Newsletter Interview

THE MUON COLLIDER: GREAT DISCOVERY POTENTIAL IN A COMPACT ACCELERATOR

Interview with Daniel Schulte, researcher at CERN and study leader for the Muon Collider

In Europe, the particle physics community is investigating the possibility of building a particle collider based on a new technique and which could have enormous potential for discoveries and precision measurements at the energy frontier: the Muon Collider, an accelerator in which muons are accelerated and collided. This project was discussed also in the Italian national workshop "INFN and the European Strategy for Particle Physics", which was held on May 6 and 7 in Rome and was well attended by the scientific community, including young researchers. During the workshop we met Daniel Schulte, CERN research who is coordinating the feasibility study for the Muon collider.

Can you describe the Muon Collider project?

Typically, in the past, we collided electrons and positrons or protons. While now we are trying to build a Muon Collider. In many ways, muons behave like electrons, but they are heavier and so when they collide, they do not undergo energy losses through synchrotron radiation and they can reach higher collision energies. That's the main advantage of building a Muon Collider. The disadvantage is that the muons are unstable, they have a limited lifetime, and therefore, we have to accelerate and collide muons before they decay.

Which are the main challenges in successfully implementing a Muon Collider?

All of the challenges come, indeed, from the fact that the preparation of the muon beams up to the collision energy has to be done very quickly. Muons are produced by sending protons into a target, from which pions are produced, and they decay into muons. However, muons come in a "shower", they do not come in nice beam but rather in a sort of spray of muons. And because of this, they need then to be "cooled", meaning that we do something to make these beams more compact. And this needs to be done very quickly again before the muons decay. We achieve this cooling by making the beams pass through thin targets of material, which is something that you cannot do with other particles used in accelerators. After that, we accelerate them rapidly, which means that in milliseconds they have to reach the full energy. And finally, we collide muons and anti-muons before they decay (we have around tens of milliseconds to do that). This cooling process is something that has never been done before, there have only been some successful tests. And also this very fast acceleration is challenging. Furthermore, we want the collider to be as small as possible so that the muons can make as many turns as possible before the decay and we increase the number of collisions. Hence, the main challenges are: the design of this cooling technology, the size of the accelerator and the very strong magnets that we need. Very fast ramping magnets are needed, because we want the beam to be available for collisions very quickly.

What are you working on right now? And how is your work organized?

Currently, we are working on the cooling modules, which need to be very compact because the path for the muons should be as short as possible. Then, we need to integrate the focusing solenoids, very strong superconducting magnets with accelerating cavities, which generate longitudinal electric fields. So, we are starting to make an engineering design of how such a system could look like so that it can be experimentally tested and improved. That's something that a research group in INFN Milano is leading. Before that, we did two designs for the fast-ramping magnets. Here, the main issue is that there is a high energy stored in the magnets and we want to recover it into our system and not just waste it. So, we designed a system that can take the energy out of the magnet and put it back later in without losing very much. So, for the magnets we are focusing on this novel high temperature superconductors, because we believe those are better for the long-term future. Furthermore, we need high fields (higher fields than those produced by other superconductors), so for the moment we are like trying superconducting cables and trying to compare them and to find ways to improve this technology.

How big should the new collider be?

Well, the collider ring could be of the order of tens of kilometers of circumference if we go to 10 TeV, which would be comparable to a 100 TeV Hadron Collider in physics reach, roughly. The accelerator ring would be somewhat larger than the LHC, around 30 km, because of the magnets dedicated to the acceleration of the beams. And actually, we are going to consider if the LHC tunnel, which is 27 km long, can be reused for that. Even if it's slightly too small, it would be easier to use an already existing tunnel. It would be significantly more compact than other accelerators with a similar physics reach.

How large is the International Muon Collider Collaboration?

We now have around 50 institutes which are full members of the Collaboration, and some tens or so that are on the way of signing an agreement or are contributing without signing a formal agreement. In our last paper, which summarizes the work we did in the past two years, we have 388 authors, which have all contributed to the study. So, the collaboration is not that small, but our budget is relatively small and people are doing lots of volunteer work.

How is the INFN contributing to the Muon Collider?

INFN is very active in the collaboration. Certainly, in the physics and in the detectors' development, INFN is leading that effort. Furthermore, in terms of the cooling technology, integrating high field solenoids with cavities, this activity is driven by INFN and its group in Milan (LASA).

Which are your expectations for the future?

Well, we hope that since we ramped up this effort over the past 2 to 3 years, also the European Union helps the project by contributing with a budget from the union and we would like that to keep also increasing. The goal would be to prepare the technology so that in about 5 to 15 years from now, everything's mature enough that you could commit to funding and building such a facility. Moreover, at the end of last year, in the US the strategy proposal by the Particle Physics Project Prioritization Panel (P5) of the United States recommended that the US should join the

Muon Collider Collaboration and should also consider hosting the Muon Collider in a laboratory in the United States. So, the Muon Collider could be an option not just for Europe but also for the US.

Do you have a competitor? Are there other scientific groups studying for a Muon Collider?

No, at this moment, I think there is a consensus that it is important to combine forces on the R&D of the Muon Collider and then, at some stage, maybe there will be a competition on whose country is going to host it. We are certainly competing in a way with other projects that use different approches for resources. In terms of physics reach, we are competing with the FCC-hh or the Chinese CepC, which would be having a similar physics case roughly. Other competitors may be the linear colliders. However, their proposals are going up to 3 TeV and so they will not quite reach the energies that we need. I mean with the Muon Collider we would consider 3 TeV to be as a potential starting energy, while for linear colliders that would be the final energy.

What could be studied with the Muon Collider?

There are different possibilities, an example is that we can do more investigations of the Higgs boson, we can measure the self-coupling of the Higgs. An advantage that the Muon Collider has, compared to a proton collider, is that it has the full energy given to the particle available, while since the protons are composite particles, only a fraction of the collision energies are available to produce new particles in a proton collider. We would have a great discovery potential, for example with the Z', predicted by some theories that go beyond the Standard Model (SM), which is similar to the Z^0 boson but it can only be measured indirectly in colliders with lower energies than those required for its production. The Muon Collider is an exploration machine, a discovery machine and, at the same time, it is a precision machine like an electron-positron collider.