large Hadron Collider (LHC) and developing experiments for it. CERN expects to start its experiments in mid-2008.

Scientists expect to run several experiments on the LHC and have already scheduled six: CMS, ATLAS, LHCb, TOTEM, LHC-forward, and ALICE.

CERN is famous not only for its basic research in subatomic physics but also for a variety of technological breakthroughs. The best known is Tim Berners-Lee's invention of the World Wide Web in 1989, originally intended to improve communication between scientists associated with CERN.