

Uta Bilow, TU Dresden

Particle Physics Outreach with Masterclasses

MSU Physics and Astronomy Colloquium / Jan 13, 2022

CERN Media coverage

Spektrum.de
ASTRONOMIE | BIOLOGIE | CHEMIE | ERDE/UMWELT | IT/TECH | KULTUR | MATHEMATIK | MEDIZIN | PHYSIK | PSYCHOLOGIE/HIRNFORSCHUNG
MAGAZINE | ARCHIV | ABO/SHOP | SERVICE | LOGIN

Startseite » Physik » Teilchenphysik: Das Higgs und die zweite Generation

Das Higgs und die zweite Generation

Neue Messungen am CERN zeigen: Das b...
Schwergewichten im Teilchenzoo zu sp...
Partikeln.
von Robert Gaal

Die Maschine, die die Welt erklären soll

Das CERN will einen Teilchenbeschleuniger

Das CERN will mit einem 100 Kilometer la...
beantworten. Was bringt das? Ein Intervie...

SUN'S No1 FOR PARTICLE PHYSICS

BANG!

Hadron Collider sets energy record
Clue to life, universe and everything

Dog went for hairdo and was strangled

Brit banks £40m lott

Our grain designs

Cern

Das größte Gerät der Welt

Für 20 Milliarden Euro wollen Europas Physiker einen neuen Teilchenbeschleuniger bauen, 100 Kilometer lang. Aber braucht man so was? Das ist gar nicht so leicht zu entscheiden.

Von Katharina Menne

24. Juni 2020, 16:51 Uhr / Editiert am 29. Juni 2020, 11:10 Uhr / DIE ZEIT Nr. 27/2020, 25. Juni 2020 / 313 Kommentare /

The Guardian

Media echo on Higgs discovery



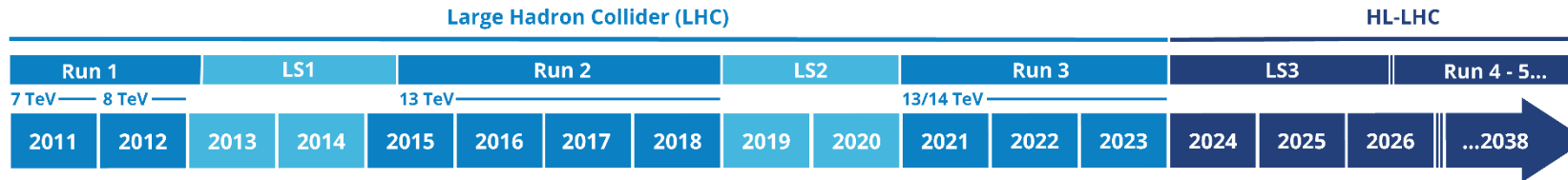
NEWS
2013 Nobel Prize in Physics goes to Englert and Higgs
20 November 2013



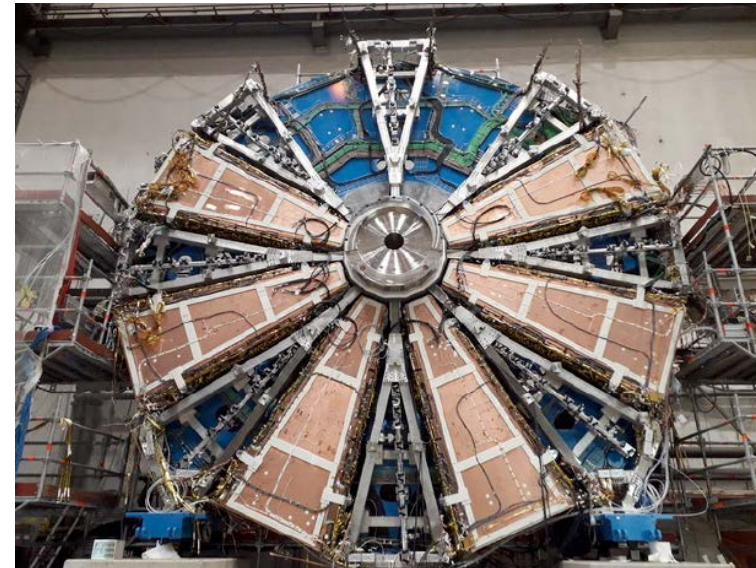
[2013 Nobel Prize in Physics](#)

Champagne corks popped at CERN on 8 October, to celebrate the award of the 2013 Nobel Prize in Physics to François Englert, professor emeritus at the Université libre de Bruxelles, and Peter Higgs, professor emeritus at the University of Edinburgh. They received the honour “for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN’s Large Hadron Collider”. The announcement of the discovery by the ATLAS and CMS collaborations took place at CERN on 4 July last year ([CERN](#)

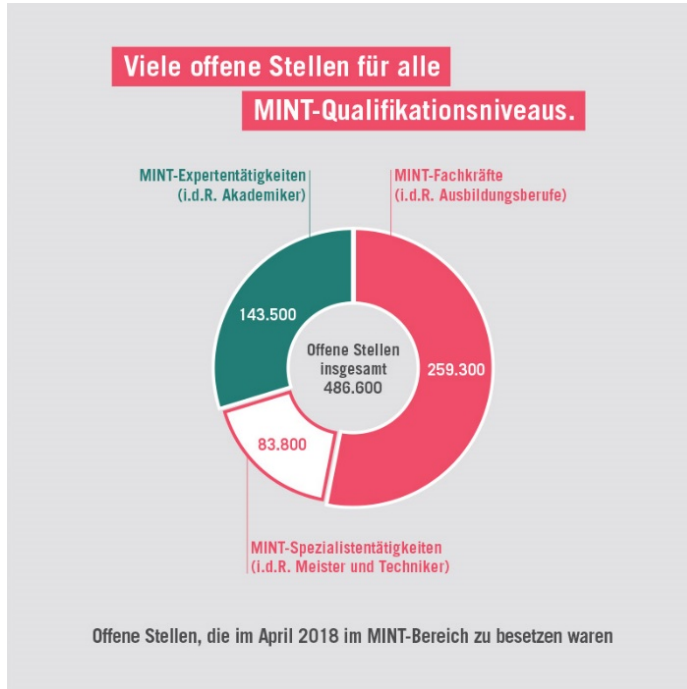
LHC schedule



HL-LHC: High Luminosity LHC
 LS: Long Shutdown
 TeV: Tera electron Volt



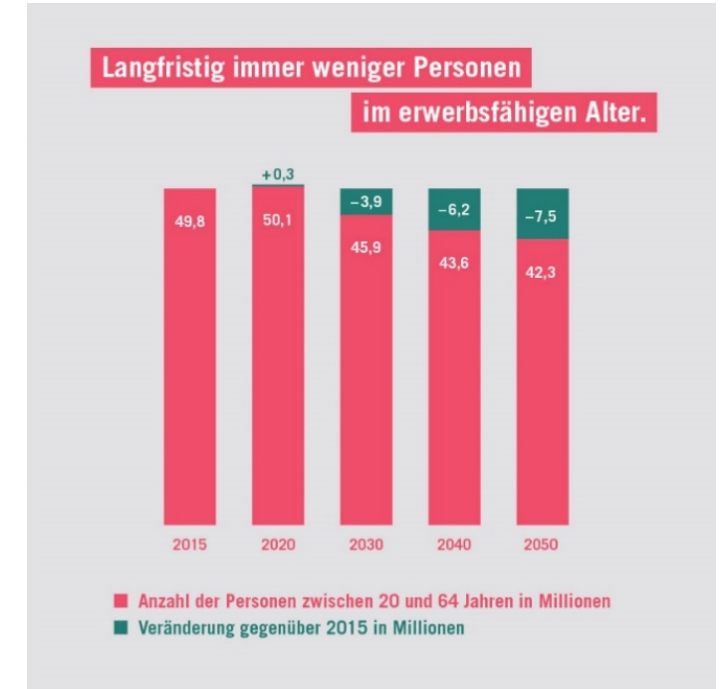
Shortage of STEM Specialists



490.000 open positions in STEM
Green: academic background



Number of open positions is growing

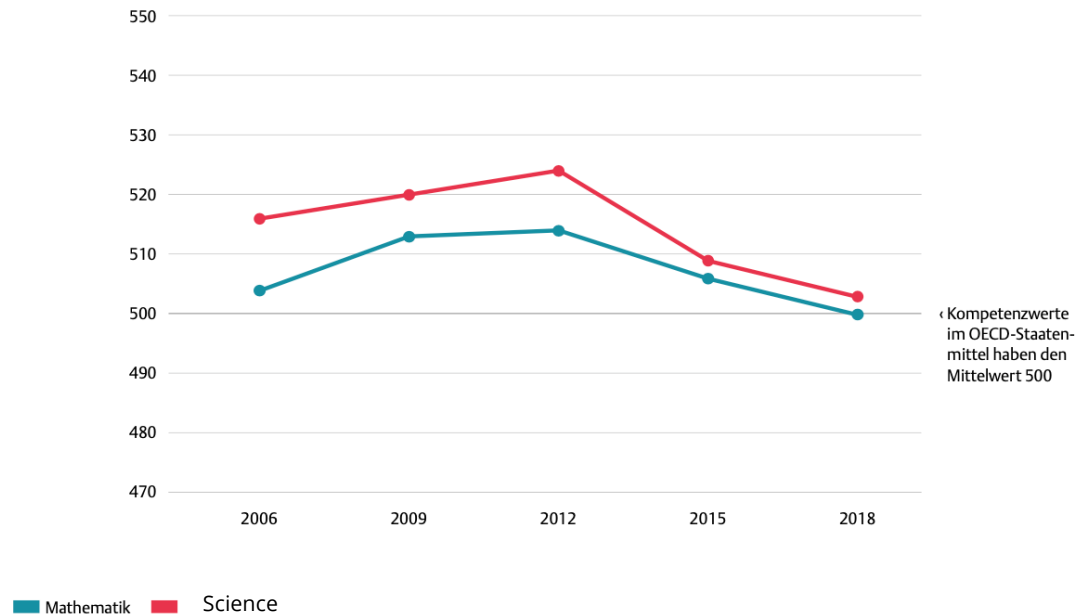


Number of working-age persons is decreasing

<https://www.insm.de/insm/themen/arbeit/fakten-fachkraeftemangel>

STEM Young talent barometer

Performance of 15-year-olds in Germany



Datenbasis: Reiss et al. 2019

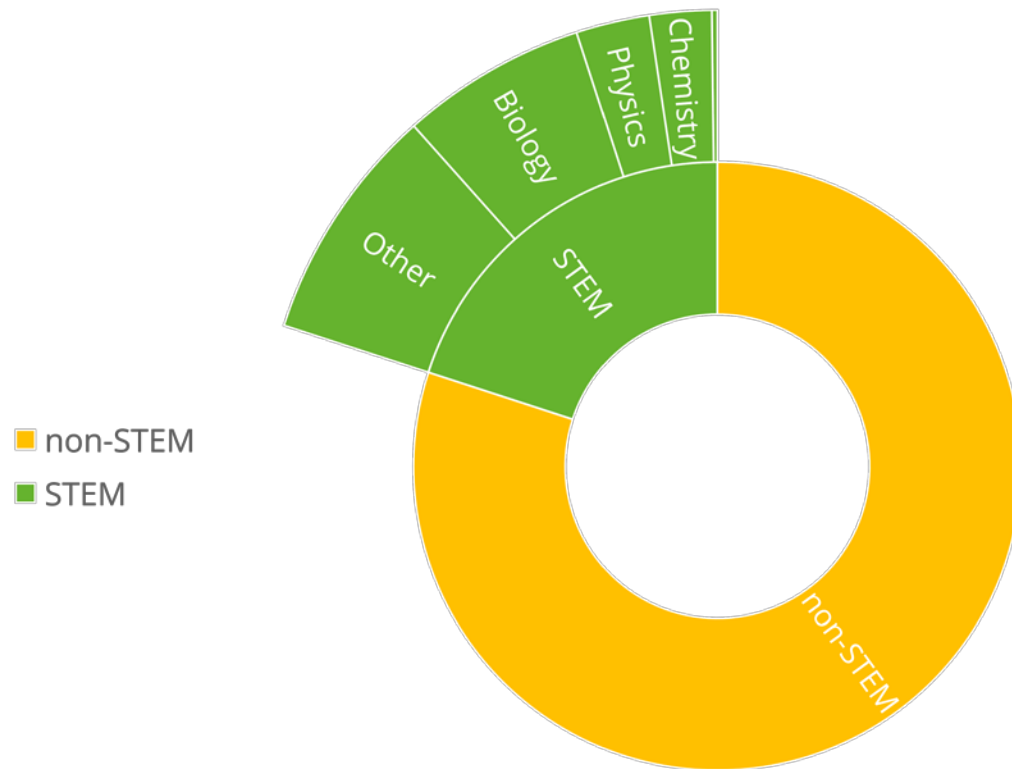
- performance of 15-year-olds declining since 2012
- Girls' and boys' performance is similar, but mainly because boys' performance deteriorates
- Girls have less interest and self-confidence in mathematics, chemistry and physics than boys, despite comparable performance
- Motivation, interest and professional self-confidence decreased

<https://www.koerber-stiftung.de/mint-nachwuchsbarometer>

More findings from STEM Young talent barometer

20 % of high school students choose science on a higher level (advanced course or “Leistungskurs”)

Low percentage of girls in physics and computer science courses:



■ Biology: 60 %



■ Physics: 26 %



■ Computer Science: 15 %



Motivation for outreach



Leon Lederman, 1980ies

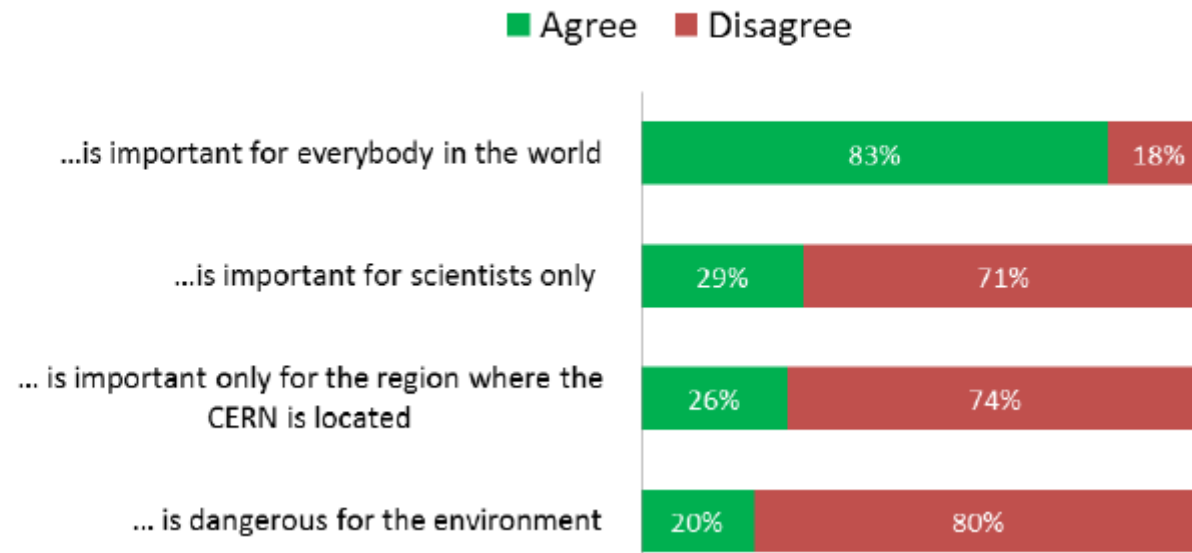


Recruitment of
future scientists

Motivation for outreach

- secure funding for our projects (“1 coffee/year”)
- **A price worth paying** R. Heuer (2020) <https://cerncourier.com/a/a-price-worth-paying/>
- **Scientific Research at CERN as a Public Good: A Survey to French Citizens** M. Florio et al. (2018) <http://cds.cern.ch/record/2635861>

Figure 8. Scientific research at CERN ... (n=1,005)



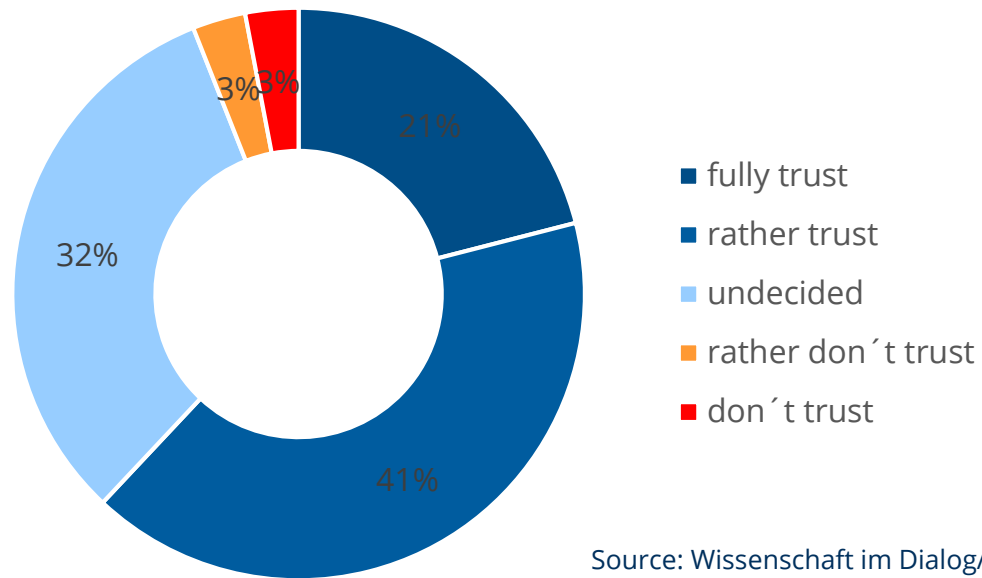
Recruitment of
future scientists

Explanation &
legitimation

Motivation for outreach

“How much do you trust science and research?”

Wissenschaftsbarometer 2021



Source: Wissenschaft im Dialog/Kantar



Recruitment of
future scientists

Explanation &
legitimation

Create
trust in science

Motivation for outreach

Quotes from Masterclasses moderators:

“The best thing is actually answering the questions and seeing how excited and how happy they are, waving at the camera. They're really excited to be talking to physicists based at CERN!”

“It is very satisfying, because we do many video conferences and rarely do people cheer on the other side if you say something. Here they do!”



Recruitment of
future scientists

Explanation &
legitimation

Create
trust in science

Intrinsic
motivation

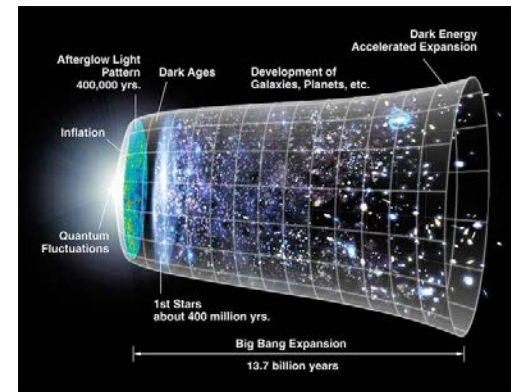
A research area with a lot of potential

Strength and chances:

- Strong media interest
- Many people are interested in fundamental questions
- Unique research methods and experimental setups
- Is connected to captivating terms, e.g. Big Bang, Antimatter

Challenges:

- Modern physics often not in school curricula
- Many new concepts and perceptions
- Large number of new terms
- Connection to everyday experience



The idea behind Masterclasses

Act as a "scientist for a day"

- Close to current research
- Own "hands-on" activities (listen = forget, see = remember, do = understand)

Get insight into the research process

- Use of relevant methods and tools
- Comparisons between experiment and theory

Authentic experiences

- Analysis of real scientific data
- Meeting and discussion with scientists



Why “Masterclass”?

As in a Masterclass in the arts, students work with an expert

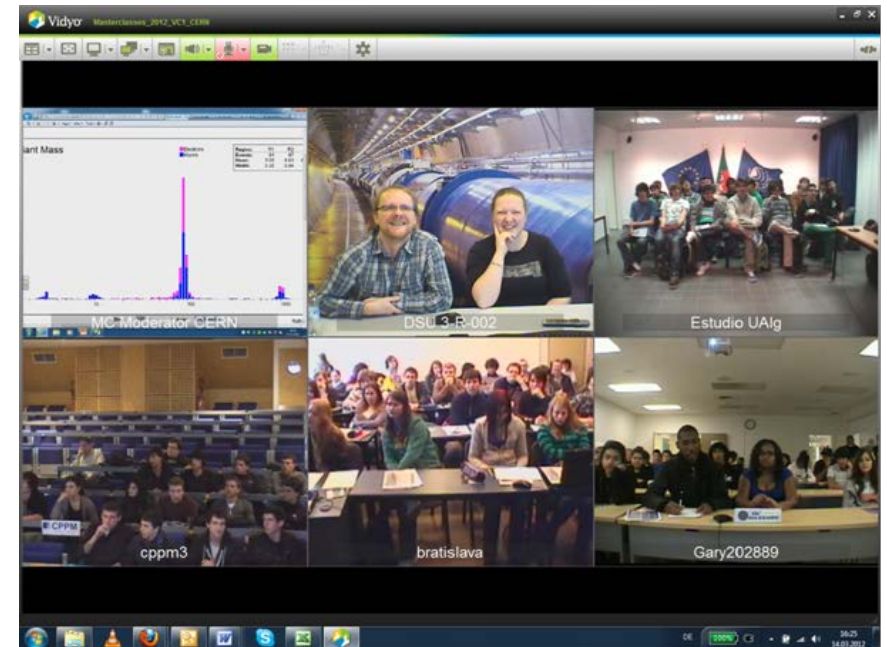
Expert = particle physicist

Instead of, say, a violin, the subject is particle physics data analysis



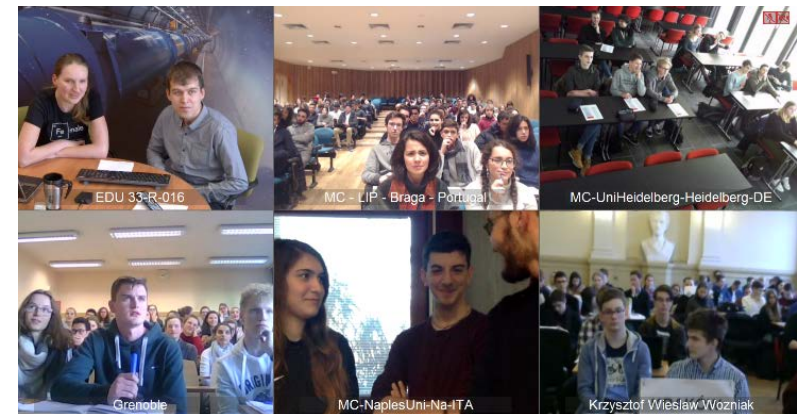
Concept of International Masterclasses

- High school students (15 – 19) are „scientists for one day“
- Get invited to a research institute or university
- Introductory talks (standard model, detectors, accelerators)
- measurement with HEP data
- International video conference (3 – 5 inst. + moderators)



Sample Agenda

Local time	Activity
8:30 - 9:00	registration & welcome
9:00 - 10:00	introduction to Particle Physics
10:30 - 11:30	second talk or tour
12:00 - 13:00	lunch
13:00 - 15:00	data analysis
15:00 - 16:00	local combination + discussion
16:00 - 17:00	international video conference



Videoconference

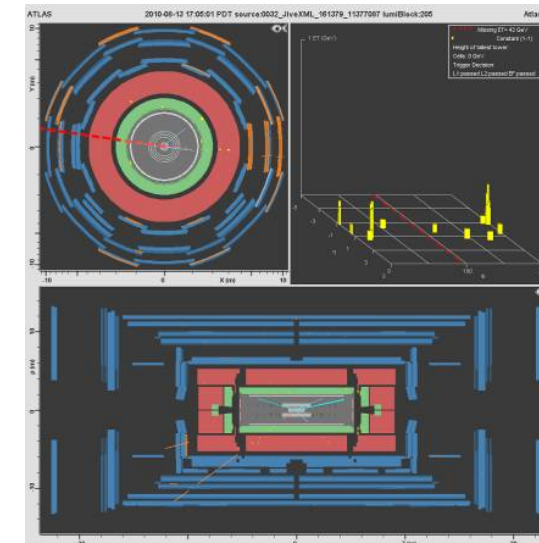
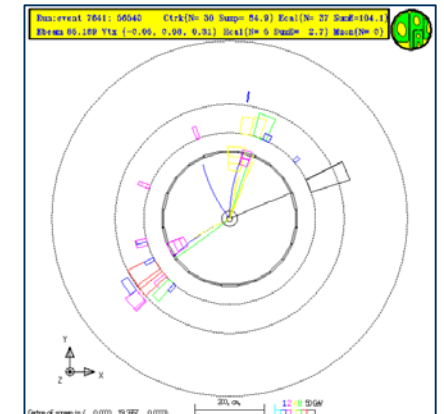
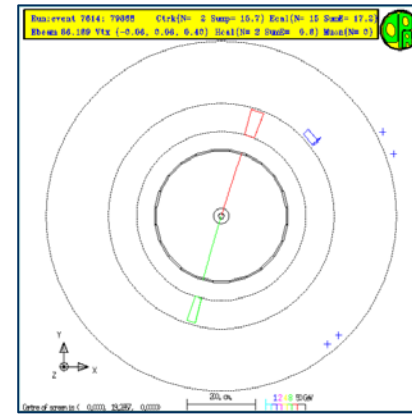
- 45-60 min
- 3-5 institutes, reflecting international collaboration
 - Same measurement, different data
- 2-3 Moderators (PhD students, Postdocs)
- Moderation centers: CERN, Fermilab, KEK, GSI, TRIUMF
- Agenda of the videoconference
 - Welcome
 - Combination and discussion of results
 - General Q & A
 - Quiz



Brief History of Masterclasses

- 1996: Idea from R. Barlow et al.
- 1997: 1. Masterclass in UK with 7 institutes
- 1998: nationwide uptake
- 2005: Adopted by EPPOG/IPPOG for all Europe
- Use of LEP data
 - OPAL Identifying Particles
 - DELPHI Hands on CERN
- 2006: U.S. joined program (QuarkNet)
- 2011: LHC-based Masterclasses only
- 2014: all 4 LHC experiments

<http://cerncourier.com/cws/article/cern/55890> (How it all begun)
<http://cerncourier.com/cws/article/cern/57305> (MC in the LHC era)



Worldwide program

- Organized by IPPOG (International Particle Physics Outreach Group)
- 60 countries involved
- 220 research labs
- 2019: 15.000 high school students
- Coordination: Ken Cecire (QuarkNet) / TU Dresden



Broad Physics Scope

Today:

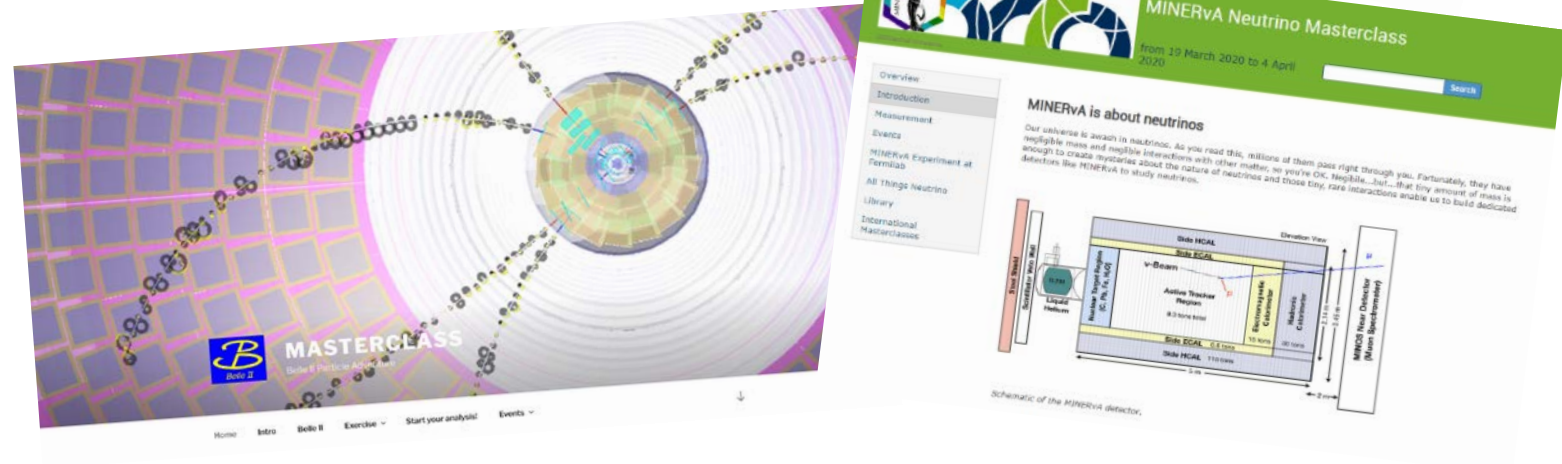
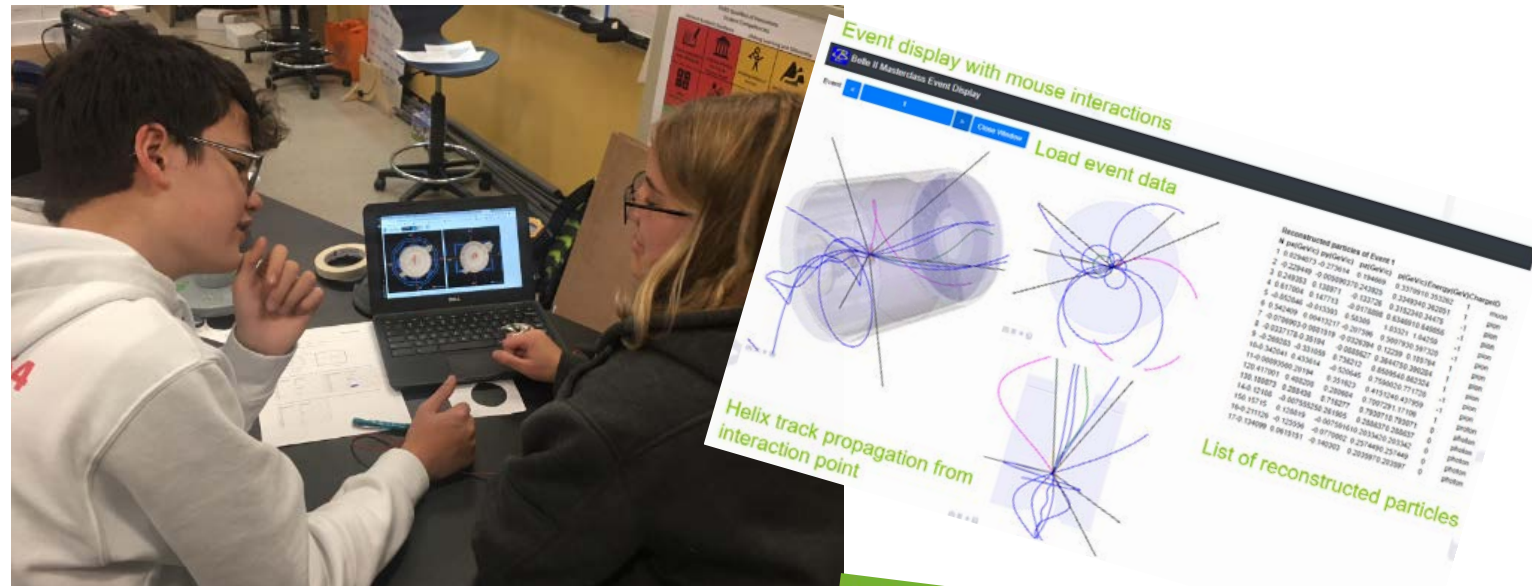
- LHC (since 2005)
- MINERvA (since 2019)
- Belle II (since 2020)
- Particle Therapy (since 2020)

Under development:

- NOvA
- MicroBooNE

More Masterclasses:

- [IceCube](#)
- [Pierre Auger](#)
- [DarkSide](#)
- ...



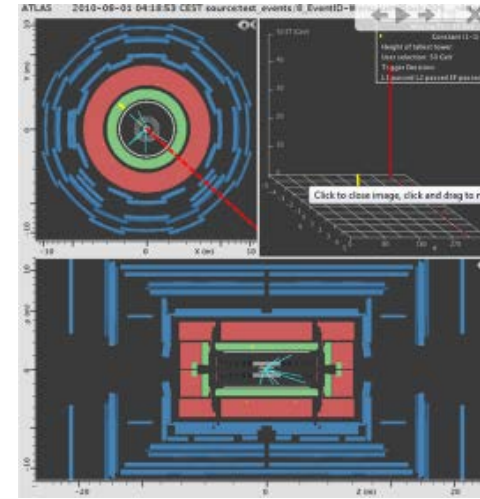
ATLAS W path

Students analyze event displays (50 collision events per pair of students)

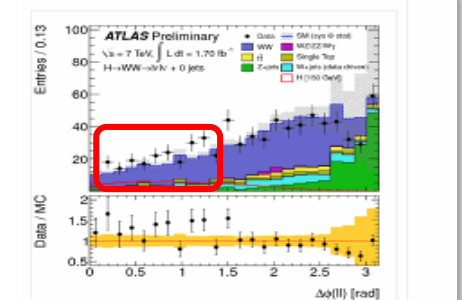
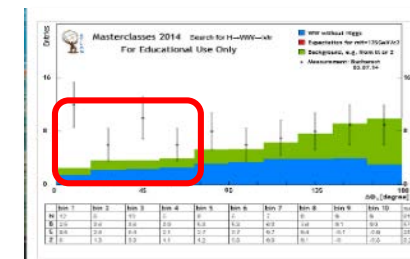
2 tasks:

- Identify W bosons, determine type and electric charge of leptons
- Resulting W⁺/W⁻ is used to reveal the inner structure of the proton (and compared to results from ATLAS)
- Identify W pairs and measure azimuthal opening angle $\Delta\phi_{ll}$
- Resulting histogram is used to provide insight into Higgs discovery process at CERN

<https://atlas.physicsmasterclasses.org/en/wpath.htm>

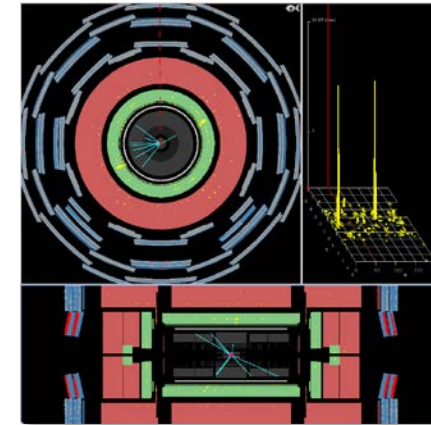


Total #	W → ... + ν				Background
	e ⁺	e ⁻	μ ⁺	μ ⁻	
532					
group A	9	4	10	1	24
group B	11	12	13	10	19
group C	5	3	1	1	19
group D	7	4	11	5	21
group E	11	10	3	2	31
group F	15	3	3	1	26
group G	6	4	3	5	27
group H	15	10	3	2	13
group I	5	3	3	4	5
group J	4	0	1	0	21
group K	5	1	5	3	18
group L	4	7	4	2	31



ATLAS Z path

- Students search for 2-lep, $\gamma\gamma$, or 4-lep events
- Calculate invariant mass, upload results to a plotting tool
- Results are combined, invariant mass distributions are built



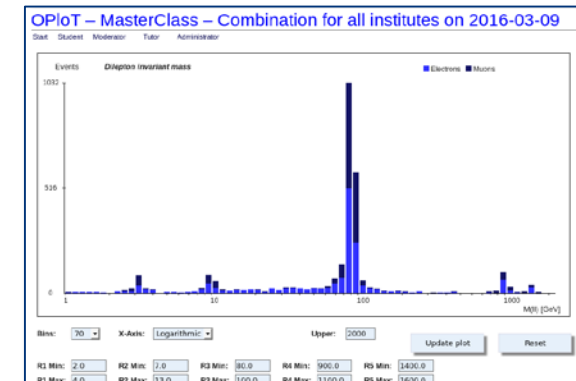
2-lep invariant mass distribution:

- Resonance peaks of known particles: Z^0 , J/Ψ , Y
- Search for new particles: Z' , graviton

4-lep, di-photon:

- Provide insight into the process of discovering the Higgs at CERN
- Explain concepts of statistics, modelling, signal significance

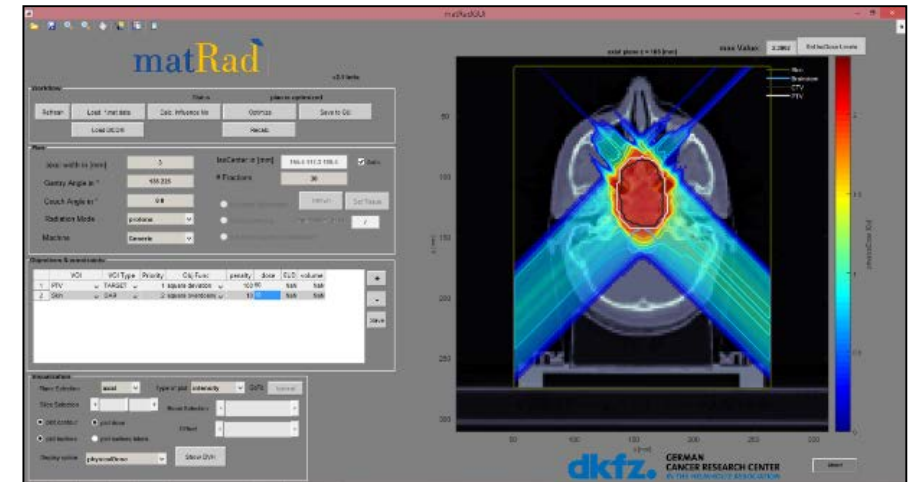
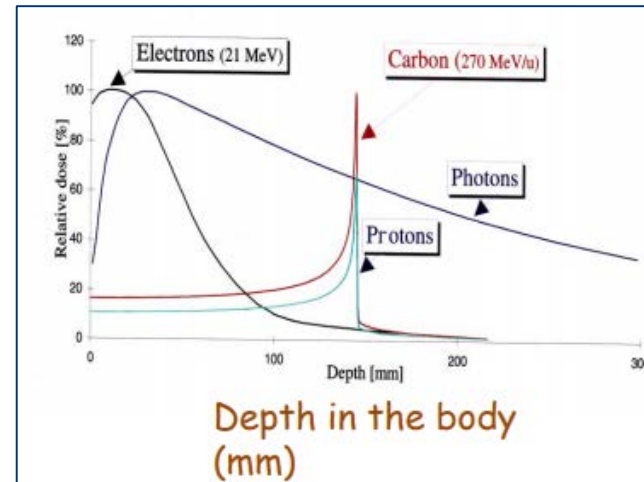
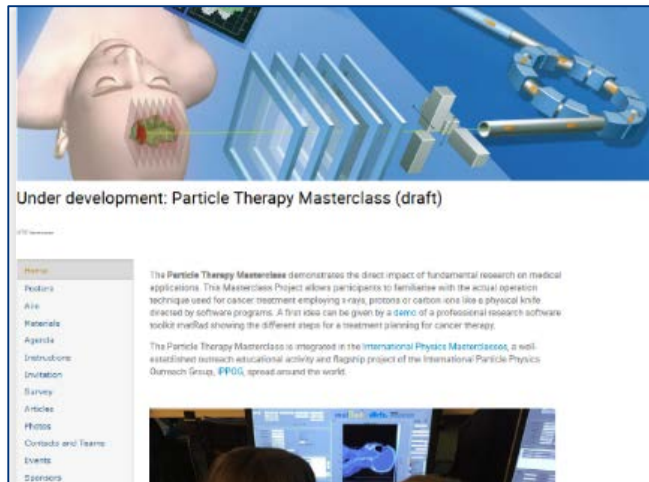
<https://atlas.physicsmasterclasses.org/en/zpath.htm>



Particle Therapy Masterclass

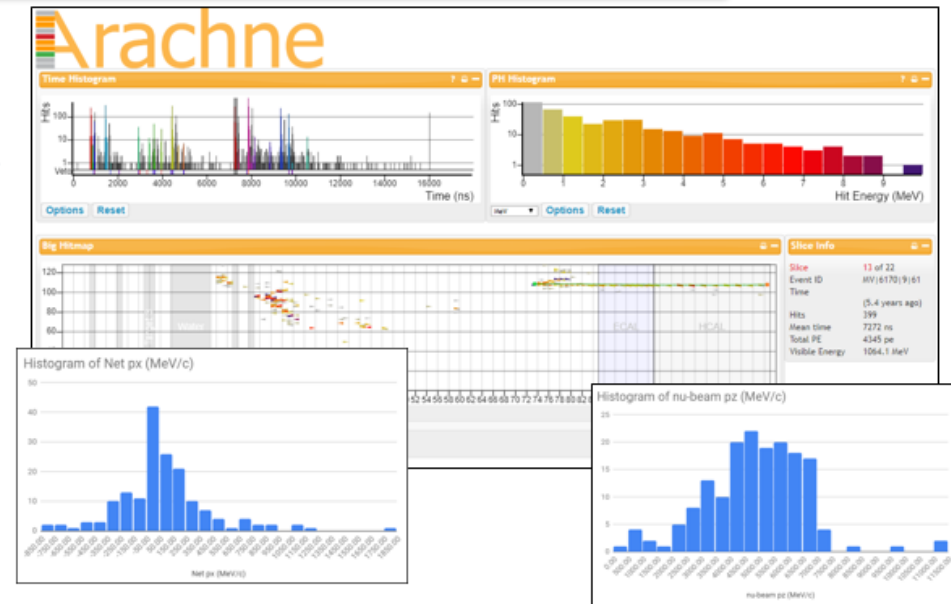
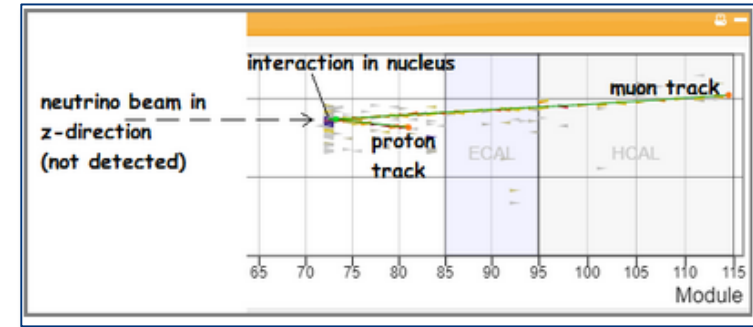
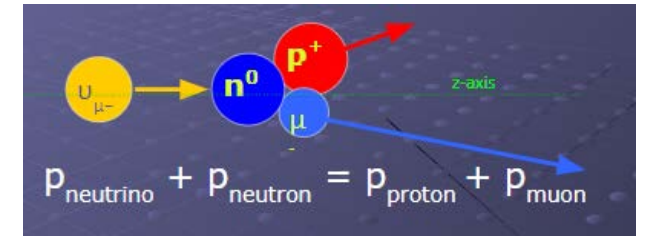
- Particle treatment planning
- highlights some of the benefits for society from the technology developed for particle physics research

<https://indico.cern.ch/event/840212/>



MINERvA Masterclasses

- Measure carbon nucleus to test interaction model
- Discover Fermi motion
- Muon neutrinos interact with carbon target
- $\nu + n \rightarrow p + \mu$
- Measure p_x and p_y of proton and muon
- momentum distribution $\rightarrow \Delta p$
- Fermi motion, nucleus is active place
- $\Delta p_x \rightarrow \Delta x \rightarrow$ bound on neutron motion \rightarrow radius of nucleus



<https://indico.fnal.gov/event/22340/>

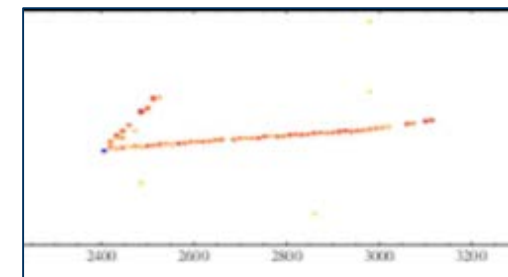
NOvA Masterclass

- New Masterclass under development by Greg Pawlowski (QuarkNet mentor) , Mike Plucinski (Neutrino fellow), QuarkNet staff
- Find ratio of Neutral Current (NC) to Charged Current (CC) events
- Compare CC:NC in FD vs in ND → evidence of oscillations
- Combine Far Detector event display analysis (small number) with python notebook (many events from Near Detector)
- Under development, concept tested with teachers
- Limited trial Masterclasses in IMC22

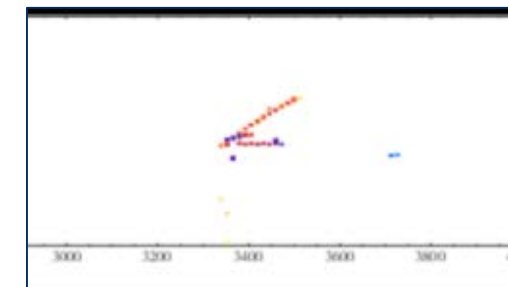
<https://quarknet.org/content/nova-masterclass-development-resources-links>



The 500-mile (800 km) subterranean path of the NOvA neutrino beam (Fermilab)



CC event:
muon (long)
and proton
(short)

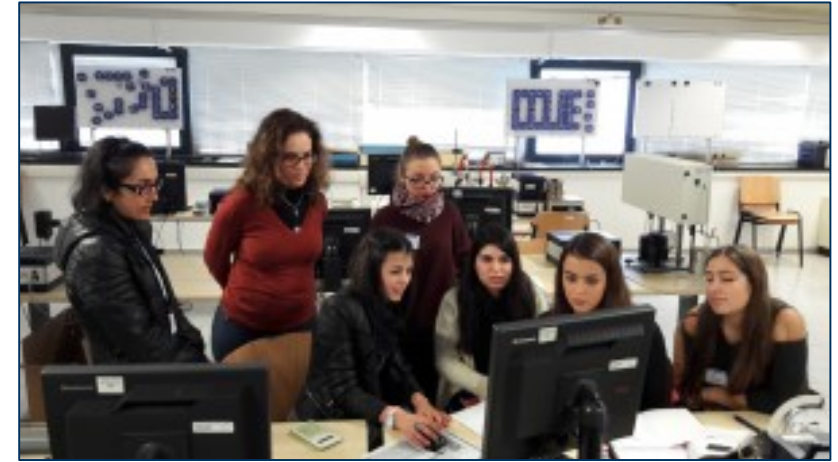


NC event:
short tracks,
multiplicities

Special events

Girls Masterclasses

- UN International Day of Women and Girls in Science
- Feb 11
- Masterclasses targeting girls
- involving female scientists



World Wide Data Day

- Students worldwide analyse data from LHC events
- Data analysis at school, physics discussion in VC
- Simplified Measurement



Impact of the COVID-19 pandemic

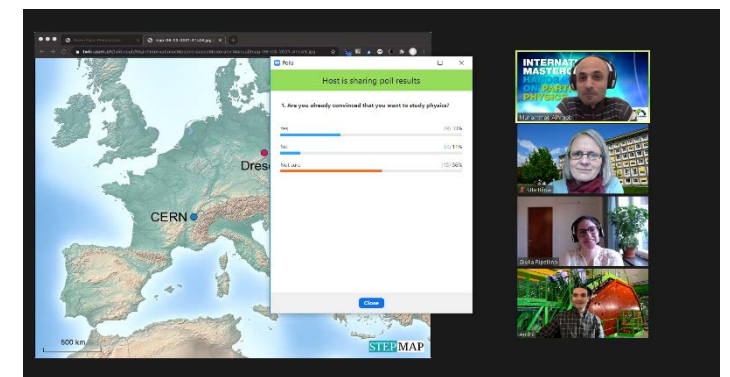
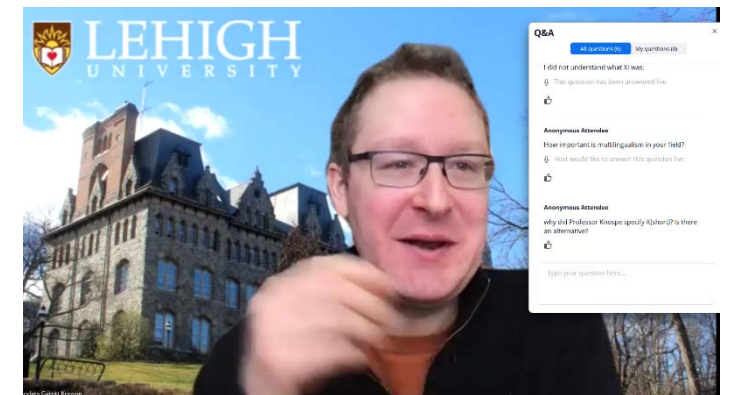
2020: program suspended by March 18, only ~ 25 % of MC completed

2021: Masterclass@home

- remote lectures
- Hands-on part in breakout rooms
- Final videoconference as Zoom webinars, up to 250 unique viewers
- Teams of 3 moderators, incl. 1 technical moderator
- Zoom polls and Q&A function

Outcome

- Reaches more people
 - Open to students without regional restriction
 - Tutors and moderators could engage from everywhere (home, office,...)
- Increases interaction during Videocon
 - All students involved via polls
 - Lively discussion and many questions via Q&A function



International Scientific Collaboration

- Active Researchers with Experience in Education & Public Engagement
- Experts in Communication & Education

Global Network

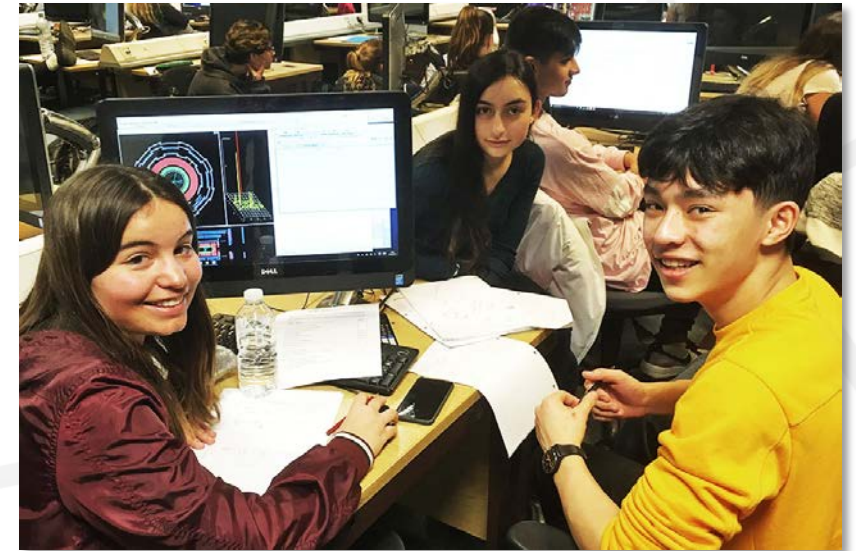
- 37 members: 30 countries, 6 experiments, 1 intl lab (CERN)
- 2 associate members: 2 national labs (DESY, GSI)

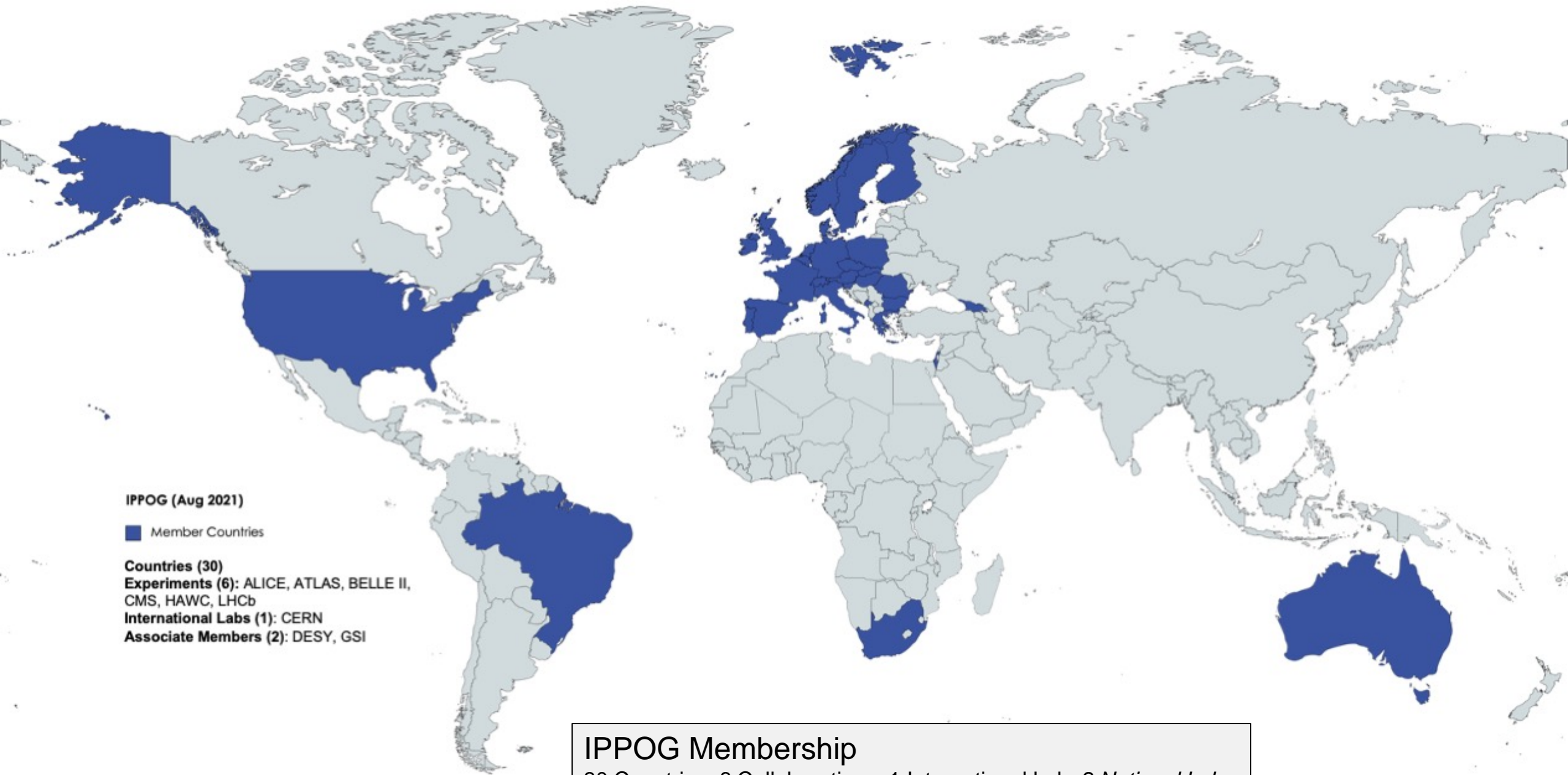
Organise Global Activities

- International Particle Physics Masterclasses
- World-Wide Data Day, Global Cosmics, etc.

Support Local Activities

- Sharing of expertise, best practices, material database
- Resources to support events, kick-start activities





IPPOG Membership
30 Countries, 6 Collaborations, 1 International Lab, 2 *National Labs*



IPPOG Origins

1997 Birth of European Particle Physics Outreach Group (EPPOG)
formed under the joint auspices of ECFA and EPS-HEPP

“...the particle physics community has a moral obligation to inform the public on its activities. To do this well, experiences must be shared among countries in view of the need to optimize the use of resources.”

- Chris Llewellyn-Smith, CERN DG

2005 Launch of International Masterclasses

2011 Global Expansion to IPPOG

Israel, Australia, USA (now South Africa, Brazil,...)

2016 Formal Scientific Collaboration

Memorandum of Understanding





IPPOG Goals

Sustainable Development of Particle Physics Outreach

- Discussion forums for scientists active in Education and Public Engagement
- Information exchange between individuals, institutions and laboratories
- Active working groups addressing specific challenges of global Outreach

Improving Outreach Standards Worldwide

- Development of strategies based on current best practices and experience
- Long-Term links between scientists and education specialists
- Continual development & improvement of explanatory material

Extending Global Reach

- Expansion to countries and peoples underrepresented in particle physics
- Usage of new methods, activities and topics to reach broader audiences
- Active online communication platforms

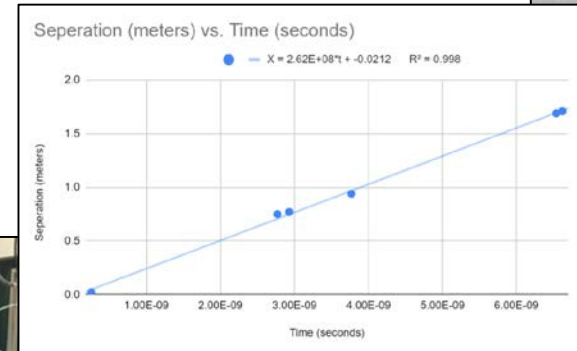


International Masterclasses

Global Cosmics

- High School Initiatives Exploring Cosmic Rays
 - International Muon Week
 - International Cosmic Day

Resources Data Base



Discover Cosmic Rays

INTERNATIONAL COSMIC DAY

HOME POSTER PHYSICS PROGRAM PARTICIPATE MAP PROJECTS PROCEEDINGS MEDIA

FAQ [Print us on](#) [f](#) [i](#) [t](#) ORGANIZATION

Global Cosmic Ray Studies

For High School Students

several projects around the world that address young people and give them the opportunity to explore cosmic particles. These projects are listed below. For further information, please visit the websites.

Callio Lab: Doing cosmic ray physics underground is something the young students are really interested in. The Centre for Underground Physics in Pyhäjärvi (CUPP) of Callio Lab, in Finland, has made it possible. The outreach program, established in 2010, is based on the experiment EMMA and particle physics. The emphasis is on the hands-on exercises with simple data and The workshops and theme days are well liked. The outreach is also taken out into the community by participating in town fair of Pyhäjärvi with general public lectures, and organizing theme weeks on physics topics together with the town of Oulu. Website: [Callio Lab](#)

Coamos à l'École: In France, a collaboration started several years ago between the "Institut National de Physique Nucléaire et de Physique des Particules" (IN2P3) of the CNRS and "Sciences à l'École", a project from the French Education Ministry which is promoting science in high schools and higher education. Large cosmic ray detectors called "Cosmodétecteurs" are built in the Marseille IN2P3 laboratory (CPPM) and given to high school teachers selected by "Sciences à l'École". These teachers are trained prior to receiving the detector – a one week-long seminar at CERN, part of the High School Teacher program, plus a technical course in Marseille to learn how to use the apparatus. These teachers then exchange information through a dedicated internet forum and present the educational activities they develop with their Cosmodétecteur. There are currently 30 such detectors in France and 15 more will be released in 2017. Website: [Sciences à l'École](#)

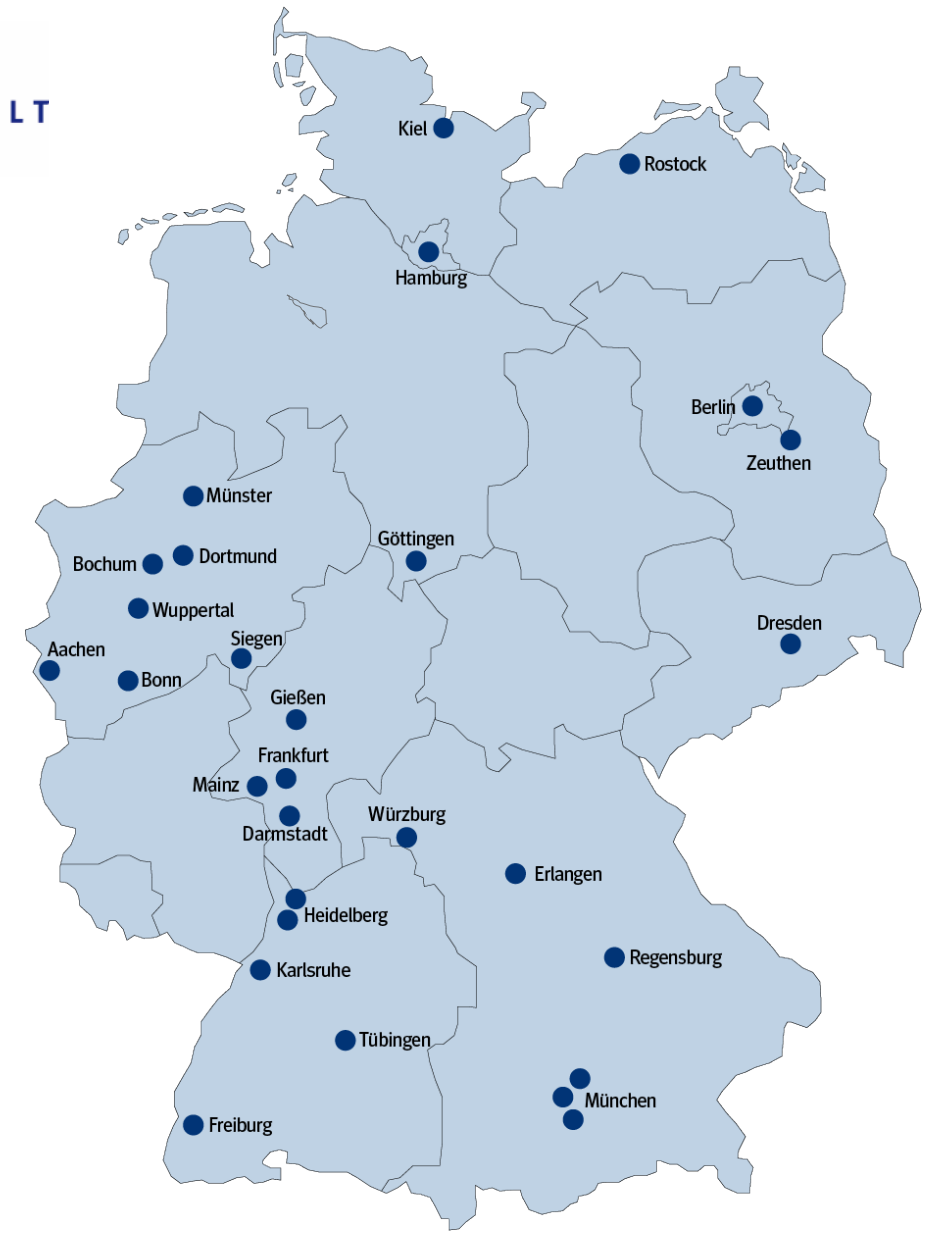
e-PÉRON: a virtual lab dedicated on cosmic rays. The Labex OCEVU is cluster of 6 research laboratories located in the south of France) and the Observatoire Midi-Pyrénées offers the possibility for the teachers and their students, from high school to university to experiment cosmic ray physics for real on a dedicated platform online. Via a website, they could select their own experiment through several ones (muon lifetime, East/West effect, Rossi experiment, Auger experiment, cosmic ray network) and download the data during a chosen period. The experiments are located on the Pic du Midi de Bigorre in the French Pyrennes and are running continuously since may 2015. The use is in open access. Website: [e-PÉRON](#) (the official website is under construction and will be available on June 2017)

Netzwerk Teilchenwelt



NETZWERK
TEILCHENWELT

- 30 universities/research labs + CERN
- Joint outreach
 - Bundle existing activities
 - Share structures and programs
- **High visibility and impact**
- Project team: TU Dresden / DESY / CERN
- + hubs in U Bonn, U Mainz, U Münster
- 2010: Particle and Astroparticle Physics
- 2019: Nuclear and Hadron Physics
- Funded as integral part of research by the German Ministry of Education and Research



Core: multi-step program for high school students



Masterclasses



Active engagement,
detector projects

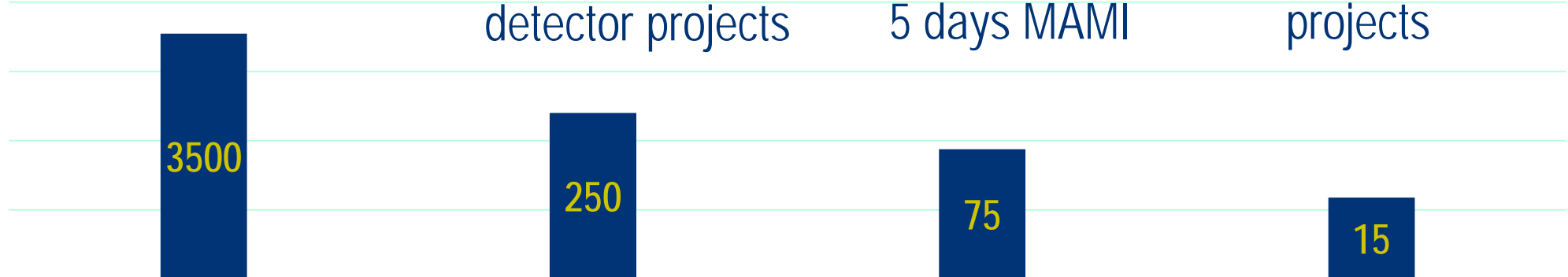


4 days CERN or
5 days MAMI



Own research
projects

Number of students
per year



Own research projects: examples

- [Deep Learning Models for Energy Estimation in CMS HGICAL L1 Trigger](#) (Felix Hansen)
- [First data classification at the InGrid detector at the CAST experiment using deep learning](#) (Carolin Kohl)
- [The AWAKE experiment](#) (Björn Dörschel)
- [The effects of radiation on the CMS pixel detector](#) (Katharina Ploog)
- [Machine-learning based identification of highly collimated electron pairs from boosted Z boson decays](#) (Sophia Veneris)



jugend  forscht



Facilitators



- ~ 150 PhD and Master students
- guide Masterclasses, supervise students' research projects
- influence students' career-related aspirations and choices

- reimbursement of expenses and travel cost
- get training courses on communication, didactics, and presentation techniques



- acquire soft skills, for personal and professional development
- experience interest in own research
- practice supervision



Fellow program



- 200 people, 50% female
 - Mainly alumni of CERN workshops
 - Now often studying physics or shortly before that
- Close connection between highly motivated students and research groups



Central offers: Fellow physics schools (HEP, detectors), “Ask the expert” sessions (online), national physics conference attendance, etc.

Local offers: internships, excursions, invitation to outreach events, colloquia, regulars´ table, etc.



Teachers as multipliers

- Development of material
 - [Teaching material for schools](#), 4 volumes (>20k printed, >35k downloaded)
 - [Portal Leifi Physik](#): Chapter on particle physics
 - [Particle profile cards](#)
 - [GeoGebra Analysis of Bubble Chamber images](#)
 - [Context material](#)
- [Teacher training „Forschung trifft Schule“](#), funded by:
 - 2-day training: Introduction to particle physics, 6 trainings p.a.
 - Summer School at CERN: 6 days, once per year



DR. HANS RIEGEL-STIFTUNG



Big Bang on the Road (Urknall Unterwegs)

- Interactive mobile exhibition modul on particle physics
 - Tunnel: time travel through the history of the universe
 - Columns: Interactions and particles, Research methods, spin-offs
 - Pavilion with games (Particle Twister, Particle Yenga)
- Target audience: general public, people with less affinity for science
- On the road since the end of July 2021



Week of Particle World (Woche der Teilchenwelt)

- 1 week in November 2020
- Research institutes organised events
 - Public lectures
 - Virtual visits
 - Masterclasses
 - Science Café
 - Science Slam
- 20 events in 5 days, despite lockdown
- [YouTube playlist](#)



10 Jahre **TEILCHENWELT** 175 Jahre Deutsche Physikalische Gesellschaft

E-Mail teichenwelt.de

→ WOCHE DER TEILCHENWELT → PHYSIK DER KLEINSTEN TEILCHEN → NETZWERK TEILCHENWELT

WOCHE DER TEILCHENWELT
02.11. – 08.11.2020

ZUM VERANSTALTUNGS-KALENDER

ENTDECKUNGSREISE VOM URKNALL BIS IN DIE WELT DER ELEMENTARTEILCHEN

Woher kommt unser Universum? Und wie hat es sich nach dem Urknall entwickelt? Welche Geheimnisse birgt der Kosmos? Und was hat es mit der „Weltmaschine“ auf sich? Gemeinsam mit Forscher*innen können Sie Antworten auf solche Fragen finden. Kommen Sie zu Workshops, besuchen Sie eine Masterclass, erleben Sie Führungen und Vorträge in Forschungszentren, Instituten und Universitäten. Und lernen Sie das CERN mit seinem gigantischen Teilchenbeschleuniger bei einem virtuellen Rundgang kennen.

Besonders viele Angebote bündelt die **Woche der Teilchenwelt** vom 2. bis 8. November 2020. Bundesweit öffnen Forschungseinrichtungen und Universitäten ihre Türen für interessierte Besucher*innen jedes Alters. Vor Ort und digital von zu Hause können Sie mit Hilfe von Expert*innen in die Welt der Physik der kleinsten Teilchen eintauchen.

Summary

- Informing the **public** is our duty as scientists
- Inspiring the **next generation** is an important task
- **Masterclasses** are a proven and robust (COVID19!) tool for outreach and comes in many flavours
- **IPPOG** is a collaboration working on sustainable development of particle physics outreach and improving outreach standards worldwide
- The German network **Netzwerk Teilchenwelt** uses Masterclasses as the basic stage in a sustainable program to attract and promote young STEM talent
- Existing programs and structures create **multiple benefit**
 - win for **high school students**: experience modern research first-hand
 - win for **facilitators/PhD students**: train their communication skills, participate in a rewarding activity
 - win for **physicists**: get young talents for the research groups

Thanks to/for

People

- Ken Cecire, QuarkNet
- International Masterclasses Steering Group
- IPPOG (esp. coordination team, chairs Steve Goldfarb + Pedro Abreu)
- Michael Kobel, TU Dresden
- Team from Netzwerk Teilchenwelt
- numerous people involved in and supporting Masterclasses (physicists, tutors, moderators, IT support, teachers, administration...)



Funding

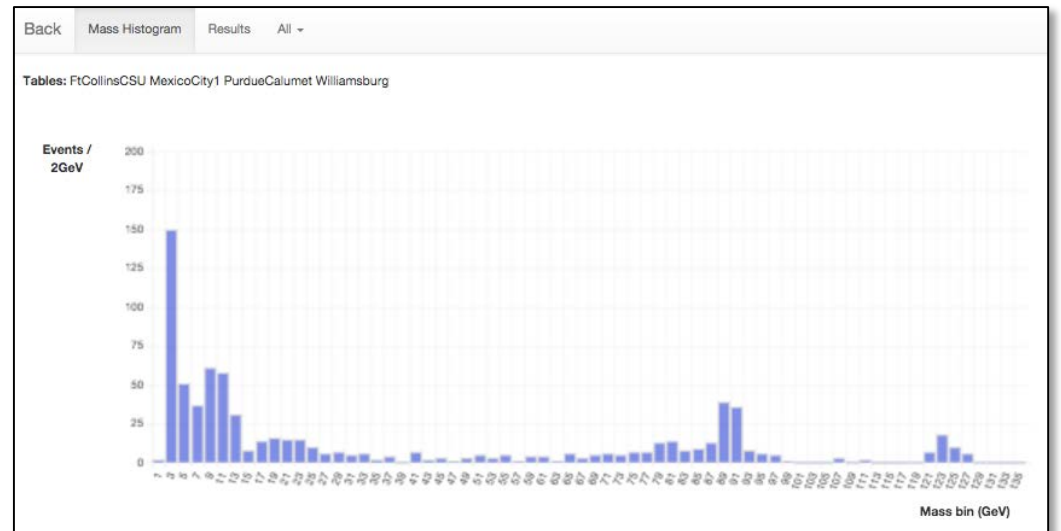
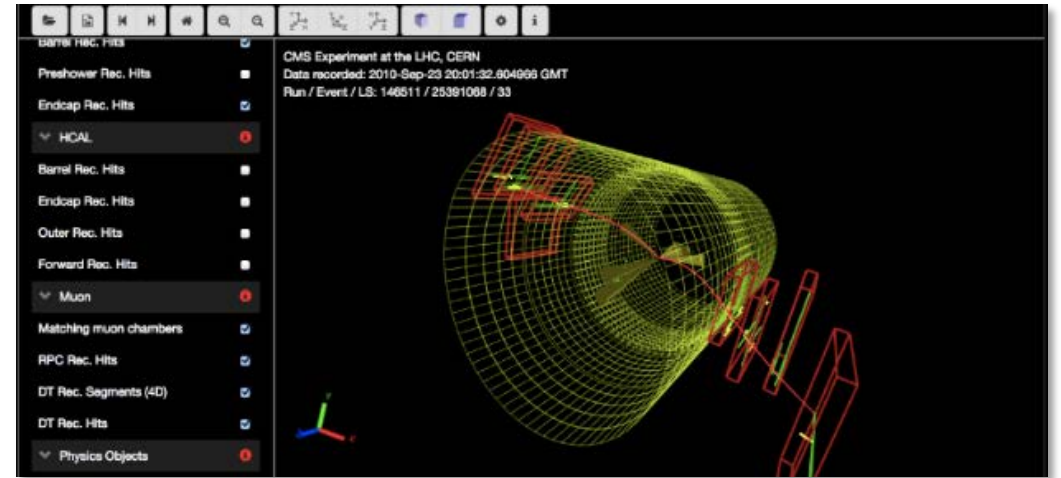
- CERN
- BMBF (German Ministry of Education and Research)

Backup slides

CMS WZH measurement

- WebGL 3D event display
- 1-, 2-, and 4-lepton events
- Students characterize W, Z, and Higgs candidates
- Create 2-l and 4-l mass plots of standard model particles, plus Higgs
- Ratios W^+/W^- , e/m

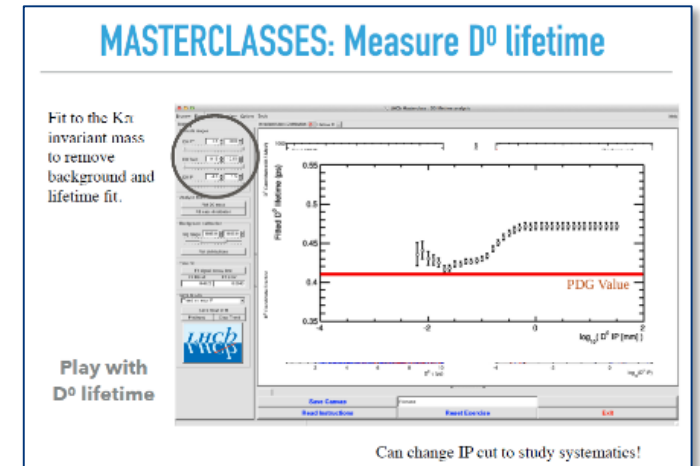
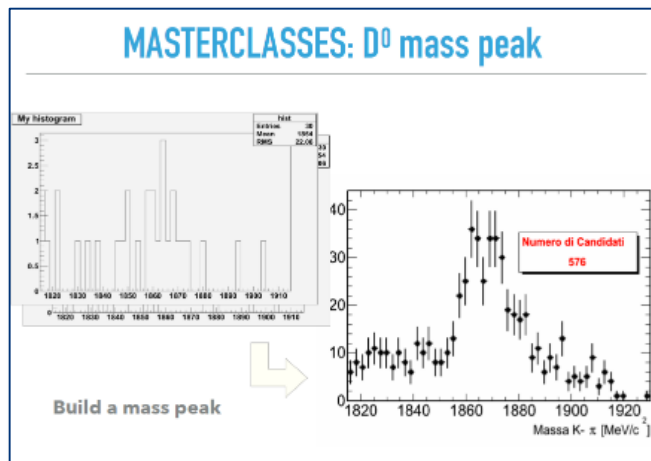
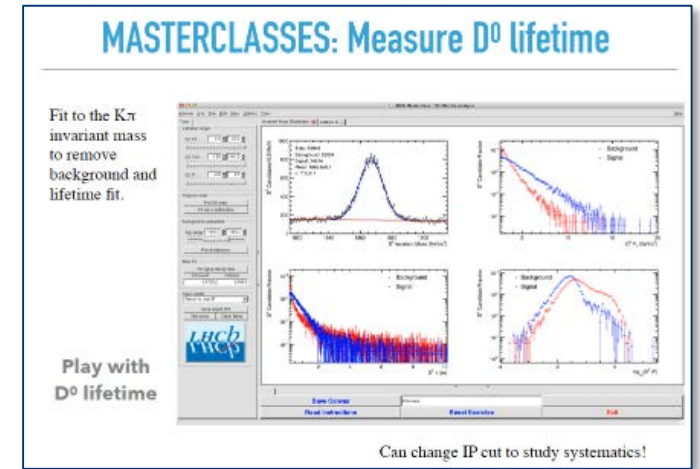
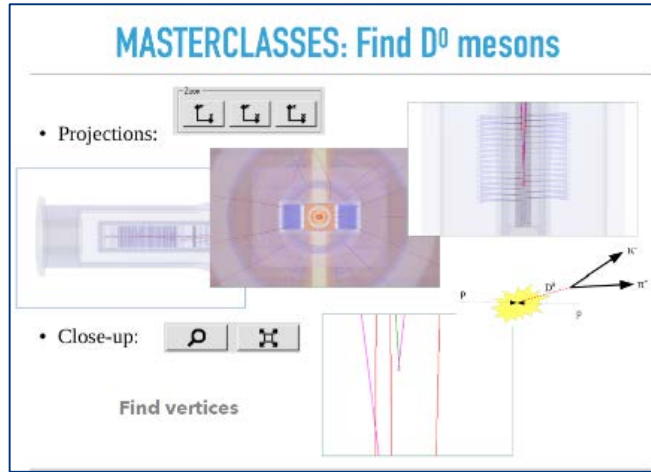
<https://web.quarknet.org/mc/cms/imc2021/cms.html>



LHCb Masterclass

- Students search for the $D^0 \rightarrow K\pi$ decay using an event display
- Students perform a lifetime measurement at the 1 % level
- Live merging of histograms from all groups in the VC

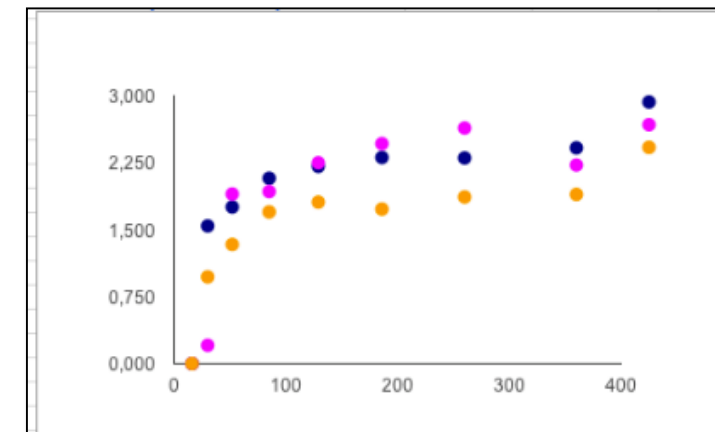
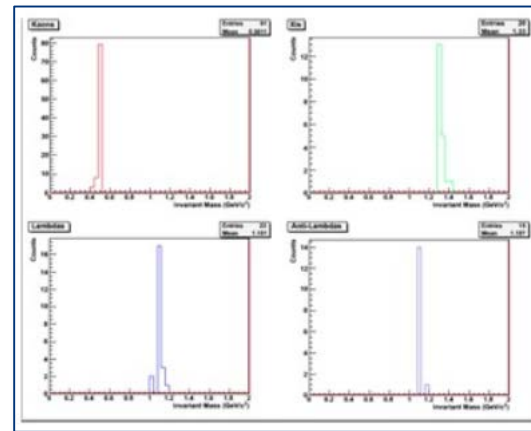
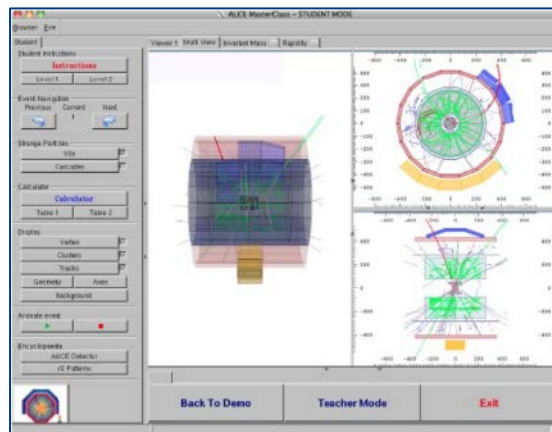
<https://lhcb-public.web.cern.ch/en/LHCb-outreach/masterclasses/en/>



ALICE I: Looking for Strange Particles

- Visual identification of V0s from decay pattern, invariant mass calculation
- First part: visual analysis of ~ 15 events per group
- Second part: Calculation of numbers of Ks, Λ , anti Λ from invariant mass distributions (fit gaussian/ polynomial to peak/background; subtract background) for different centrality regions in lead-lead collisions
- Concepts conveyed: invariant mass; centrality of PbPb collisions; background
- Results: observe strangeness enhancement in PbPb collisions comparing with pp collisions

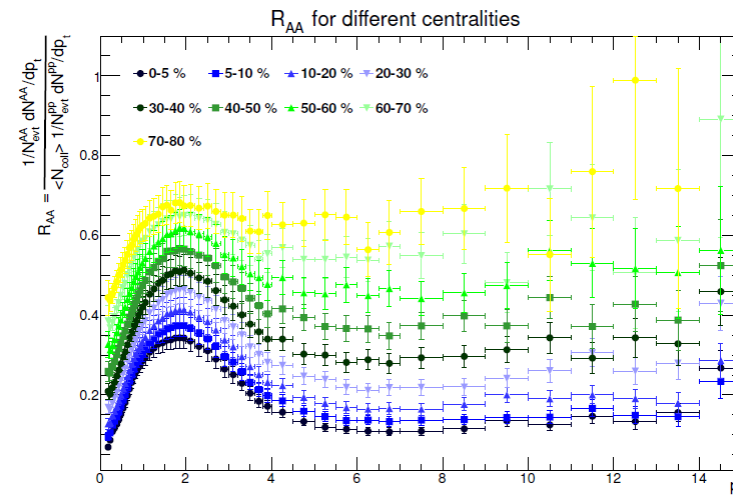
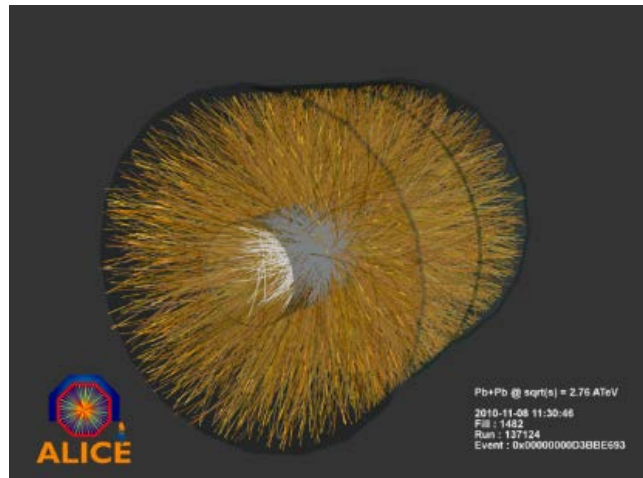
<https://alice-masterclass.web.cern.ch/>



ALICE II: Nuclear Modification Factor

- event-display based visual analysis
- RAA simply via counting of tracks
- ROOT based large scale analysis
- RAA as a function of momentum in various Pb-Pb centrality classes
- students discover jet suppression!

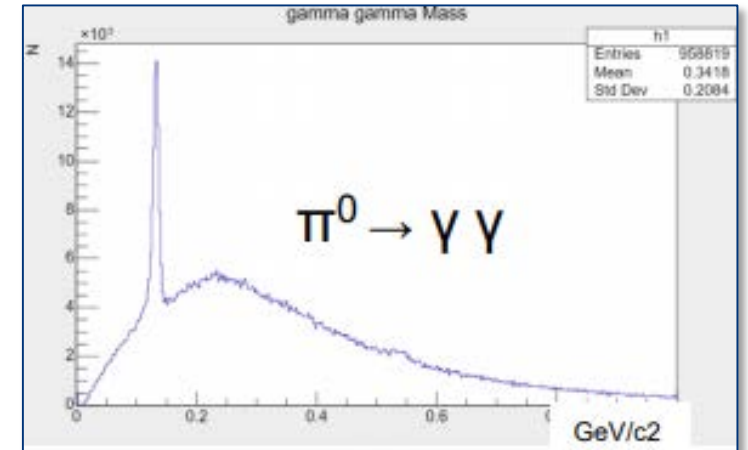
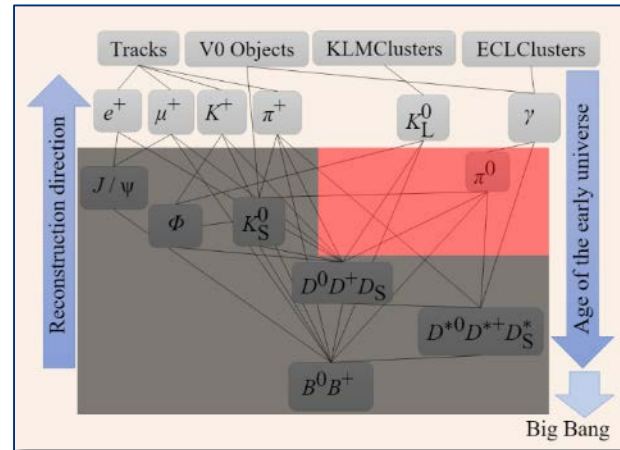
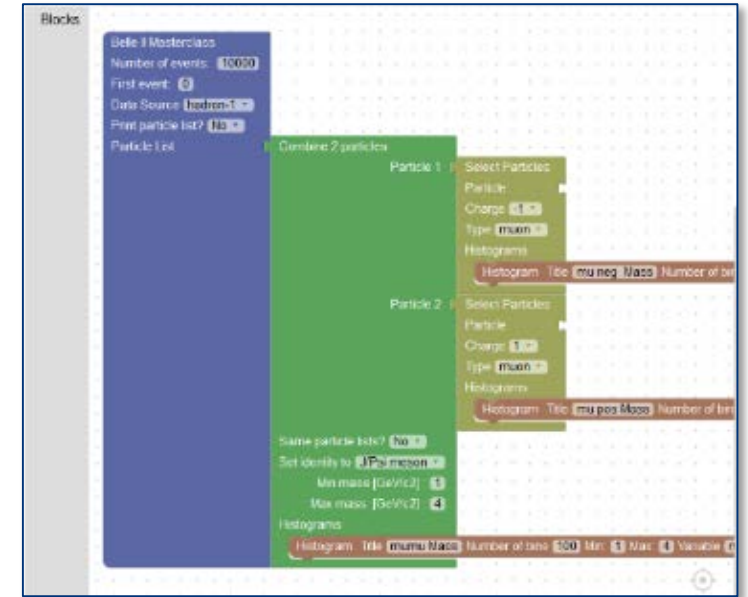
<http://www-alice.gsi.de/masterclass/>



Belle II Masterclass

- Shows students how to code B-physics analysis
- Students describe decays, make simple cuts, “discover” particles
- Visual code editor Blockly
- Running from the web or download virtual machine
- Analysis of 6M clean reconstructed events
- Basic/advanced level (fit peaks, determine width)
- Videoconference with KEK

<http://belle2.ijs.si/public>



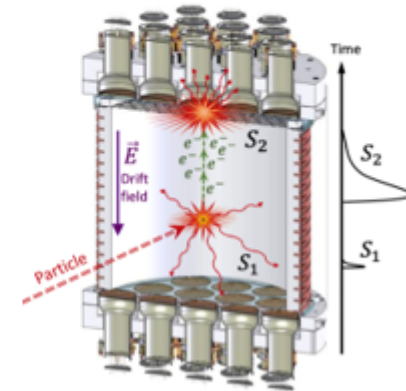
Darkside Masterclass

- By Francesca Carnesecchi, University and INFN of Bologna, Centro Fermi Roma, et al.
- Darkside experiment at Gran Sasso
- Dark Matter / WIMPs in a dual phase Ar TPC
- Talks on DM and Darkside experiment
- Data analysis via excel
- Reconstruction position part (few events): to exclude background signals
- Analysis of events (~20000) of background and few “good” WIMPs.
- Plot of f_{90} vs S_1 and then apply some cuts: to select WIMPs signals

<https://sites.google.com/unisa.it/darksidemasterclass/home-page>

Darkside experiment: how to detect WIMP

- WIMP-nucleus elastic collisions revealed by a detector capable of unambiguously identifying a small number of nuclear recoils



- **Dual phase (gas + liquid) Argon TPC** for direct detection of WIMPs

