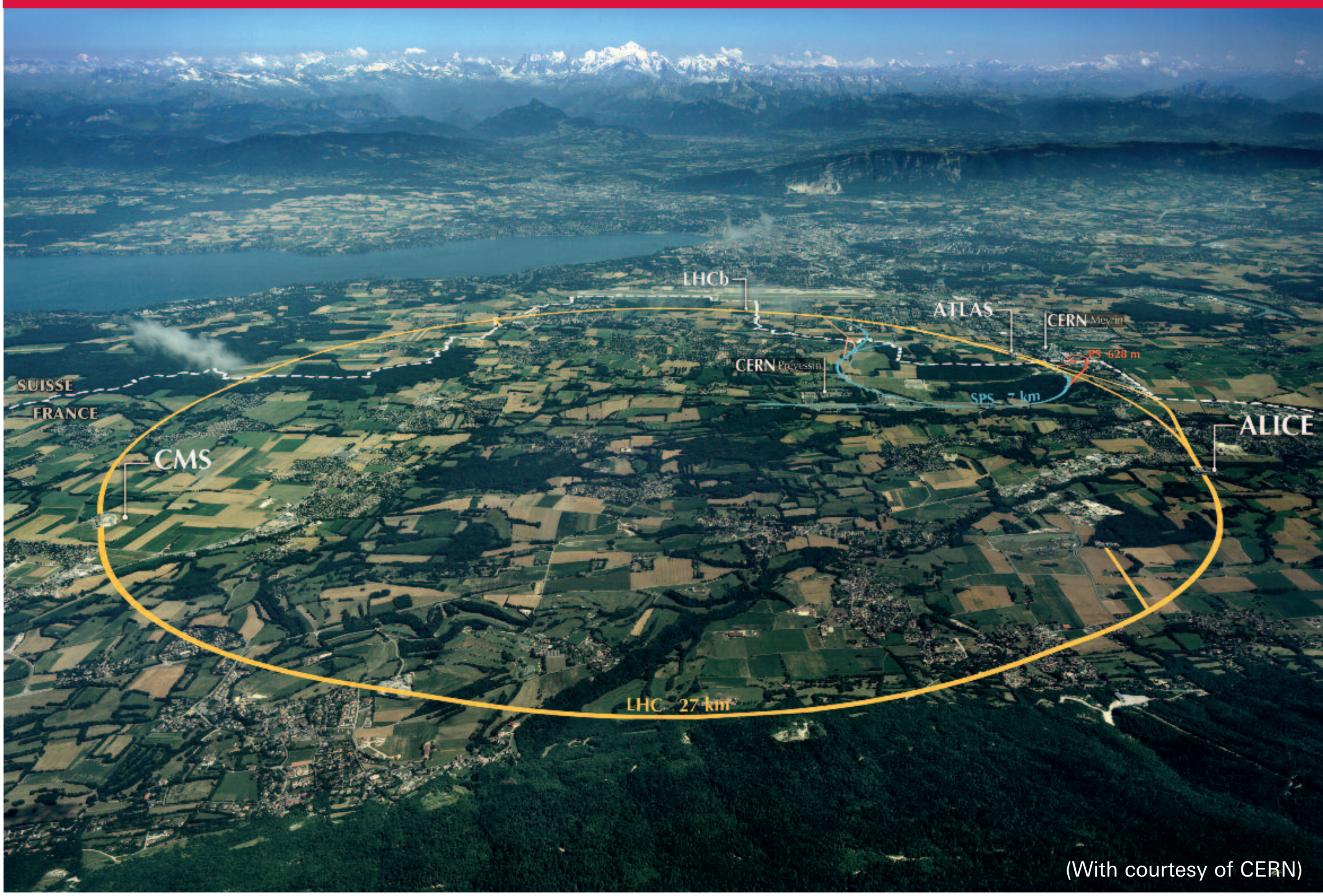
On the trail of the Higgs boson

The world's largest vacuum system relies on vacuum solutions from Pfeiffer Vacuum

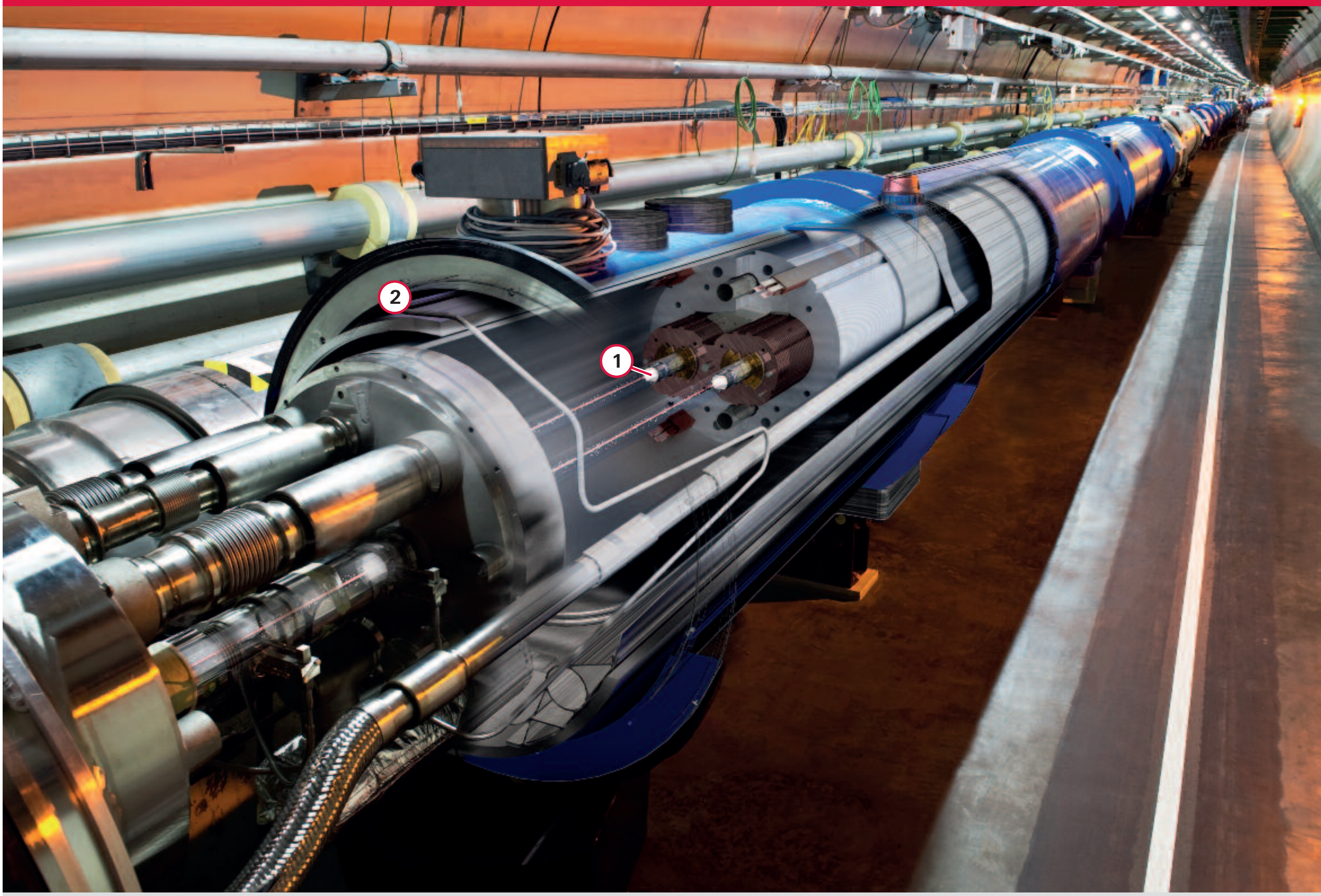


(With courtesy of CERN)

Pfeiffer Vacuum supplied key vacuum components to CERN´s Large Hadron Collider (LHC)

CERN, the European particle physics laboratory based in Switzerland, is the largest research center for particle physics in the world. Founded in 1954, it houses approximately 2,500 employees and more than 10,000 guest scientists from around the world. The main task of CERN is to discover what the universe is made of and how it works. In doing so, the aim is to complete the standard model of elementary particle physics, which describes the basic building blocks of matter and the forces acting between them. This model is missing an important component which has not yet been experimentally proven: the Higgs boson.

In order to implement its research, CERN operates a number of particle accelerators. The most extraordinary of them is the LHC (Large Hadron Collider), installed in an underground tunnel. Its circumference measures 26.7 km, making it the largest particle accelerator in the world. In the LHC, two opposing particle beams are accelerated to nearly the speed of light and brought to collision at defined locations in large detectors. During this collision process new particles are produced. The records of the detectors provide conclusions about the characteristics of the collisions as well as the newly created particles. In this way, scientists hope to be able to prove the Higgs boson. On July 4, 2012, the research groups for the ATLAS and CMS detectors reported that they had found a new particle. Whether this is the Higgs boson described by the standard model must still be proven by determining its characteristics.



Construction of the LHC accelerator (With courtesy of CERN)

1 Beam vacuum
In order to prevent the particles from colliding with gas molecules on their paths through the accelerator, the beam lines must be under an ultra-high vacuum of 10^{-11} hPa. This so-called beam vacuum is created in a multi-stage pump process. First, the beam lines are pre-evacuated to 10^{-8} hPa using Pfeiffer Vacuum HiPace 300 turbopumps. The advantage of these pumps is that they have a very high compression ratio for light gases. This is especially important as hydrogen (the lightest gas present in the air) determines the ultimate pressure in the ultra-high vacuum domain. After the pre-evacuation, a NEG (Non-Evaporable Getter) coating developed by CERN is thermally activated inside the beam lines. This coating acts as an additional absorbtion vacuum pump. It absorbs the remaining gas molecules, creating the necessary ultimate pressure of 10^{-11} hPa.

2 Insulation vacuum
Extremely powerful, superconducting magnets, cooled down with liquid helium to 1.9 K (approx. -271 °C), ensure that the particles in the LHC are kept in their orbit. To ensure that the low temperature of the magnets can be maintained, a good thermal insulation of the entire cooling system is essential. For this purpose, similar to a thermos flask, an insulation vacuum is created around the magnets, which reduces the heat input into the cryogenic system to a minimum. The insulation vacuum must be permanently maintained at less than 10^{-6} hPa. As superfluid helium may leak into the insulation vacuum due to unavoidable leaks in the cooling system, HiPace 300 turbopumps by Pfeiffer Vacuum are permanently in use in order to maintain the insulation vacuum. Due to its uniquely high pumping capacity and the large compression ratio for light gases, the HiPace turbopumps are particularly suitable for pumping off helium.

The importance of vacuum

An important factor for the operation of a particle accelerator is a reliable and powerful vacuum system. However, an extraordinary machine such as the LHC also has very specific requirements for the installed vacuum technology. The smallest errors could put the entire accelerator out of service for several hours. Therefore, the complete vacuum system must be extremely reliable. In addition, all equipment used within the accelerator must be able to withstand radiation levels of up to 1,000 Gy/a. Equipment responsible for delivering these complex measurements cannot leave the accelerator's radiation zone. Therefore, it is very critical that the equipment can be maintained on-site.

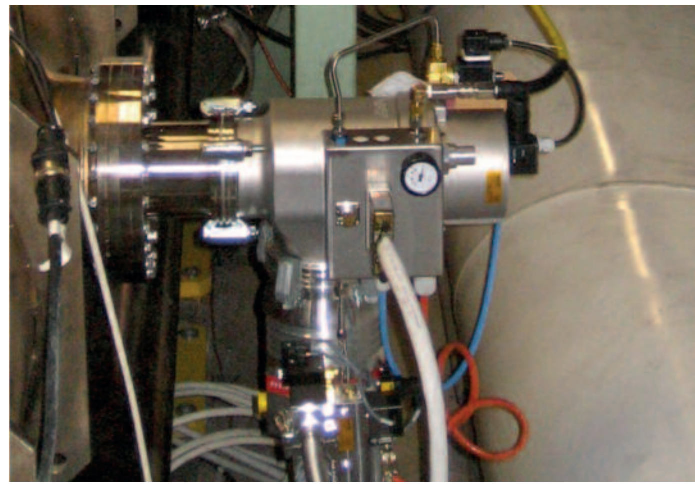
In order to meet these especially high requirements, Pfeiffer Vacuum has developed and implemented special vacuum solutions for vacuum generation, vacuum measurement and vacuum analysis in coordination with CERN.

Vacuum generation

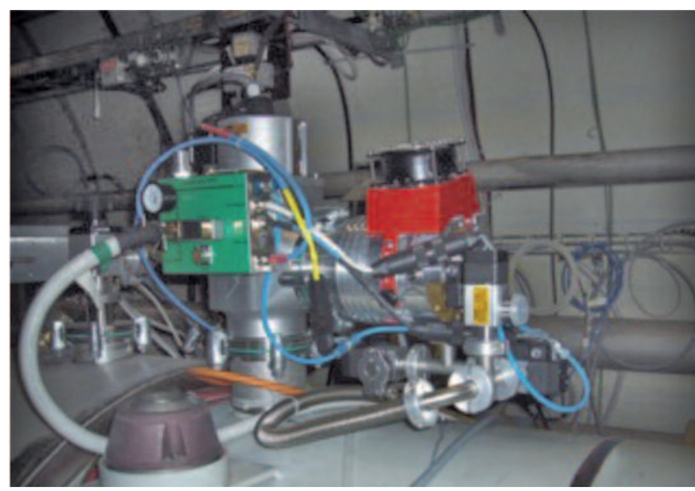
The LHC differentiates between two vacuum systems: the beam vacuum and the insulation vacuum. Pfeiffer Vacuum turbopumps are used for both applications. These were modified to fulfill the special requirements of the LHC. In order to be able to operate the turbopumps in the radioactive environment, no electronic components could be used in the pumps. To meet those requirements, Pfeiffer Vacuum developed a sensor-free drive concept, which enables the mechanical part of the pump to be separated from the electronics. Using this concept, the electronics can be located up to 1,000 m away from the turbopump and positioned in a shielded area.

Vacuum measurement

The generated vacuum is measured with specially developed measuring devices by Pfeiffer Vacuum. The devices used are modified Pirani and Cold-cathode vacuum gauges. They permanently monitor the pressure in the accelerator and ensure that, in case of an increase in pressure, appropriate action can be taken. As the vacuum gauges are also exposed to high radiation levels, they are constructed as passive sensors without integrated electronics. All electronics are housed in a radiation-safe area and are connected to the passive sensors via long cables. The required cables are specified in close collaboration with CERN. This allows the Cold-cathode vacuum gauges to measure pressures up to 10^{-11} hPa. A special ignition process offers the advantage of enabling the Cold-cathode vacuum gauges to be turned on easily even at very low pressures. As the lifetime of an accelerator is approx. 30 to 40 years, only those electronic components, that would be available for a long time, were selected.

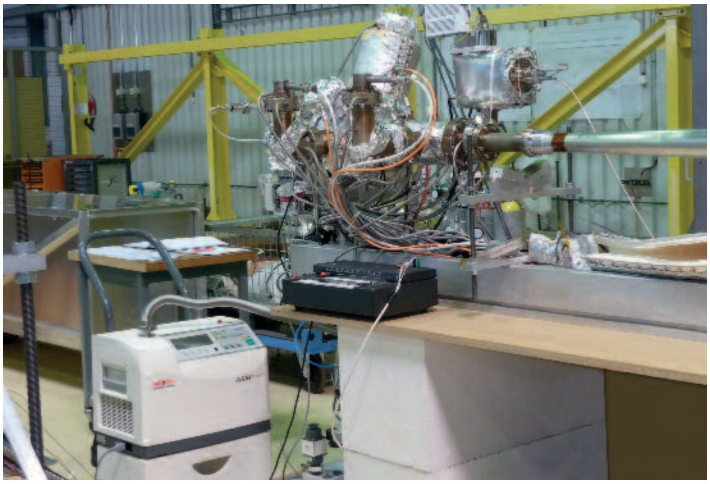


Beam vacuum generation with HiPace 300 turbopump

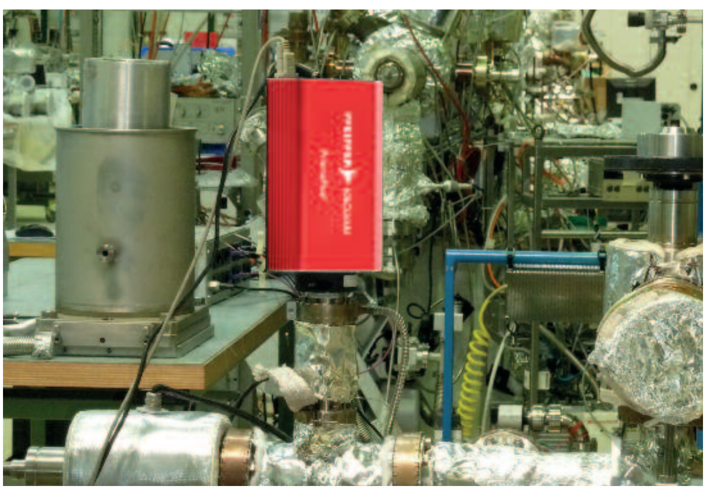


Insulation vacuum generation with HiPace 300 turbopump

Vacuum measurement with PKR 261 gauge



Leak testing system for LHC components with ASM Graph



Testing system for the outgassing behavior of LHC components with PrismaPlus

Helium leak detection
For the ultra-high vacuum pressures required for the LHC, it is important that the components used for the accelerator have extremely low leakage rates. Therefore, before installing the components, an extensive leak test is essential. For the leak tests, CERN uses helium leak detectors from the ASM series. Using these, even the smallest leakages to 10^{-13} Pa·m^3/s can be reliably detected.

Vacuum analysis
Not only the pressure but also the composition of the residual gas is an important factor for the proper operation of the accelerator. Using a residual gas spectrometer, conclusions can be drawn about the outgassing of the materials used in the accelerator. To draw residual gas spectra, CERN uses mass spectrometers by Pfeiffer Vacuum. For this residual gas measurement in the ultra-high vacuum, it is especially important that the analyzers of the mass spectrometers themselves demonstrate a low outgassing rate. In addition to a vacuum-annealed ion source, Pfeiffer Vacuum analyzers used at CERN also have a vacuum-annealed rod system. Using this, the analyzers produce an extremely low underground signal and are thus particularly well-placed in order to record the actual residual gas ratios in the accelerator.

Example products of Pfeiffer Vacuum at CERN

Vacuum generation
HiPace 300

Vacuum measurement
ModulLine

Helium leak detection
ASM 310

Vacuum analysis
PrismaPlus

André Kägi (left) and Florian Henss (right) from Pfeiffer Vacuum with Dr. José Miguel Jimenez

Interview at CERN
A conversation with Dr. José Miguel Jimenez, Head of CERN's Vacuum, Surfaces & Coatings Group in the Technology Department

Dr. Jimenez, how do you feel working at one of the world's largest and most respected centers for scientific research?
I am very proud and happy to work with CERN. It's true that people from outside see mainly the CERN challenges towards fundamental Physics, but the technological developments and international partnerships behind are extremely motivating. As an engineer, I really appreciate the huge perspective that the construction and accelerators offers to many types of technologies.

It looks like the long-sought Higgs boson was discovered at CERN now. Which role does the vacuum technology play in research work in general?
To be more precise, a new particle was discovered and we still need to accumulate collisions and to study data to confirm that we have found the Higgs boson.

Regarding the role of vacuum technology in our research work, without a very good ultrahigh vacuum the accelerator and the detectors will not be able to operate.

What is the purpose of vacuum technology in the LHC accelerator ring?
Vacuum technology is used in beam and isolation vacuum. Beam vacuum is the most important one and in particular for the high energy accelerators. Inside the beam lines there need to be pressures in the 10^{-10} hPa range in presence of beams or 10^{-12} hPa in static mode. This ultrahigh vacuum is required in the experimental areas and also several hundreds of meters upstream and downstream of the detectors, to keep a low background in the detectors and to preserve their electronics. Indeed, the more collisions between the primary protons beam particles and the molecules from the residual vacuum, and the more "noise" and damage to the detectors..

For the isolation vacuum on LHC, we are using turbopumps to pump the helium gas. Even the magnets are operated at 1.9 K (-273°C) and the quantity of helium gas that we can condense on the surface is very small, because the helium has a very low condensation temperature. In case we have to face a leak in this very long complex liquid helium circuit, we need to have some pumping margin to be able to continue the operation of the accelerator. For that reason we need turbopumps to be installed in the tunnel.

Most of the vacuum technology we need at CERN is available in the market; the problem is the integration of all this technology into the very specific environment of the accelerator. This is what requires the development of vacuum technologies for the LHC and for all the other CERN accelerators.

Which special requirements have to be fulfilled from the pumping system?
An important part of the successful operation of a particle accelerator is a high performance vacuum system. The vacuum system needs to have high reliability, be electro-magnetic compatible and radiation-resistant as well as assuring the ease of maintenance.

What products/systems/components from Pfeiffer Vacuum are employed here?
The LHC employs vacuum instrumentation and residual gas analyzers provided by Pfeiffer Vacuum. All the gauges, gauge controller and residual gas analyzers are supplied by Pfeiffer Vacuum. We also have a large number of HiPace turbopumps, installed permanently in the tunnel or used as mobile pumping stations, in order to allow intervention in the tunnel or in the laboratories.

What do you appreciate about products from Pfeiffer Vacuum? Which aspects might have contributed to the decision that vacuum solutions from Pfeiffer Vacuum are significantly used at CERN?
The collaboration with Pfeiffer Vacuum did not start with the LHC; it started more than 30 years ago with the Intersecting Storage Ring (ISR), which was the first large ultra-high vacuum accelerator in the world, and Large Electron-Positron Collider (LEP) projects.


Dr. José Miguel Jimenez explains the specific environment of the accelerator and the necessary adjustments of a vacuum system.

The quality, reliability and performances of the Pfeiffer Vacuum products fits with the requirements of our particle accelerators. We learned how to implement these products in our complex configurations.

CERN's relationship with Pfeiffer Vacuum is longstanding. This is important since our accelerators need to operate for several decades.

Which specific advantages of the turbopumps are required in this application?
In the LHC, the turbopumps have to provide a huge compressing rate for helium and hydrogen in order to allow very-low ultimate vacuum. The pumps must be electro-magnetic and radiation compatible and their reliability must be very high to reduce LHC down-time. Some of them also require being able to stand long bake-out cycles, more than 24 hours at 250°C to decrease even further the ultimate vacuum.

Please describe briefly the specificity of the environmental conditions in the accelerator ring. How did the turbopumps need to be modified?
I will use the example of the permanent pumps installed on the cryostats of the superconducting magnets and liquid helium cryogenic transfer line. People have to realize that even at 1.9 K (ca. -271°C), only a very small fraction of helium gas can be condensed. In case a small leak occurs in these complex cryogenic circuits, the permanently installed turbo-pumps will allow continuing the LHC operation. These pumps therefore need to be compatible with very long cables and with the electro-magnetic perturbations in the tunnel resulting from the magnets but also from local beam losses.

To be suitable for the operation on the LHC the turbopumps have to withstand a radiation dose up to 1.000 Gy/a. This high level of radiation prohibits the operation of any semi-conductor components inside the pump. To overcome this problem we are using a new sensorless drive concept, which was developed together with Pfeiffer Vacuum. This allows the complete removal of any electronics from the body of the pump and an installation outside the tunnel in radiation protected service galleries. Although the electronics are placed far away from the pump, they can still notify the users of all the important status parameters of the turbopump.

Please estimate the approximate amount of Pfeiffer Vacuum products that are used at CERN.
The amount of Pfeiffer Vacuum products is quite significant. In the accelerators, we have in total 89 km of beam vacuum systems. If we count the liquid helium transfer line and the Insulation vacuum of the LHC we count up to 128 km of vacuum system.

For vacuum generation, vacuum measurement and the analysis of the partial pressure, a huge number of vacuum equipment is used and a large proportion of it is supplied by Pfeiffer Vacuum.

At the LHC for example, nearly 95 Percent of the gauges and gauge controllers used, 70 Percent of the turbopumps, 65 Percent of the leak detectors and 50 Percent of the primary pumps as well as a large number of residual gas analyzers (RGAs), valves and fitting components are supplied by Pfeiffer Vacuum.

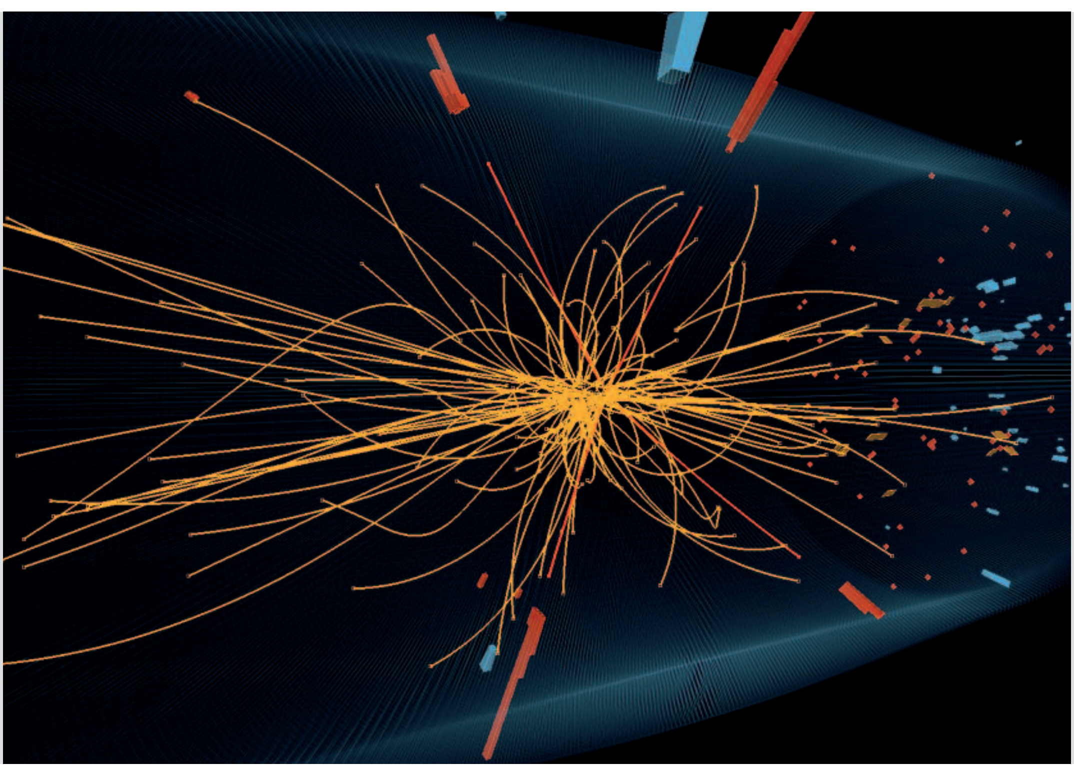
How do you assess the cooperation with Pfeiffer Vacuum?
We are using many products from Pfeiffer Vacuum and most of the vacuum solutions are custom-tailored to our specific needs. We consider them like strong partners, committed to our future concerns.

To you, how important is technical support of the vacuum components?
For all the products which are installed and in contact with the beam vacuum, like turbopumps or backing pumps, despite the fact that our components never get activated in terms of radiation and never get contaminated, the procedure we have to declassify the products to be able ship them outside is very complex. Because the procedure is based on the nuclear installation, we are very strict in the follow up of this shipping procedure. So we try to avoid shipping the products outside. This is why the local presence of service engineers is very important to us.

It appears that the Higgs boson is found. What does that mean for the research work at LHC? Is research completed now? What happens next?
A particle which could be the Higgs boson has been found, this is a fantastic reward to the efforts made by a very large community of Scientists and Technical staffs all around the world.

The LHC project started in the 1980s, the project was approved in 1994, the construction started in 1998, the installation was completed in 2008 and now we have this new particle discovered in 2012. It was a long way but it is a magnificent achievement.

Going forward, we have to continue operating the LHC to confirm that we have found the Higgs boson and then study all other properties of this particle. This implies operating the LHC at even higher energies and intensities and push this fantastic accelerator to its limits. We are all confident that many more discoveries within the Standard Model, or not, will come. A better understanding of "Dark Matter" is one of them.



Real CMS proton-proton collisions events in which 4 high energy electrons (red towers) are observed (With courtesy of CERN)

Vacuum solutions from a single source

Pfeiffer Vacuum stands for innovative and custom vacuum solutions worldwide, technological perfection, competent advice and reliable service.

Complete range of products

From a single component to complex systems: We are the only supplier of vacuum technology that provides a complete product portfolio.

Competence in theory and practice

Benefit from our know-how and our portfolio of training opportunities! We support you with your plant layout and provide first-class on-site service worldwide.

Are you looking for a perfect vacuum solution? Please contact us:

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