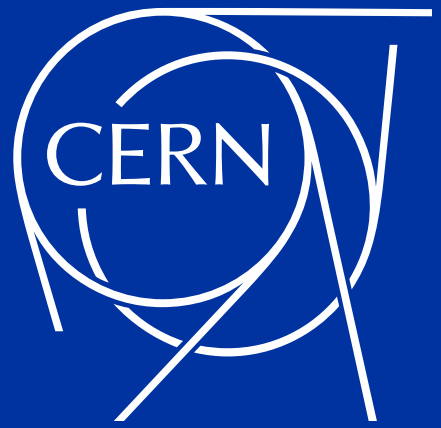
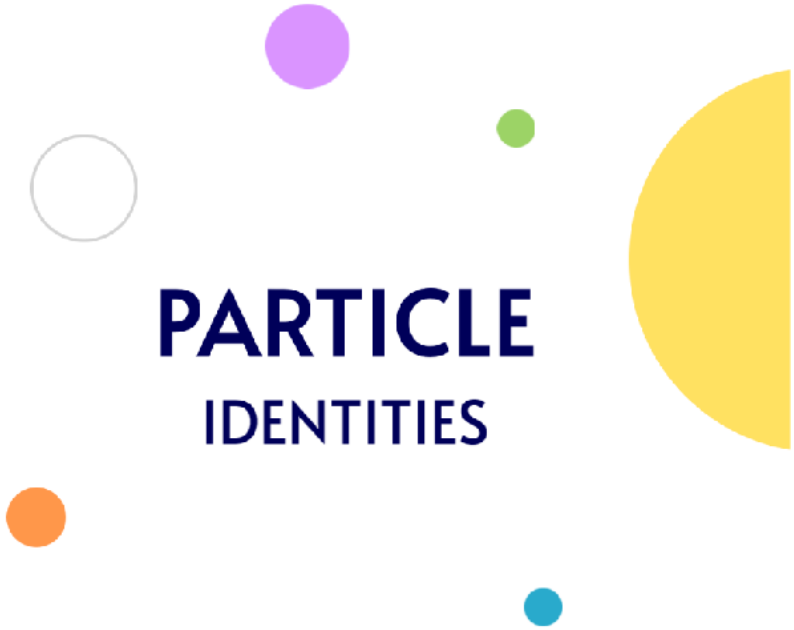


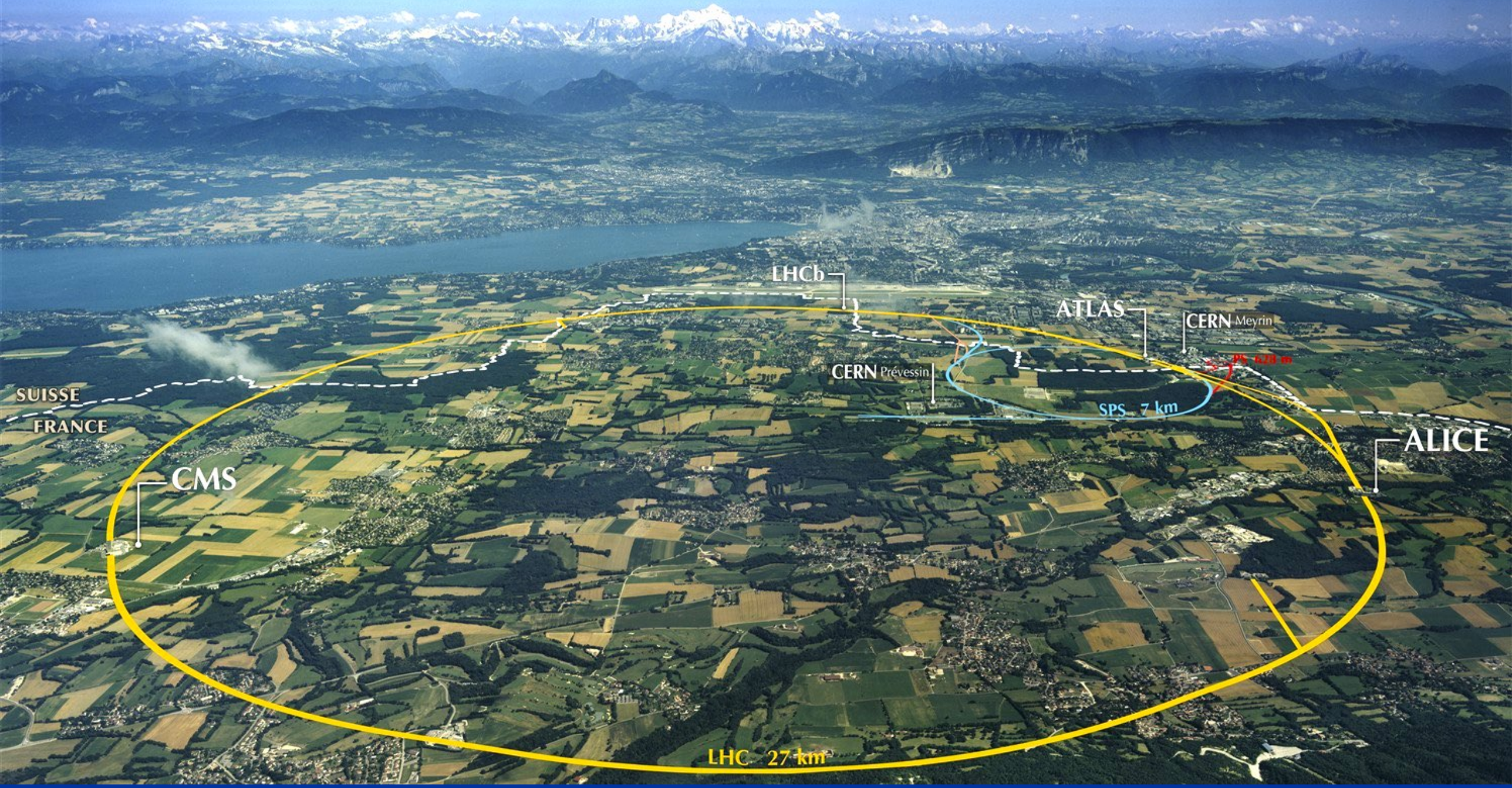
Elementary particle physics in the classroom

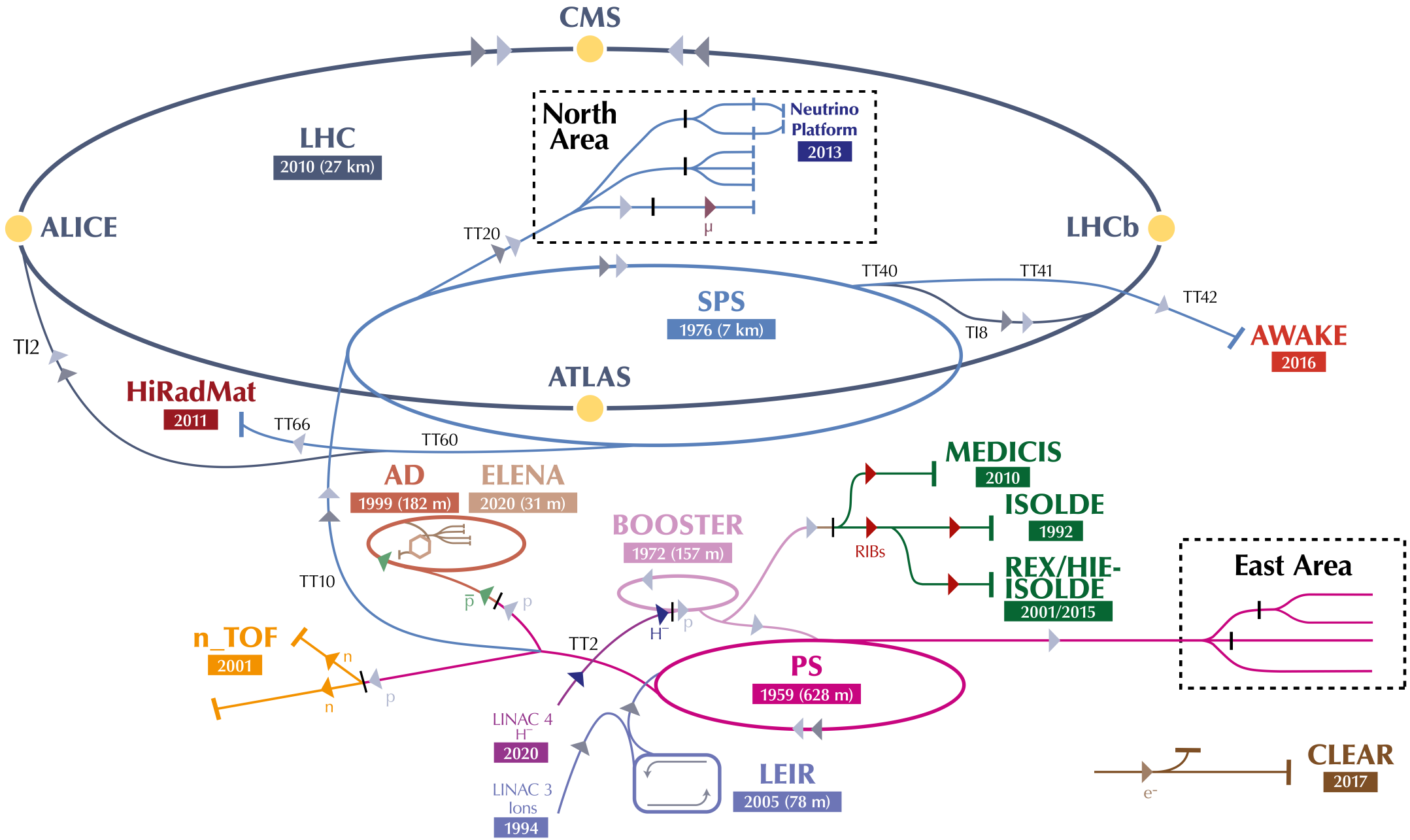
4th ONLINE Ukrainian Teacher Programme

Dr Jeff Wiener – 29 April 2024



cern.ch/identities


LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SUISSE
FRANCE
SPS 7 km
ALICE
CMS
LHC 27 km


CMS
LHC
2010 (27 km)
North Area
Neutrino Platform
2013
μ
ALICE
LHCb
TT20
TT40
TT41
TT42
SPS
1976 (7 km)
TI8
AWAKE
2016
TI2
ATLAS
HiRadMat
2011
TT66
TT60
AD
1999 (182 m)
ELENA
2020 (31 m)
BOOSTER
1972 (157 m)
MEDICIS
2010
ISOLDE
1992
RIBs
REX/HIE-ISOLDE
2001/2015
East Area
TT10
n_TOF
2001
n
p
TT2
PS
1959 (628 m)
LINAC 4
H⁻
2020
LINAC 3
Ions
1994
LEIR
2005 (78 m)
e⁻
CLEAR
2017

OPEN ACCESS PAPERS
Phys. Educ. **51** (2016) 035001 (7pp) iopscience.org/ped

Introducing the LHC in the classroom: an overview of education resources available

Gerfried J Wiener[1,2], Julia Woithe[1,3], Alexander Brown[1,4] and Konrad Jende[1,5]

[1] CERN, European Organization for Nuclear Research, Geneva, Switzerland
[2] Austrian Educational Competence Centre Physics, University of Vienna, Austria
[3] Department of Physics/Physics Education Group, University of Kaiserslautern, Germany
[4] Institut Universitaire pour la Formation des Enseignants, University of Geneva, Switzerland
[5] Institute of Nuclear and Particle Physics, TU Dresden, Germany

E-mail: gerfried.wiener@cern.ch, julia.woithe@cern.ch, alexander.brown@cern.ch and konrad.jende@cern.ch

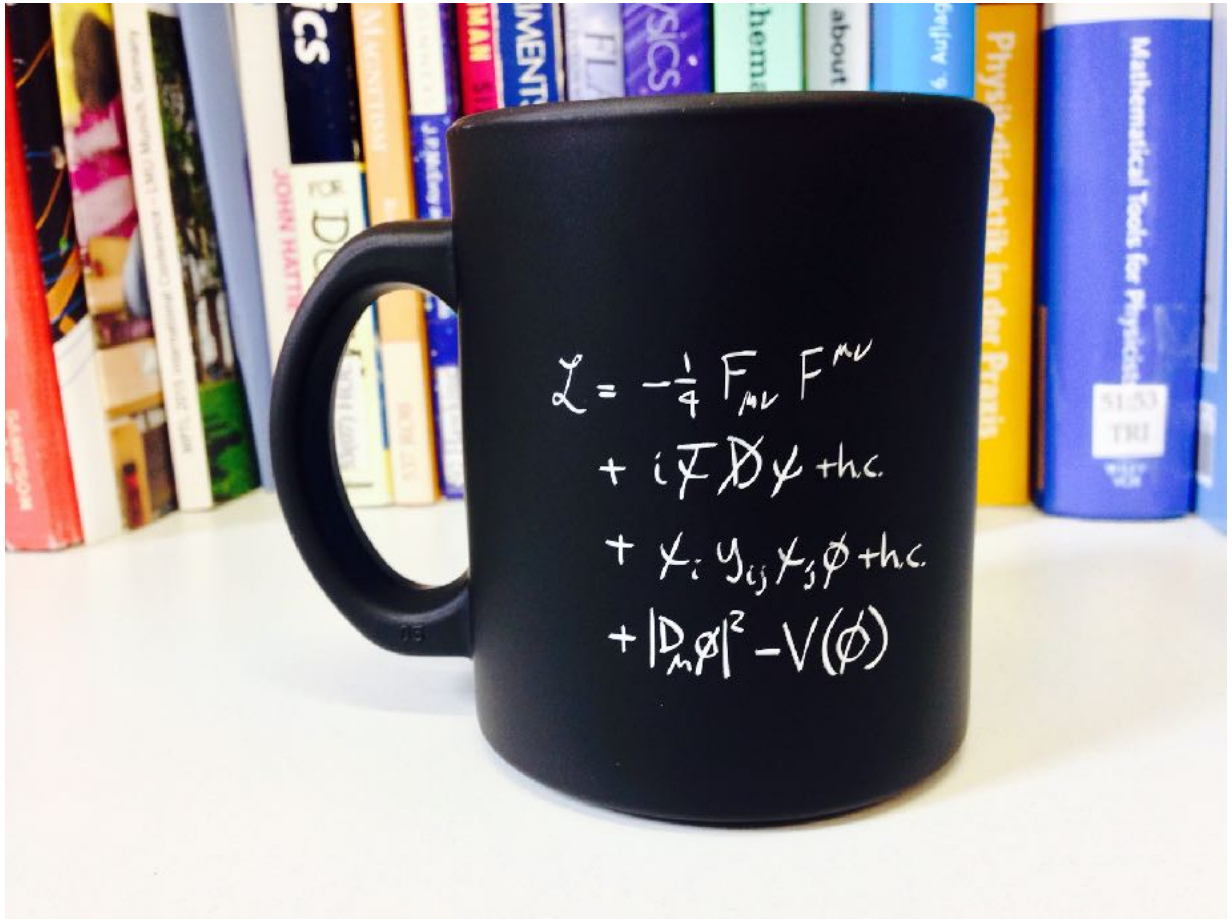
Abstract
In the context of the recent re-start of CERN's Large Hadron Collider (LHC) and the challenge presented by unidentified falling objects (UFOs), we seek to facilitate the introduction of high energy physics in the classroom. Therefore, this paper provides an overview of the LHC and its operation, highlighting existing education resources, and linking principal components of the LHC to topics in physics curricula.

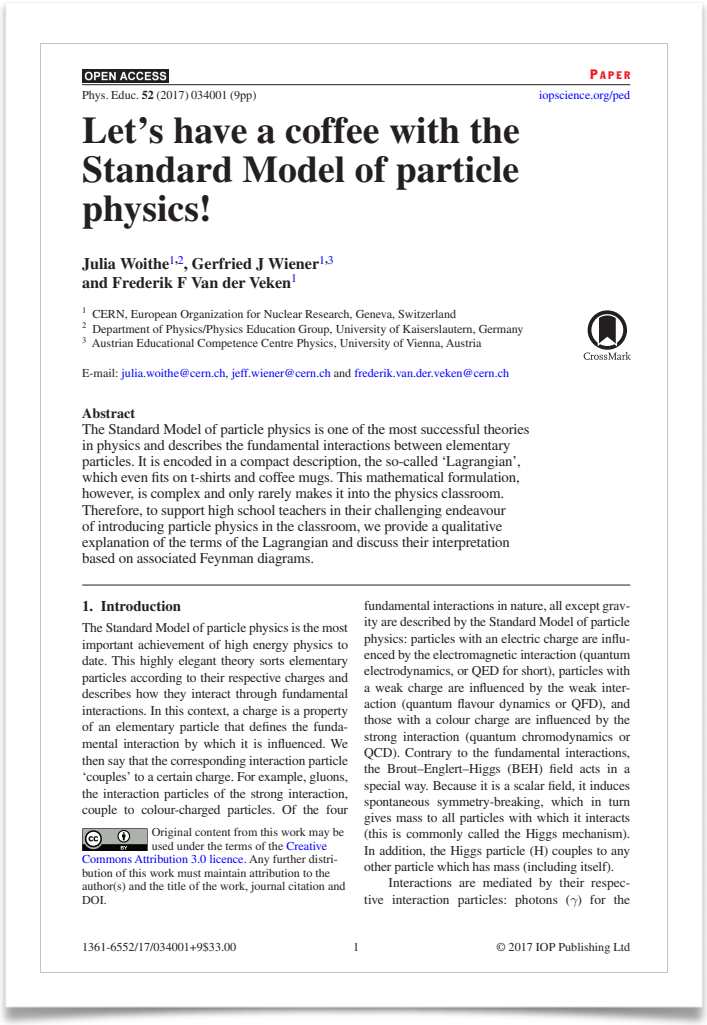
Introduction

Early in 2015, CERN's Large Hadron Collider (LHC) was awoken from its first long shutdown to be re-ramped for Run 2 at unprecedented beam energy and intensity. Intense scrutiny was required to verify the full and proper functioning of all systems. This included a special run of the machine to ensure a well-scrubbed LHC [1]. However, due to the increased beam currents, a critical but familiar issue reared its head during the run. Interactions between the beams and unidentified falling objects—so called UFOs—led to several premature protective beam dumps (see figure 1). These infamous UFOs are presumed to be micrometre-sized dust particles and can cause fast, localised beam losses with a duration on the order of 10 turns of the beam. This is a known issue of the LHC which has been observed before. Indeed, between 2010 and 2011, about a dozen beam dumps occurred due to UFOs and more than 10000 candidate UFO events below the dump threshold were detected [2]. Thus, UFOs presented more of an annoyance than a danger to the LHC, by reducing the operational efficiency of the machine. However, as beam currents increase, so does the likelihood of UFO-induced magnet quenches at high energy, creating a possible hazard to the machine. Therefore, particular care is taken to keep an eye on the timing and frequency of UFO occurrences. As the number of UFOs during Run 1 decreased over time, it is hoped that this will be the same in Run 2.

The recent re-start of the LHC at higher collision energies and rates presents high school

cern.ch/PER


$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$+ i\bar{\psi} \not{D} \psi + h.c.$
$+ \psi_i y_{ij} \psi_j \phi + h.c.$
$+ |D_\mu \phi|^2 - V(\phi)$



OPEN ACCESS PAPER

Phys. Educ. **52** (2017) 034001 (9pp) iopscience.org/ped

Let's have a coffee with the Standard Model of particle physics!

Julia Woithe[1,2], Gerfried J Wiener[1,3] and Frederik F Van der Veken[1]

[1] CERN, European Organization for Nuclear Research, Geneva, Switzerland
[2] Department of Physics/Physics Education Group, University of Kaiserslautern, Germany
[3] Austrian Educational Competence Centre Physics, University of Vienna, Austria

E-mail: julia.woithe@cern.ch, jeff.wiener@cern.ch and frederik.van.der.veken@cern.ch

Abstract

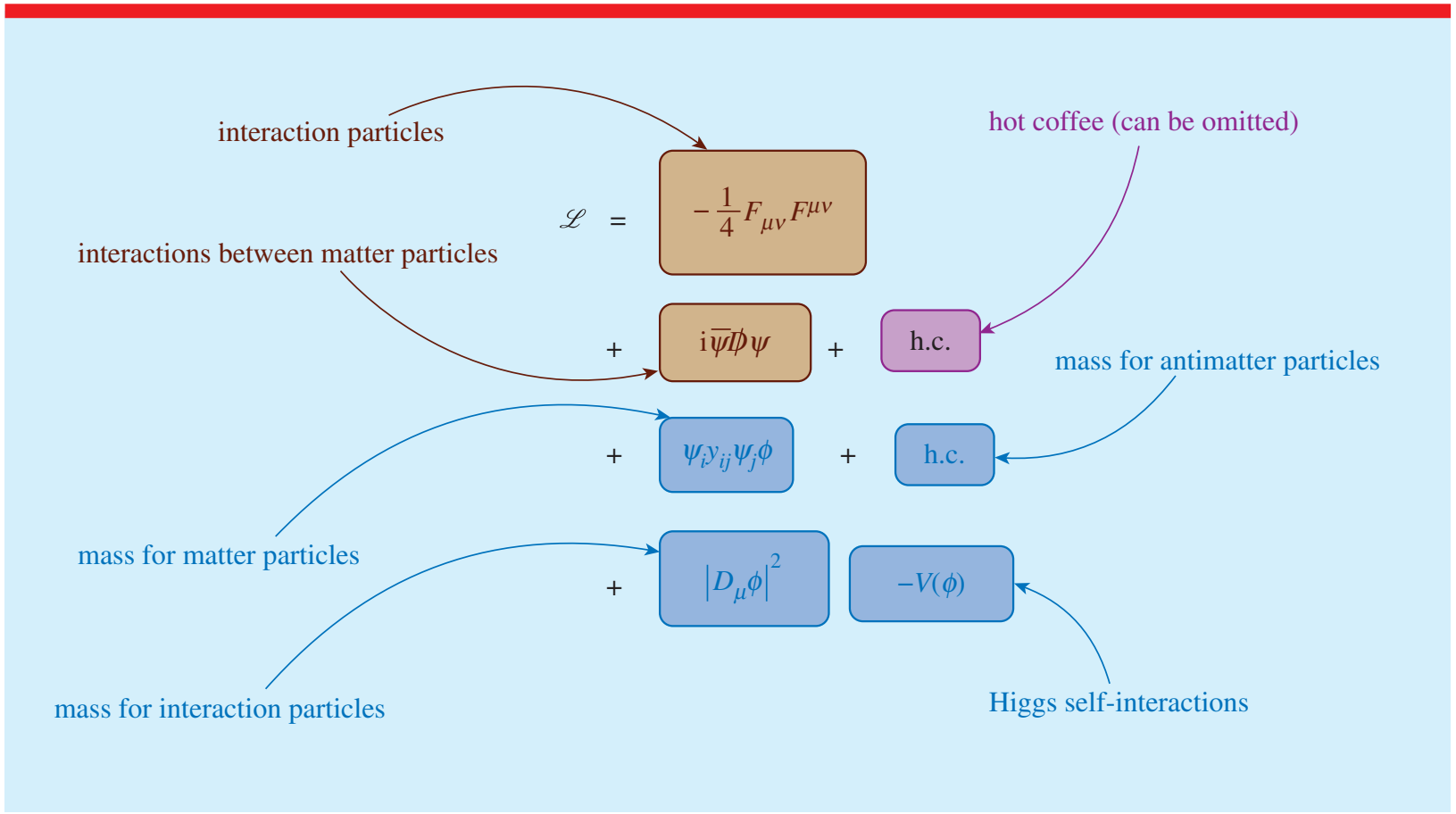
The Standard Model of particle physics is one of the most successful theories in physics and describes the fundamental interactions between elementary particles. It is encoded in a compact description, the so-called 'Lagrangian', which even fits on t-shirts and coffee mugs. This mathematical formulation, however, is complex and only rarely makes it into the physics classroom. Therefore, to support high school teachers in their challenging endeavour of introducing particle physics in the classroom, we provide a qualitative explanation of the terms of the Lagrangian and discuss their interpretation based on associated Feynman diagrams.

1. Introduction

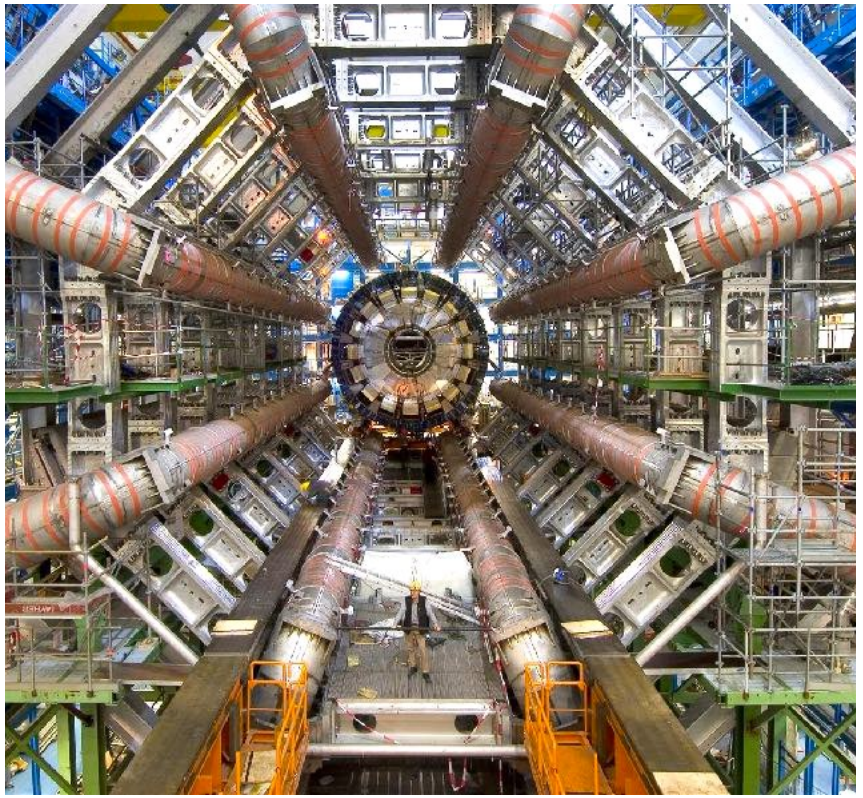
The Standard Model of particle physics is the most important achievement of high energy physics to date. This highly elegant theory sorts elementary particles according to their respective charges and describes how they interact through fundamental interactions. In this context, a charge is a property of an elementary particle that defines the fundamental interaction by which it is influenced. We then say that the corresponding interaction particle 'couples' to a certain charge. For example, gluons, the interaction particles of the strong interaction, couple to colour-charged particles. Of the four fundamental interactions in nature, all except gravity are described by the Standard Model of particle physics: particles with an electric charge are influenced by the electromagnetic interaction (quantum electrodynamics, or QED for short), particles with a weak charge are influenced by the weak interaction (quantum flavour dynamics or QFD), and those with a colour charge are influenced by the strong interaction (quantum chromodynamics or QCD). Contrary to the fundamental interactions, the Brout–Englert–Higgs (BEH) field acts in a special way. Because it is a scalar field, it induces spontaneous symmetry-breaking, which in turn gives mass to all particles with which it interacts (this is commonly called the Higgs mechanism). In addition, the Higgs particle (H) couples to any other particle which has mass (including itself).

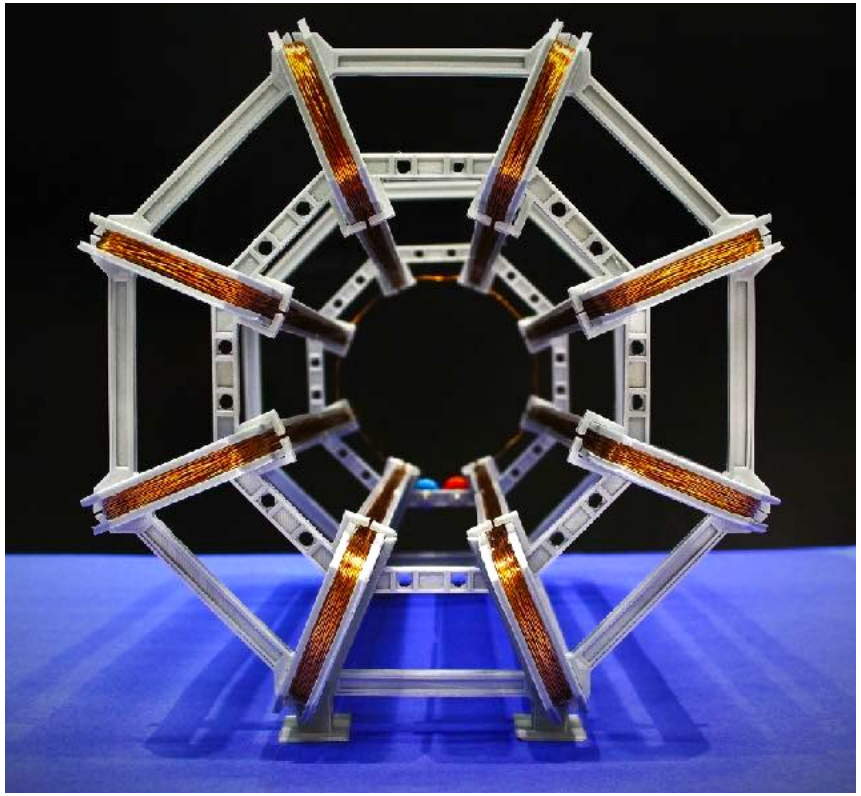
Interactions are mediated by their respective interaction particles: photons (γ) for the

cern.ch/PER

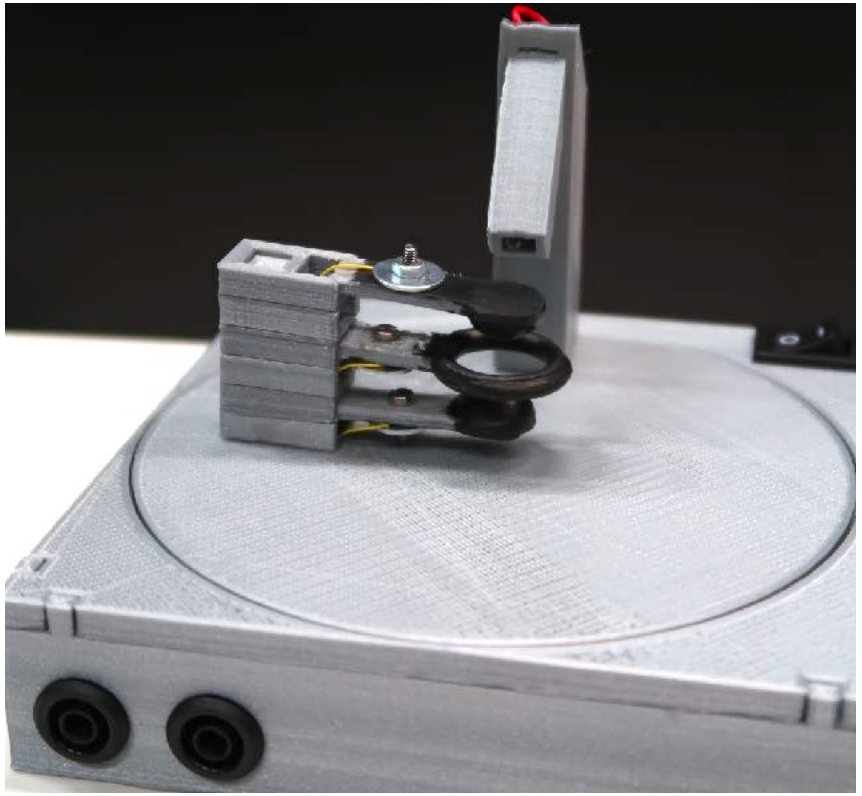

interaction particles
hot coffee (can be omitted)
$\mathscr{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$
interactions between matter particles
$+ \quad i\bar{\psi}\not{D}\psi \quad +$
h.c.
mass for antimatter particles
$+ \quad \psi_i y_{ij} \psi_j \phi \quad +$
h.c.
mass for matter particles
$+ \quad |D_\mu \phi|^2$
$-V(\phi)$
mass for interaction particles
Higgs self-interactions


Superconductivity Lab
...in action!
90 min hands-on workshop for 16-19 year old students
Prediction
Task
Observation
Explanation

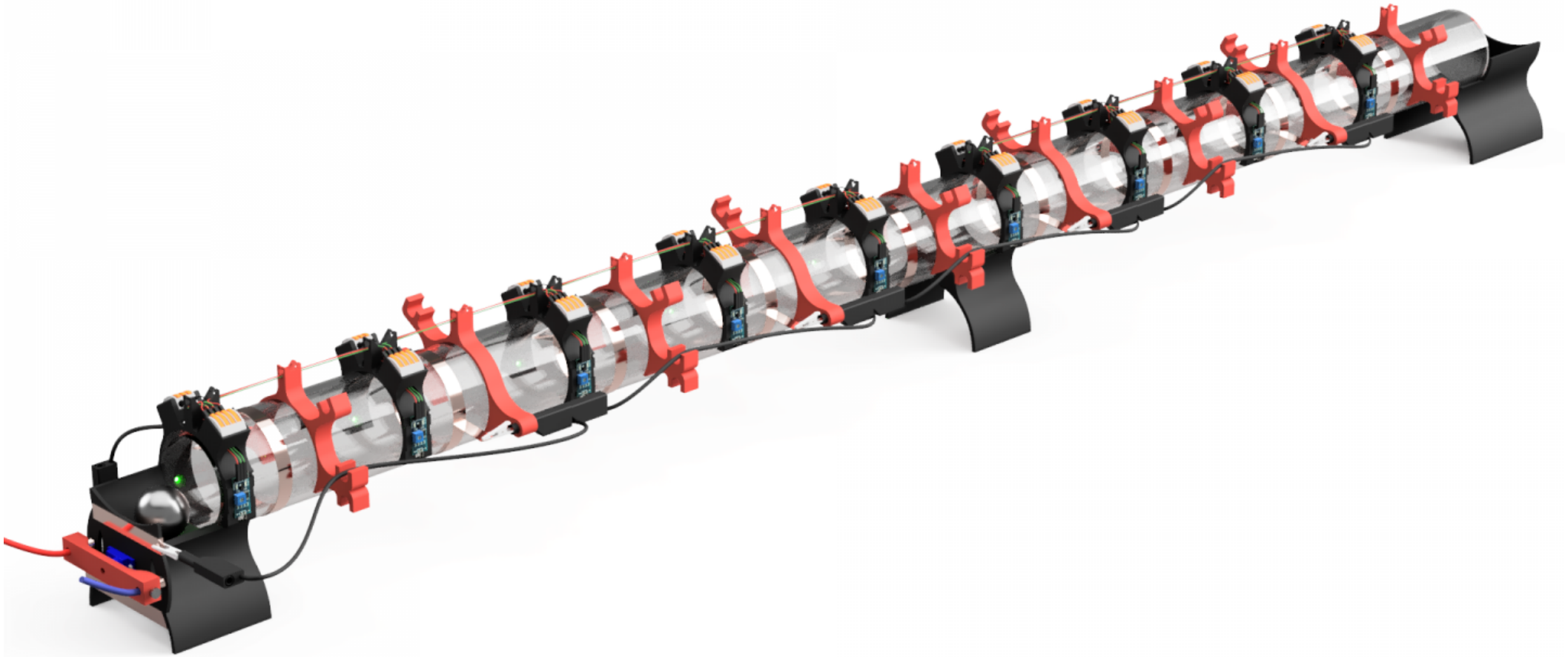




cern.ch/PER

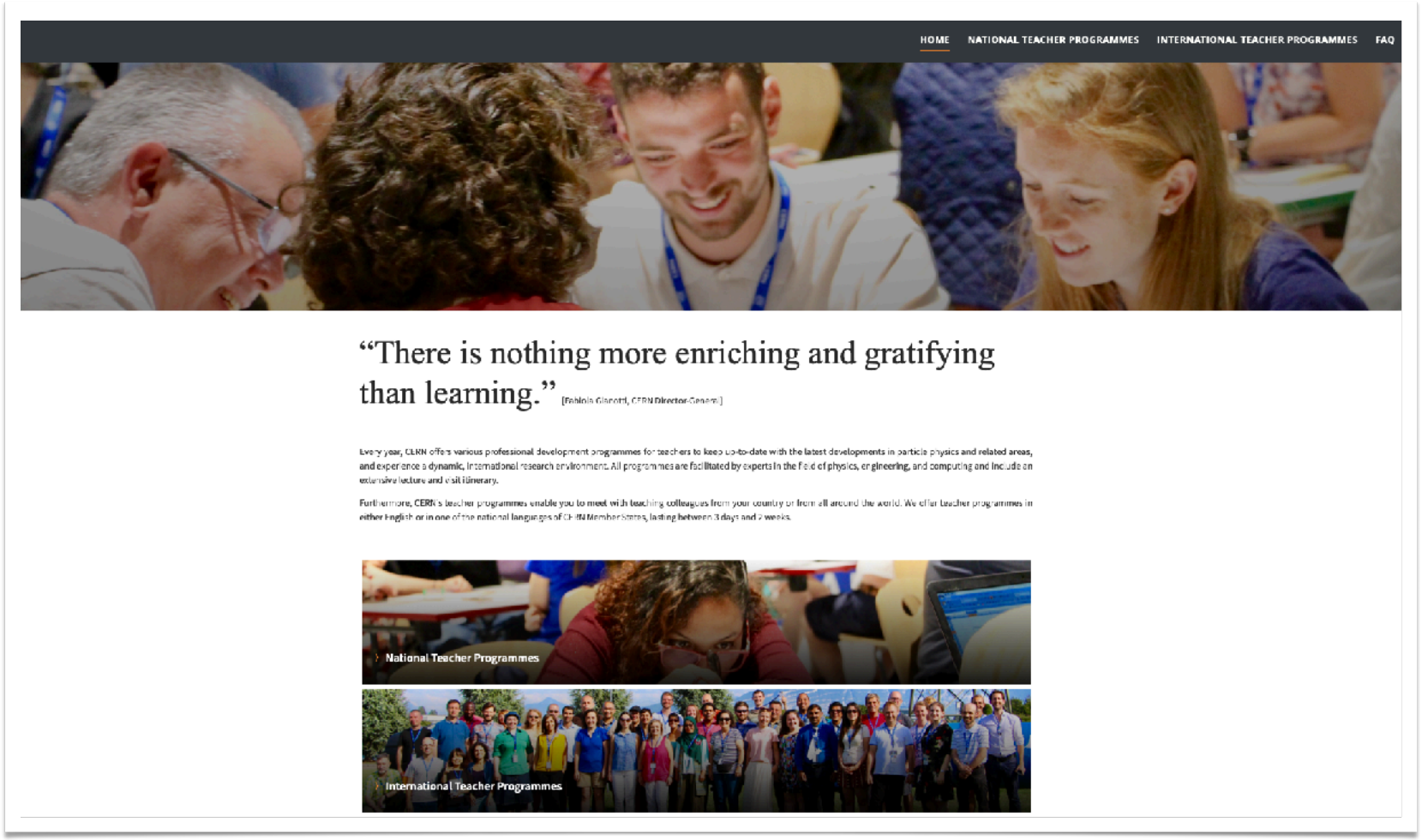


cern.ch/PER



cern.ch/PER

https://bit.ly/AT_MOOC23



teachers.cern

International Teacher Programmes 2025

International High School Teacher Programme
6 - 19 July 2025

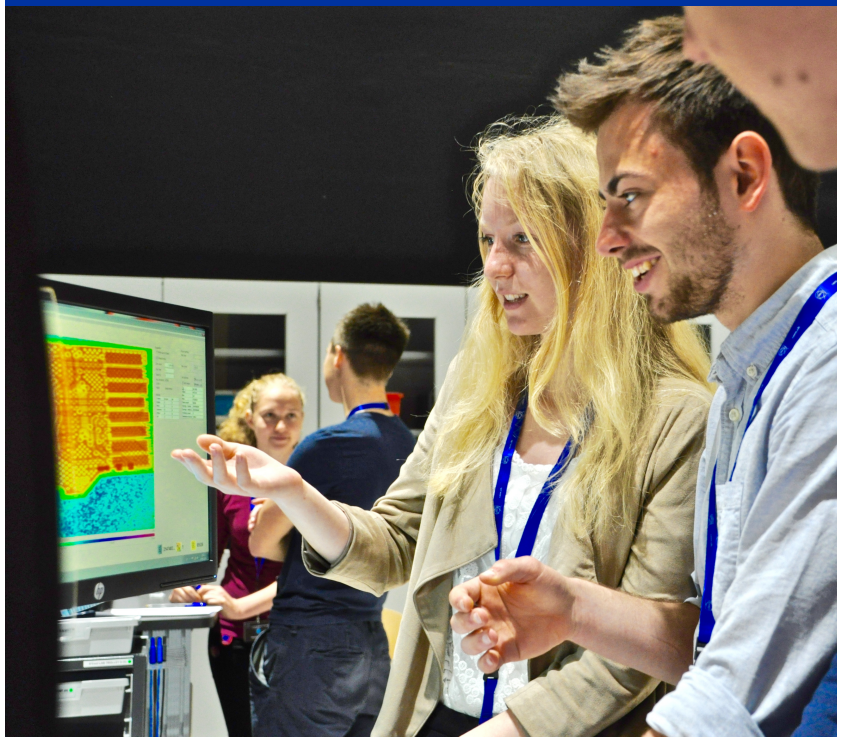
International Teacher Weeks Programme
3 - 16 August 2025

The application process for HST2025 & ITW2025 will be open from 1 November 2024 – 13 January 2025!
teachers.cern

For your students

Beamline 4 Schools

CERN-Solvay
Education Programme



Science Gateway

Merci bien!

Questions?

teachers.cern