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European Particle Physics Masterclasses make Students Scientists for a Day

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Abstract

In 2005 the European Particle Physics Masterclasses attracted 3000 students from 18 European countries to visit one of 58 universities and education centres. The participants worked with data from real high energy particle collisions, learned about particle physics, and experienced research and education environments at European universities. In an evaluation of the masterclasses 70% of the participants reported that they learned much or very much about the organisation of scientific research and more than 80% of the participants, in some countries more than 95%, highly appreciated the masterclass program in general. The appreciation of the masterclasses was independent of gender, pre-knowledge of particle physics and computer knowledge. An event like the masterclasses, where the students are engaged in an experimental research process, has the potential to add valuable experiences to physics education in school environments.

Introduction

Providing opportunities for students and teachers to take part in an authentic research process is an interesting and accepted way to improve the understanding of scientific research. Particle Physics Masterclasses provide such an opportunity by inviting high school students to spend one day at one of the participating universities or research centres, where they attend lectures and perform measurements on real data from particle physics experiments (Fig. 1). By using the same tools as professional scientists, the measurements mirror the research process and the activities of researchers in particle physics.

Fig. 1 Students at the National Technical University of Athens, Greece.

Particle Physics Masterclasses began in the UK in 1997 [1], the centenary of J. J. Thomson's discovery of the electron, and are run since then by particle physicists at various institutes all over the UK. Masterclasses have also been carried out by several institutes in Belgium, Germany and Poland. The World Year of Physics 2005, commemorating Einstein's *annus mirabilis*, set the scene for a vast spread of the Particle Physics Masterclasses. Between March 7, and March 19, 2005 more than 3000 European high school students participated in a 2-weeks program organized by the European Particle Physics Outreach Group EPPOG. In order to work like scientists, the students spent one day at one of 58 universities or research centres in 18 countries across Europe. Here we report on the results of the evaluation of this first international masterclass program [2].

The EPPOG International Masterclasses

The primary aims of Particle Physics Masterclasses are:

- stimulate the interest in science
- demonstrate the scientific research process
- make data of modern particle physics experiments available for students
- explore the fundamental forces and building blocks of nature

To achieve these aims, real data of particle physics experiments are arranged in several web-browser-based educational packages, using original "event displays" to visualize the detector response of the produced particles as tracks or colour-coded energy deposits. Introductory lectures teach the students how to interpret such event displays, identify different sorts of elementary particles and perform their own measurements. For the EPPOG International Masterclasses three different packages [3-5] were chosen as a central task for the students, all using data from experiments at CERN's Large Electron Positron Collider LEP, operational from 1989 to 2000. To facilitate the use of these programs, EPPOG undertook the effort to translate the educational packages into a total of 16 different languages, with the awarded "Hands on CERN" project [3] now existing in 15 languages[1]. Using these packages, the students learn very quickly how to use the event display, and have little problems to identify the different particle decays.

Fig. 2 The video session in Dresden, Germany.

[1] Catalan, Czech, Danish, English, French, Galician, German, Greek, Hungarian, Italian, Norwegian, Portuguese, Slovak, Spanish, and Swedish.

A new element of the EPPOG International Masterclasses is the international video conference at the end of each day, gathering all student groups at the four to six participating sites (Fig. 2). The linkup is technically supported at CERN and moderated by scientists from the Large Hadron Collider (LHC) and from ATLAS and CMS, huge experiments presently under construction at the LHC, each carried out by nearly 2000 scientists from more than 35 countries all over the world. Using the same VRVS/EVO video technology [6] as professional particle physicists, the scientific results from the different student research groups are combined and discussed. In such an environment the students can feel as members of an international collaboration, performing tasks similar to those of the scientists. Informal meetings with the local particle physics researchers give the masterclass participants insight into the research and teaching environment at the universities and make them feel part of a real research activity.

The European Particle Physics Outreach Group
The European Particle Physics Outreach Group (EPPOG) [7] is the European forum where the European particle physics Masterclasses 2005 was initiated and launched. EPPOG promotes the outreach activities of particle physics institutes and laboratories in CERN's member states and acts as a forum for the exchange of ideas and experiences related to particle physics education and outreach.

Masterclasses 2006 and 2007

The International Masterclasses were repeated in 2006 and 2007. They lasted for two weeks with five to seven participating universities each day. In both 2006 and 2007 a total of about 95 masterclasses were organised. As a novelty, a quiz was introduced in the video conference, engaging the students more efficiently in discussions, and its technical quality was improved. The number of Masterclasses with video conference increased from 70 in 2006 to over 90 in 2007. With the participation of several US universities and of a student group from South Africa the Masterclasses now spread outside Europe

Particle physics task

In high energy particle collisions one can study the fundamental building blocks of nature, the quarks and the leptons. Some of these existed naturally only at the very beginning of the universe, while only one lepton, the electron, and two quarks, the "up" and "down" quark, building up the neutrons and protons, are needed to construct the world around us today. In collisions of cosmic rays with the earth's atmosphere, and especially in high energy collisions of particle beams at a few large physics laboratories two heavier groups of quarks and leptons have been discovered. One of the central physics tasks of the masterclass day is to study and compare the properties of these heavier groups of quarks and leptons with those of the light partners, the electron and the up and down quarks. All these particles, with the exception of the heaviest quark, the top quark, appear in decays of the Z^0 particle, the neutral mediator of the electroweak interaction. The Z^0 rapidly transforms into a lepton and an antilepton, where the lepton can be an electron, a muon or a tauon (Fig. 3), or into a quark and an antiquark (Fig.4), where each quark gives rise to a jet of particles. Nearly 20 million of Z^0 particles were produced at LEP, the predecessor of the LHC at CERN, in high-energy collisions of electrons and positrons, the antiparticles of electrons. The precise measurements of all features of the Z^0 particle by the four LEP collaborations [8] include the so-called branching fractions of the Z decays to quarks and leptons. The DELPHI and OPAL experiments have made 1000 Z events available to students for identifying the different decay products and measuring their branching fractions.

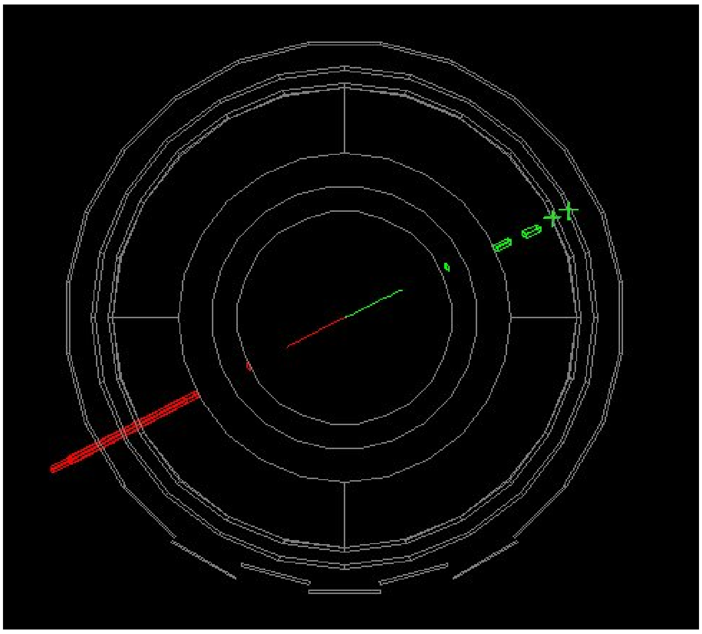

Fig. 3: The production of a Z^0 particle decaying into a pair of tauons. One of the tauons decays to an electron and invisible neutrinos, the other to a muon and invisible neutrinos.

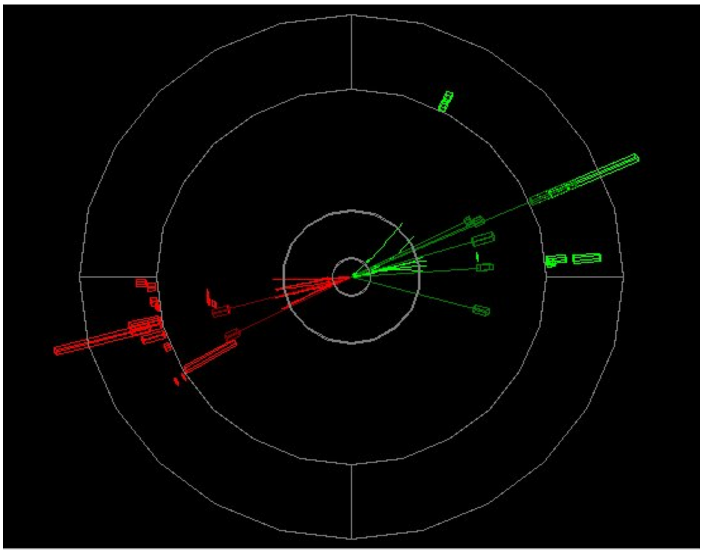

Fig. 4: Two-jet event. The production of a Z^0 particle decaying into a pair of quarks (a quark and an antiquark) giving rise to two jets of particles deposing their energy in the calorimeters (rectangles).

The results confirm, that indeed the charged leptons, the electron, muon and tauon, have very similar properties, and that the quarks appear much more frequently and dominate the Z-decays. The students are invited to speculate about the origin of this difference. A large part of this factor originates from the quarks appearing in 3 different “colour” charges of the strong interactions, tripling the number of possible quark states.

For the students who want to do more, the data offer further measurement options, like the determination of the strong coupling constant, α_s from the rate of additional jets in Z decays, the production rate of Z bosons as a function of the beam energy of the collider, and the measurement of the branching fractions of the charged mediators of the electroweak interaction, the W^+ and W^-, which were produced in a second phase of LEP.

Evaluation sample

The evaluation of the Masterclasses is based on 1291 replies to questionnaires, inquiring how the participants perceived the Masterclasses (Table 1).

Table 1: Distribution of the number of questionnaires among the participating countries.

Country	**Students**
Greece	213
Italy	197
Germany	185
Poland	172
Belgium	159
Other countries	365
Sum	**1291**

84% of the students visited the Masterclass with a subgroup of the class either nominated by a teacher or on their own initiative and 16% came with their school class. The average age of the students was 17.5 years with 93% of them aged between 16 and 19 years. Students under 16 and over 19 years of age were excluded from the analysis. The sample of the overall evaluation consisted of 373 female (31%) and 825 male students (69%) from 18 European countries. There was no age difference between male and female students.

Evaluation results

The evaluation studies possible gender differences and the students' attitudes towards the masterclass program, especially towards the lectures, exercises and the video conference. The students' perception of the program with a-priori conditions of the students, were rated on a 5-point Likert scale with "1" showing no agreement at all and "5" reflecting full agreement with the statement.

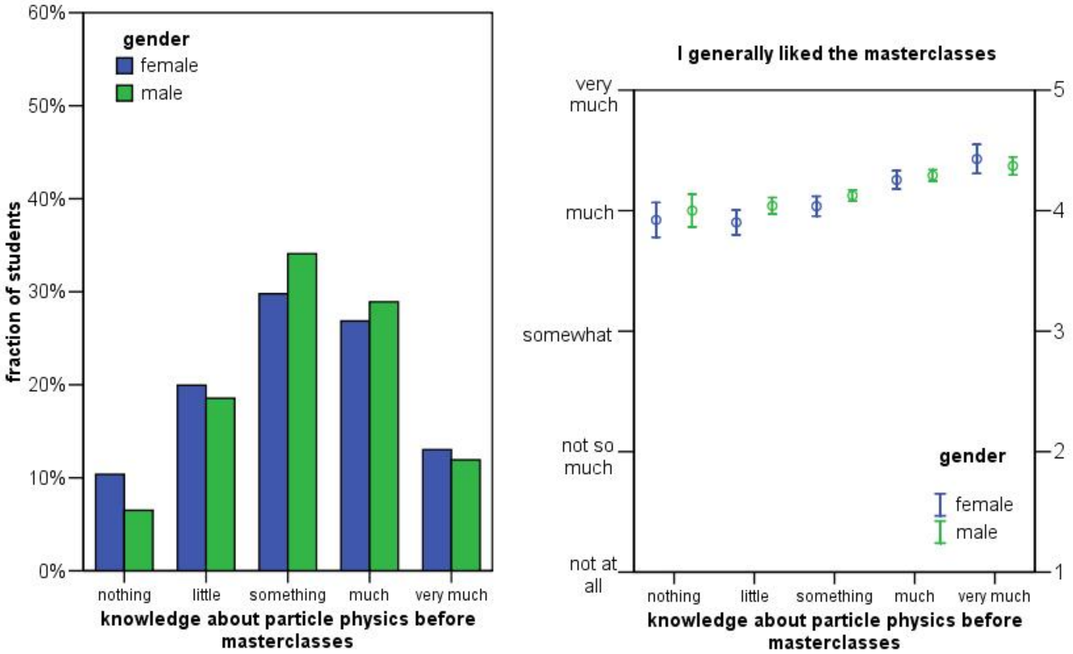

Fig. 5 The students' pre-knowledge of particle physics (a) and the popularity of the Masterclasses as a function of it (b).

Fig. 5a shows, that the self-judgement of the participating students concerning their own pre-knowledge is very broadly distributed, with about 1/3rd of them knowing “nothing” or “little”, 1/3rd knowing “something”, and 1/3rd knowing “much” or “very much” about particle physics before the Masterclasses. An overwhelming majority of the students liked the Masterclass much or very much (82%), while only 4% of the participants did not enjoy the program. Fig. 5b shows that this high appreciation of the Masterclasses does not depend on the pre-knowledge of particle physics, and that there are no significant differences between the males and the females[2].

The perception of the lectures turned out to be the most important factor for the appreciation of the Masterclasses. As visible in Fig. 6a, a large majority of the participants found the lectures interesting (81%), again with little difference between girls and boys. In addition, as is visible in Fig. 6b, there is a clear correlation with a correlation coefficient of 51% between interesting lectures and the overall appreciation of the Masterclasses, with small differences between the males and the females. About 68% of the girls and boys judged the lectures easy or very easy to understand, contributing to their positive response. The influence of the lectures on the attitude of the students towards modern physics is also very large, as discussed below.

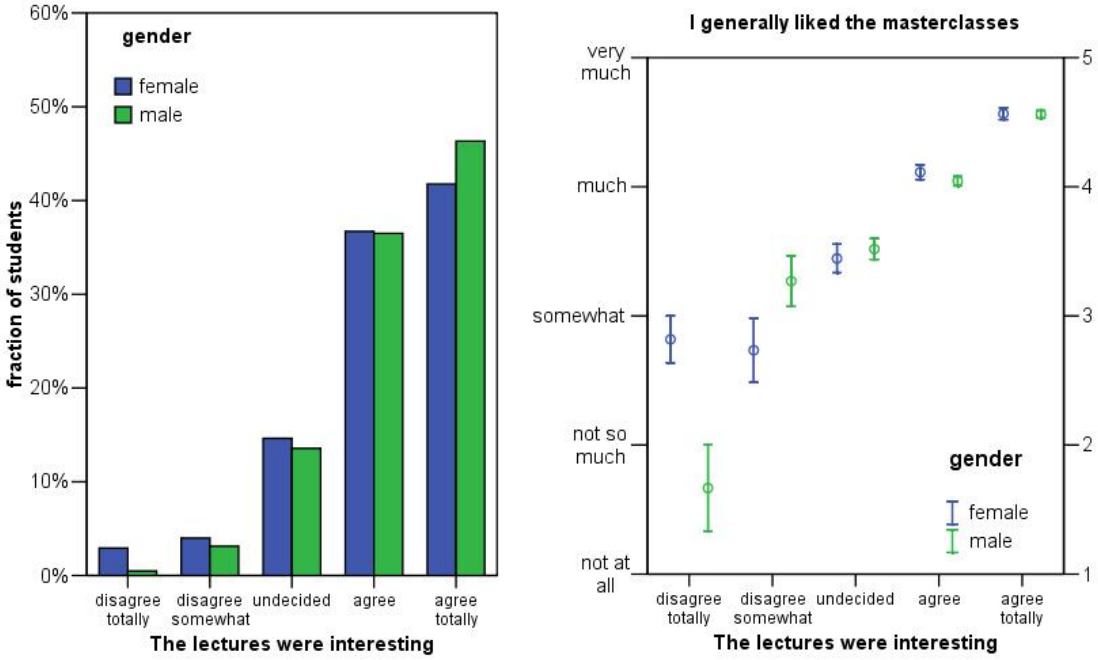

Fig.6 The popularity of the lectures(a) and the popularity of the Masterclasses as a function of it(b).

The masterclass exercises included quite a lot of computer work with particle collision data. Fig. 7a shows the amount of time the students spent using the computer at home, which is clearly much larger for boys than for girls. However, the amount of computer work at home does affect neither the males’ nor the females’ appreciation of the Masterclasses (Fig. 7b). Most of the girls and the boys experienced their own competence in working on the various tasks on the computer (65% agree or agree fully). For 60% of the students the Masterclass was exactly right in terms of difficulty and complexity. Only for 1% respectively 3% the program was too difficult or too easy.

[2] The error bars in this and all following plots indicate the statistical uncertainty of the average on 1-sigma (68% CL) level

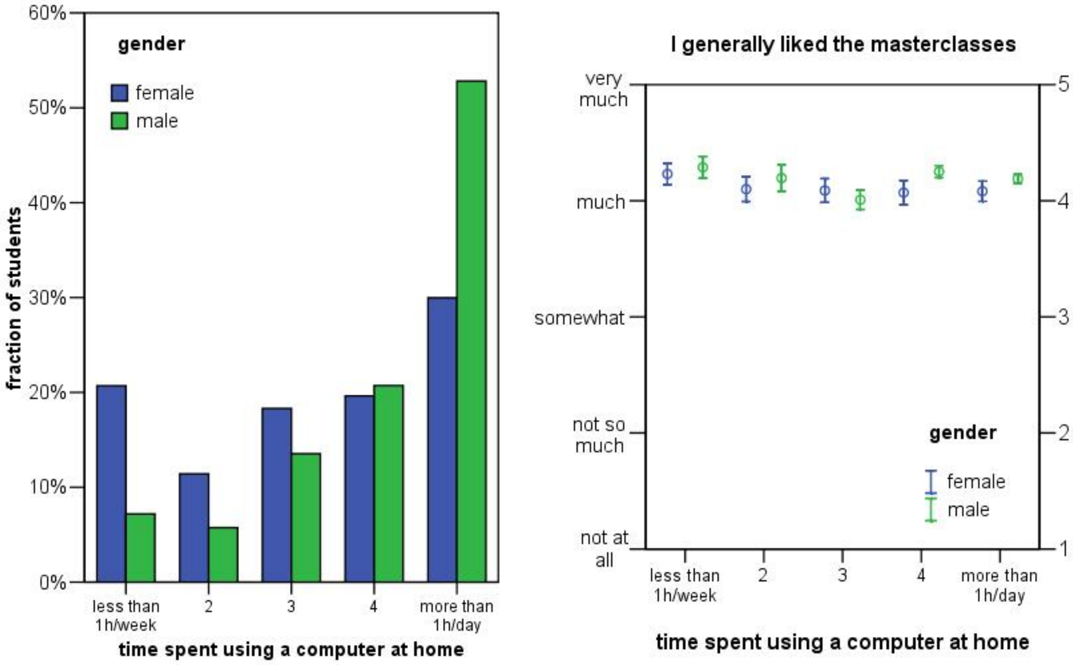

Fig. 7: The amount of time spent on a computer at home (a) and the popularity of the Master-classes as a function of it (b).

Correlations

To further investigate the factors, which contribute to the overall appreciation of the Masterclasses, we examined three possible sources in a linear regression fit to the data: the reception of the lectures, the increase in knowledge of particle physics, and the insight in the way, how scientific research is organized. The resulting *partial* correlation coefficients describe the genuine influence of each factor while keeping the other factors constant. As listed in Table 2, the significant correlations range from very large values of over 50%, evident in Fig. 6b, to moderate correlations of 10%, still clearly perceptible in Fig. 8.

Table 2: Partial correlation coefficients (in %) and their statistical errors in a linear regression fit for some of the sources, which contribute to the students' judgements.

Appreciation of Masterclasses

Correlation Source in Masterclass	**Total**	**Female**	**Male**
Interesting lectures	51.0 ± 2.4	57.7 ± 4.4	47.9 ± 3.0
Learning about organisation of research	15.6 ± 2.4	15.0 ± 4.4	15.4 ± 3.0
Learning about particle physics	7.9 ± 2.4	2.7 ± 4.4	10.1 ± 3.0

Increase of general interest for physics

Correlation Source in Masterclass	**Total**	**Female**	**Male**
Interesting lectures	29.3 ± 2.8	38.0 ± 4.9	25.2 ± 3.4
Learning about organisation of research	10.3 ± 2.8	18.3 ± 4.9	6.0 ± 3.4
Learning about particle physics	13.5 ± 2.8	6.0 ± 4.9	17.3 ± 3.4

Wish to have more modern physics at school

Correlation Source in Masterclass	**Total**	**Female**	**Male**
Interesting lectures	32.6 ± 2.8	36.3 ± 5.0	30.5 ± 3.4
Learning about organisation of research	14.5 ± 2.8	16.8 ± 5,0	12.5 ± 3.4
Learning about particle physics	1.5 ± 2.8	0.0 ± 5.0	2.7 ± 3.4

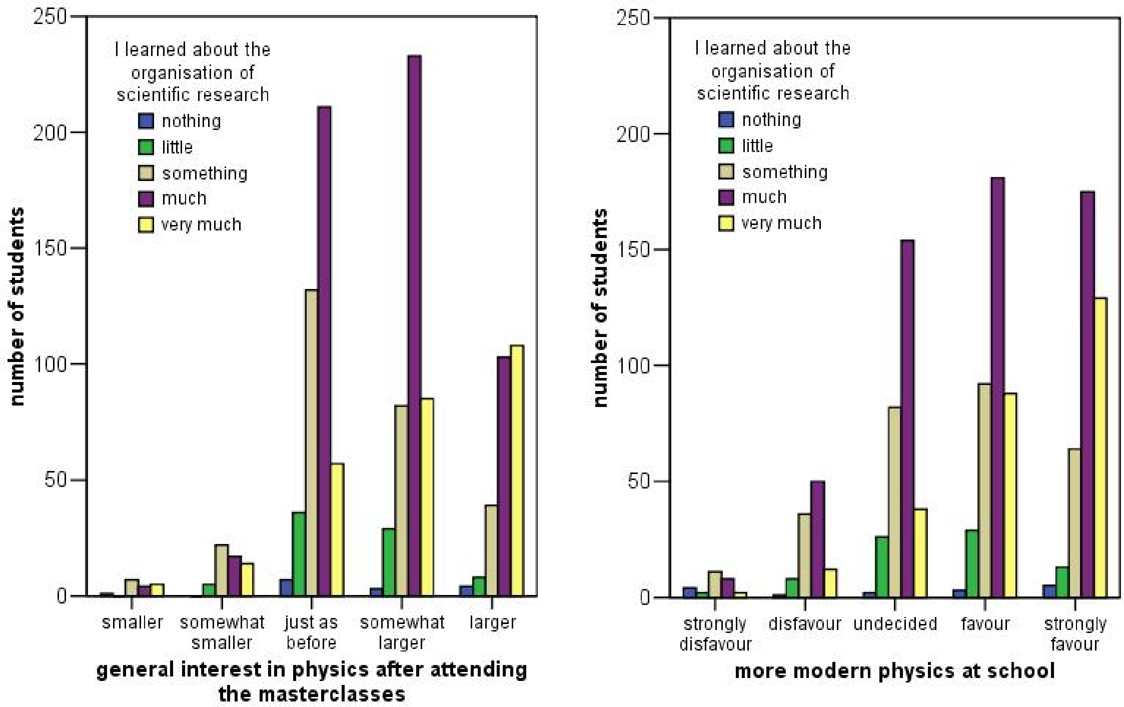

Fig. 8 The general increase of interest in physics (a) and the wish for more modern physics at school (b) after attending the masterclasses. The five columns show how much the participants reported to have learned about the organisation of scientific research.

The distribution of answers along the horizontal axis in Figs. 8a and 8b show that the students' participation in the Masterclasses resulted in an increase of their interest for physics (Fig. 8a) and a wish to have more modern physics at school (Fig. 8b).The insight into how scientific research is organized, has a correlation of about 15% with these topics. The fraction of students having learned "much" or "very much" about the organisation of scientific research (Fig. 8a yellow and purple columns), clearly grows with increasingly positive answers on the questions about modern physics (Fig. 8b) and increase of general interest. About 70% of the students confirmed to have learned much or very much about the organisation of scientific research.
For all the three topics the by far largest correlation of typically 30-50% is coming from the interesting lectures, where the correlation tends to be always slightly higher for girls than for boys. Some of the sources contributed differently for girls and boys to their increased general interest for physics. The girls become more interested by learning how science is organized, ((18 ± 5) % correlation), while the boys become interested by learning about the science ((17± 3) % correlation). The respective correlations for the other gender are insignificant. How much the students actually learn about particle physics only weakly influences their overall appreciation of the Masterclasses. Still, a large majority of the students learned a lot about "Quarks and Leptons" (84%), "Particle Detectors" (81%), "Particle Physic in General" (79%) and "Particle Accelerators" (74%).

Summary
The dominating feature of the Masterclass project was the overwhelming appreciation of the Particle Physics Masterclasses all over Europe. This appreciation was independent of gender and also independent on the pre-knowledge of particle physics. Also those who did not know very much about particle physics appreciated a whole day of particle physics in a scientific research environment, and wished to learn more about modern physics at school.

The lectures and the opportunity to ask questions, but also the exercises and the very inspiring and positive atmosphere were very much appreciated. The more the students liked and managed to follow the lectures, the better prepared they were for the coming exercises, and the more they liked the Masterclasses. They were surprised that they could do so many interesting experiments on such an advanced level in one day, both on their own and together with other young scientists.

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