PROCEEDINGS OF SCIENCE

International Masterclasses - from collider physics to neutrinos and cosmic rays

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International Masterclasses (IMC) is an annual programme for high school students organized by the International Particle Physics Outreach Group (IPPOG) in collaboration with universities and research centres around the globe. In a single day, the students are fully immersed in the activities and challenges of modern research. From morning lectures to afternoon hands-on measurements with real data from large experiments, they have the opportunity to listen to scientists, ask questions and seek professional guidance in solving problems during the data analysis. At the end of the day, the students from several countries join the video conference to discuss their results at the international level. The IMC physics topics include all major LHC experiments, Belle II, Particle Therapy Masterclass, Minerva and, the latest addition, Pierre Auger Masterclass. IMC continue their geographical expansion and currently attract more than 13 000 students from 60 countries. We describe the main features of the programme including its growing physics scope.

XVIII International Conference on Topics in Astroparticle and Underground Physics (TAUP2023)
28.08_01.09.2023
University of Vienna

PoS(TAUP2023)326

1. Introduction

International Particle Physics Masterclasses (IMC) [1-4] is an annual one-day event for high school students across the globe. They work under the guidance of scientists at a local university, performing measurements on the data released by experiments at the Large Hadron Collider (LHC) at CERN. The idea is to let participants get the first hand experience with the latest research, its challenges and rewards.

IMC trace their origin to the UK where Roger Barlow and Ken Long formulated the basic concepts in 1997. Masterclasses spread to continental Europe in 2005 and quickly became international when the USA and South Africa joined the programme. Currently, 13 000 high school students participate every year at more than 200 universities in about 60 countries. The last few years also witnessed a significant broadening in the physics scope of IMC when the traditional LHC measurements based on data from ATLAS, CMS, ALICE and LHCb experiments were supplemented by Belle II, Minerva neutrino masterclass, the GSI particle therapy masterclass and Pierre Auger cosmic ray masterclass.

A typical day starts with morning lectures about the basic building blocks of matter and the way we study them experimentally, continues with the hands-on analysis of real data, and concludes with the videoconference – a platform for students to discuss their results at the international level. Throughout the day, the students interact with scientists, ask questions and seek their help in solving problems. To handle the large numbers of institutions, the upper limit is five universities per videoconference and masterclasses are held every workday within six or seven week period in the spring. Videoconferences have five moderating centres: CERN, Fermilab, KEK, GSI, and Malargue.

We describe here the organization of the programme including its growing physics scope and our commitment to reach out to new countries and audiences.

2. IPPOG Collaboration

IMC are organized by the International Particle Physics Outreach Group (IPPOG) [5-7] in collaboration with universities and research centres in 60 countries. IPPOG is a global network with 41 members: 33 countries, 7 experiments and CERN (international laboratory) and two associate members: DESY and GSI (national laboratories), cooperating on the basis of Memorandum of Understanding. Members nominate representatives who are active researchers experienced in outreach and informal science education in particle physics or educators and communication specialists.

IPPOG goal is to raise the standards of science education and public engagement, inspire the next generation of researchers, help achieve better public understanding of the scientific method and appreciation of evidence-based decision making and to extend the global reach, expanding to new countries and audiences and pioneering new outreach methods and activities.

While IMC is the most visible programme, IPPOG organizes, co-organizes and supports other global activities and competitions, including World Wide Data Day, Global Cosmics, and Girls, do Physics! The Collaboration also supports local events such as exhibitions, music/cultural festivals, and competitions. IPPOG develops Resources Database for outreach

material in particle physics to assist scientists, teachers and communicators in finding effective ways/tools to teach/communicate physics.

The Collaboration Forum (CF) meets twice a year to develop and share ideas, coordinate the programmes, present key activities and success stories and organize topical panel sessions.

Five working groups (WG):

- Explaining Particle Physics to a lay audience
- Outreach of Applications for Society
- Exhibits and Exhibitions
- Bringing Masterclasses to New Countries
- Diversity, Inclusion and Accessibility

work throughout the year and also report during the CF meetings.

IMC is managed at the international level by the IMC Steering Group with conveners Uta Bilow (Dresden) and Ken Cecire (Notre Dame). Members include the developers of each Masterclass exercise.

3. IMC exercises

3.1 LHC Masterclasses

LHC masterclasses [8] replaced original LEP masterclasses (2005 – 2010) in 2011 when the students for the first time analysed data from ATLAS [9], ALICE [10] and CMS [11] experiments. LHCb experiment [12] joined in 2014. The essence of ATLAS and CMS exercise is to visually inspect, one by one, typically 50 events of proton-proton collisions. Students work in pairs, assisted by undergraduate or graduate students or scientists. They look for signatures of particles such as electrons, muons, photons, hadrons and learn the Nobel prize winning methods of the reconstruction of short-lived particles which include W and Z bosons and the Higgs boson, discovered at CERN in 2012.

ALICE exercise brings insights into the physics of the collisions of heavy nuclei – the goal is to study the so-called strangeness suppression in these collisions, the sign of quark-gluon plasma which we believe was the state of nuclear matter in the early Universe. In LHCb measurement students determine the lifetime of unstable D^0 particle using both visual and large scale/statistical analysis of data.

3.2 Beyond the LHC

Since 2020, IMC have been expanding to include non-LHC particle experiments. Belle II exercise [13] focuses on e+ e- collisions at SuperKEKB [14] with the goal to reconstruct several unstable mesons needed to study a hypothetical new physics in B mesons. The new physics could be responsible for matter-antimatter asymmetry in the Universe.

MINERvA Neutrino Masterclass [15] teaches students about the interactions of muon neutrinos with carbon nuclei – a crucial input for DUNE experiment in the United States aiming for groundbreaking discoveries in neutrino physics.

Particle Therapy Masterclass [16], coordinated by GSI [17], demonstrates the impact of fundamental research for the benefit of society. Students plan an optimal treatment for cancer

therapy using an open source toolkit matRad to calculate doses induced in the patient's tissues by X rays, protons and carbon ions.

Finally, Pierre Auger Masterclass [18], coordinated by LIP [19], Portugal, addresses the question What is the origin of ultra-high-energy cosmic rays? Analysing data from Pierre Auger Observatory [20] with a beautiful interactive tool to visualize cosmic ray events, students reconstruct the arrival direction of the primary cosmic ray and fit the data to determine the energy of the ray.

4. New countries and audiences

IMC continue to expand to new countries and new institutions. Among the latest newcomers we find Quito (Ecuador), Maputo (Mozambique), Ben Guerir (Morocco), Lusaka (Zambia), Patra (Greece), and Kharkiv (Ukraine).

IPPOG reaches out to underrepresented regions and audiences. A special Spanish Language edition of IMC has been running since 2017. We have reached African teachers through African School of Physics. A cooperation with Physics Without Frontiers brought masterclasses to Palestine and Nepal.

World Wide Data Day [21] is a new form of masterclasses organized by high school teachers directly at their schools as part of the Physics classes. Masterclass exercises are simplified for this purpose.

Since 2016, IMC for girls are held annually on the UN International Day of Women and Girls in Science to support and promote the access of women and girls to science education.

5. Conclusion

IMC is the IPPOG's most successful programme. Key factors include the hands-on experience with the latest research, distribution of the workload between the IMC Steering Group and the local organization, enthusiasm of the organizers and the spirit of cooperation in the field of particle physics. Workload is spread and synergies created.

Masterclasses help inspire a new generation of researchers and contribute to a better understanding of the scientific method and the role of science in modern society.

Acknowledgements

Ivan Melo acknowledges the financial support of the Ministry of Education of the Slovak Republic via project FEPO.

References

[1] R. Barlow, *How the Particle Physics Masterclasses began*, *CERN Courier*, Jan 22, 2014, Retrieved from https://cerncourier.com/a/how-the-particle-physics-masterclasses-began/.

[2] K. E. Johansson, M. Kobel, D. Hillebrandt, K. Engeln, and M. Euler, *European Particle Physics Masterclasses make Students Scientists for a Day, Physics Education*, **42**, pp. 636-644, 2007

[3] M. Kobel, *Masterclass spreads the word for physics*, *CERN Courier*, Sep 28, 2005. Retrieved from https://cerncourier.com/a/masterclass-spreads-the-word-for-physics/.

[4] M. Bardeen, H. P. Beck, U. Billow, K. Cecire, F. Ould-Saada, M. Kobel, *International Masterclasses in the LHC era*, CERN Courier, June, 2014. https://cds.cern.ch/record/2064567/files/vol54-issue5-p037-e.pdf.

[5] The International Particle Physics Outreach Group, https://ippog.org/.

[6] S. Goldfarb, *International Particle Physics Outreach Group: Reaching across the globe with science*, *PoS* (ICHEP2020) 942, 2020, https://pos.sissa.it/390/942/pdf.

[7] I. Melo, *The International Particle Physics Outreach Group – building trust in science,* Proceedings of the International Conference on Education and New Learning Technologies EDULEARN 2021, online conference, 5-6 July, 2021, pp. 4865-4871, 2021 https://library.iated.org/view/MELO2021INT2.

[8] International Masterclasses, https://physicsmasterclasses.org/.

[9] ATLAS experiment at the LHC, https://atlas.cern/.

[10] CMS experiment at the LHC, https://cms.cern/.

[11] ALICE experiment at the LHC, https://alice.cern/.

[12] LHCb experiment at the LHC, https://home.cern/science/experiments/lhcb.

[13] Belle II Masterclass, https://belle2.ijs.si/public/belle-ii/.

[14] SuperKEKB Project, https://www-superkekb.kek.jp/.

[15] MINERvA Neutrino Masterclass, https://indico.fnal.gov/event/22340/.

[16] Particle Therapy Masterclass, https://indico.cern.ch/event/840212/.

[17] GSI Helmholtzzentrum für Schwerionenforschung, https://www.gsi.de/en/start/news.

[18] Pierre Auger Masterclass, https://augermasterclasses.lip.pt/.

[19] LIP, Portugal, https://www.lip.pt/.

[20] Pierre Auger Observatory, https://www.auger.org/.

[21] The World Wide Data Day (W2D2), https://quarknet.org/content/world-wide-data-day.