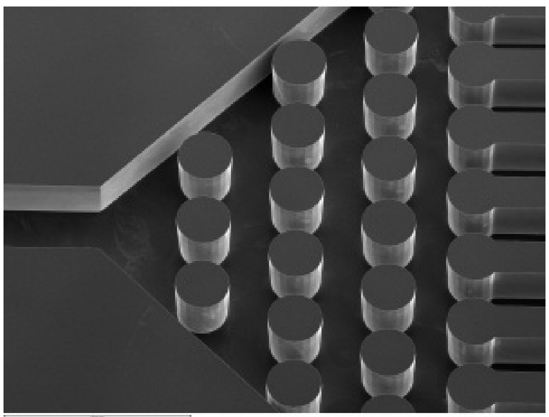
LC NEWSLINE
THE NEWSLETTER OF THE LINEAR COLLIDER COMMUNITY

FEATURE



Cool sensors: new silicon detectors have their fridges built in

How 3D printing could get to the heart of the ILC detectors

by Marcel Vos (researcher at IFIC Valencia and member of the DEPFET collaboration)

Silicon-based devices for the detection of charged particles form the core of every modern collider experiment. As position-sensitive devices get thinner and thinner, supports and services must be more and more integrated into the sensor itself. IFIC Valencia, HLL-MPG Munich and Bonn University show the viability and cooling performance of a process that integrates the cooling channels in the active silicon sensor.

AROUND THE WORLD

From metal sheet to particle accelerator (part 3 of 3)

Into the yellow pipes

by Ricarda Laasch

If you're an electron, a ride in a cavity is pretty much the coolest thing that can happen to you. If you're an accelerator and you need huge numbers of cavities you better make sure they're all of outstanding quality – which is what the X-ray free-electron laser European XFEL under construction in Hamburg has just finished. In a series first published in DESY inForm, we look at how a niobium sheet turns into a curvy beauty. Part three describes how they make their way from test benches into the cryomodules and, finally, into the tunnel.

DIRECTOR'S CORNER

What Is Basic Science Good For?

by Hitoshi Murayama

Humans are curious creatures, always trying to make sense of the world around them. Basic science pushed the humankind forward and will continue to do with projects like the LHC and the ILC. Hitoshi Murayama, Deputy Director of the Linear Collider Collaboration and enthusiastic public lecturer explains why.

IMAGE OF THE WEEK

National Lab Day

Image: Argonne, Mark Lopez

Fermilab, SLAC, JLab, Brookhaven, Argonne... these are all major players in particle physics and accelerator R&D. They are also the U.S. Department of Energy's (DOE's) "national labs". All national research labs came to Washington, D.C. on 20 April to show their work to members of Congress and other visitors. Pictured is Dick Durbin, Illinois senator, giving his address. DOE has 17 national laboratories that address a variety of scientific and technological challenges to energy, environmental and national security. The laboratories employ more than 30,000 scientists, engineers and support staff in 19 states, and operate major scientific facilities for the benefit of the nation's research and development community.

IN THE NEWS

from *Mainichi Shimbun*
11 May 2016
素粒子施設と夢テーマに絵
市立胆沢中学校の建設工事現場のフエンスに６日、素粒子実験施設「国際リニアコライダー」と夢をテーマにした絵が掲示された。絵は、同地区の中学生や保育園児が描いたという。(On the fence of construction site for Isawa Junior high school in Oshu city, Iwate prefecture, big drawing with a ILC as a theme was posted on 6 May. This drawing was produced by kindergartner and junior high school students in the city)

from *Popular Science*
9 May 2016
TAKE A LOOK AT THE INFINITY MACHINE
…. the Infinity machine was built to help measure components for the proposed Compact Linear Collider, a new particle accelerator that would smash together different types particles than the existing Large Hadron Collider.

from *Daily Engineering and Construction news*
9 May 2016
岩手県／ＩＬＣ誘致実現へ新たな検討組織立ち上げ／水門調査業務プロポ公告
岩手県は北上山地に「国際リニアコライダー」（ＩＬＣ）を誘致するための取り組みを本格化する。本年度の早い時期に課長・部長級職員らで構成する庁内の検討組織を立ち上げ、事業計画の検討や誘致に向けた働き掛けを強める方針だ。(Iwate prefecture shift into full swing about their activity toward the realization of the ILC in Kitakami region. They will establish new framework consist of department head and chief-class staffs, and discuss the plan and make representations toward the ILC.)

from *newswise*
5 May 2016
SLAC's Historic Linac Turns 50 and Gets a Makeover
Since the Department of Energy's SLAC National Accelerator Laboratory powered up its "linac" half a century ago, the 2-mile-long particle accelerator has driven a large number of successful research programs in particle physics, accelerator development and X-ray science. Now, the historic particle highway is getting a makeover that will pave the way for more groundbreaking research.

from *iBC*
5 May 2016
「ＩＬＣかるた」　一関市が配布
ＩＬＣ＝国際リニアコライダーの計画について、楽しみながら理解を深めてもらおうと、一関市が「ＩＬＣかるた」を、市内の小学校や児童クラブに配付しました。（Ichinoseki-city distributed ILc playing cards to elementary schools in the city to gain understanding of the ILC)

CALENDAR

Upcoming events

ECFA Linear Collider Workshop
Santander, Spain
30 May- 05 June 2016

Upcoming schools

The 2016 European School of High-Energy Physics
Skeikampen, Norway
15- 28 June 2016

View complete calendar

PREPRINTS

1605.02259
Stability of soliton families in nonlinear Schroedinger equations with non-parity-time-symmetric complex potentials

1605.01363
Vector and Axial-vector resonances in composite models of the Higgs boson

1605.00418
Performance of the SDHCAL technological prototype

1604.08307
Probing the origin of 750 GeV diphoton excess with the precision measurements at the ILC

1604.08122
Top physics at high-energy lepton colliders

1604.07921
Electroweak radiative corrections to triple photon production at the ILC

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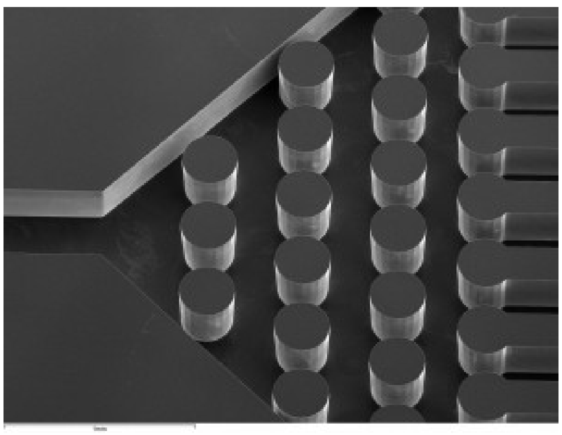
FEATURE

Cool sensors: new silicon detectors have their fridges built in

How 3D printing could get to the heart of the ILC detectors

Marcel Vos (researcher at IFIC Valencia and member of the DEPFET collaboration) | 12 May 2016



The micro-channels etched into the primary handle wafer before sealing the circuit with the second sensor wafer. Image: L. Andricek, MPG-HLL, Munich.

Riding the wave of progress in semi-conductor industry, pixel vertex detectors have improved their performance dramatically over the last decades. It is now possible to build ultra-thin devices with a spatial resolution of several microns, while maintaining a read-out speed and power- consumption that is adequate for lepton collider experiments such as the ILC.

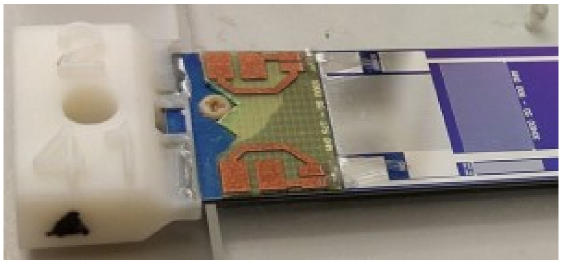
Several groups are developing the next generation of detectors for e+e-colliders. The most well-known are the monolithic devices of the CMOS-family and the DEPFET active pixel detectors (the name stands for Depleted Field Effect Transistor). Both these technologies have reached maturity; MAPS and DEPFET vertex detectors are being constructed for use in collider experiments as we speak. Further progress is expected from HV-CMOS, 3D-integrated devices,

These new devices can discriminate signals of a few 100 electrons. This has allowed to reduce thickness of the sensors drastically, from the equivalent of nearly one millimetre of silicon to close to 100 microns. Getting rid of every gram of material that we can is key to achieving the resolution required by lepton collider experiments, as charged particle trajectories are affected by interactions with the detector material. The obsession with losing weight does not only extend to the active sensor, but to all parts of the detector system that get in the way of the particles.

At the heart of the detector for the ILC there is no room for bulky support structures or cooling systems. The DEPFET collaboration therefore integrates these functionalities in the detector design. In an R&D effort partly financed by the AIDA2020 project, Max Planck Society's semiconductor lab in Munich MPG-HLL, the University of Bonn and IFIC in Valencia are developing a process to integrate the cooling circuit in the active silicon sensor. In industry, micro-channel cooling is used to cool, for instance, memories. In high-energy physics (HEP) experiments, LHCb, NA62 and ALICE use silicon cooling plates based on the principle. A monolithic integration of the cooling system in the same silicon wafer that acts as active detector material, however, has not yet been attempted.

The process starts off with two silicon wafers. The cooling manifold of arbitrary layout is etched (using DRIE etching) in a thick handling wafer. A photograph of part of one of the manifolds from first test production run is shown in Fig. 1. The circuit is sealed with the sensor wafer that is bonded on top of the handle wafer. All except the strictly necessary material can now be removed by combination of mechanical and chemical processes. The result is an ultra-thin self-supporting detector with a tiny cooling circuit hidden inside.

The connection of the tiny inlet and outlet – with a cross section of 350 x 400 mm² – to the main cooling circuit is possibly the biggest hurdle for the deployment of micro-channel cooling in high energy physics. State-of-the-art solutions, such as the soldered Kovar connectors used by LHCb, are too bulky for application at the heart of the experiment. The IFIC-Bonn-MPG groups have therefore opted for plastic connectors, such as those shown in Fig. 2. These complex structures can be fabricated quickly and at very low cost thanks to



A mechanical sample with integrated cooling with the 3D-printed interface to commercial fittings. Image: M. A. Villarejo, IFIC Valencia

the advent of 3D-printing. The high precision of this process ensures that the cooling lines in connector and sensor self-align. The experience so far has been very positive; the first batch of assemblies has been built with 100% yield.

A number of prototypes have been tested at the thermo-mechanical laboratory at IFIC, with very encouraging results. A tiny trickle of cooling fluid (i.e. 1 l/h of water) is sufficient to remove up to several tens of watts from the sensor area. As the cooling liquid and the heat source are separated by only a few tens of microns of silicon, the temperature difference between coolant and the hottest spot on the sensor is minimal. The first structures have moreover been submitted to leak and pressure tests at CERN, where they are found to stand well over 100 bar (How did we find out? Though one of the most smashing experiences after all the careful handling of our prototypes…).

The success of this first exploratory study encourages us to further develop micro-channel cooling for HEP applications. It provides a good example of how advancing technology may help us to satisfy the ever more challenging specifications of collider experiments. The possibilities offered by ultra-precise silicon lithography and processing are well-known, but many opportunities remain to be exploited. And we are only just beginning to explore the vast potential of 3D stereo-lithography!

Further reading: L. Andricek, M. Boronat, I. Garcia Garcia, P. Gomis, C. Marinas, J. Ninkovic, M. Perello Rosello, M.A. Villarejo, M. Vos, Integrated cooling channels in position-sensitive silicon detec tors, arXiv:1604.08776, submitted to JINST (https://arxiv.org/abs/1604.08776)

Video of the pressure test

Results are to be presented at the tracker mechanics forum in Bonn, the tracker/vertex detector session of the ECFA Linear Collider meeting in Santander and in the AIDA2020 annual meeting. AIDA2020 is funded by the EU H2020 framework programme under grant agreement.

AIDA2020 | DEPFET | DETECTOR R&D | IFIC | MPG-HLL | UNIVERSITY OF BONN

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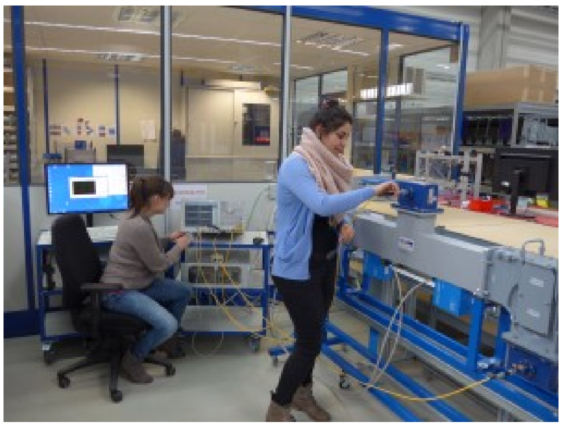
Into the yellow pipes

Ricarda Laasch | 12 May 2016


Two colleagues from the WATF team measuring and tuning waveguide components.

For the operation of the European XFEL, 800 cavities will be installed in 100 accelerator modules. The cavity production has already been outlined in the two previous stories published in LC NewsLine (and first published in DESY inForm). For their assembly, there is a weekly transport of cavities to France. From there, they return to DESY as operational modules where they are tested and provided with a custom-made "energy supply" before they are transferred into the tunnel.

The assembly of the modules takes place at the research centre CEA (Commissariat à l'énergie atomique) in Saclay near Paris. Lorries transport the cavities directly to the gates of the so-called XFEL Village where staff members of the industrial contract partner ALSYOM receive and "check in" the cavities. "We from CEA regard ourselves as the connecting link between research and industry; so it was clear to us to get industry on board with ALSYOM," explains Olivier Napoly, project leader of the XFEL project in Saclay. "With this, we had a two-tiered learning phase: first, CEA learned from DESY how to assemble XFEL modules; then, we passed on our new knowledge to ALSYOM."

The whole infrastructure and almost all tools of the XFEL Village are provided by CEA. The main contribution of ALSYOM is the technical staff. In its seven-week production time, each module stays for one week at one of the seven assembly stations. "We finish one module per week," says Napoly. "In the beginning, this rate was a real challenge; however, with a good cooperation and by optimising our organisation and personnel, we made it. In 2015, at times we even completed one module every four working days."


In the Waveguide Assembly and Test Facility. Photos: Valery Katalev, DESY

The first two stations are located in dust-free cleanrooms. There, the cavities get the "cold part" of their new couplers, provided by LAL (CNRS-IN2P3, Paris-Sud University), and, in the string assembly area, they are assembled to a string of eight cavities. The so-called string is the core of the accelerator module. The next stations are located outside the cleanroom, in regular assembly halls. There, the strings are equipped with several sensors, the helium supply, cables and other parts which are necessary for future operation. This requires great accuracy and care at each individual procedure. No matter whether bolted, welded or stretched – everything must fit perfectly and stay clean. Finally, the module is packed into a large yellow vacuum tank. "Of course, we carry out a thorough quality control at each step. This ensures that each module leaving Saclay is fully operational," says Napoly.

As soon as the completed module has successfully passed the final test, it starts its one-day journey to DESY. Here, it is again received by Jacek Swierblewski´s team in the AMTF hall. The Polish team from Cracow (see DESY inForm 1/2016) is also running the three module test stands. The test takes 21 days. The module is cooled down to its operating temperature of 2 Kelvin (minus 271 degrees Celsius). The test includes many steps and measurements to ensure the function of the module. Moreover, the accelerating properties of the individual cavities are measured and the data are transferred to the waveguide experts. Waveguides secure the energy supply of the module – they transport the microwaves used for particle acceleration to the cavity.

"The measured data from the module tests help us to produce a tailor-made energy supply for each cavity," explains Stefan Choroba, head of the work package radio frequency system. "First, we calculate the required power distribution and subsequently we adapt the necessary parts." This customised production takes place in the so-called Waveguide Assembly and Test Facility (WATF), located in close proximity to the module test stands. At five stations, a 27-person team from Bulgaria, Russia and DESY assembles the complete waveguide supply for each individual module. "For the waveguides, we have a collection of standard components which are appropriately put together and tuned," explains Valery Katalev, head of the WATF team. The tuning – i.e. the adjustment to the requirements of each cavity – is carried out with great care. The tailor-made energy supply makes it possible to operate each cavity in each module with maximum capacity. Therefore, the module is not limited by its weakest cavity.

Simultaneously, two or three of these waveguide distribution systems are assembled and tested, thus producing a rate of one and a half completely installed distributors per week. "This rate is an enormous achievement of the team," says Choroba. "Within that time, not only customised production but also the attachment to the module must fit accurately to the millimetre." More than 80 000 bolts must be tightened for all 100 distributors without mechanically warping the couplers. "This exactitude and this rate could only be achieved by optimising the work flow," explains Katalev. "Before mounting and during the installation of all parts and connections, all components are double-checked by two colleagues."

When all components are assembled, a load test is carried out with full capacity of up to 2.5 megawatts per distribution system. With this, the colleagues ensure that everything will work in the accelerator as it should. When the distribution system passes this test, the WATF team will mount it at the module. After that, the module with the distribution system is ready for the final step of its journey: the installation into the accelerator tunnel.

CAVITY | CEA-IRFU | CNRS/IN2P3 | CNRS/LAL | DESY | EUROPEAN XFEL | SACLAY | SCRF

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DIRECTOR'S CORNER

What Is Basic Science Good For?

Hitoshi Murayama | 12 May 2016

I spend a fair amount of time giving public lectures on particle physics and cosmology around the world. Quite often, I receive the same question from the audience, "*what is this good for?*"

There is a wonderful movie titled *Particle Fever*, a documentary about the discovery of the Higgs boson at the Large Hadron Collider (LHC) at CERN filmed over five years. It describes the excitements, disappointments, challenges, and the human emotions experienced by the scientists. I highly recommend this movie, which is available on iTunes and Netflix. Lyn Evans, who led the construction of the LHC and is the Director of Linear Collider Collaboration, appears many times in the movie.

About twenty minutes into the movie, David E. Kaplan, the producer of the movie and one of my collaborators, is shown answering precisely this question what the research in particle physics is good for. He answers simply, "*I have no idea*," and the audience bursts into laughter. And David continues. "*We have no idea. When radio waves were discovered, they weren't called radio waves because there were no radios. They were discovered as some sort of radiation. Basic science for big breakthroughs needs to occur at the level where you are not asking what is the economic gain. You are asking what do we not know, and where can we make progress. So, what is the LHC good for? It could be nothing, other than just understanding everything.*"

We humans are curious creatures, always trying to make sense of the world around us. This curiosity propelled us from apes to an intelligent life form, capable of manipulating the environment rather than being subject to it. It has its downside, namely that we create havoc to the environment to the extent that we are now changing the climate of the entire planet we live on. Yet it is undeniable that our curiosity allowed us to improve our quality of life. We changed ourselves from hunters-gatherers to members of modern civilisation. We don't worry about getting eaten by predators; we worry whether we have enough savings after retirement.

Indeed, basic science aims at making sense of *everything*. We want to know why we age and die. We want to know how we evolved into different races, ethnicities, cultures, and languages. We want to know how life was born on this planet, or possibly on other planets. We want to know how our solar system was made. We want to know *how we came to be*.

How did we come to be? Modern science, in particular particle physics, astrophysics, and cosmology, revealed a stunning story. Much of our bodies were synthesised in stars that exploded billions of years ago. The stars were formed by the gravitational pull of elusive dark matter, a mysterious matter that dominates the Universe yet none of us managed to meet so far. Atoms in our bodies would vaporise in nanoseconds if there weren't for the Higgs boson that is frozen everywhere in space. We live on the sacrifice of a billion friends that annihilated together with dangerous anti-matter; we still don't know how a billionth of matter could survive. And the whole thing started from quantum fluctuations, lending and renting tiny amounts of energy due to the uncertainty principle, when the whole Universe we see today was much much smaller than the size of an atomic nucleus.

Why do we care about these questions? I don't know. But *we do*. People were burned and arrested when we realised that we are not at the centre of the Universe, but rather circled around the Sun. Now we know the Sun is not the centre of the Universe either, and circles around the centre of galaxy every 200 million years. And our galaxy is only one of a hundred billion galaxies in the Universe we can see. Moreover, what makes up the galaxies is not atoms we are made of, but mostly rather the mysterious dark matter.

Actually, the modern civilisation was built pursing these seemingly useless questions. We can fire canons and missiles, and launch artificial satellites because we managed to understand how planets and stars move. We can call friends in different countries because we managed to understand what light is. We can carry smart phones in our pockets because we managed to understand what tiny electrons do in semiconductors. We can build maglevs much faster than Shinkansen in Japan because we were curious to study what happens to metal when it is cooled to very low temperatures. We developed magnets to keep the protons running at 99.999999 percent of the speed of light inside the circular tunnel, which led to medical imaging to spot where cancer cells are. And we can buy books and clothing from our living room because of the web invented at CERN for scientists to exchange data for this kind of pursuit.

There is a famous episode about Michael Faraday, when he was trying to understand how electricity and magnetism work. When William Gladstone, then British Chancellor of the Exchequer (minister of finance) asked of the practical value of electricity, Faraday responded, "*One day sir, you may tax it*." I seriously doubt Faraday had any idea what role electricity plays in modern civilisation, but he was absolutely correct. We live and tax on power.

There are probably two reasons why basic science pushed the humankind forward. One is that the acquired knowledge from curiosity itself is crucial to advance technology. The other is that the tools needed to acquire knowledge drive fundamentally new technology. Either way, the pure curiosity has been the driver for more and more sophisticated technologies, which help our daily lives to make things possible that used to be unthinkable.

Projects like LHC and International Linear Collider (ILC) belong to the second category. They require such demanding technology, they inevitably lead to technological breakthroughs. Even though it is difficult to foresee, just like what David said, building ILC would lead to new breakthroughs and innovations, which in turn will help our society in some big way.

BASIC SCIENCE | LHC | MOVIE | OUTREACH | PARTICLE FEVER | TECHNOLOGY BENEFITS

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IMAGE OF THE WEEK

National Lab Day

Image: Argonne, Mark Lopez | 12 May 2016

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Image: Argonne, Mark Lopez

ARGONNE | BROOKHAVEN | DOE | FERMILAB | JLAB | SLAC