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Pure Science and So Much More: Particle Detector Development in France

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Pure Science and So Much More: Particle Detector Development in France

—**Sam Meehan** (Edited by Kristin Brodeur and Brigid C. Casellini)

While it is easy to understand how advances in the applied sciences will benefit society, people sometimes question the practical role of fundamental science research and the need to invest money in such research. However, I learned firsthand the importance of such efforts while working with a new type of particle detector called the Micromegas detector. Fundamental physics research like this contributes to the development of new technologies that can be used for pragmatic applications in medicine and other fields. For instance, knowledge of the proton and its interactions with matter has allowed for the development of a much safer form of radiation therapy for cancer patients. In the future, the Micromegas detectors may be used in medical imaging. With applications like these, it is easy to see why research at the fundamental level is necessary not only for the noble pursuit of knowledge but to help society advance in the twenty–first century.

A well–deserved break: Sam Meehan visited the Colosseum in Rome after completing his research in France.

With this in mind, in summer 2008 I received funding from the International Research Opportunities Program (IROP) at the University of New Hampshire to conduct research at the Commissariat á l'Energie Atomique (CEA) laboratory in Saclay, France, a suburb near Paris. My objective was to study Micromesh Gaseous Structure particle detectors, commonly referred to as Micromegas detectors, which were first invented at the CEA in the 1990s.

CLAS12 : The Bigger Picture

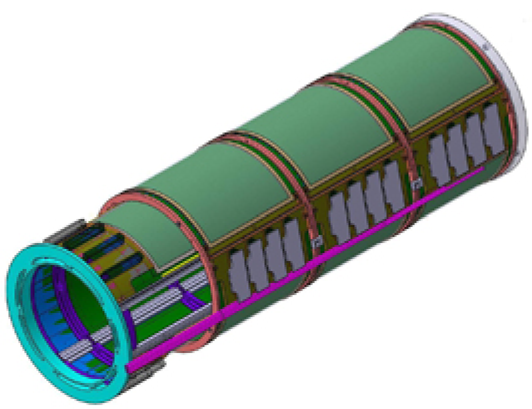
Particle detectors come in a wide variety of designs, and all are used to determine information about a physical interaction; for my research we studied the interaction between an electron and a proton. When a group of particle detectors is installed in conjunction with a magnet, the resulting device is called a spectrometer, which can be used to filter particles and study only those of interest. Such a spectrometer is the focus of the Continuous Electron Beam Accelerator Facility Large Acceptance Spectrometer (CLAS12) international collaboration, a fundamental science research initiative underway at Jefferson Laboratories in Newport News, Virginia, of which the CEA in Saclay is a part. There, the installation of Micromegas detectors will allow for experiments using electron beams of energies up to 12GeV (giga electron volts). This is equal to the energy of an electron after being accelerated through a 12 billion volt electric potential, and is the source of the name CLAS*12*.

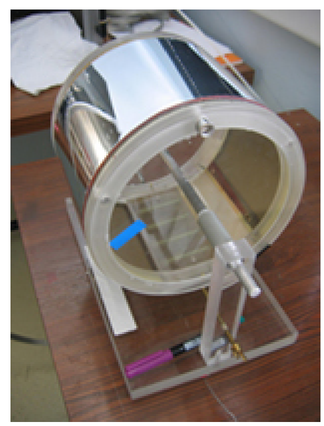
One of the benefits of using a large acceptance spectrometer is that it allows us to study particles in a greater area around their interaction point. Moreover, by increasing the energy of the electrons used, theories can be tested on a wide range of parameters, allowing for exploration of new phenomena that may exist only at higher energies. A primary aim of this international collaboration of physicists, engineers, and students at Jefferson Lab is to study the substructure of the proton. Empirical measurements necessary for studying the proton substructure require the use of very accurate detector systems. By including Micromegas detectors in the inner tracking system of the spectrometer, more accurate measurements may be taken.

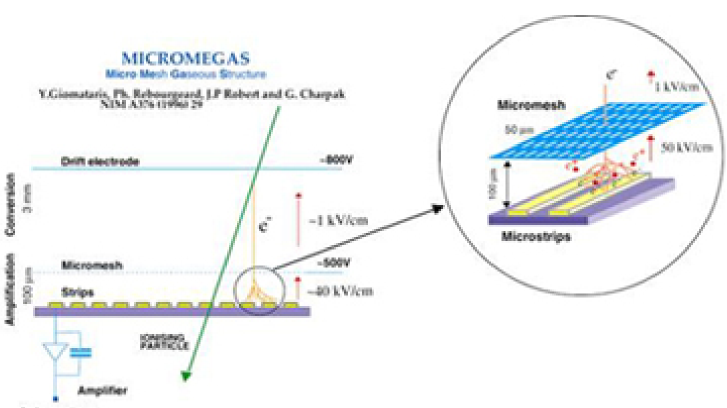
To ensure proper operation of these detectors in CLAS12, we must understand how they behave. My research focused on the lateral drift of electrons in the Micromegas detector when under the influence of a magnetic field. My goal in conducting this research and spending time in France was twofold. First, I hoped to contribute to the development of technologies with practical implications beyond fundamental science. Second, I hoped to gain a more global perspective by immersing myself in a culture so different from my own.

It Does What? How Micromegas Detectors Work

When installed in the spectrometer, the Micromegas detectors will form a multilayer system that allows physicists to reconstruct the trajectory of a particle thereby providing information about the initial interaction that occurs in the experiment (Fig. 1). Each Micromegas detector within this layered system is itself a multilayer gas–filled particle detector with a typical construction as shown in Figures 2 and 3.







TOP LEFT: *Fig. 1 – Micromegas detector set up for use in CLAS12. Three layers of detectors will allow for the mapping of the particle trajectory. (2)*

TOP RIGHT: *Fig. 2 – Micromegas detector prototype after bending.*

LEFT: *Fig. 3 – Close up cross section of Micromegas detector showing electrons in the amplification gap. (1)*

A Micromegas detector is comprised of two thin metal sheets, or electrodes, that create an electric field and are separated by very fine wire micromesh. The space between the two sheets is filled with a special gas mixture that optimizes the detector's ability to determine a particle's location, the energy deposited by a particle, and the time of a particle's detection. The space above the micromesh is called the conversion gap, and the space below it is called the amplification region.

When an energetic particle (e.g. proton, neutron, photon) passes through the detector, a force is created between the particle and the electrons in the gas. This force rips the electrons, usually five to ten of them, away from the gas atoms in the conversion gap. In our experiment, the energetic particles were photons emitted by a laser.

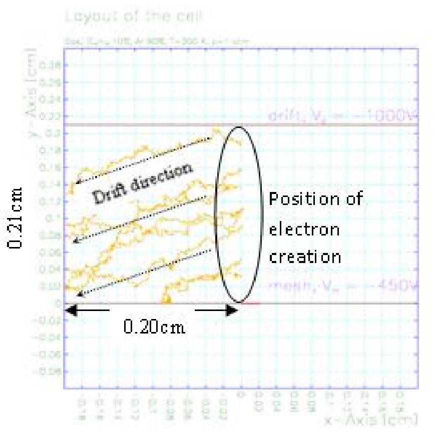


Fig. 4 – Data from CERN simulations under normal laboratory conditions in CLAS12. (3)

The freed electrons then drift through the micromesh into the amplification region. Because the distance between the micromesh and bottom metal sheet is much smaller, a very high electric field exists. This amplifies the free electrons, creating thousands of electrons that deposit themselves on metal strips running parallel to each other on the bottom metal sheet. After the electrons land on the metals strips, a voltage signal is sent to computers which analyze the signal to determine the particle's position.

However, it must be taken into consideration that the high magnetic field in the conversion gap forces the electrons to drift laterally along the detector before crossing the micromesh. This means that the electrons, which represent the position where the original particle passes through the detector, are detected away from where the particle actually crosses the detector. Simulations previously performed at CERN (Conseil Européen pour la Recherche Nucléaire) show the drifting distance to be quite large (Fig. 4).

My study aimed to characterize this drifting and determine a way to minimize its effect on determining the position of the incident particle.

Espresso and Lasers: My Study

After spending a few days learning how these detectors work, I began testing them in different magnetic fields. My days in the lab were filled with long hours taking data and trying to find a balance between understanding the French scientists around me and the science in front of me. They were also filled with the necessary breaks for espresso, taken religiously after lunch and at least once, if not twice or more, in the afternoon. With each labored conversation over the strong brew, my proficiency in the French language slowly grew. By the last few days of the summer, I was able to communicate with my fellow scientists entirely in French.

I set out to characterize the lateral drift of electrons by using a parameter called the Lorentz angle (Fig. 5). I used a smaller detector prototype designed to exaggerate the electron drifting in order to improve the accuracy of the Lorentz angle measurements. This prototype was placed in a 1.5 Tesla (T) magnetic field, and although this is not as high as the field used in CLAS12, it provides a reliable preliminary indicator as to how the detector will operate in the 5T magnetic field.

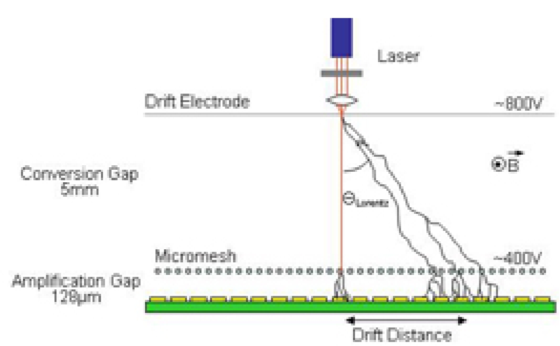
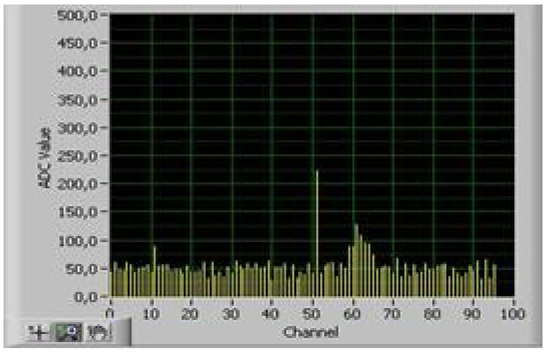


Fig. 5 – Experimental setup used to study the Lorentz angle. (4)

We designed two experiments to determine the dependence of the Lorentz angle on different factors. In the first experiment, we set the strength of the electric field between the metal sheets to a constant value and varied the magnetic field. In the second experiment, we set the magnetic field to a constant value and varied the strength of the electric field.

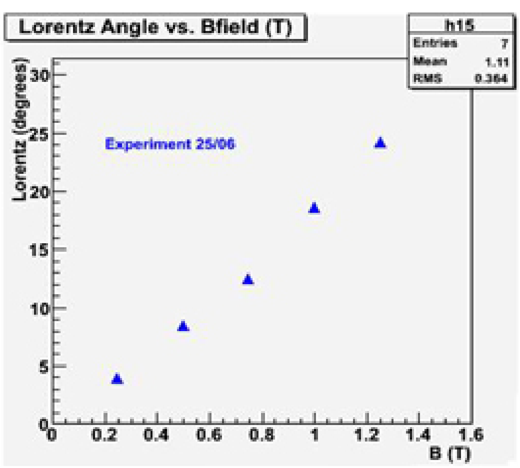
We focused a laser on the detector to simulate incident energetic particles. With no magnetic field, the detector functioned as expected and the electrons drifted toward the mesh in the vicinity of where they were first created. When the magnetic field was turned on, the electrons drifted by a certain Lorentz angle and were detected at a point away from where the energetic particle originally passed into the detector.

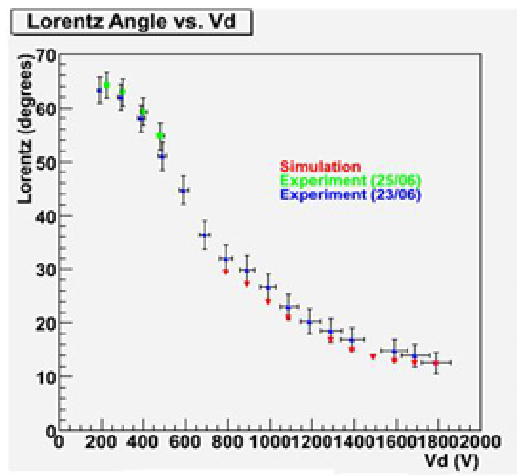


LEFT: *Fig. 6 – Example of data output from Micromegas detector electronics. Seen here is the sharp peak from the laser (left) and the drifted electrons (right) (5)*

BOTTOM LEFT: *Fig. 7 – Plot showing observed Lorentz angle versus strength of the magnetic field. In this test, the electric field in the drifting region is constant.*

BOTTOM RIGHT: *Fig. 8 – Plot showing observed Lorentz angle versus drift voltage. In this plot, there are two runs of experimental data and one of simulated data superimposed in different colors. In these experiments, the magnetic field strength was constant.*





To determine the Lorentz angle, we used data from the readout electronics to calculate the position of the voltage spike, which represents the location where the photons entered the detector. We also determined the center of the broader distribution of voltage spikes that appears next to the initial spike and represents the electrons' positions as they drifted across the detector (Fig. 5). We used the distance between these two positions to calculate the Lorentz angle.

In the first experiment, conducted under a constant electric field, a higher magnetic field caused a larger Lorentz angle. As the magnetic field increased from 0.2T to 1.3T, the electrons experienced a stronger lateral force and were pushed farther across the detector as they drifted to the strips (Fig. 7).

In the second experiment, conducted under a constant magnetic field, we reduced the window of time the electrons had to drift laterally by increasing the drift voltage and thereby creating a higher electric field (Fig. 8). As a result, a smaller Lorentz angle was produced.

Although the magnetic field (1.5T) used in this experiment was not high enough to empirically understand what will happen in the CLAS12 environment (5T), it is important to note that the data and simulations were consistent with previous simulations conducted at CERN. These data suggest that the simulations adequately model the behavior of the detector and that one may decrease the Lorentz angle in high magnetic fields by increasing the drift voltage. Indeed, recent tests performed at Virginia's Jefferson Laboratories in a high magnetic field have confirmed that the Lorentz angle can be successfully minimized to about 15 to 20 degrees by increasing the drift voltage.

Outside the Lab

Apart from research, my summer brought a wealth of cultural experiences. I discovered a true French culture separate from the stereotyped ideas held by many Americans. First, I discovered that the French are not a rude and exclusive people. On many occasions, I found myself engaged in conversation with Parisians I met while going about my daily activities. One night, while making dinner in my dorm, I spoke with a French student. Upon learning I was American he exclaimed, "Americain! C'est cool!" and insisted we speak English. This seemed to be a habit of many Parisians I met, and despite my attempts to learn French, it was sometimes difficult to practice my language skills. However, to my surprise, near the end of the summer I became quite good at holding a conversation, and on a trip to Spain I actually spoke with a man from the Middle East in our only common language: French.

Although my previously held opinion of the French people changed dramatically during my stay, I was pleased to find that my preconceptions of French food and drink were confirmed and in many cases exceeded. Every day for me was a new adventure in cuisine, even in the dining hall at the CEA. Some days, as when I tried *boudin* (French blood sausage) and *andouillete* (sausage from pig intestines), my palette felt bewildered and lost. Other times, when I dined on a Nutella–filled crepe or steaming escargots in garlic butter with a glass of Bordeaux, I was in heaven. The coffee was a special treat for me, and something I discovered the French take very seriously. My mentor, Jacques Ball, said it best by describing American coffee as "a warm brown liquid that bears a slight resemblance."

The everyday lifestyle in France was new to me. Relaxed and sincere, the French truly know how to savor all of life. They take time to enjoy the simpler things, whether that may be going to the market on a Sunday afternoon or playing football (which was not always a relaxed venture given that half of those playing imagined themselves as players of their favorite club). No matter the situation, I always found plenty of smiles and something new to discover.

Beyond Pure Science

This project was multifaceted in its purpose and went beyond the research that was being performed. As science advances in the twenty–first century, the sheer size of experiments will require international collaborative efforts. This project introduced me to what it means to be part of a global community and to practice fundamental science research with a group of diverse individuals. It can be difficult with most fundamental research to find direct applications for new knowledge, but my study shows great potential in several seemingly unrelated fields.

The first of these is in obtaining a more fundamental understanding of the proton, which is necessary for further development of proton radiation therapy for cancer treatment. As opposed to conventional radiation therapy, which often uses x–rays, protons can be controlled in such a way that they deposit their energy at a more precise location, thus causing less collateral damage to tissue surrounding the cancer. Another area where my research may be applied is in the development of the Micromegas detectors themselves. Because these detectors can be shaped into a variety of geometric configurations, such as a cylinder, they may be used in medical imaging technologies that could encompass entire extremities, such as a head cap to image the brain. Although my research was fundamental in nature, it reaches beyond pure academic pursuits and holds much promise for producing knowledge and technologies with great benefits to society.

I would like to extend my infinite gratitude to all those who worked with me and on my behalf to make this project possible: The Hamel Center for Undergraduate Research and International Research Opportunities Program for giving me this opportunity; Dr. Maurik Holtrop (UNH) and Dr. Jacques Ball (CEA) for mentoring me with so much more than just science along the way; and to Dr. Franck Sabatie, Dr. Marouan El Yakoubi, Dr. Herve Moutard, and Piotr Konczykowski for everything while at the CEA.

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Author Bio

*A physics major from Chazy, New York, senior **Samuel Meehan** has spent the last four years at the University of New Hampshire seeking opportunities to expand his knowledge of the world. From late May through early August 2008, Sam lived in France while he researched particle detectors. The research, funded by the International Research Opportunities Program (IROP), was designed to complement research being done for his Honors thesis project. "By doing this, it helped me to find a unique type of satisfaction by balancing being a student and learning from others with being a researcher and discovering for myself," he said of the experience.*

After graduating in May 2009 with a Bachelor of Science in physics and a minor in applied mathematics with an honors designation from the University Honors Program, Sam plans to attend graduate school. Ultimately, Sam aspires to become a physics professor. "I have always loved learning and discovering and showing others the interesting aspects of nature through teaching them what I know," he said. "I have realized that the more I learn, the less I know and [more] I want to discover."

Mentor Bio

*Dr. **Maurik Holtrop** is an associate professor in the Physics Department at the University of New Hampshire. Lately he has been focusing his teaching on quantum mechanics, which he admits can be challenging. His research focuses on studying the details of particles, specifically how quarks combine into particles such as the proton. Dr. Holtrop has mentored several undergraduate and graduate students in the past, and found the* *opportunity to mentor Sam Meehan very rewarding. "It has been great working with Sam," he said. "It is very satisfying to see a young person's career take off."*

Though he is now on the faculty, Dr. Holtrop also knows what it's like to be a student at UNH: He graduated with a bachelor's of science in physics in 1987. He then went to M.I.T. for his graduate studies before returning to his alma mater in 1995 as a post–doctoral student. In 2000 Dr. Holtrop joined the research faculty, and in 2002 he became part of the teaching faculty.