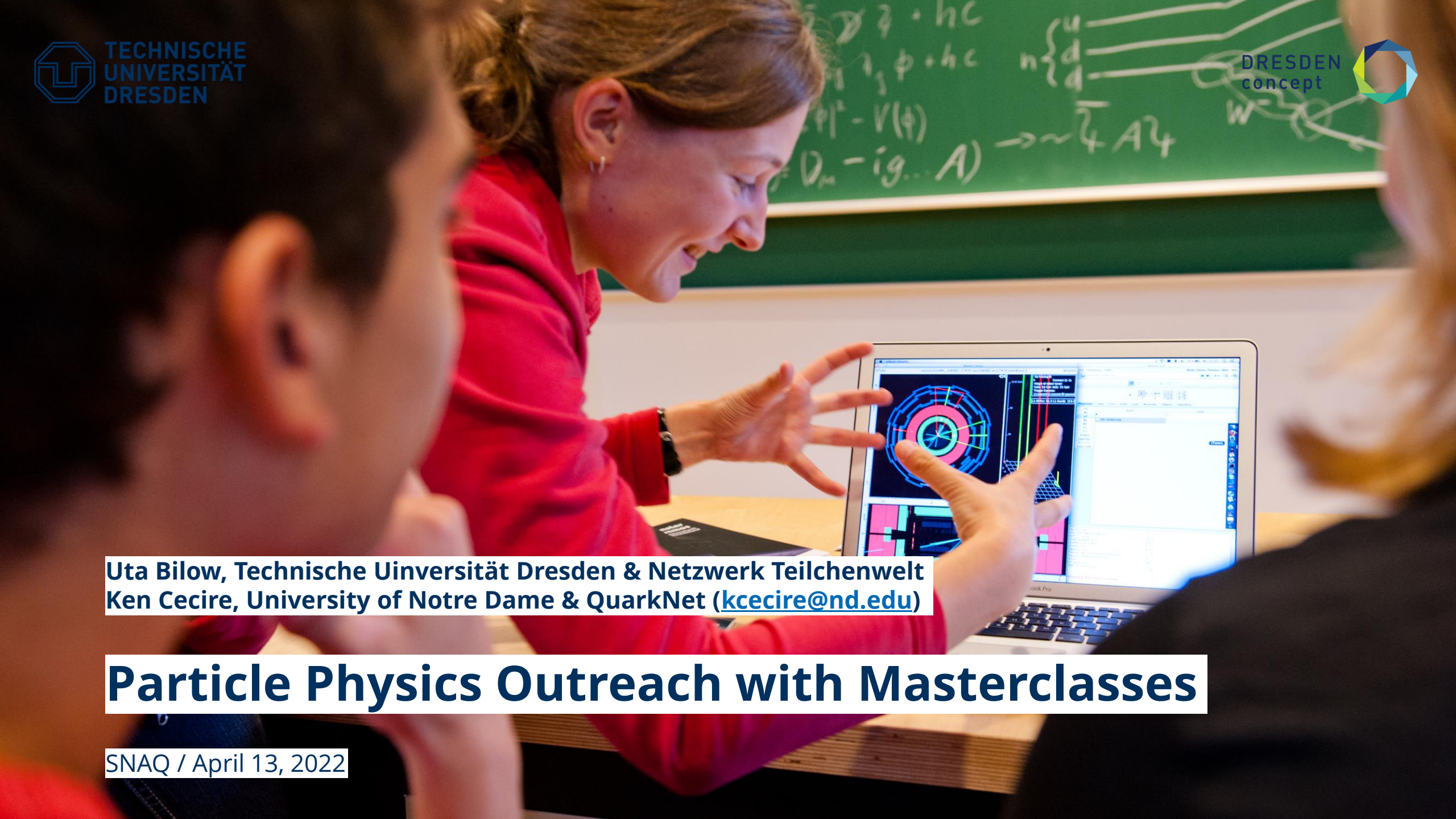


Uta Bilow, Technische Uinversität Dresden & Netzwerk Teilchenwelt
Ken Cecire, University of Notre Dame & QuarkNet (kcecire@nd.edu)

Particle Physics Outreach with Masterclasses

SNAQ / April 13, 2022

The idea behind Masterclasses

Act as a "scientist for a day"

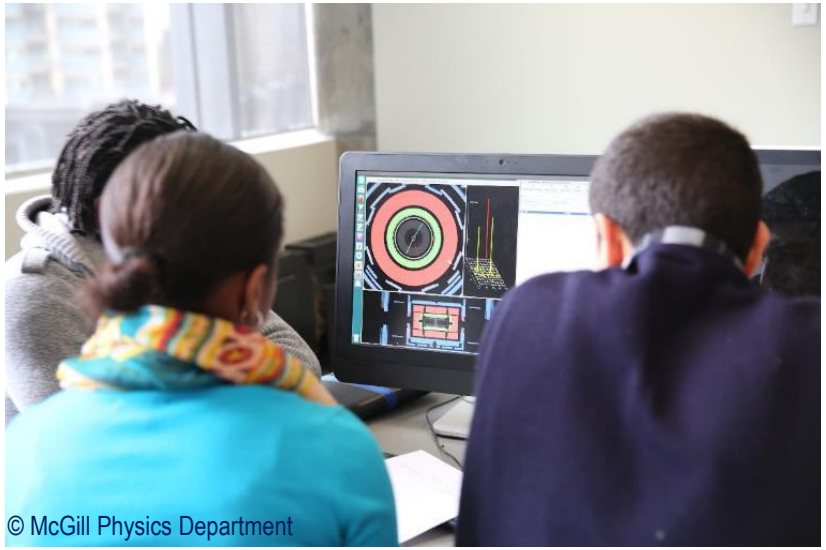
- Close to current research
- Own "hands-on" activities (listen = forget, see = remember, do = understand)

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”?

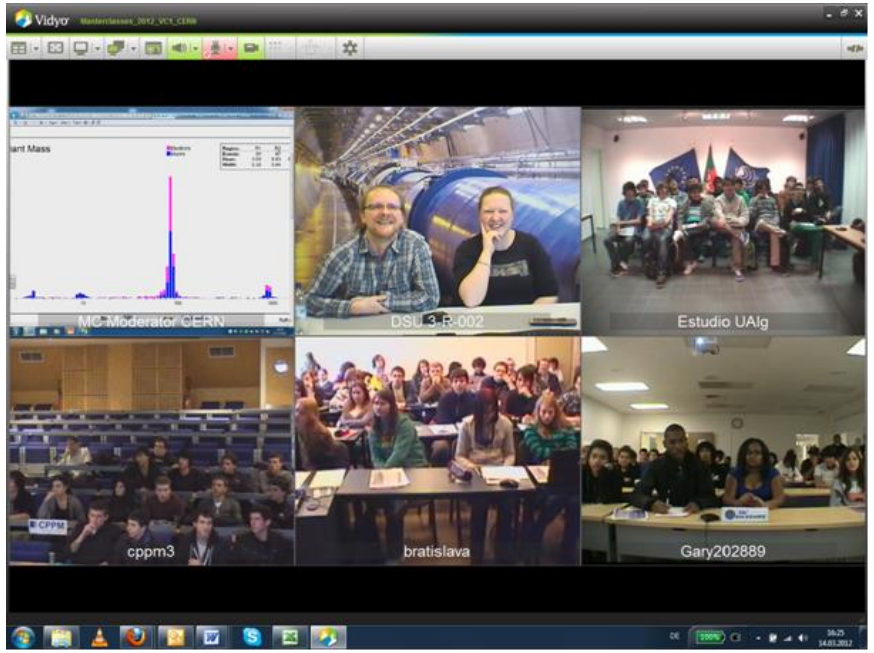
As in a Masterclass in the arts, students work with an expert

Expert = particle physicist

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

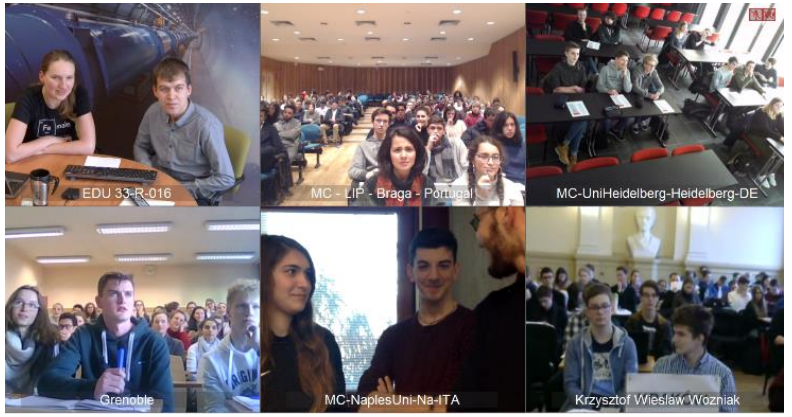
Concept of International Masterclasses

- 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)
- Students learn from, work with, and get to know physicists



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

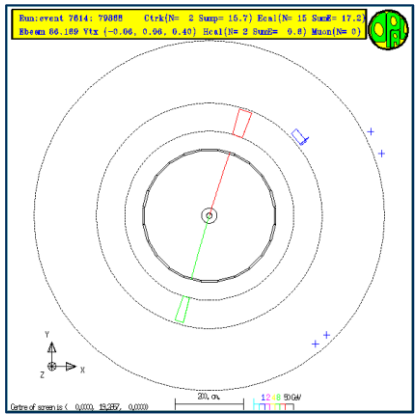


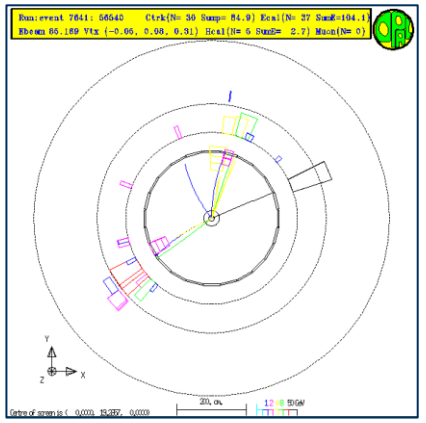
Videoconference

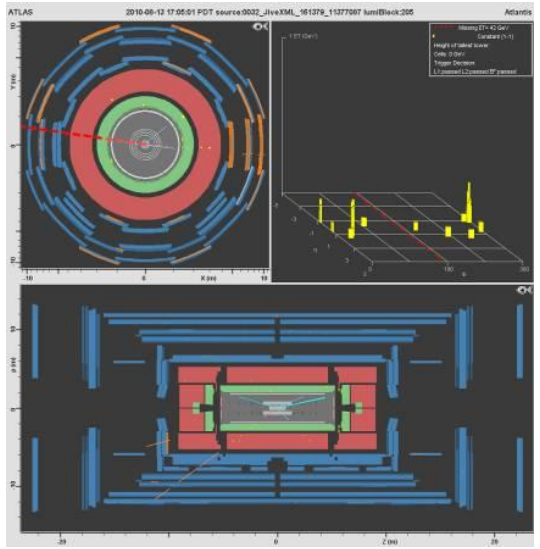
- 45-60 min
- 3-5 institutes, reflecting international collaboration
  - Same measurement, different data
- 2-3 Moderators (PhD students, Postdocs)
- Moderation centers: CERN, Fermilab, KEK, GSI, TRIUMF
- Agenda of the videoconference
  - Welcome
  - Combination and discussion of results
  - General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







Read in CERN Courier:

- http://cern.ch/go/BdH6 (How it all begun)
- http://cern.ch/go/qW9n (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: Uta Bilow (TU Dresden) / Ken Cecire (QuarkNet)

Broad Physics Scope

Today:

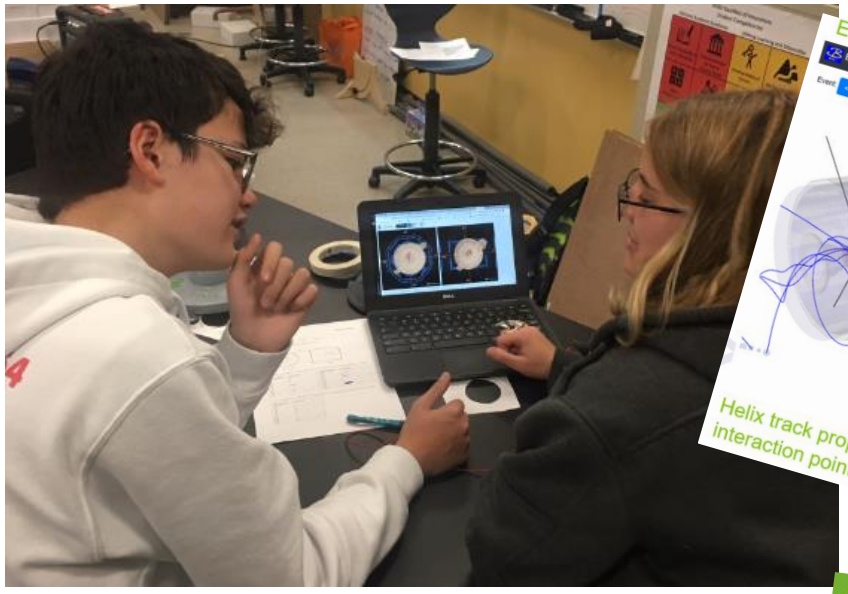
- LHC (since 2005)
- MINERvA (since 2019)
- Belle II (since 2020)
- Particle Therapy (since 2020)

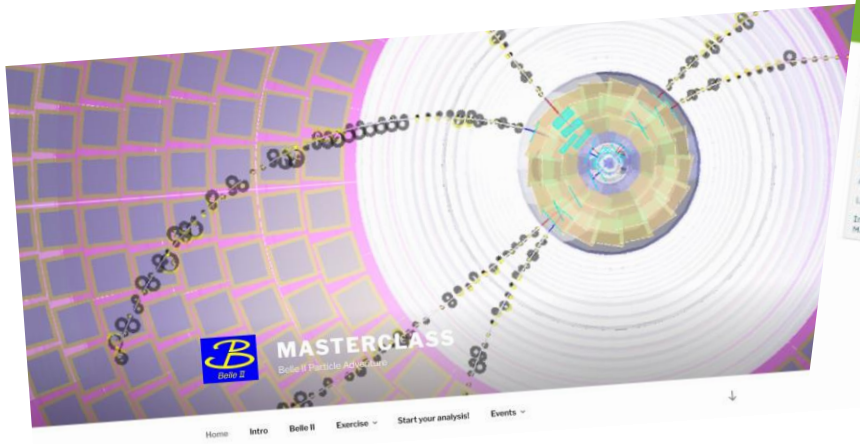
Under development:

- NOvA
- ProtoDUNE

More Masterclasses:

- IceCube
- Pierre Auger
- DarkSide … and what else is coming?

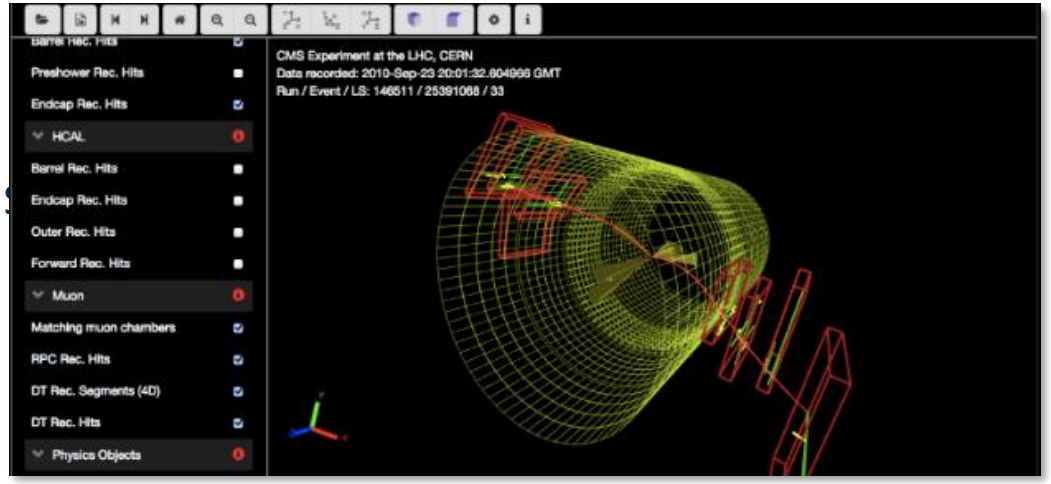


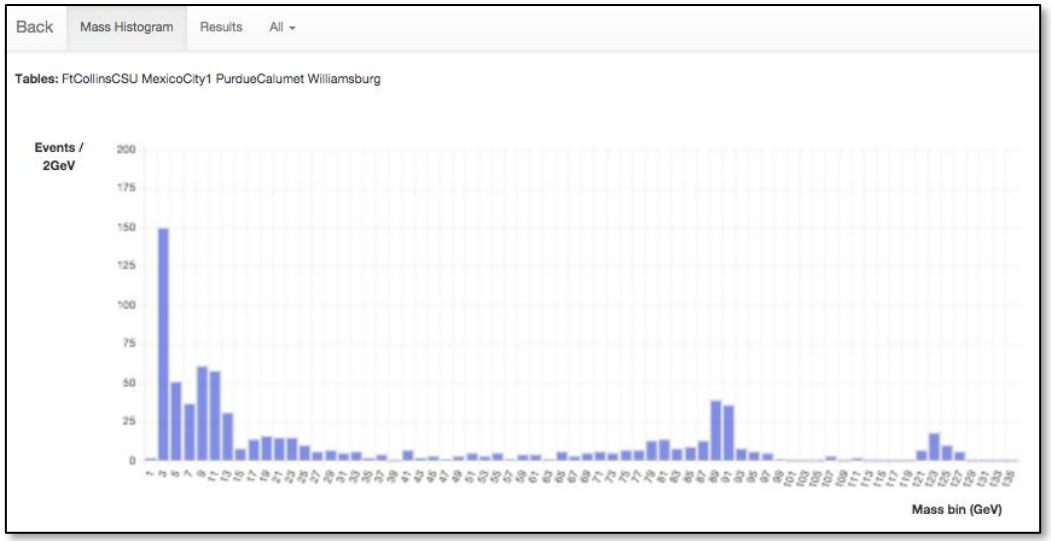


CMS WZH measurement

- 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

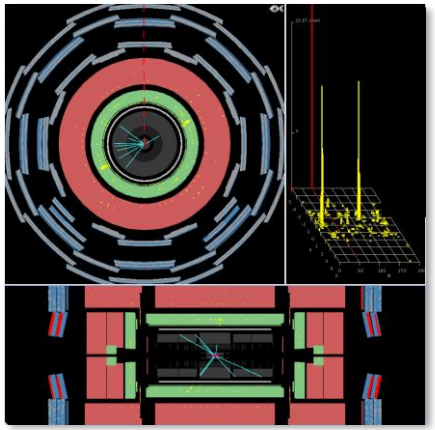
- Website: http://cern.ch/go/P87g





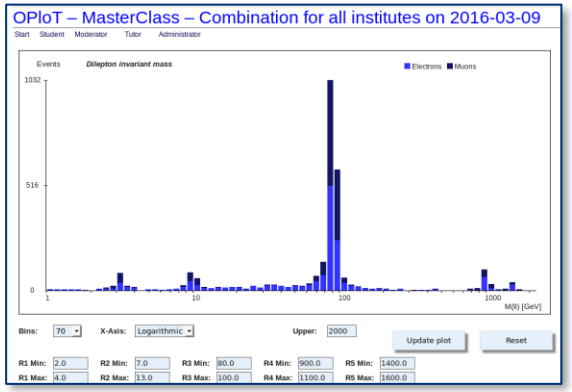
ATLAS Z path

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



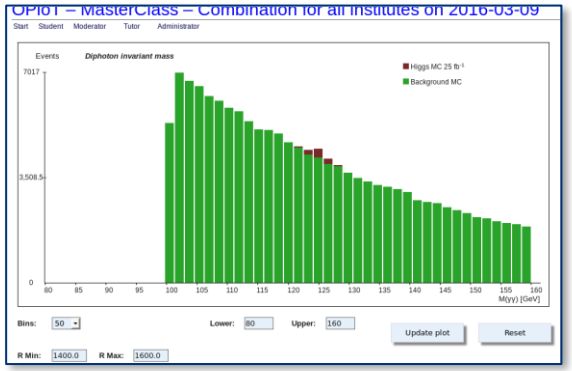
2-lep invariant mass distribution:

- 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



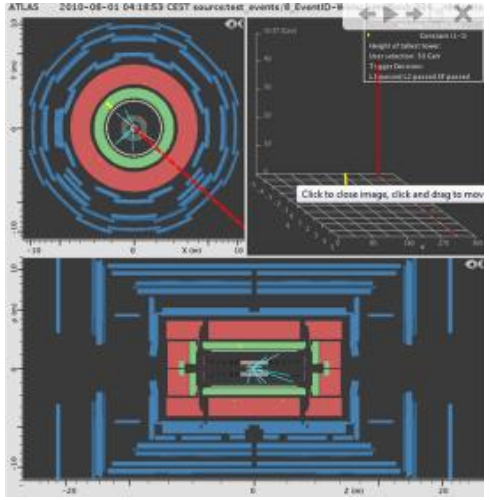
- Website: http://cern.ch/go/6Jzs

ATLAS W path

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

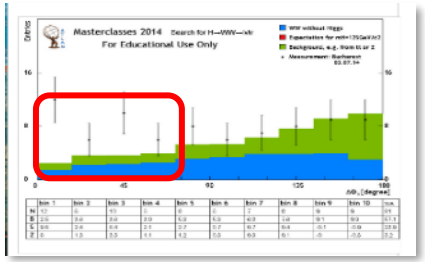
2 tasks:

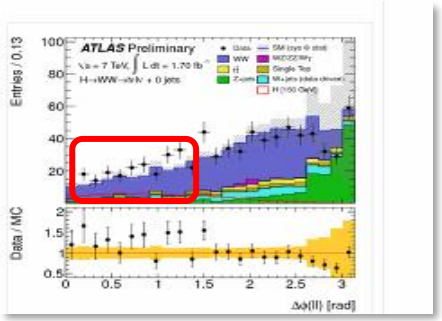
- Identify W bosons, determine type and electric charge of leptons
- Resulting W+/W- is used to reveal the inner structure of the proton (and compared to results from ATLAS)



Total #	W → ... + ν				Background
532	e^+	e^-	μ^+	μ^-	
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

- Identify W pairs and measure azimuthal opening angle Δφll
- Resulting histogram is used to provide insight into Higgs discovery process at CERN



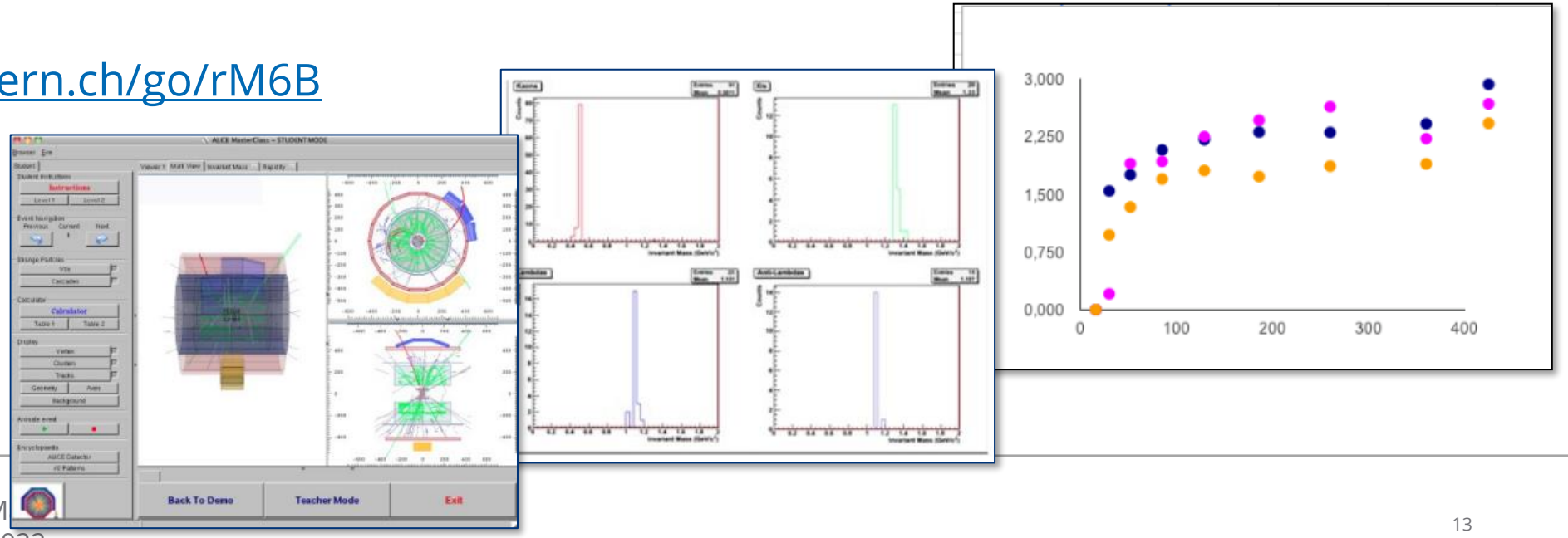


- Website: http://cern.ch/go/qsc8

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

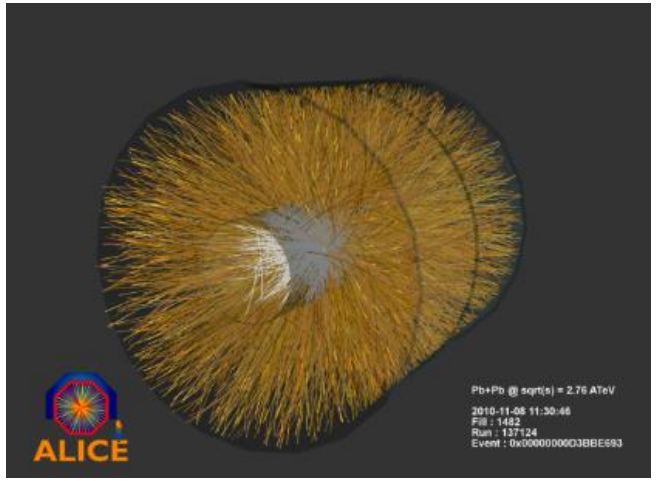
- Website: http://cern.ch/go/rM6B

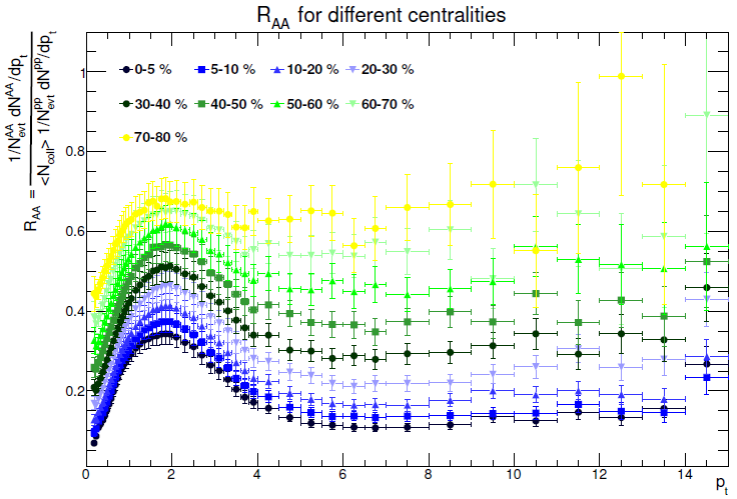


ALICE II: Nuclear Modification Factor

- 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!

- Website: http://cern.ch/go/9Tkn

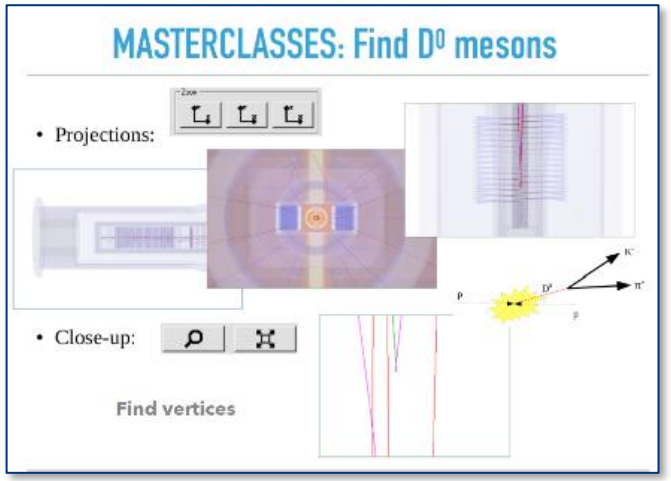


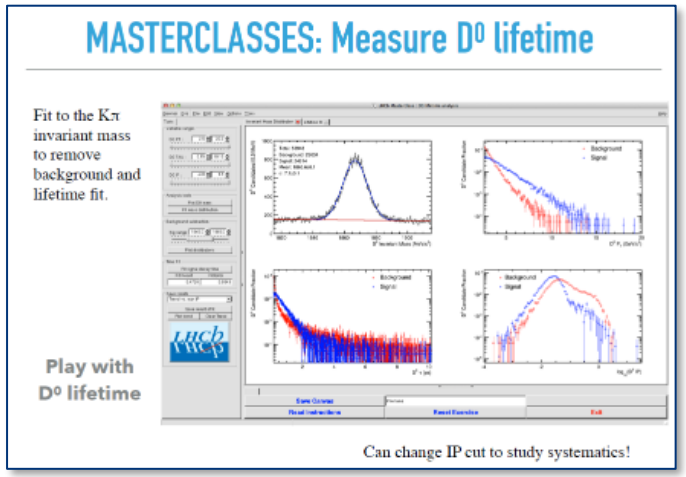


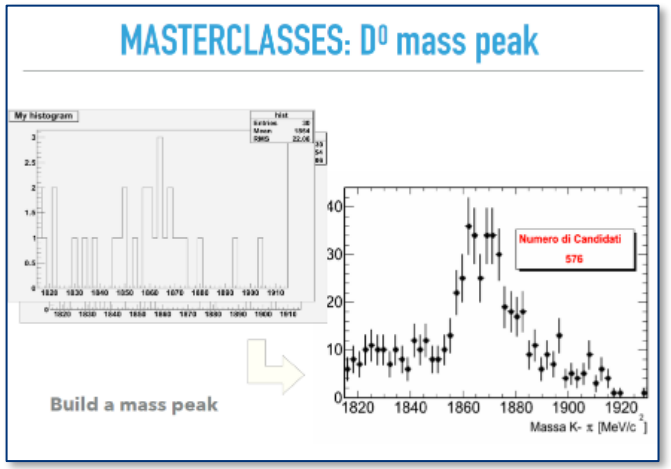
LHCb Masterclass

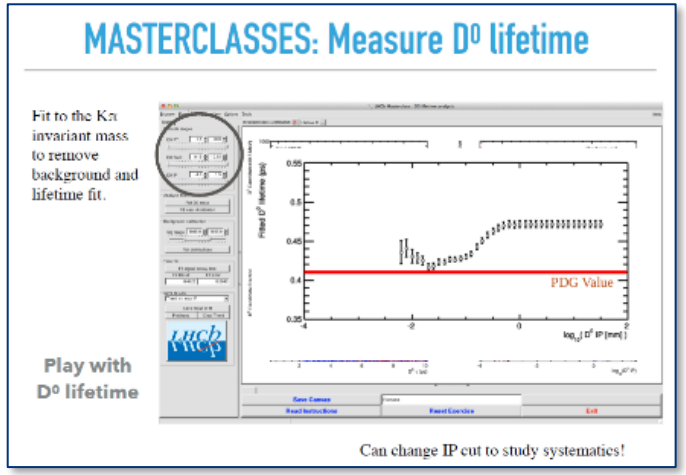
- Students search for the $D^0 \rightarrow K\pi$ decay using an event display
- Students perform a lifetime measurement at the 1 % level
- Live merging of histograms from all groups in the VC

Website:
http://cern.ch/go/tn9r





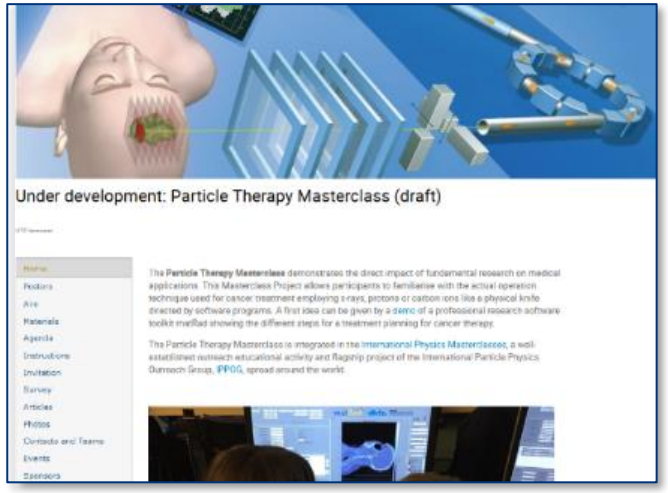


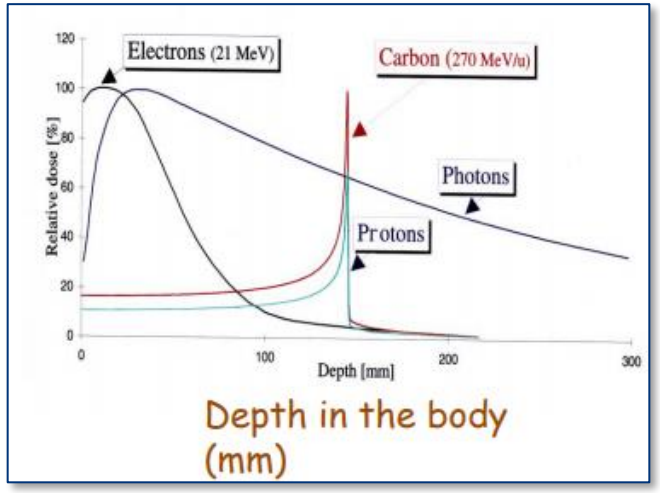


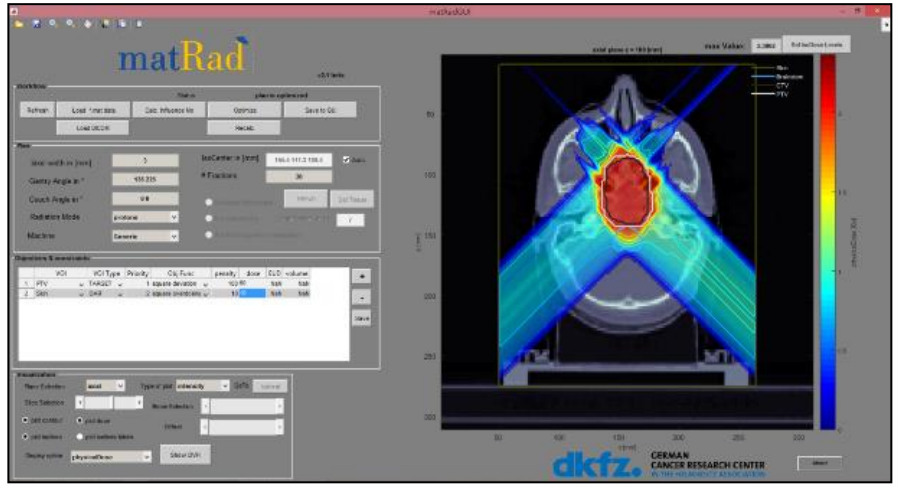
Particle Therapy Masterclass

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

- Website: http://cern.ch/go/W9tr



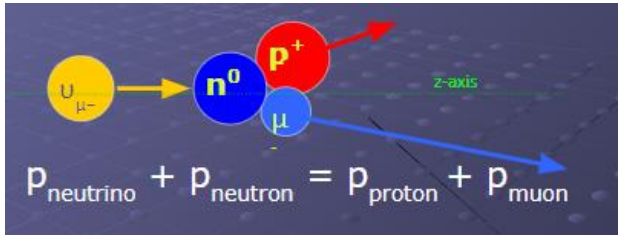


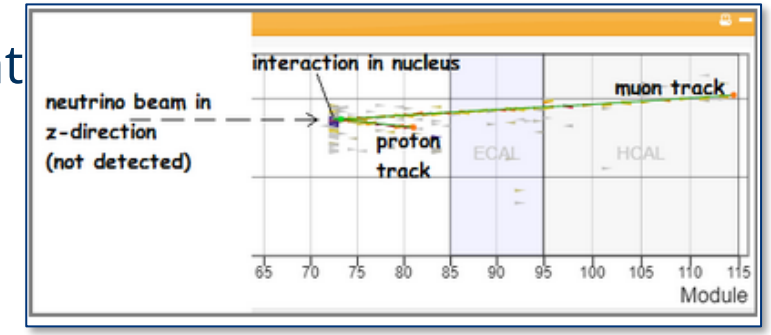


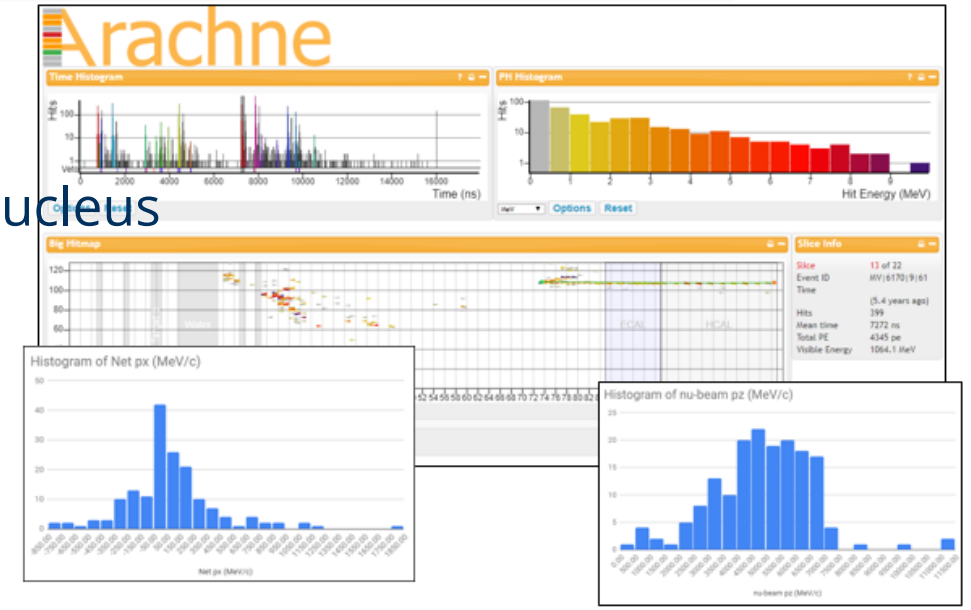
MINERvA Masterclasses

- Measure carbon nucleus to test interaction model
- Discover Fermi motion
- First neutrino masterclass, first Fermilab experiment
- Muon neutrinos interact with carbon target
- $\nu + n \rightarrow p + \mu$
- Measure px and py of proton and muon
- momentum distribution → Δp
- Fermi motion, nucleus is active place
- $\Delta px \rightarrow \Delta x \rightarrow$ bound on neutron motion → radius of nucleus

- Website: http://cern.ch/go/6lHm

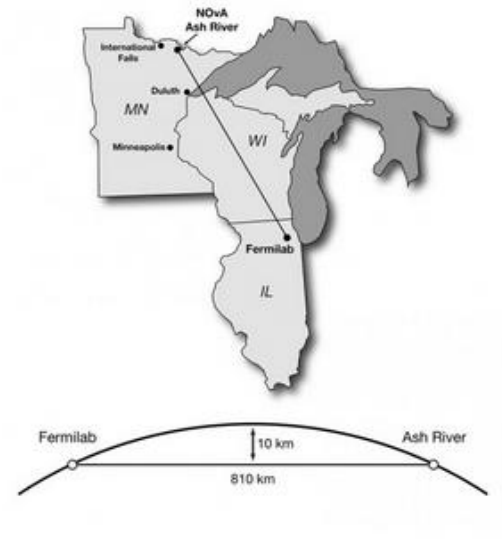




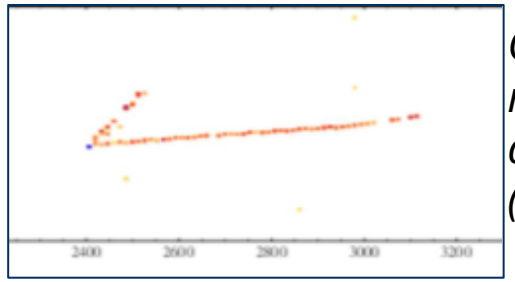


NOvA Masterclass

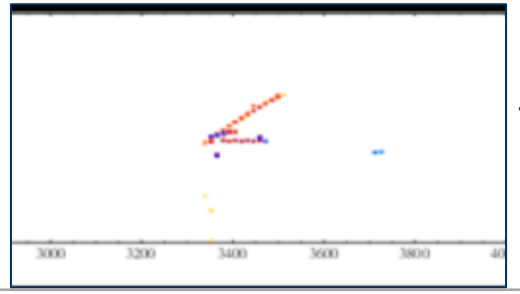
- New Masterclass under development by Greg Pawlowski (QuarkNet mentor) , Mike Plucinski (Neutrino fellow), QuarkNet staff
- Find ratio of Neutral Current (NC) to Charged Current (CC) events
- Compare CC:NC in FD vs in ND → evidence of oscillations
- Combine Far Detector event display analysis (small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



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



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

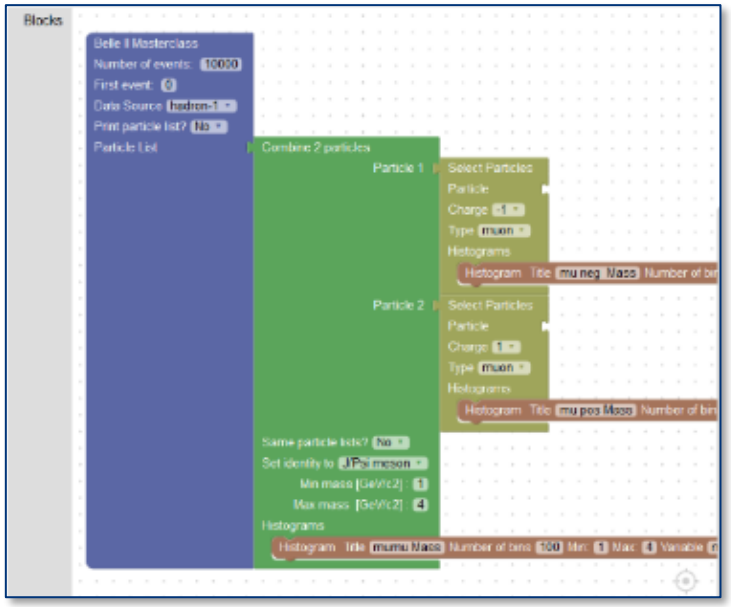


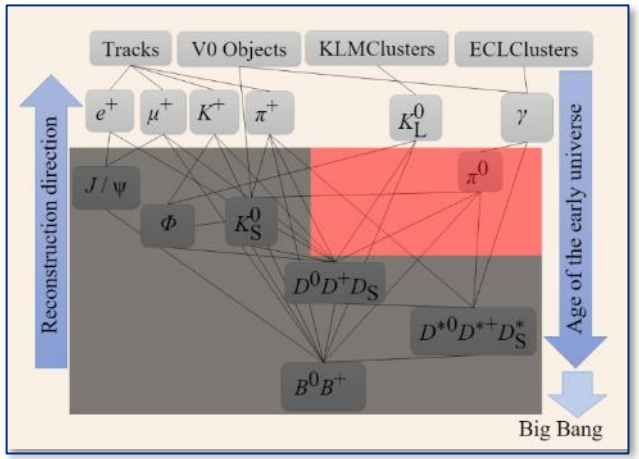
NC event: short tracks, multiplicities

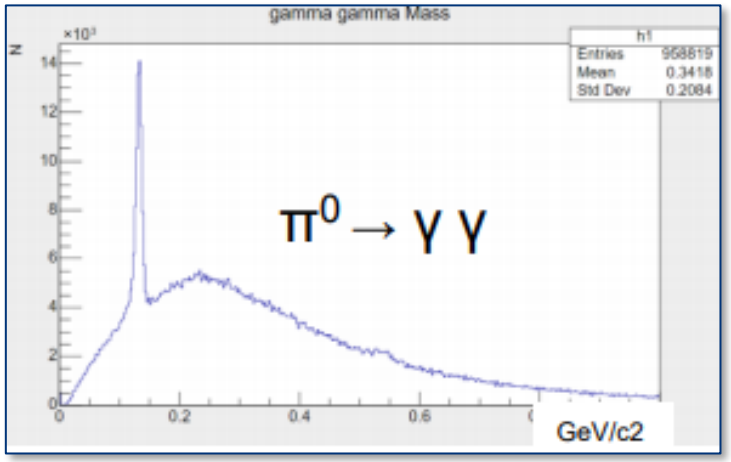
Belle II Masterclass

- Shows students how to code B-physics analysis
- Students describe decays, make 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

- Website: http://cern.ch/go/PNM7







Darkside Masterclass

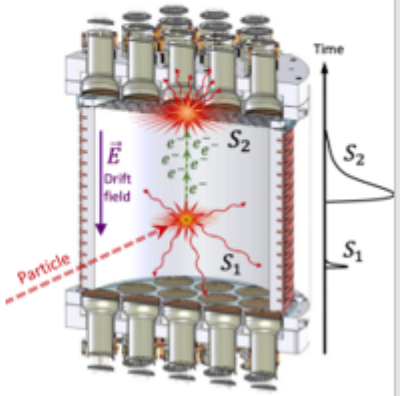
- By Francesca Carnesecchi, University and INFN of Bologna, Centro Fermi Roma, et al.
- Darkside experiment at Gran Sasso
- Dark Matter / WIMPs in a dual phase Ar TPC
- Talks on DM and Darkside experiment
- Data analysis via excel
- Reconstruction position part (few events): to exclude background signals
- Analysis of events (~20000) of background and few “good” WIMPs.
- Plot of f90 vs S1 and then apply some cuts: to select WIMP signals

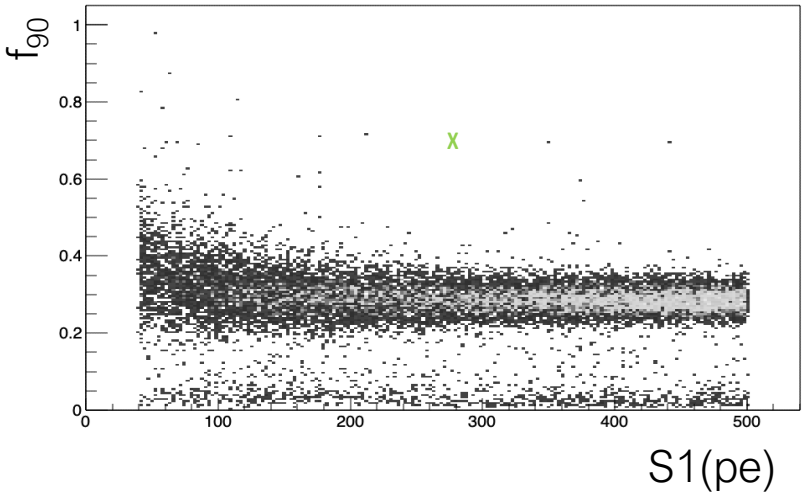
- Website: http://cern.ch/go/dq7m

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





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

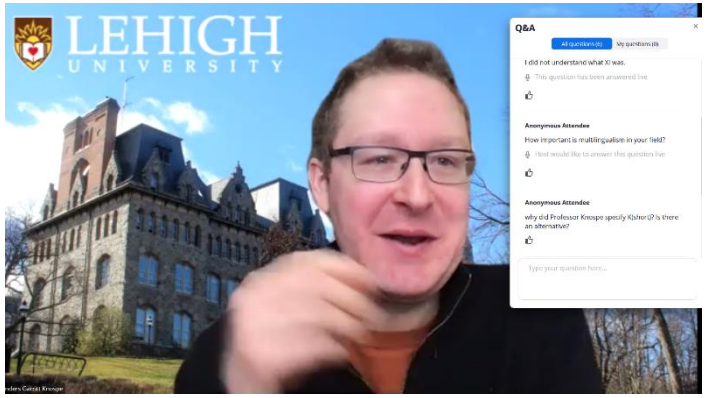
Impact of the COVID-19 pandemic

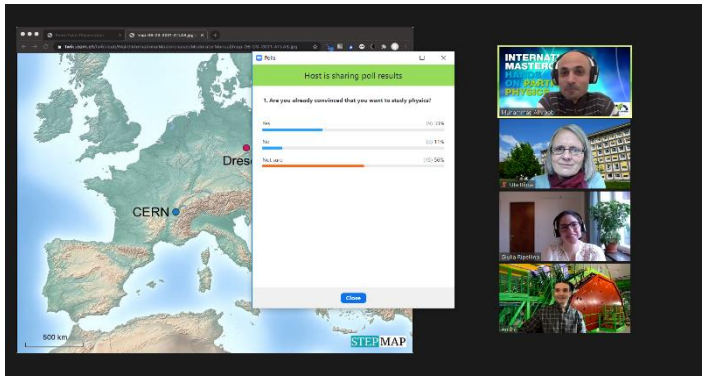
2020: program suspended by March 18, only ~ 25 % of MC completed

2021: Masterclass@home

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

Big Analysis of Muons

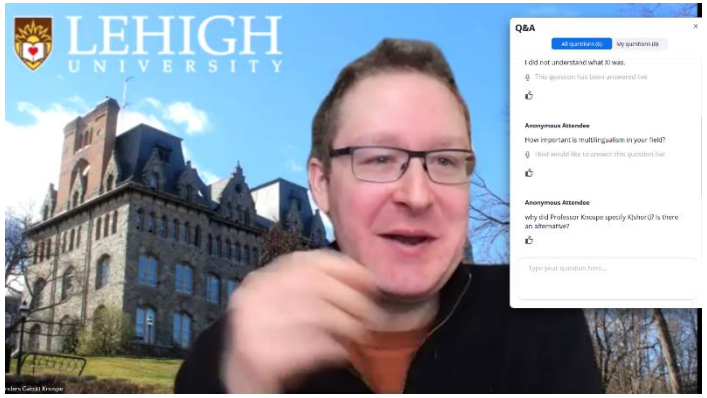


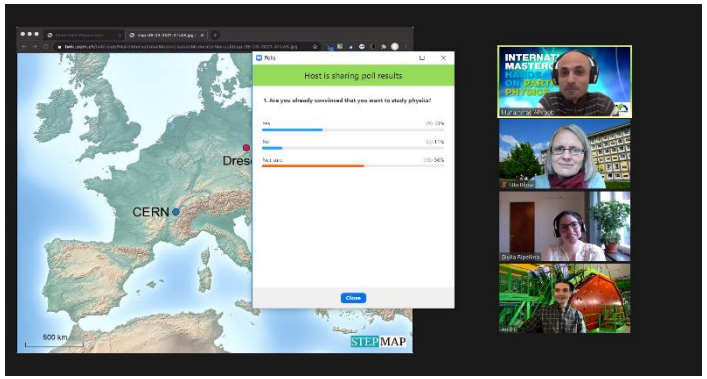


Impact of the COVID-19 pandemic

Outcomes

- 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





IPPOG

International Scientific Collaboration

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

Global Network

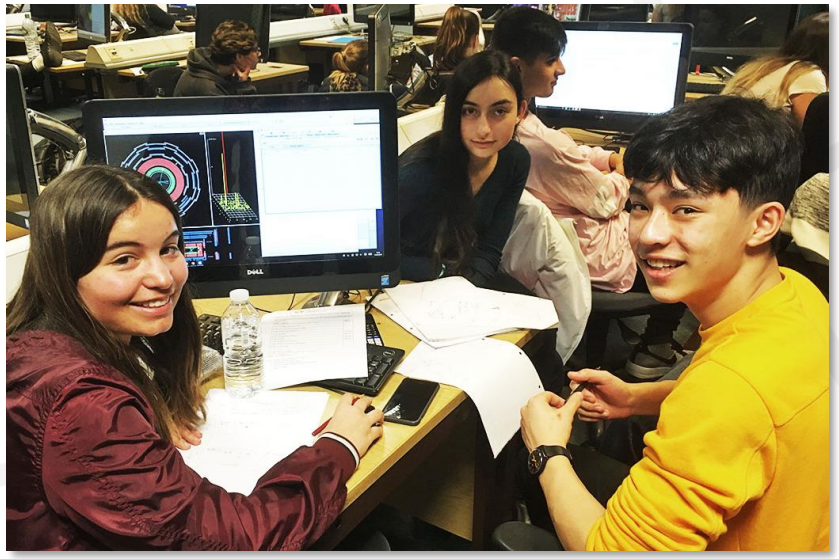
- 37 members: 30 countries, 6 experiments, 1 intl lab (CERN)
- 2 associate members: 2 national labs (DESY, GSI)

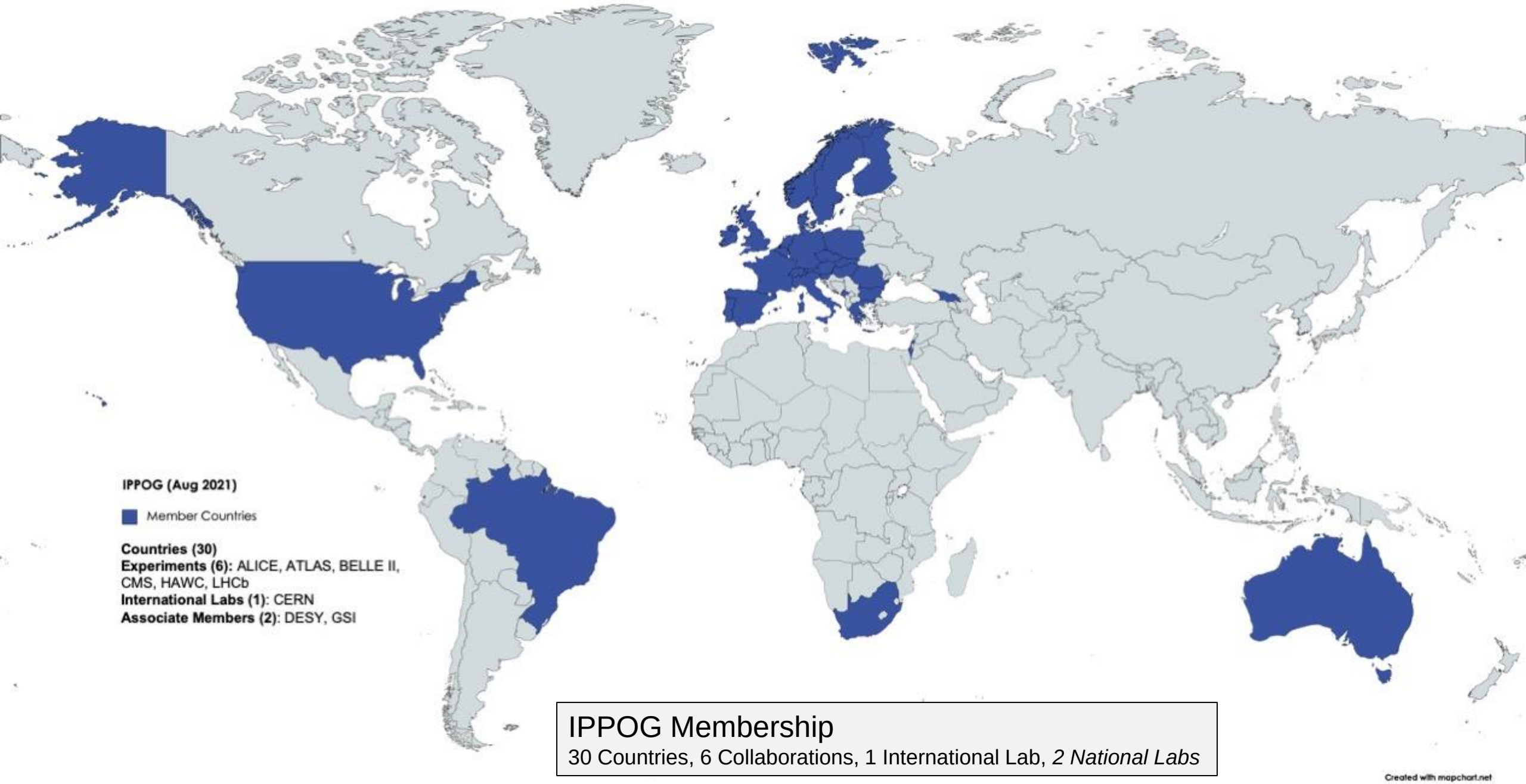
Organise Global Activities

- 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

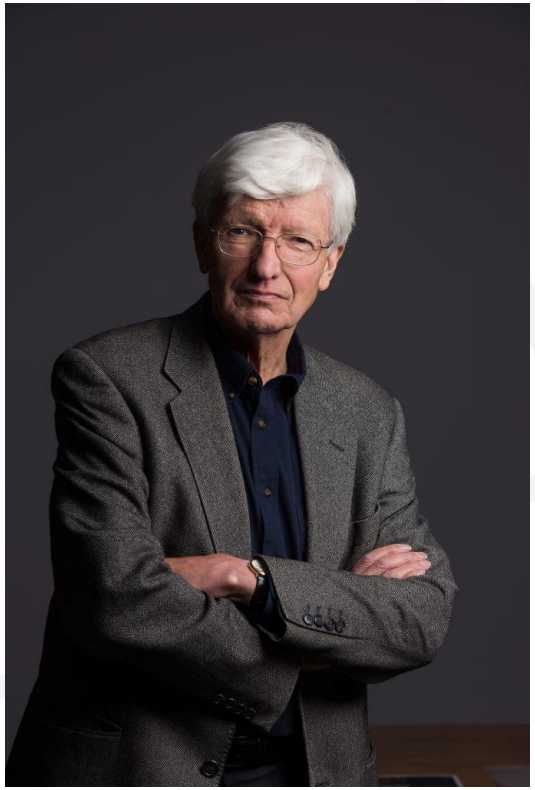
30 Countries, 6 Collaborations, 1 International Lab, *2 National Labs*

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

Activitites

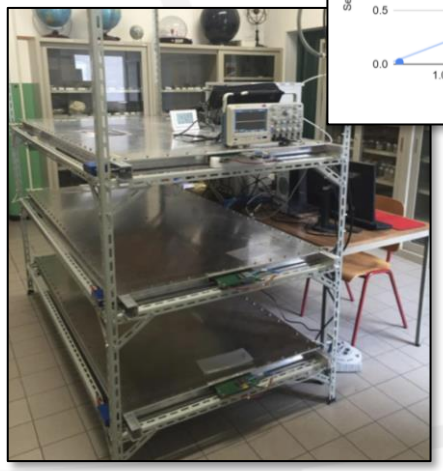
International Masterclasses

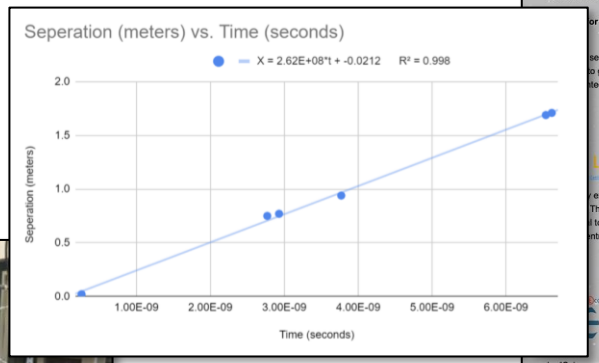
Global Cosmics

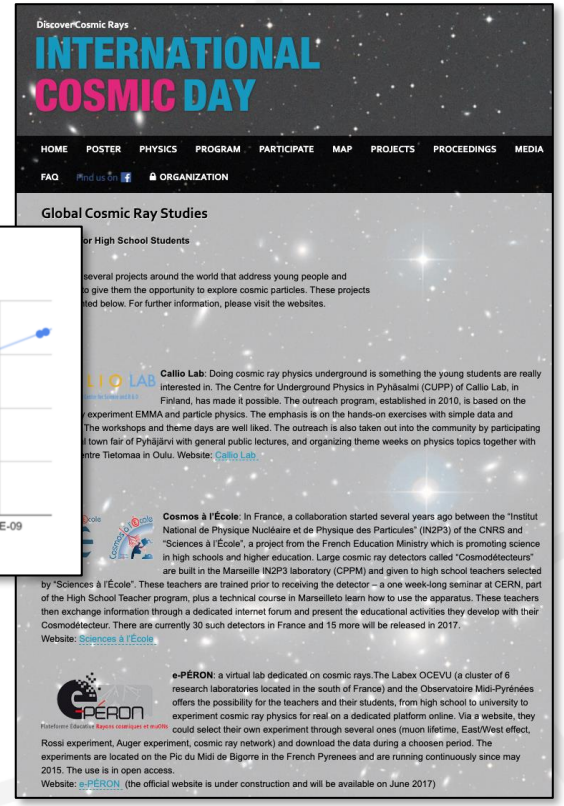
- High School Initiatives Exploring Cosmic Rays
  - International Muon Week
  - International Cosmic Day

Resources Database:

http://cern.ch/go/78NS







Netzwerk Teilchenwelt

- 30 universities/research labs + CERN
- Joint outreach in Germany
- Shared programs and structures
- Masterclasses in classrooms
  – Mobile offers, no local restriction
- Various levels of specialization (from Masterclass to CERN workshop and own research projects)

160 Masterclasses in 2019

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