Chapter 4
Sharing LHC Research and Discovery with High School Students

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Abstract Research institutes and universities around the world invite students and their teachers for a day-long programme to experience life at the forefront of basic research. These *International Masterclasses* (www.physicsmasterclasses.org) give students the opportunity to be particle physicists for a day by analysing real data from CERN's Large Hadron Collider (LHC). The project attracts each year more than 13,000 high school students from 46 countries.

In the *International Masterclasses*, high school students work with real data collected by the experiments at the LHC. The programme bridges the gap between science education at school and modern scientific research. Participants can explore the fundamental forces and building blocks of nature and are informed about the new age of exciting discoveries in particle physics, e.g. the discovery of the Higgs boson. Moreover, they can actively take part in cutting-edge research and improve their understanding in science and the scientific research process. The programme offers authentic experience and adds valuable experiences to physics education at school, thus stimulating the students' interest in science.

4.1 Introduction

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. The 27 km ring is situated next to Geneva, Switzerland, at the CERN site. Scientists at the LHC are conducting a broad research programme, which aims at fundamental questions on origin and structure of our world. By tracing processes between elementary particles, they shed light on the development of the universe 10^{-12} s after the Big Bang (see Fig. 4.1).

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M. Pietrocola (ed.), *Upgrading Physics Education to Meet the Needs of Society*,
https://doi.org/10.1007/978-3-319-96163-7_4

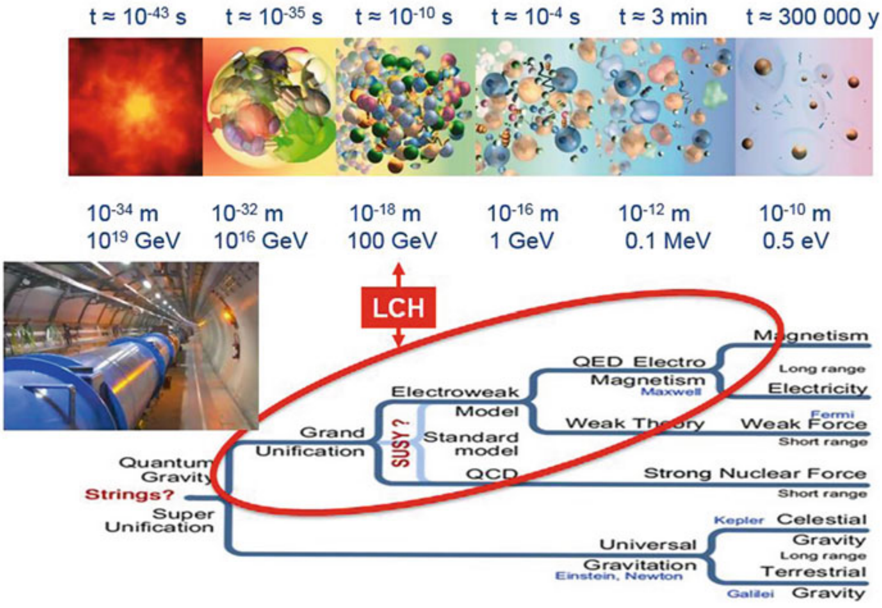

Fig. 4.1 Evolution of the universe from the Big Bang to the present: the LHC looks at $<10^{-10}$ s after the Big Bang

Results of the experiments at the LHC are followed with great interest, not only by physicists but also by the general public. The discovery of the Higgs boson at the LHC in summer 2012 led to a huge media echo and large public interest. Although particle physics is one of the most fascinating and emerging fields in science, it is often not covered in curricula and school lessons. There are several reasons for this situation: Introducing particle physics requires many new concepts and perceptions, e.g. strong charge, weak charge, messenger particles, and thus a large number of new terms. In addition, there is no strong connection between the world of elementary particles and everyday experience. In contrast to that, particle physics has inherent strength and attractive features and thus offers several chances to successfully introduce high school students to the subject:

- Unique experimental setups with highly complex technique create superlatives, e.g. one of the coldest places on earth, largest superconducting installation, biggest operational vacuum system
- Fundamental questions on origin and development of our universe, elementary building blocks which make up the world around us and the fundamental forces between them
- Fascinating terms, e.g. Big Bang, antimatter
- Strong presence in the media

Fig. 4.2 High school students at a masterclass

4.2 Particle Physics Masterclasses

International Masterclasses[1] is a programme that has been created to offer high school students (aged 15–19) the chance to explore this field of cutting-edge physics by working with recent, authentic data from experiments at the LHC (Bilow and Kobel 2014; Bardeen et al. 2014). In this way, *International Masterclasses* bridges the gap between science education at school and modern scientific research. The basic idea of the annual programme is to let students work as much as possible like real scientists in a format that is called masterclass (Fig. 4.2).

As in a masterclass in the arts, high school students work with a particle physicist as an expert on the subject particle physics data analysis. The students get invited to a nearby research institute or a university to be "scientists for 1 day" and to experience life at the forefront of basic research by analysing real data from LHC experiments. This unique hands-on approach ensures that the knowledge and insight that students acquire during the masterclass is action-orientated.

The programme is run every year in spring. In 2016, *International Masterclasses* were held from 11.2. to 23.3. in more than 200 research labs or universities in 46 countries (Fig. 4.3), with up to ten institutes participating per day.

Although the participating institutions are able to configure some aspects of the event individually, each masterclass follows a uniform scheme. In the morning of the day, students listen to introductory talks about particle physics. Presentations are adjusted to students' level and given by the masters—scientists familiar with outreach and education. In the lunch break, there is the opportunity for the students to talk to undergraduates, graduate students and professors.

After the lunch break, the practical part follows, which takes place on PCs. Students work with data from particle collisions recorded at the LHC on an own measurement. After an appropriate introduction to the programmes, they perform the

[1] http://www.physicsmasterclasses.org/

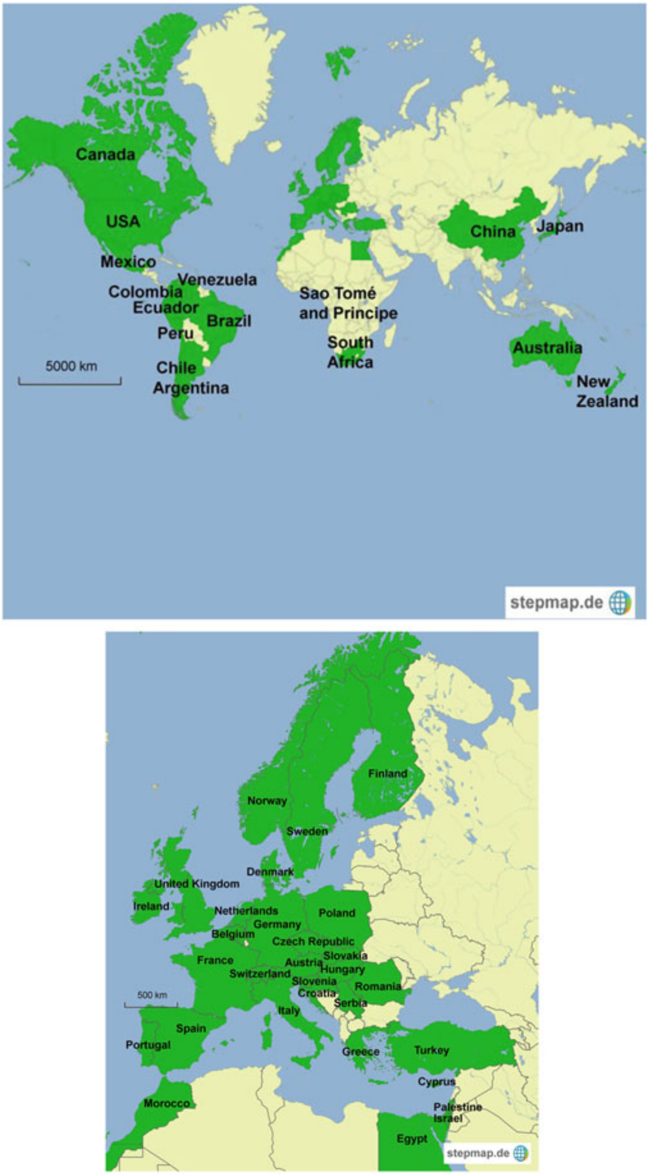

Fig. 4.3 Maps displaying countries that participate in *International Masterclasses*

measurement task autonomously, supported by the masters. At the end their findings are discussed with the group.

To simulate a real scientific working environment, each masterclass ends with a video conference, where up to five student groups from different countries connect

Fig. 4.4 Screenshot of a videoconference with five student groups and moderators at CERN (top left)

with two moderators at CERN or Fermilab (Batavia, Illinois, USA) to combine and discuss their results (Fig. 4.4). Students can also pick their moderators' brains in a Q&A section. Most video conferences end with a multiple-choice quiz on particle physics. More than 60 physicists have volunteered to moderate the video conferences at CERN or Fermilab.

4.3 LHC Data for High School Students

All LHC experiments provide large samples of recent data. Six measurements with a wide range of study tasks are available. For example, students can rediscover the Z boson or the structure of the proton, reconstruct "strange particles" or measure the lifetime of the D^0 particle. One of the highlights is the hunt for Higgs bosons. ATLAS and CMS have made available real Higgs candidate events for students to track this rare, elusive and very short-lived particle. Typically, a research lab selects a measurement with which the physicists have a deep relationship, guaranteeing that authentic experts are available to talk with students about what they know best. The following sections present two exemplary measurements.

The ATLAS W path[2] deals with the structure of the proton and the search for Higgs (Bilow et al. 2014). Students analyse events (Fig. 4.5) and look for a W boson decaying into a charged lepton and a neutrino (missing energy) and build the charge ratio $\frac{N_{W^+}}{N_{W^-}}$. The simple view of uud quarks leads to a naive approximation of $\frac{N_{W^+}}{N_{W^-}} = 2$.

[2]http://atlas.physicsmasterclasses.org/en/wpath.htm

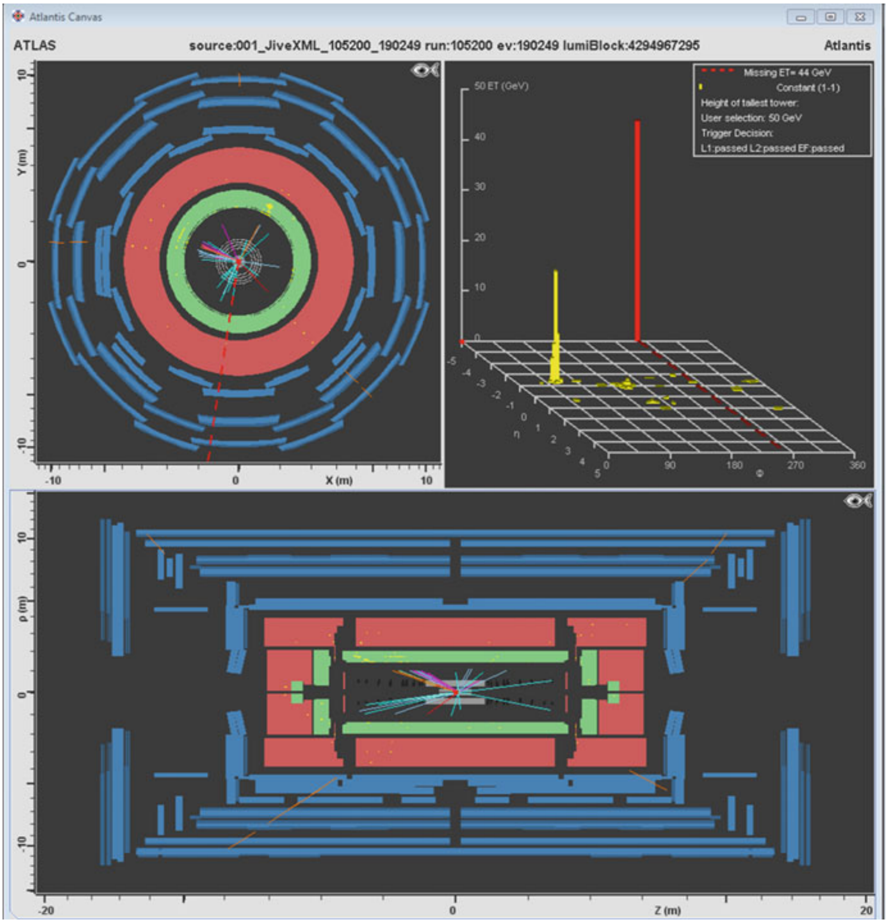

Fig. 4.5 Event display Minerva

The presence of sea quarks and gluons complicates the picture, bringing the ratio down to ~1.5, compatible with what ATLAS and CMS have measured. The next challenge is to study events containing W^+W^- pairs, characterized by two oppositely charged leptons and neutrinos. The Higgs boson decaying to W^+W^- would enhance the distribution of the azimuthal angle between the charged leptons at low values.

In the CMS measurement,[3] students use a 3D event display (iSpy-webgl). Based on the signatures of leptonic decays, they determine whether each event is a W candidate, a Z candidate, a Higgs candidate or background. For W bosons, they use the curvature of the single measurable lepton track to decide if it is a W^+ or W^- to derive the charge ratio of W boson production and characterize events as muon or

[3] http://cms.physicsmasterclasses.org/cms.html

Fig. 4.6 Students with histogram built from sticky notes

electron events to measure the electron-to-muon ratio. For Z and Higgs candidates, students put, respectively, the invariant masses of lepton and di-lepton pairs in a mass plot. They discover the Z and the Higgs peaks, including a few other resonances they might not have expected. The analysis can be done on a PC or, as shown in Fig. 4.6, by building a histogram with sticky notes.

4.4 Organization and Development of the Program

International Masterclasses are organized by the IPPOG[4] (International Particle Physics Outreach Group) collaboration (Alexopoulos et al. 2015). IPPOG is a network of scientists, science educators and communication specialists, working in informal science education and outreach for particle physics. The collaboration includes representatives from 27 states (incl. the CERN member states) and major experiments from several countries.

A steering group manages *International Masterclasses* in close cooperation with IPPOG. The coordination is provided through TU Dresden and QuarkNet: while the TU Dresden-based coordination is responsible for ~170 institutes in Europe, Africa and the Middle East, coordination through QuarkNet covers North and South America, Australia and Oceania and the Far East (~45 institutes).

International Masterclasses have developed from a programme run in the UK since 1997. The idea of particle physics masterclasses was adopted by IPPOG for the whole Europe in 2005, the World Year of Physics. At that time, masterclasses were organized in 17 countries, with 3000 students participating. With the LHC being still under construction, data from the former accelerator, CERN's LEP, was analysed. Since then the programme has experienced steady growth (Fig. 4.7). In 2006, the USA joined the programme. More countries from the Middle East or Latin America have been attracted in recent years, leading to enormous numbers of participants.

[4]http://ippog.org/

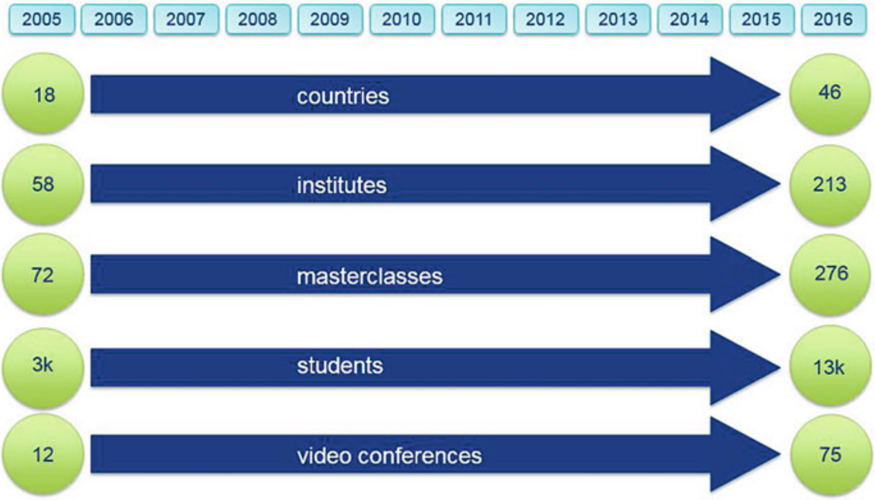

Fig. 4.7 Development of *International Masterclasses* from 2005 to 2016

4.5 The German Programme Netzwerk Teilchenwelt

International Masterclasses has led to other masterclass initiatives, e.g. national programmes, remote programmes for students in areas far from research labs, professional development programmes for teachers including masterclass elements, activities in science centres and museums and masterclasses in other fields of physics. The largest national programme exists in Germany and is called *Netzwerk Teilchenwelt*[5] (Network Particle World) (Rockstroh et al. 2013). In this multi-level programme which is led and organized at TU Dresden, 28 research labs in Germany are working in close cooperation with CERN. On its basic level, young facilitators, mostly PhD and master's students, bring CERN's data to schools and hold a masterclass. By doing so, each year about 4000 students are introduced to particle physics and get the chance to work with data from LHC experiments. The most interested students are invited to further qualification and specialization levels, which include workshops at CERN and can lead to students' own research projects (Fig. 4.8).

On parallel levels, astroparticle activities can be conducted. Students can work with detectors for cosmic rays and perform a variety of measurements, e.g. angular distribution, coincidence, determine the muon lifetime or study particle showers. Cloud chamber sets are loan to schools, and web experiments with data from the Pierre Auger observatory offer further opportunities for students to work on the subject.

[5] www.teilchenwelt.de

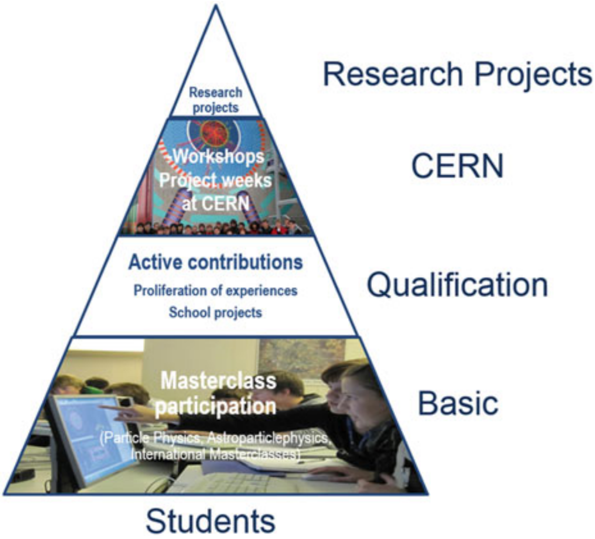

Fig. 4.8 Pyramid showing the multi-level programme of Netzwerk Teilchenwelt

Further, the wide range of activities in *Netzwerk Teilchenwelt* covers the development of various supporting material for facilitators and teachers, e.g. four volumes of teaching material for particle physics,[6] particle profiles[7] and the relaunch of the particle physics section on the largest German physics portal for schools.[8]

As described above the key feature of a masterclass is an authentic experience for high school students. They are brought as close as possible to current research and in direct contact with physicists, where they can perform own hands-on activities, using the same methods and tools like scientists. Informal learning environments like the masterclass setup are known to add valuable experiences to physics education at school and affect students' motivation and interest in science, resulting in positive effects on the students' attitudes towards physics.

4.6 Evaluation Study

The basic programme of *Netzwerk Teilchenwelt*, masterclasses with LHC data, has been evaluated concerning the issues of students' interest in particle physics and their perception of the event (Gedigk et al. 2014; Gedigk and Pospiech 2015). Different aspects of interest were studied with a questionnaire, containing items with closed answer format with a 5-point Likert scale. About 500 high school students were

[6] www.teilchenwelt.de/tp

[7] www.teilchenwelt.de/material/materialien-fuer-lehrkraefte/teilchensteckbriefe/

[8] www.leifiphysik.de/themenbereiche/teilchenphysik

Fig. 4.9 Design of the study on students' interest and motivation before and after a masterclass (MC)

evaluated, asking questions on their interest in particle physics and the perception of the event. The study followed a pre-/post-/follow-up design (Fig. 4.9).

Results of the evaluation confirm that masterclasses are very much appreciated by students. An important feature for this success is authenticity as well as challenge. Masterclasses are especially successful for a group of students with a high interest in doing particle physics 6–8 weeks after the masterclass. This success group is remarkable large, with 26% of all participants. The investigation of this group shows the same positive effect on all students, independent on gender and level of education. Moreover, the study shows that the success group rated the features of the masterclass, e.g. challenge or authenticity, better than the other students. Students develop a long-term interest in particle physics; evidence for this is deduced from the realization of intended actions of interest in particle physics in the follow-up evaluation.

4.7 The *International Masterclasses* in Brazil

Brazil takes part in the *International Masterclasses* since 2008, starting with universities and high schools from São Paulo and Rio de Janeiro. In the following years, other cities joined the masterclasses. Figure 4.10 shows a map of Brazil indicating the cities participating in the *International Masterclasses* nowadays. It also lists the LHC experiments from which the events were analysed by each of them. Local organizers are always physicists working at universities, federal institutes or research institutes. Not all of them are members of one of the LHC experiments. Appendix lists all the local organizers and their institutions. The participants are:

- High school students and their teachers
- Teachers: physics, chemistry, geography, philosophy/sociology
- Undergraduate students, mostly from physics, but also from engineering, biblioteconomy (librarians), chemistry, philosophy

In order to participate in the videoconference with CERN and universities from other countries at the end of the activities, the local organizers in Brazil adapt the programme suggested by CERN to the time difference between Brazil and CERN in two different ways:

- Starts in the afternoon of the day before the videoconference, continues the next day, meets at noon with CERN and the other participating institutes (São Paulo, UNESP + UFABC; Curitiba, UFTPR, Rio de Janeiro, UFRJ).

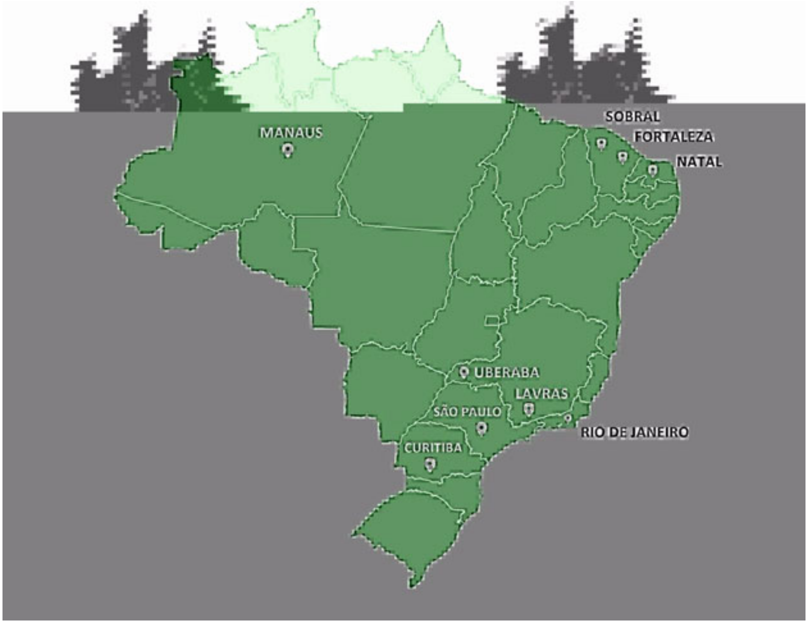

Fig. 4.10 The map of Brazil showing the cities where the *International Masterclasses* are realized, indicating from which LHC experiment are the events analysed by them

- Performs at least 3 days of activities with seminars/colloquia about particle physics, astrophysics and the experiment to be analysed in the morning and event analysis in the afternoon. The participants can also analyse some events at home and bring questions for discussions. At the day of the videoconference, final discussions are done in the morning. A virtual visit to the experiment can also be arranged, and it is normally done in the afternoon of the last day, after the meeting with CERN and other institutes (Rio de Janeiro, UERJ; Natal, UFRN + IFRN; São Paulo, USP; Lavras, UFLA; Manaus, UEAM; Uberaba, UFTM; Curitiba (UFTPR) since 2016; São Paulo, UNESP + UFABC, 2 days activities since 2013).

If the videoconference is done with Fermilab, it will happen by the end of the day. Still it follows the same organization and uses the "extra" afternoon for further discussions and the virtual visit.

The experiments ATLAS and CMS offer virtual visits allowing the students and their teachers to see the detector and the control room; depending on the time of the year, it is possible to see the detectors open. It is like being at CERN visiting the detectors. More details can be found in (http://atlasvirtualvisit.web.cern.ch/ and https://cms.cern/interact-with-cms/virtual-visits). Experiments ALICE and LHCb offer virtual tours which can be accessed at (https://www.youtube.com/watch?v=vQVEkbEvTaA, http://lhcb.web.cern.ch/lhcb/News%20of%20pit8/Pictures/LHCbVirtualTour/cern_flash.htm).

Many times the virtual visit is done before the masterclass in order to raise the interest about the experiment, LHC, CERN and particle physics. It is easier to organize, shorter and therefore easier to place in the school calendar. Of course, we talk about the *International Masterclasses*, the schools showing interest keep in contact, and the participation and collaboration begin.

Since 2008 different ways to reach the students and their teachers have been used. The best, so far, are personal contact with the schools and the teachers, Facebook pages (Masterclass BR, Masterclass-RN, MasterClass RN, Masterclass UFTM, LAPE UFRJ, SPRACE, LHC–CP2), web pages (https://www.sprace.org.br/masterclass), posters sent to the schools (Fig. 4.11) and email. The less effective are press releases: short texts in newspapers, magazines and internal journals. Twitter has worked only with UFRJ, in Rio de Janeiro. Orkut (long gone), Google Groups and similars showed no effectiveness at all.

The Brazilian Physical Society organizes a National Program for Physics Teachers together with the Portugal-CERN School, in Portuguese, where teachers from Brazil can take part through the CERN School of Physics Program. It is coordinated by Prof. Nilson Garcia from UFTPR. Some of those teachers contact

Fig. 4.11 Example of the posters sent to Brazilian high schools to announce the *International Masterclass*

us once they are back from CERN and join the group participating in the *International Masterclass* later on.

Beyond the masterclasses in March–April, the time of the videoconferences, other activities are organized:

- São Paulo (USP) offers a course about nuclear and particle physics to (mostly) physics teachers during the USP-Escola (USP-School) (http://hepic.if.usp.br/?q=pt-br/evento/curso-de-extensão-inserção-da-f%C3%ADsica-moderna-no-ensino-médio-através-do-estudo-dos).
- São Paulo (USP) and Rio de Janeiro (UFRJ and UERJ) do the masterclasses-hands-on particle physics along the year in different schools, as long as the teachers show interest in doing it.
- São Paulo (UNESP/SPRACE) realized in 2012 and 2015 a workshop for physics teachers and undergraduate physics students who will become teachers.
- The LHCb group at UFRJ (Rio de Janeiro) is developing a new exercise for the LHCb Masterclass.
- To help the learning process, São Paulo (UNESP/SPRACE) and Rio de Janeiro (UERJ) develop educational games.
- To remember the masterclass, Rio de Janeiro (UERJ) and Natal (UFRN+IFRN) teach the students to produce mugs (Fig. 4.12) or T-shirts. It is also a good publicity.
- Local organizers of the masterclass in Brazil normally work together with physicists from physics education, producing publications, master's and PhD theses in this area. The group at the University of São Paulo (USP) is the most successful in that topic.

The participants of the *International Masterclasses* are not followed after it is finished, but many of them get in contact with us. Most of them did the masterclasses in a 3-day period. All of them continue to study, not necessarily physics. Some participants become undergraduate research fellows under our supervision and later on, even master's and PhD students, continue to work with us.

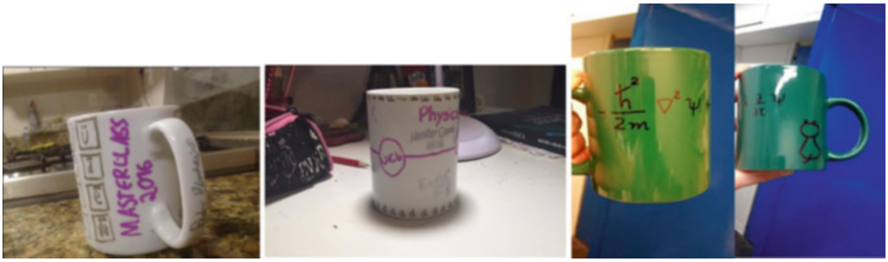

Fig. 4.12 Example of mugs produced by the masterclass students in Natal (UFRN) and Rio de Janeiro (UERJ)

The participants may give a feedback if they want to. It is not mandatory. It can be anonymous (written in a paper) or not (through email, WhatsApp, Facebook, even spoken). It helps to improve the activities, the plan for next year. They can be resumed as:

- Students ask to participate again in the Masterclass, next year.
- Most common complaint: “It is too short!”
- “It is hard work!” (not as a complaint).
- From the teachers: It helps in the process to bring modern and present physics to the students at high school level. Although everything is new, it is not a burden; on the other way round, it awakens the interest of the students.
- From the geography teacher: It shows the students there is a big world out there.
- From the students: We learn to work in group, to help each other and everything gets better.
- From the students: We did not know in time about this activity. Why don’t you put it in WhatsApp and all social media?
- About the mugs: “Everybody loves it!”
- Drawing the events in a paper using different pens or painting the events: “Never do it again. It is too boring!” Therefore this activity was cancelled.
- Best comment I (Marcia Begalli) ever received: “You will not dare to stop this amazing activity right now, right?” just after the video conference with CERN (March, 23, 2016).

4.8 Conclusion

The format of masterclasses which is used in both programmes, *International Masterclasses* and *Netzwerk Teilchenwelt*, as well as the ones used in Brazil, has proven to affect students’ attitude towards physics, as well as in science and technology in general, and to be able to sustain interest independently from gender and class or school form. The programmes have an inherent potential to inspire high school students for modern physics. Under this aspect, the further growth of national and international programmes using the format of masterclasses and their spread to more and more parts of the world are highly beneficial.

Appendix

The Masterclass Local Organizers in Brazil

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UFABC (Federal University of [the] ABC [region])
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USP (University of São Paulo)

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