



International Masterclasses - from collider physics to neutrinos and cosmic rays

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International Particle Physics Masterclasses (IMC)



<http://www.physicsmasterclasses.org/>

High school students become 'particle physicists' for one day

Programme (9 am – 5 pm):

- Lectures about particles and their interactions
- Hands-on analysis of real data from large particle experiments
- International videoconference: 3 - 5 universities join with CERN, Fermilab, GSI, KEK, Pierre Auger



Held annually in the spring over 6 weeks: 13 000 students, 225 institutes, 60 countries



Green: participating countries in 2023

Masterclasses is the flagship activity of IPPOG Collaboration



IPPOG Collaboration – International Particle Physics Outreach Group (1997 -)

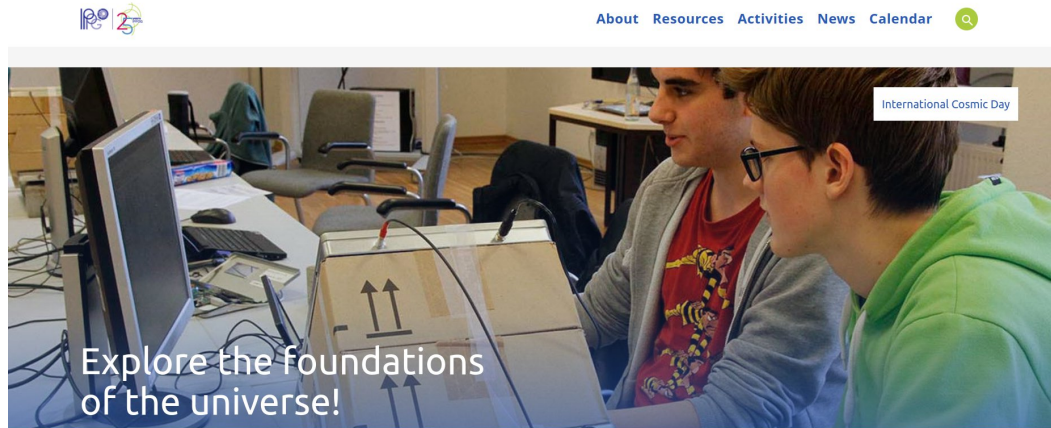


International Scientific Collaboration (since 2016)

- active researchers experienced in outreach and informal science education in particle physics
- educators and communication specialists

Global network

- Members: 41 members: 33 countries, 7 experiments and CERN (international laboratory)
- Associate members: DESY (national laboratory), GSI (national laboratory)
- National networks



Web page: <https://ippog.org/>



25th IPPOG Meeting, Sofia, Bulgaria, May 2023

IPPOG Goals



- Raise the standards of science education and public engagement
 - discussion forums
 - working groups
 - database of best practices and resources
- Inspire the next generation of researchers
- Better public understanding of the scientific method and appreciation of evidence-based decision making
- Extend the global reach, expansion to
 - new countries and audiences
 - new methods and activities



Masterclasses in Podgorica, Montenegro



Pohoda, the largest music/art festival in Slovakia
science talks & workshops

IPPOG: Means to achieve goals



Organization (and support) of global activities

- **International Particle Physics Masterclasses**, World Wide Data Day
- Global Cosmics, Girls, do Physics!,...

Support of local activities

- Exhibitions, music/cultural festivals, competitions ...

Resources Database for outreach material in particle physics

- materials related to particle physics outreach and informal education
- to assist scientists, teachers and communicators in finding effective ways/tools to teach/communicate physics

Collaboration Forum meetings (to develop and share ideas, coordination of the programmes)

- held twice a year
- presentations of key activities, topical panel sessions

Working groups (WG) work throughout the year

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

<http://ippog.org>

<http://facebook.com/ippog>

<http://facebook.com/groups/friends.ippog>

<http://twitter.com/ippogOrg>

<http://instagram.com/ippogOrg>

ippog-friends@cern.ch



(a sample of) Activities 2022



Higgs anniversary event in Valencia



CERN Portuguese Language Teachers Programme



Show «One step away from the Big Bang» in Bologna during ICHEP conference.



*International Cosmic Day:
Winners of the Cosmic Selfie*



*Cultural Collisions Students at work
in Austria*



*Quantum and Dark Matter Road
Trip team in Australia*

Activities 2022



Virtual tour of CERN in Bulgaria



Outreach activities in schools in Réunion (Indian Ocean) parallel to the EDSU2022 conference



Cosmic ray workshops for schools in Brazil



Kinder university in Germany, with ALICE LEGO



Illustration of the journey of a proton in the LHC in a dance performance, [Science & Nature festival](#) in Zurich

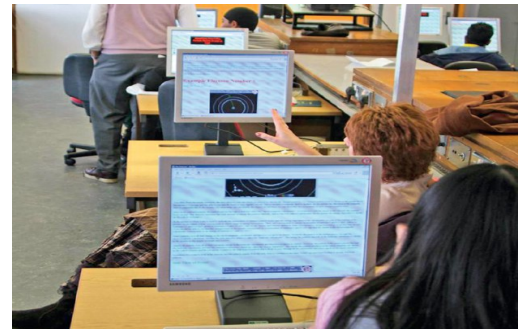


Music and Higgs boson meet at a cultural centre in Slovakia

Masterclasses - UK beginnings 1997

Roger Barlow and Ken Long suggested programme for high school students with a hands-on experience with modern research

Data from LEP at CERN and use of emerging computer clusters and the World Wide Web



Key success elements (R. Barlow)

1. balance between national organization and local university teams (spread of huge workload to manageable level)
2. measurement on real data with guidance of masters (physicists) brings students into direct contact with the cutting edge research.
3. organisers are enthusiasts who do it purely for fun and because they want to.

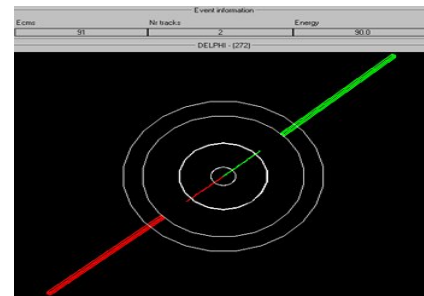
26 years later, the three key elements still apply, coupled with ability to stand up to new challenges

European LEP Masterclasses (2005 - 2010)



2005: 3000 European high school students, 58 universities, 18 countries

- students' task: to study the decay products of the Z^0 particle (Fig.)
- videoconference at the end of the day was introduced



Z^0 decay into pair of electrons at DELPHI detector at LEP

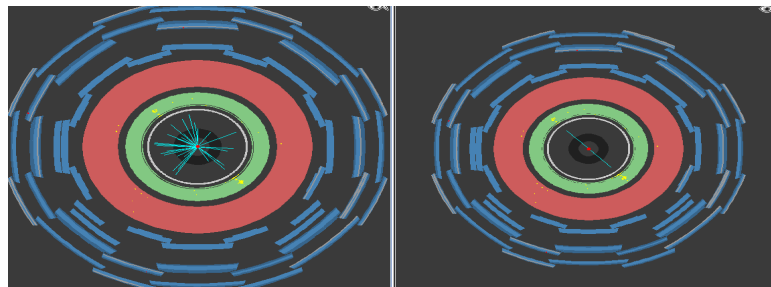
2006 – 2007: Masterclasses expanded to the United States and to South Africa
→ International Masterclasses (IMC)

International LHC Masterclasses (2011 - 2023)

The LHC Collider at CERN started in 2010 - exciting opportunity for IMC

2011: students analysed data released by ATLAS, CMS and ALICE (LHCb joined in 2014)

2023: IMC organized by 225 institutions in 60 countries, 13,000 participants



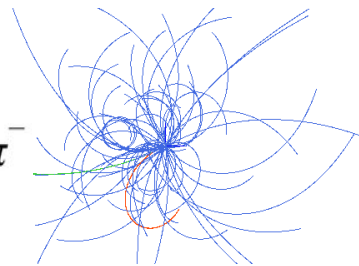
Z^0 decay into a pair of electrons at the LHC

International LHC Masterclasses (2011 - 2023)



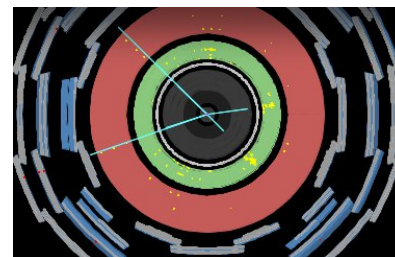
ALICE MC: Strangeness suppression
and R_{AA}

$$K_s^0 \rightarrow \pi^+ \pi^-, \Lambda \rightarrow p + \pi^-$$



Both visual and
large scale analysis

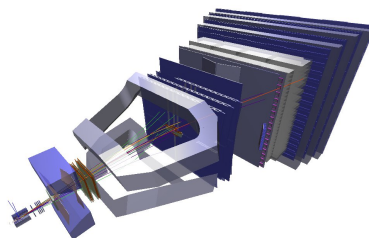
ATLAS and CMS MC: reconstruction of Z_0 , W^+ , W^- bosons
and search for the Higgs boson, discovered at CERN in 2012



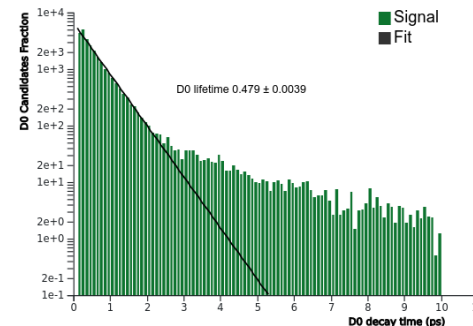
Visual analysis of 50 events

LHCb MC:

lifetime of the charm particle D^0

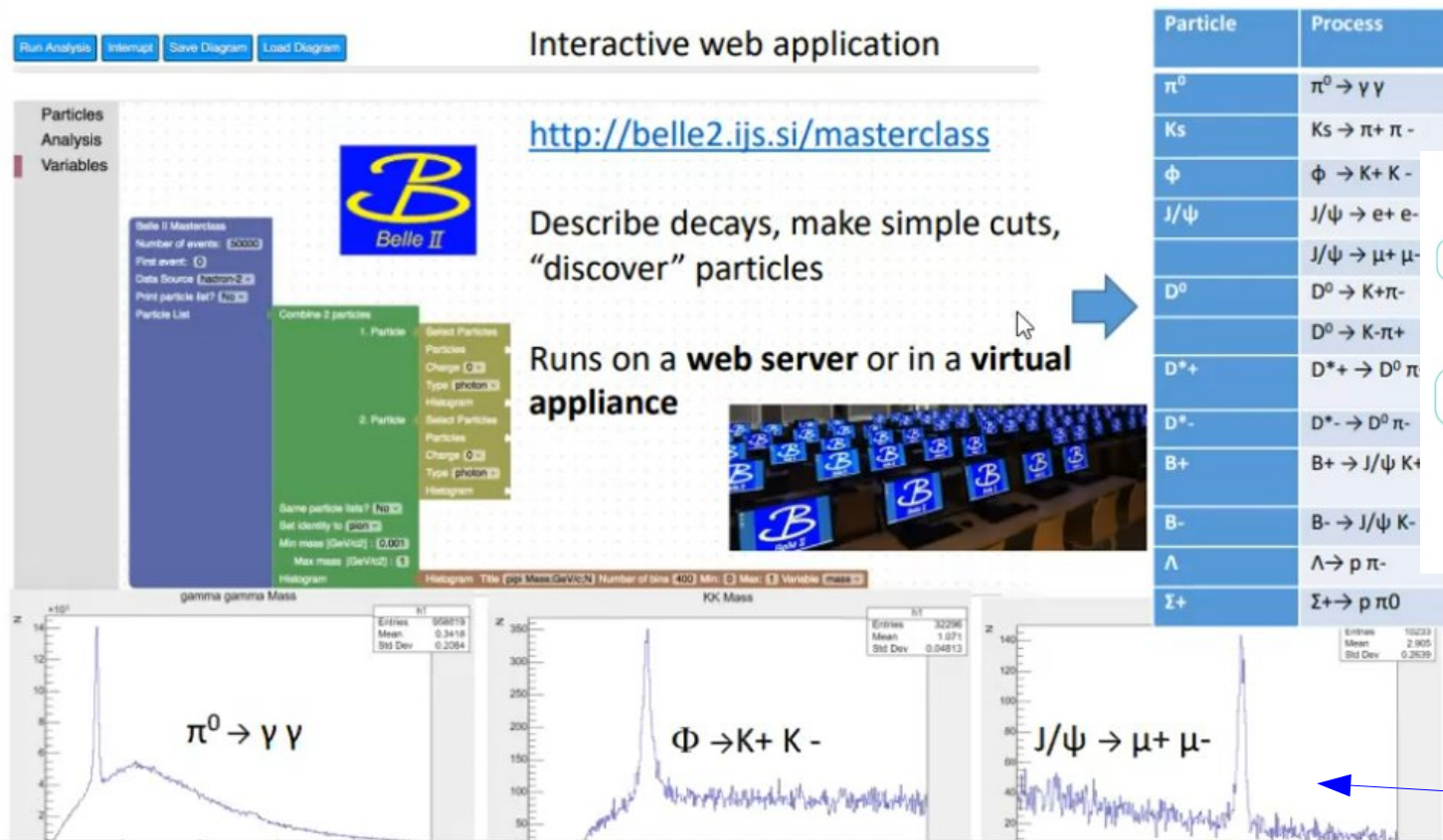


Both visual and
large scale analysis

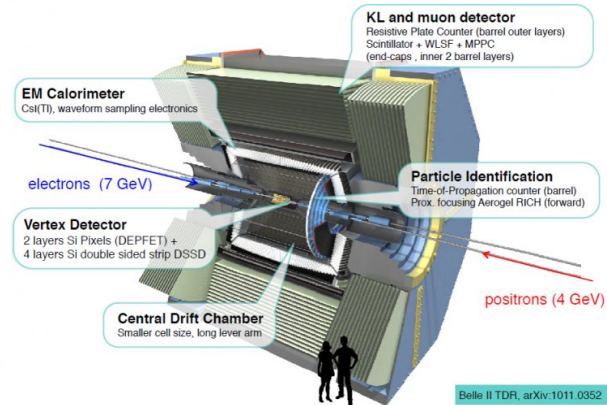


since 2020

Belle II (KEK, Japan)



e⁺ e⁻ collisions at SuperKEKB



New physics in B mesons
Matter- antimatter asymmetry

statistical analysis

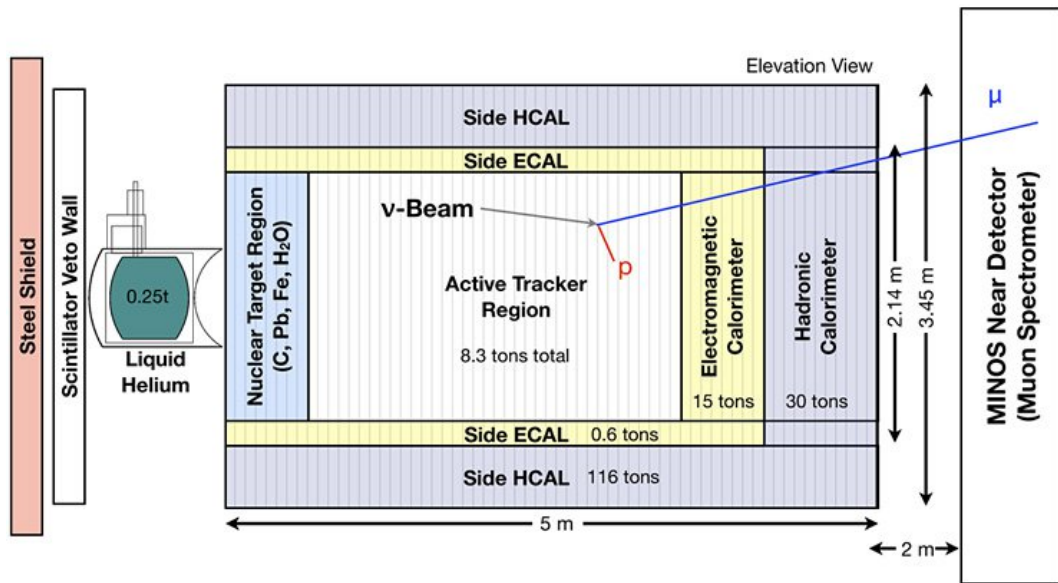
since 2020

MINERvA Neutrino Masterclass

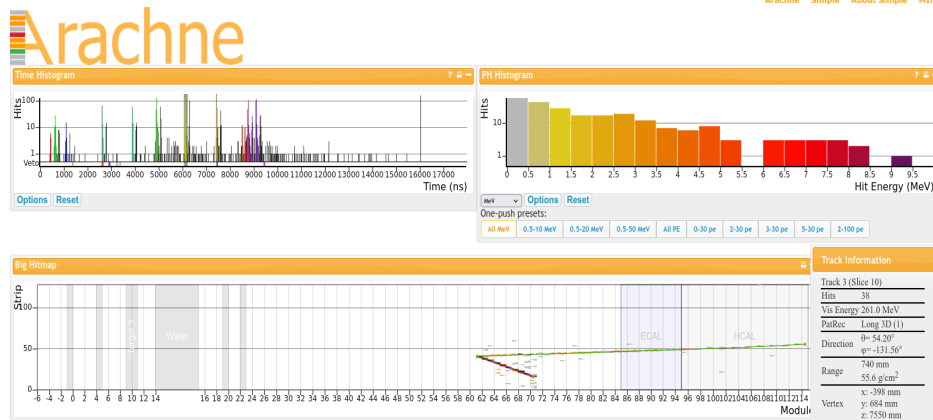
coordinated by QuarkNet & Fermilab



Interactions of muon neutrinos with carbon nuclei – input for neutrino oscillations at DUNE



MINERvA experiment at Fermilab



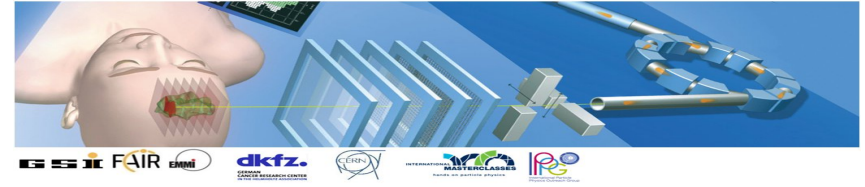
50 events each pair of students
histograms of net momentum:

- neutrino beam energy
- neutron momentum – Fermi gas behaviour

since 2020

Particle Therapy Masterclass

coordinated by GSI, Germany



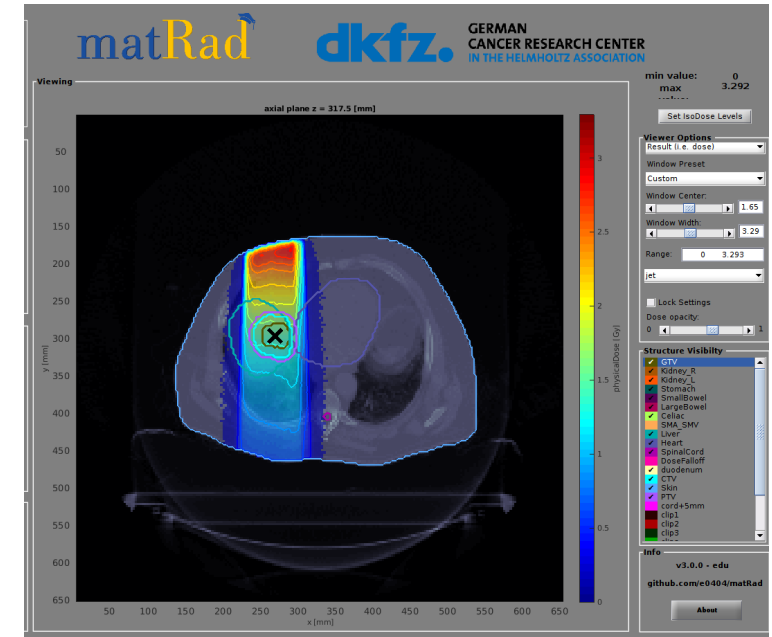
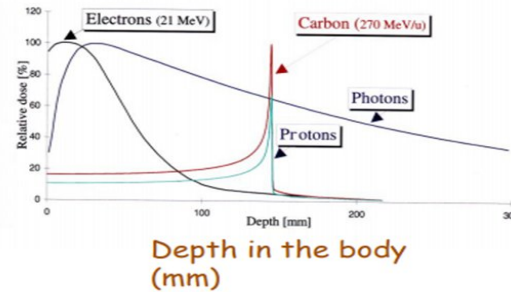
Demonstration of impact of fundamental research on medical applications

Students plan treatment for cancer therapy using

X rays

protons

carbon ions

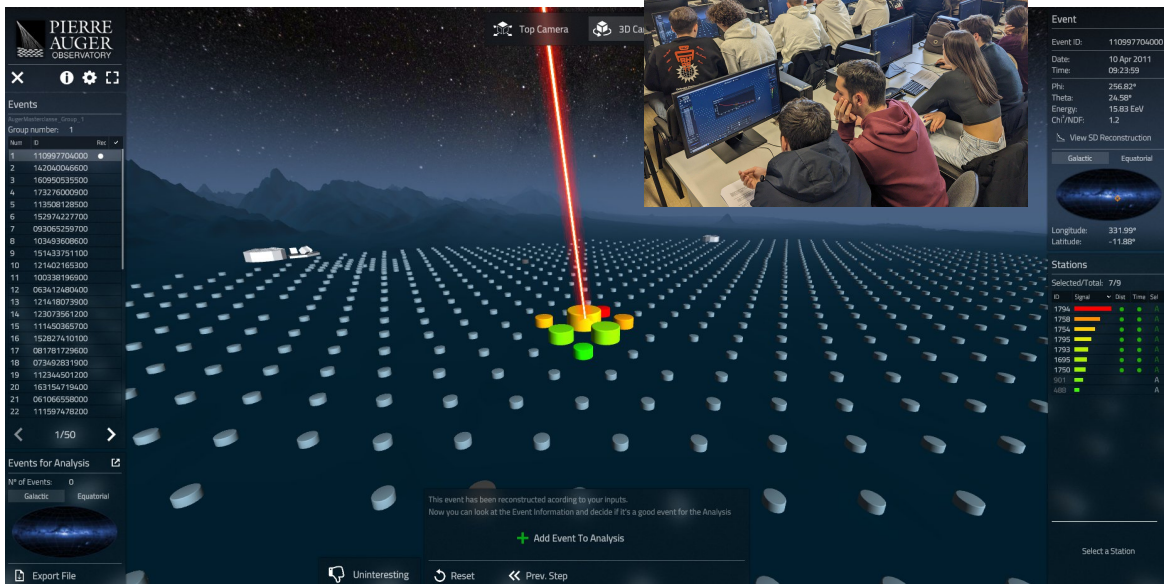


open source toolkit matRad to calculate doses

since 2023

Pierre Auger Masterclass

coordinated by LIP, Portugal



What is the origin of ultra-high-energy cosmic rays?

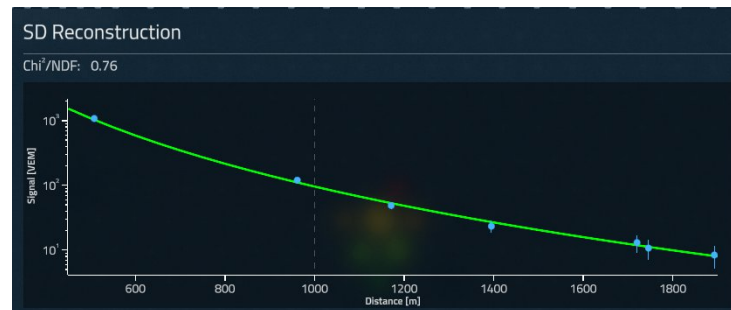
Visualization of events using an interactive display of the observatory

Separation of stations with signal from those with background

Visual reconstruction of the arrival direction of the primary cosmic ray

Fitting the data to determine the energy of the primary cosmic ray

Application of criteria to select events which point to the source



Statistics for IMC 2023

numbers from 2022 in brackets



CERN LHC Masterclasses

211 MCs (191):

- 99 ATLAS (94)
- 56 CMS (51)
- 26 LHCb (22)
- 30 ALICE (24)

Fermilab LHC Masterclasses

40 MCs (32):

- 29 CMS (22)
- 11 ATLAS (10)

MINERvA Masterclasses

8 MCs (9)

NOvA Masterclasses

2 MCs new!

KEK Belle II Masterclasses

16 MCs (11)

5 VCs (3)

Malargue Pierre Auger Masterclasses

12 MCs new!

3 VCs

GSI Hadron Therapy Masterclasses

30 MCs (28)

9 VCs (5)

New countries, audiences and formats



IMC continue to expand to new countries and new institutions

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 – IMC at high schools rather than universities, guided by physics teachers

New in 2023



- Quito, Ecuador, Escuela Politécnica Nacional
- Maputo, Mozambique, Universidade Eduardo Mondlane
- Ben Guerir, Morocco, Mohammed VI Polytechnic University
- Lusaka, Zambia, University of Zambia
- Patra, Greece, Hellenic Open University
- Kharkiv, Ukraine Kharkiv National University

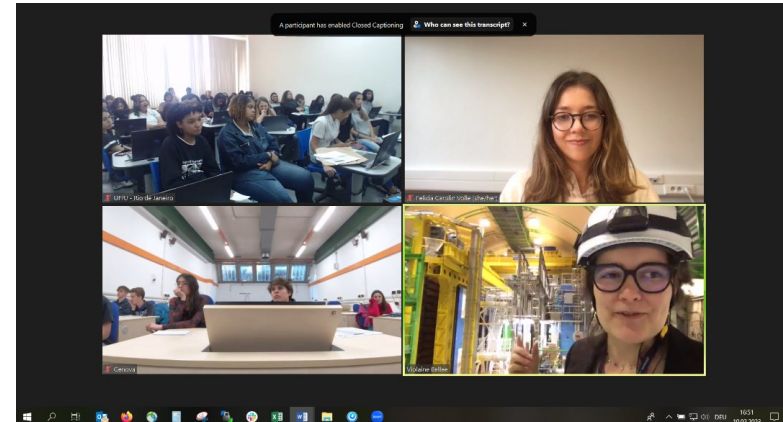
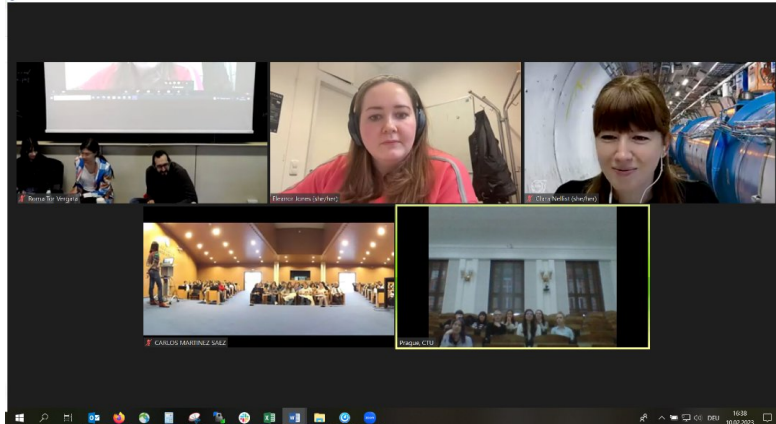


International Day of Women and Girls in Science



- LHC MCs for girls http://physicsmasterclasses.org/index.php?cat=women_in_science
- On Feb 10th (Friday)
- 14 groups participating (11)
- ~ 500 students (550)
- Female lecturers and tutors (as much as possible)
- 5 videoconferences at CERN (4)
- 10 female moderators (8)

	Feb 10, 2023	Feb 10, 2023	Feb 10, 2023	Feb 10, 2023	Feb 10, 2023
	VC 1 ATLAS W	VC 2 ATLAS Z	VC 3 CMS	VC 4 ALICE	VC 5 LHCb
moderators	Ana	Eleanor	Sudeshna	Despina	Violaine
moderators	Joni	Clara	Sonia	Ina	Felicia
	Cosenza 	Valencia 	São Paulo SPRACE 	Thessaloniki and Chania 	Rio de Janeiro, UFRJ
	Rome Tre 	Rome Sapienza 	Santiago de Compostela 	Darmstadt, Frankfurt, Muenchen, Muenster (ALICE R_AA) 	Genoa
	Biblioteca Alexandrina 	CTU Prague 		Cape Town, (Themba LABS) 	
		Rome Tor Vergata 			



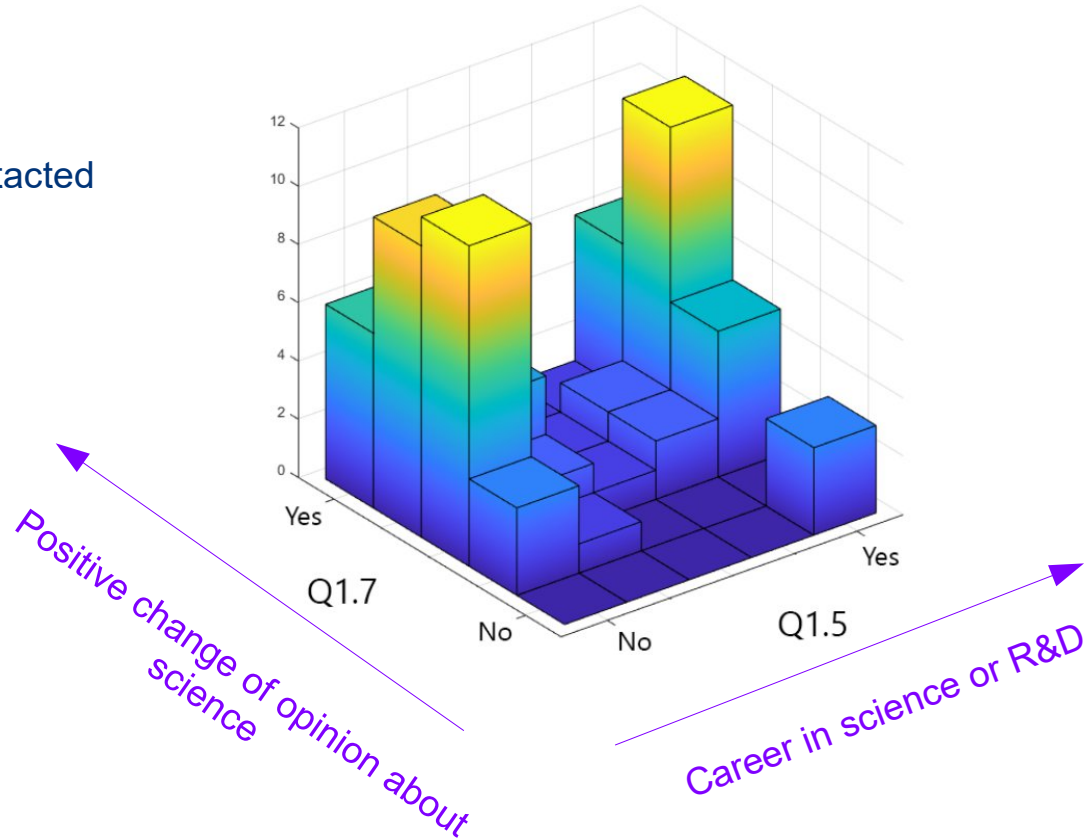
Study of long-term impact of IMC in Slovakia and the Czech Republic

„On the long-term impact of non-formal learning in particle physics“ Júlia Kekeláková and Boris Tomášik, <https://arxiv.org/abs/2307.15906>

- Survey in April - May 2023
- 351 former participants from 2011 - 2015 were contacted
- 71 participants responded
- 55% outside science and R&D
- 35% reported IMC influenced their decision to study physics or related subject

Q1.5 I contribute to the development of science—I am scientific associate, or I work for a company focussed on R&D

Q1.7 Thanks to Masterclasses I positively changed my opinion about science, research, and physics



Conclusions

Since 2011, more than 100,000 high school students participated in the IMC from 60 countries

8 different topics under the IMC umbrella: from LHC to neutrinos, particle therapy and cosmic rays

IMC owe much of their success to the spirit of cooperation in particle physics and IPPOG

IMC is fun for both organizers and the participants

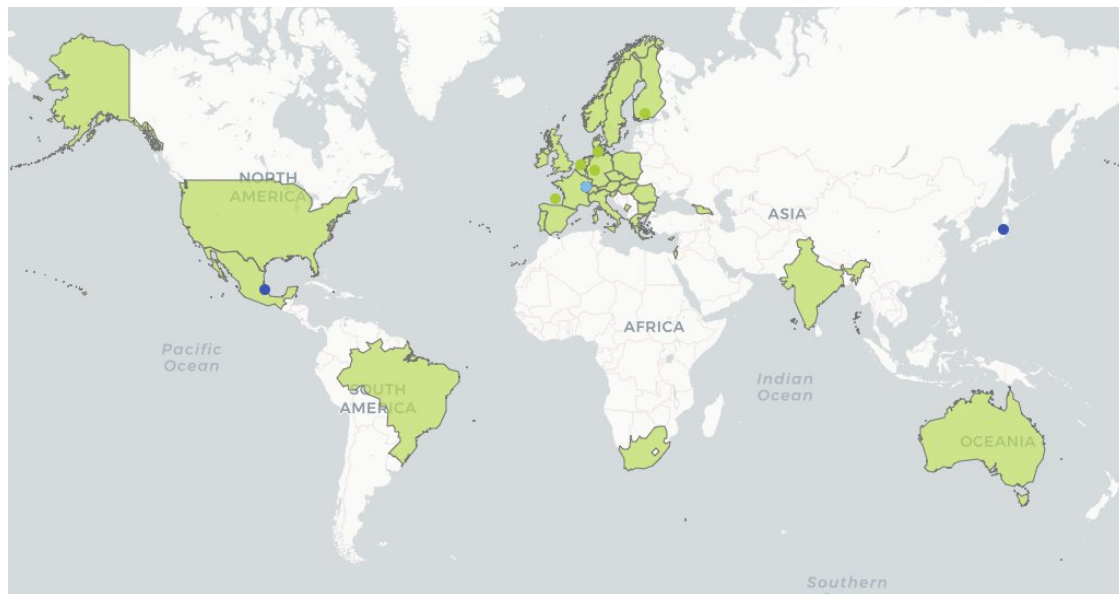
We inspire the next generation



Back-up slides


IPPOG members


33 countries, 6 experiments and CERN (international laboratory)



 Countries

 CERN

 Associated members (DESY, GSI)

 International Experiments ([ALICE Collaboration](#), [ATLAS Collaboration](#), [Belle II Collaboration](#), [CMS Collaboration](#), [HAWC Collaboration](#), [LHCb Collaboration](#))

Welcome Pierre Auger Observatory!

Country/Lab./ Exp.	Signatory Organization	Representative
ALICE	ALICE Collaboration	Despina Hatzifotiadou
ATLAS	ATLAS Collaboration	Sascha Mehlhase
AUSTRALIA	CoEPP	Paul Jackson
AUSTRIA	HEPHY, OAW, ÖPG	Natascha Hoermann
BELGIUM	F.W.O. and F.R.S.-FNRS	Dirk Ryckbosch
BELLE II	BELLE II Collaboration	Zdenek Dolezal
BRAZIL	RENAFAE	Marcelo Munhoz
BULGARIA	Sofia Techpark	Roumyana Hadjiskia
CERN	CERN	Ana Godinho
CMS	CMS Collaboration	Freya Blekman
CYPRUS	University of Cyprus	Tassos Christofides
CZECH REPUBLIC	Institute of Physics of the Czech Academy of Sciences	Vojtech Pleskot
DENMARK	Danish CERN Instrumentation Centre, NICE	Ian Bearden
DESY (Associate)	DESY	Thomas Naumann
FINLAND	Helsinki Institute of Physics	Sami Lehti
FRANCE	CNRS / IN2P3	Nicolas Arnaud
GEORGIA	Ministry of Education, Science, Culture and Sport	Alexander Sharmazanashvili
GERMANY	DESY for KET	Christian Klein-Bösing
GREECE	Ministry for Education, Research and Religious Affairs	Nick Tracas
GSI (Associate)	GSI	Ralf Aeverbeck
HAWC	HAWC Collaboration	Jose Ruben Alfaro Molina
HUNGARY	Wigner Research Centre for Physics	Dezso Horvath
ISRAEL	Weizmann Institute of Science	Ehud Duchovni
INDIA	National Institute of Science Education and Research	Bedangadas Mohanty
IRELAND	Dublin Institute for Advanced Studies	Jon-Ivar Skullerud
ITALY	INFN	Catia Peduto
LHC-b	LHC-b Collaboration	Bolek Pietrzyk
MONTENEGRO	Ministry of Science of Montenegro	Ivana Lagator
NORWAY	Physics Department of the University of Oslo	Farid Ould-Saada
MEXICO	BUAP	Arturo Fernandez Tellez
POLAND	The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences	Krzysztof Wozniak
PORTUGAL	LIP	Ricardo Gongalo
ROMANIA	Institute of Atomic Physics	Gabriel Stoicea
SLOVAK REPUBLIC	Ministry of Education, Science, Research and Sport	Ivan Melo
SLOVENIA	Josef Stefan Institute, Ljubljana	Andrej Gorisek
SOUTH AFRICA	iThemba Labs. for the National Research Foundation	Sahal Yacoub
SPAIN	Spanish National Particle Physics Programme	Alberto Ruiz
SWEDEN	Swedish Physical Society	Jonas Strandberg
SWITZERLAND	CHIPP	Katharina Mueller
THE NETHERLANDS	NIKHEF	Charles Timmermans
UK	STFC	Darren Price
USA	Univ. Notre-Dame on behalf of Quarknet	Spencer Pasero