



THE UNIVERSITY OF  
MELBOURNE

# ENGAGING THE CLASSROOM

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ATLAS VISITS, VIRTUAL VISITS, MASTERCLASSES, CHEAT  
SHEETS AND MORE



Joni Thu LH Pham (CoEPP, University of Melbourne), on behalf of the ATLAS Collaboration

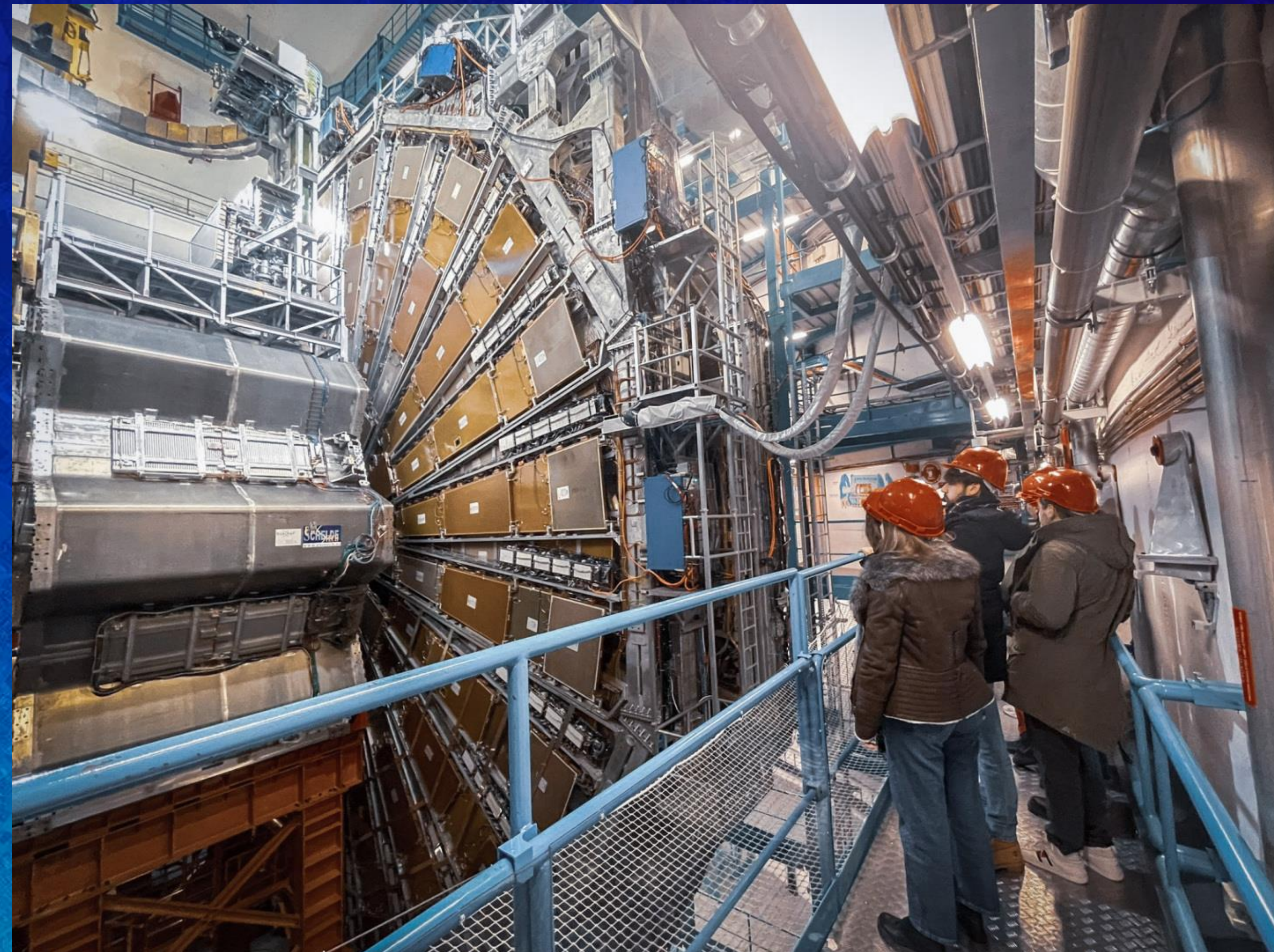


# MOTIVATION

- Students of all ages and levels can benefit from visual resources for learning particle physics.
- Aim to bring the excitement of scientific exploration and discovery into classrooms.
- Interactions between particle physicists and students are extremely beneficial on both ends.



University of Bologna students visiting the  
ATLAS Underground Cavern, Jan 2023





## ATLAS VISITOR CENTRE



- One of CERN's official visit sites
- Adjacent to ATLAS Control Room (P1, Meyrin), with windows that can be made transparent or opaque.



# ATLAS VISITOR CENTRE

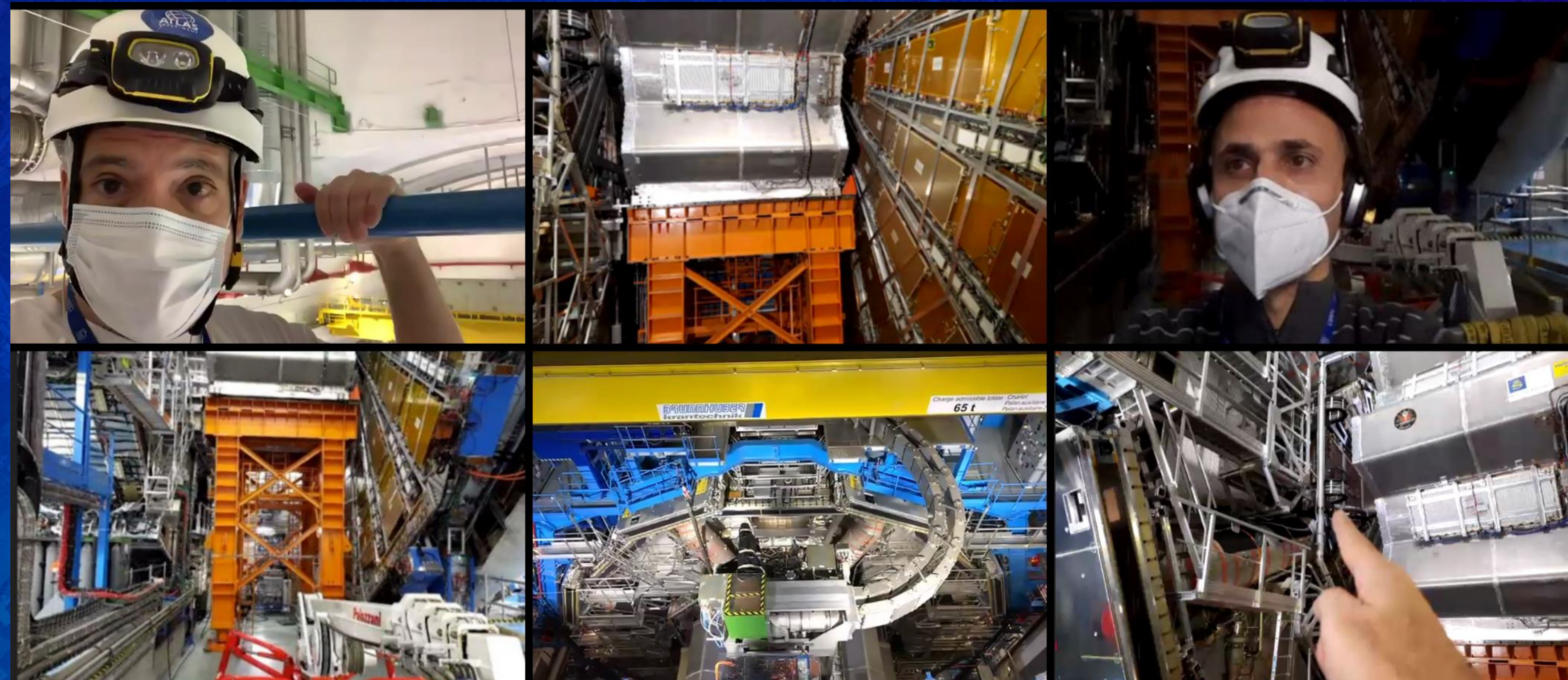
- Many interactive screens and exhibitions





## VIRTUAL VISITS

- Virtual Visits designed to give participants an experience without coming to CERN.
- Remote connection (Zoom) from ATLAS Cavern or Visitor Centre.
- Average of ~120 visits per year.
- Visitors from all over the world.



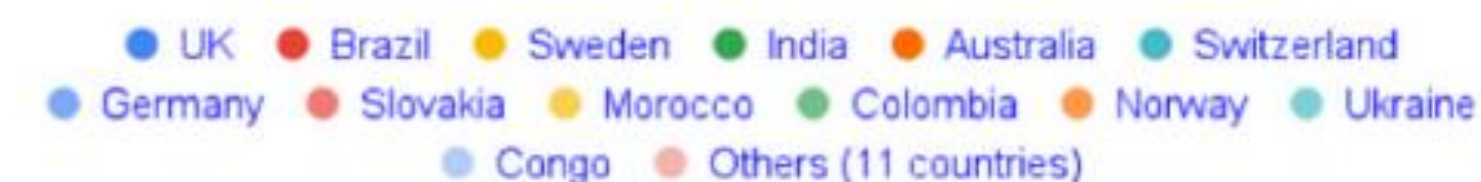


## VIRTUAL VISITS

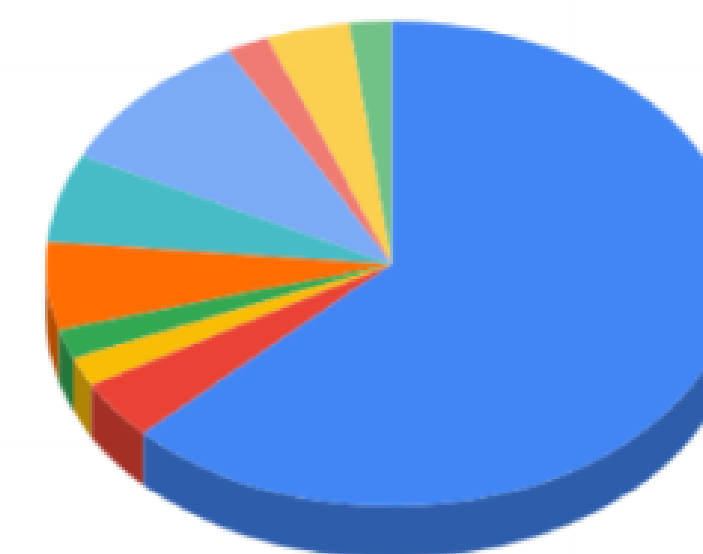
- 2023: 50+ visits from 24 countries in the first 6 months.
- 2022: 121 visits from 36 countries, 8 languages.
- Between 10-600 participants per visit.
- Open visits for individuals on a regular basis.
- Cavern visit streamed when possible.



Countries booking virtual visits in 2023



Languages of Virtual Visits in 2023





# VIRTUAL VISITS

- Some visits livestreamed to YouTube, TikTok, or other platforms.





# INTERNATIONAL MASTERCLASSES

Annual program in collaboration with IPPOG.



13,000 high school students, 200+ places, 55 countries (2023):

- Get insight into topics and methods of basic research at the fundamentals of matter & forces.
- Perform measurements on real CERN experiments' data
- Participate in an international video conference for discussion of results.



Dr Goldfarb and Ukrainian students Tiulchenko & Boreiko hosted ATLAS VV for IMC, Kharkiv, Apr 2023.



# FACT SHEETS

- Collect facts about ATLAS detector, collaboration, and physics programme all in one place.
- Clear, concise and visually appealing.
- 10 sheets currently available.

## CALORIMETERS

Calorimeters measure the energy of particles created in high-energy LHC collisions. They are designed to absorb most of the particles coming from a collision, forcing them to deposit all of their energy and stop within the detector. ATLAS calorimeters consist of layers of an "absorbing" high-density material that stops incoming particles, interleaved with layers of an "active" medium that measures their energy.



### LIQUID ARGON

The Liquid Argon (LAr) Calorimeter measures the energy of hadrons. It features layers of metal that absorb incoming particles, creating new, lower energy particles. These particles, produced between the layers, produce light. By combining all of the light, the energy of the original particle can be determined.



The central region of the calorimeter identifies electrons and photons. It has an accordion structure, with a high density of material so that no particle escapes unchanged.

To keep the argon in liquid form, the calorimeter is kept at -184 °C. Specially-designed, vacuum-insulated pipes bring the electronic signals from the warm area where the readout electronics are located to the cold area.

### TILE HADRONIC

The Tile Calorimeter surrounds the central region of the calorimeter. It is made of plastic scintillating tiles. As particles pass through the tiles, they produce a shower of new particles, which produce photons. The intensity of the light is proportional to the energy of the particle.



The Tile Calorimeter is made of plastic scintillator tiles working in synergy with the ATLAS experiment, weighing in at over 100 tonnes.

<https://atlas.cern>

## TRIGGER & DATA ACQUISITION

ATLAS sees up to 1.7 billion collisions every second – but not all of these events are worth studying. The Trigger and Data Acquisition system ensures optimal selection of the most interesting collision events for study.



The Trigger and Data Acquisition system is responsible for selecting the most interesting collision events for study.

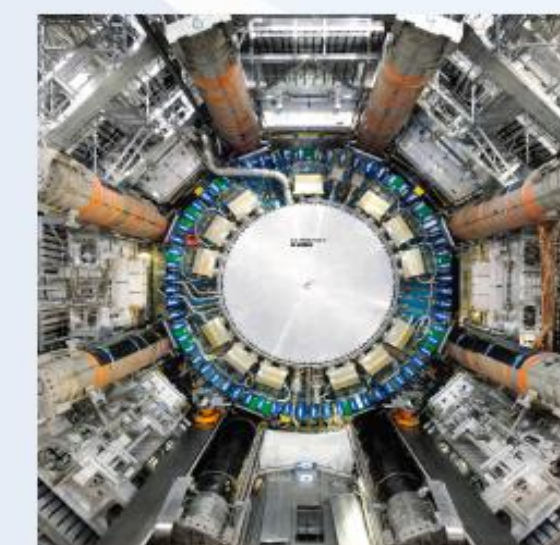
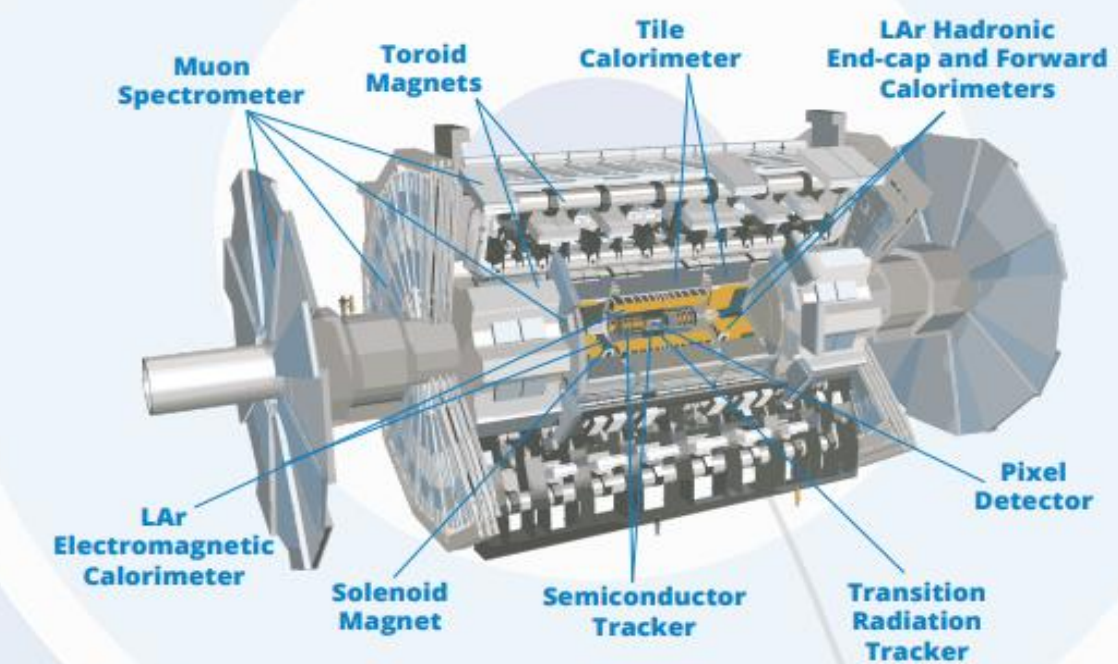


The Trigger and Data Acquisition system is responsible for selecting the most interesting collision events for study.

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<https://atlas.cern>

## DETECTOR OVERVIEW



ATLAS is the largest detector ever constructed for a particle collider: 46 m long and 25 m in diameter. Its construction pushed the limits of existing technology.

ATLAS is designed to record the billions of high-energy proton or ion collisions at the LHC. New particles fly out from the collision point in all directions and interact with the different ATLAS sub-detectors.

Each sub-detector makes up a different layer of the detector and plays a unique role. More than 100 million sensitive electronics channels are used to record the particles produced by the collisions, which are then analysed by ATLAS scientists to identify and reconstruct individual particles.



# CHEAT SHEETS

- Designed to make ATLAS' online scientific material more accessible to a wider audience.
- One concept covered per sheet.
- 5 sheets currently available.
- Coming soon: Statistical Significance Cheat Sheet.



<https://atlas.cern/Resources/Cheat-sheets>

### CONSERVATION LAWS


Conservation laws govern the reactions we observe in particle physics. The deep relationship between fundamental symmetries of nature and conservation laws has been a guiding principle in the development of the Standard Model. Particle physicists study these laws with high precision, as their violation would be a sign of new physics.

#### WHY WE NEED THEM

The Standard Model describes all fundamental particles and their interactions. It has been tested with extreme precision and found to describe nature very well. It relies on certain conservation laws, which allow some processes to occur, while forbidding others.

#### ENERGY AND MOMENTUM

One of the most important conservation laws is the conservation of energy. This means that energy can be neither created nor destroyed. Since energy and mass can be exchanged, one result of conservation of energy is that a particle cannot decay into particles whose summed masses are greater than its own mass.

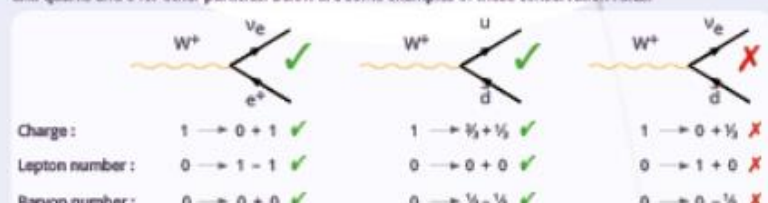


Mass:  $91 \text{ GeV} > 2 \times 4.18 \text{ GeV}$        $91 \text{ GeV} < 2 \times 173 \text{ GeV}$

Momentum is another important quantity which must always be conserved. This is useful for estimating the "missing transverse momentum" in a proton-proton collision event. Since the incoming protons have no momentum in the direction perpendicular to the beam (transverse direction), the transverse momenta of all particles resulting from the collision must sum to zero. If they do not, this missing transverse momentum can be associated with undetected particles such as neutrinos or, possibly, dark matter.

#### ELECTRIC CHARGE, LEPTON NUMBER, BARYON NUMBER

These properties are expected to be conserved in all processes. The lepton number is defined to be 1 for leptons, -1 for anti-leptons and 0 for all other particles. Similarly, baryon number is  $\frac{1}{3}$  for each quark,  $-\frac{1}{3}$  for anti-quarks and 0 for other particles. Below are some examples of these conservation rules:



Charge:  $1 \rightarrow 0 + 1$  ✓       $1 \rightarrow \frac{1}{3} + \frac{1}{3}$  ✓       $1 \rightarrow 0 + \frac{1}{3}$  ✗  
 Lepton number:  $0 \rightarrow 1 - 1$  ✓       $0 \rightarrow 0 + 0$  ✓       $0 \rightarrow 1 + 0$  ✗  
 Baryon number:  $0 \rightarrow 0 + 0$  ✓       $0 \rightarrow \frac{1}{3} - \frac{1}{3}$  ✓       $0 \rightarrow 0 - \frac{1}{3}$  ✗

#### BREAKING CONSERVATION LAWS

ATLAS physicists are searching for evidence of processes that might violate the existence of heavy right-handed neutrinos, which would violate lepton number conservation.

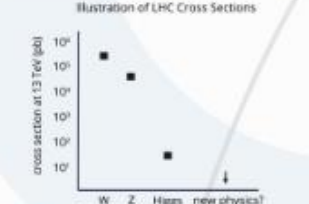
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### CROSS SECTION AND LUMINOSITY

Cross section and luminosity are commonly used terms, but in particle physics they describe important metrics of particle collisions that determine the likelihood of seeing interactions resulting in new particles.

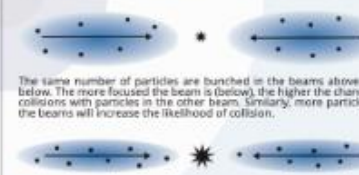
#### CROSS SECTION

Particle physicists use the term cross section to describe the probability that two particles will collide and interact in a certain way. When proton beams cross in the Large Hadron Collider (LHC), many different processes can occur. The cross section of a particular process depends on the type and energy of the colliding particles. At the LHC, certain particles such as W and Z bosons have large cross sections, so they will be observed more often. The production of a Higgs boson at the LHC has a much lower cross section, so it is more difficult to produce.



#### LUMINOSITY

Instantaneous luminosity measures how tightly particles are packed into a given space, such as the LHC's proton beam. A higher luminosity means a greater likelihood particles will collide and result in a desired interaction. This can be achieved by packing more particles in the beam, or by focusing the beam more tightly.



Integrated luminosity, on the other hand, considers the total number of events during a period of data-taking. The ATLAS Experiment accumulated over 160 inverse femtobarns of data during the LHC's 13 TeV run from 2015-2018, which equates to about 16 million billion proton-proton collisions!

#### UNITS

Nuclear and particle physicists use an unusual unit called a barn. This may sound like a large surface area, but in reality it is about the size of a uranium nucleus ( $10^{-28} \text{ m}^2$ ). Cross sections are typically much smaller than a barn, so frequently used units are picobarns ( $\text{pb}, 10^{-36} \text{ m}^2$ ) and femtobarns ( $\text{fb}, 10^{-39} \text{ m}^2$ ). The units for luminosity are inverse picobarns per second ( $\text{pb}^{-1} \text{s}^{-1}$ ) or inverse femtobarns per second ( $\text{fb}^{-1} \text{s}^{-1}$ ).

#### HOW ARE CROSS SECTION AND LUMINOSITY RELATED?

Luminosity measures how many particles pass through a square centimetre per second. Cross section measures the likelihood that a desired event will happen. These two are inversely related in that the luminosity times the cross section gives the number of expected events per second:

$$\text{number of events per second} = \text{luminosity} (\text{pb}^{-1} \text{s}^{-1}) \times \text{cross section} (\text{pb})$$

#### EXAMPLE: HIGGS BOSON PRODUCTION AT THE LHC

During its 13 TeV run, the LHC reached a peak instantaneous luminosity of 0.0206 inverse picobarns per second, and the total production cross section of a 125 GeV Higgs boson was measured to be about 50 picobarns. Using this information and the equation above, we can calculate the number of Higgs bosons produced per second:

### FEYNMAN DIAGRAMS

Feynman diagrams (named after theoretical physicist Richard P. Feynman) are found in almost every paper published by ATLAS and are a powerful tool to visually represent particle interactions, as well as to conduct elaborate calculations. This sheet covers the basics of how to read Feynman diagrams, taking as an example one possible mode of production and decay of a Higgs boson at the LHC.

#### THE BUILDING BLOCKS

**Lines:** Each line represents a particle:  
 • a straight line is for a fermion (electron, muon, neutrino, quark, ...)  
 • a wavy line is for a photon or a W or Z boson  
 • a curly line is for a gluon  
 • a dashed line is for a Higgs boson

**Vertices:** These represent an interaction. Certain rules must be obeyed when connecting lines into a vertex. Some of these rules are general – e.g. conservation of electric charge and momentum – while others depend on the details of the theory. This example shows a W boson decaying into a quark and an antiquark.

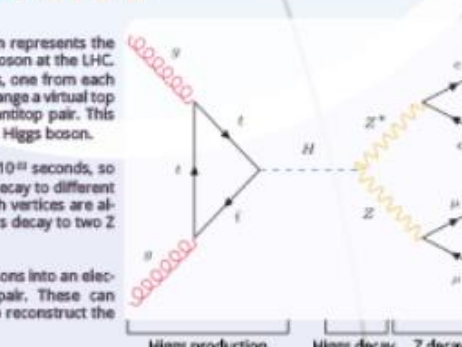
**Directionality:** In a Feynman diagram, the horizontal direction represents time, from left to right, and the vertical direction space (roughly speaking). This means that: incoming particles are on the left and outgoing particles on the right. Fermion lines are usually drawn with arrows, where particle lines are pointing away from the vertex and antiparticle lines towards the vertex. Although this might seem to imply that antiparticles are moving backwards in time, we prefer to think of the direction of the arrows as the flow of (electric) charge.

#### AN EXAMPLE: THE HIGGS BOSON

**Higgs production:** The left side of this Feynman diagram represents the main production mode of the Higgs boson at the LHC. The incoming particles are two gluons, one from each colliding proton. The gluons then exchange a virtual top quark, which produces a virtual top-antitop pair. This pair then annihilates to produce a real Higgs boson.

**Higgs decay:** The Higgs boson only lives for about  $10^{-13}$  seconds, so it cannot be detected directly. It can decay to different types of particles (depending on which vertices are allowed by the theory). Here we show its decay to two Z bosons, one of which is virtual ( $Z^*$ ).

**Z boson decays:** The final step is the decay of the Z bosons into an electron-positron and muon-antimuon pair. These can be detected by ATLAS and allow us to reconstruct the Higgs boson.



**Describe a given process, all of which they do not all contribute to reach a targeted precision, all leading or next-to-leading order.**

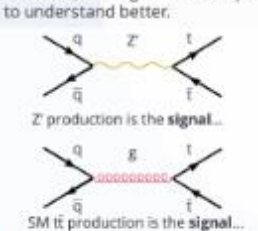
<https://atlas.cern>

### SIGNAL AND BACKGROUND

The processes that particle physicists are interested in are often very rare, which makes them difficult to observe. Researchers must sift through large amounts of data to find only a few possible occurrences of the process of interest, making it similar to looking for a needle in a haystack. Fortunately, ATLAS physicists have developed strategies to help with this task.

#### WHAT IS SIGNAL?

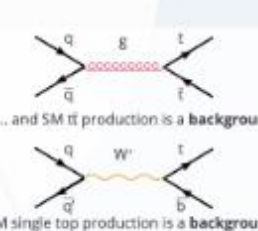
The word "signal" is used to designate the process of interest in a given analysis. There are two main types of analyses: searches and measurements. For searches, the signal is a sign of some new physics phenomenon, for example a new particle not predicted by the Standard Model (SM). For a measurement, the signal is a SM process that we wish to understand better.



Z production is the signal...

#### WHAT IS BACKGROUND?

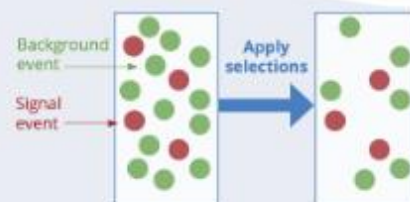
The word "background" is used to describe anything that mimics a signal, leaving a similar signature in the detector. It could come from a known Standard Model process, or other sources. Note that what is considered a signal for one analysis could be a background for another.



...and SM  $t\bar{t}$  production is a background.


#### EVENT SELECTION

One of the main goals of a search or measurement is to increase the signal-to-background ratio. This is done by applying selection criteria to the particle-collision events that favour the signal. For example, one could require a minimum momentum threshold for certain objects, or a specific number of leptons or photons. This filters out events that are most likely to be background and therefore makes the signal easier to spot.



#### DISCRIMINATING VARIABLES

After applying the selection criteria, physicists identify one or more quantities that are expected to be very different between signal and background, called discriminating variables. These quantities are visualised in histograms (as shown below). If the collision data agree with the combined signal-plus-background prediction, this could be an indication that the signal of interest is indeed present.



#### MACHINE LEARNING TECHNIQUES

Many analyses today use machine learning techniques to better separate signal and background. Instead of selecting only a few discriminating variables, machine learning algorithms can use information from many different variables to make a decision about whether a given event looks more like signal or background. This can lead to large improvements in precision.

<https://atlas.cern>

### THE STANDARD MODEL

The Standard Model (SM) is a theory which classifies all fundamental particles based on their properties and introduces rules that determine which interactions between them can occur and at what rate. The SM has been verified experimentally with high precision by particle-physics experiments, but physicists are still looking for measurements that could show deviations from SM predictions, and point the way to new physics.

#### BOSONS AND FERMIONS


There are two main groups of particles in the Standard Model: bosons and fermions. This classification is based on an intrinsic property called spin, which, for elementary particles, can take the value 0,  $\frac{1}{2}$  or 1. Particles with integer spin (0, 1) are bosons, while those with half-integer spin ( $\frac{1}{2}$ ) are fermions. Fermions and bosons act differently in interactions.

#### FORCE MEDIATORS

An interaction between particles can be viewed as the exchange of a boson. Therefore, the spin-1 bosons in the SM are called "force mediators". Each boson is responsible for mediating a specific force: the photon carries the electromagnetic force, the gluons the strong nuclear force, and the W and Z bosons the weak nuclear force. Each force has an associated charge which particles must have in order to participate in that interaction: electric charge for the electromagnetic force, colour charge for the strong force, and weak charge for the weak force. If a boson carries the charge corresponding to the force it mediates (which is the case for the gluons as well as the W and Z bosons), then it can interact with itself.

#### MATTER PARTICLES

The fermions are the particles that make up matter and are separated into two categories: quarks and leptons. The main difference is that quarks have colour charge, whereas leptons do not. This means that quarks can interact with gluons through the strong force. Both quarks and charged leptons can interact via the electromagnetic and weak forces. There are three generations of quarks and leptons, where particles in different generations have similar properties but differ in mass. For example, the top quark (third generation) is about 80,000 times more massive than the up quark (first generation). For each of these particles, there exists a matching antiparticle with opposite charges.



#### THE HIGGS BOSON

The Higgs boson is unique because it is the only known elementary spin-0 particle. The field associated with the Higgs boson is responsible for the masses of other fundamental particles. All particles which interact with this field have mass, with more massive particles interacting more strongly. The discovery of the Higgs boson in 2012 by the ATLAS and CMS Collaborations was the last piece of evidence needed to confirm the SM.

#### BEYOND THE STANDARD MODEL

Even though no deviation from the SM has been observed so far, we know that it is incomplete, with gravity and dark matter being the main missing pieces. There are also many other questions that cannot be answered with the current SM, such as why there is more matter than antimatter in the Universe. For these reasons, many theories Beyond the Standard Model are currently being investigated by physicists in an attempt to modify or extend our picture of the SM.

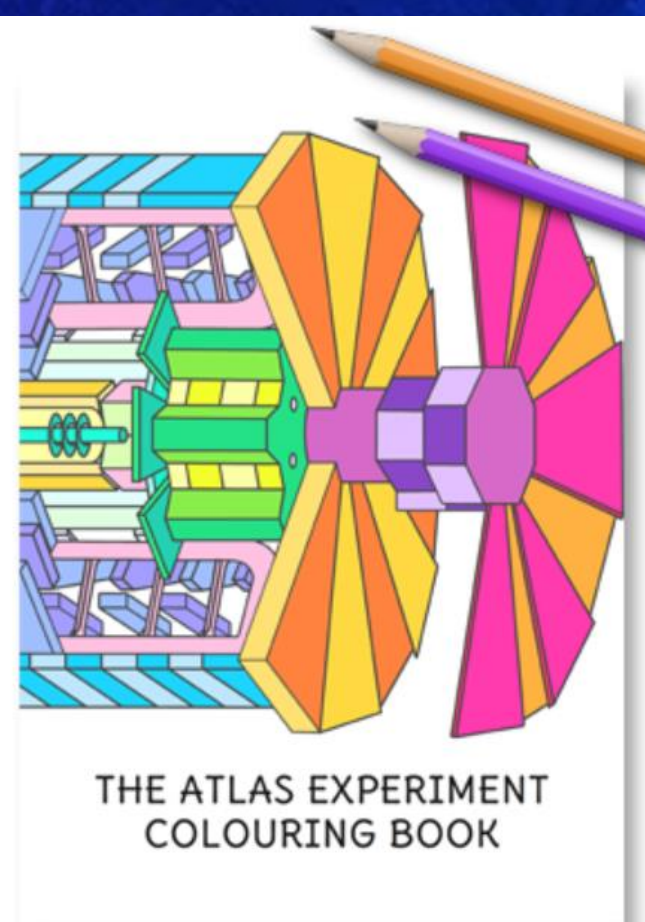
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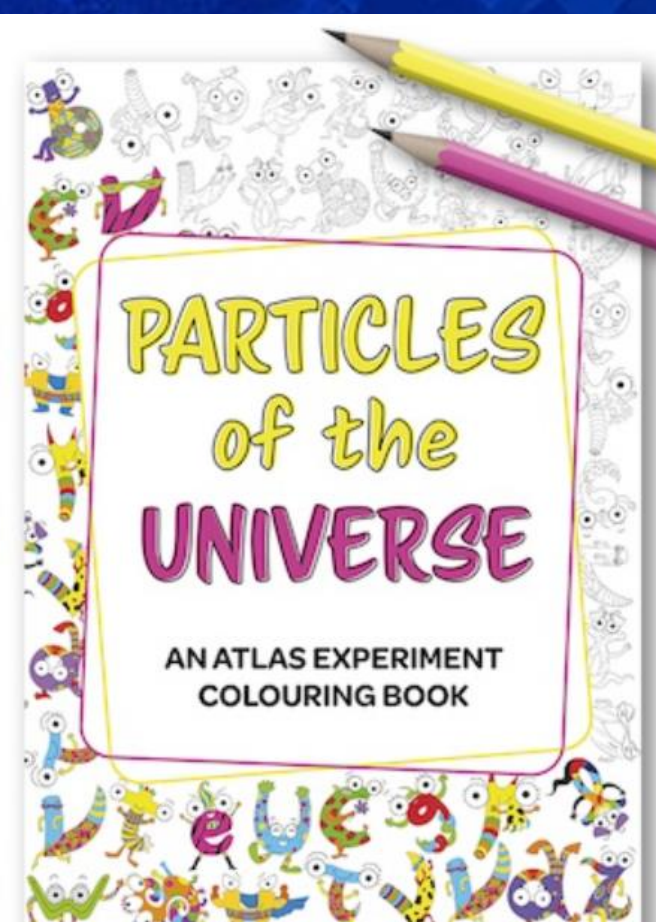
## ACTIVITY BOOKS

- Wide range of educational materials for all ages & levels of expertise.
- Colouring Books (2), Teachers Guide (1) & Activity Sheets (5)
- Printed & Distributed by CERN Education Team & others for events & schools

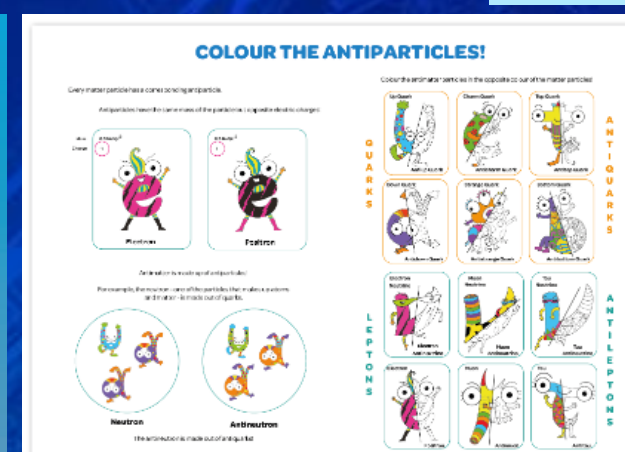
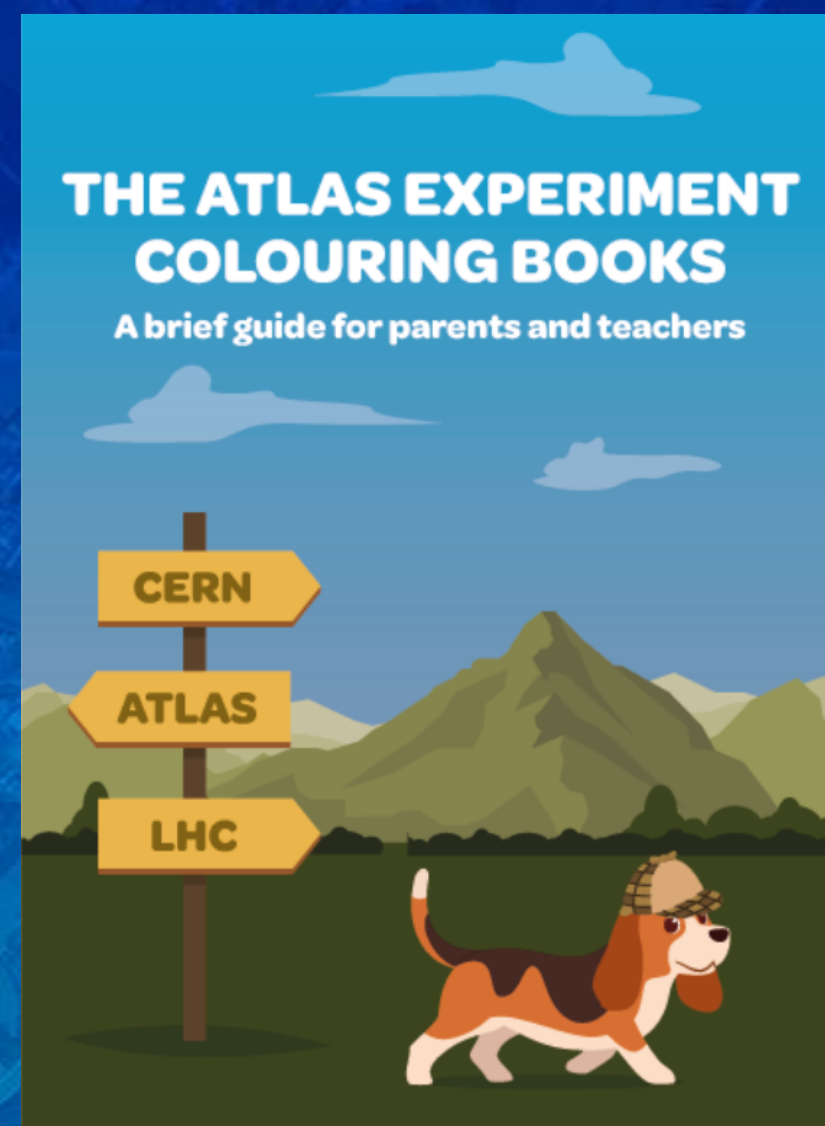
<https://atlas.cern/Resources/Colouring-Books>



ATLAS Experiment  
Colouring Book

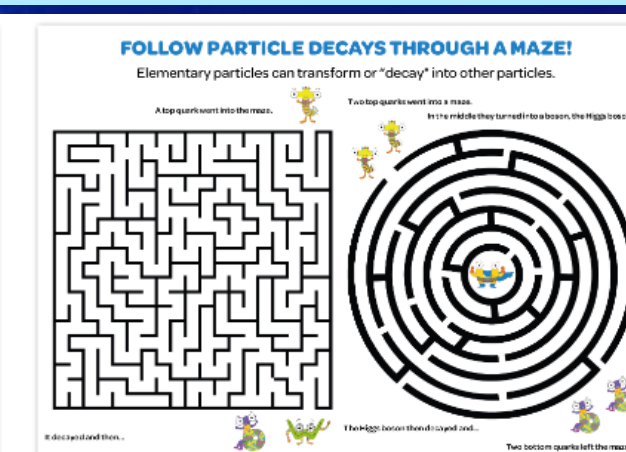


Particles of the Universe  
Colouring Book



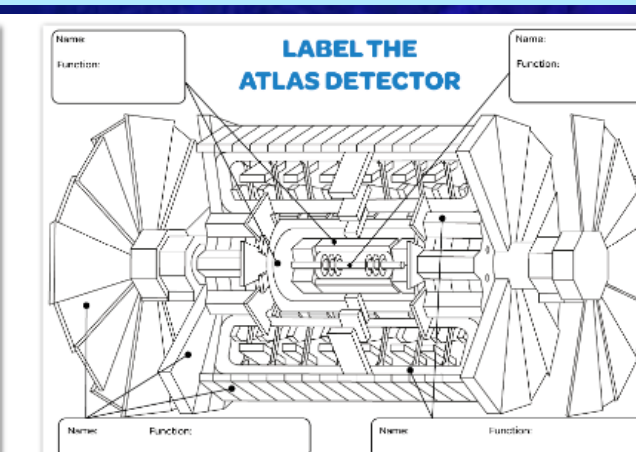
Particles vs. Antiparticles

Download in English, French, Spanish, German,  
Italian, Portuguese, Chinese



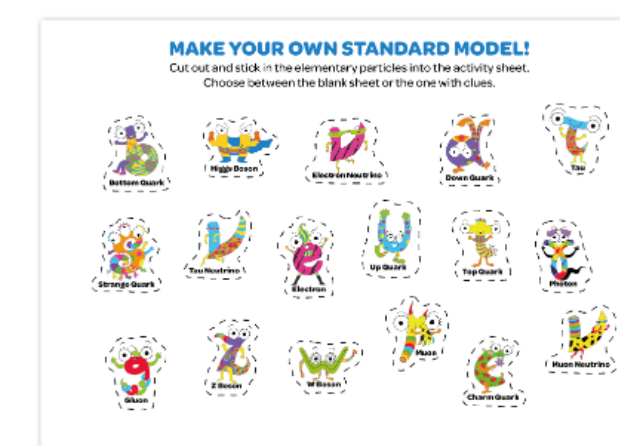
Follow particle decays through a maze

Download in English, French, Spanish, German,  
Italian, Portuguese, Chinese

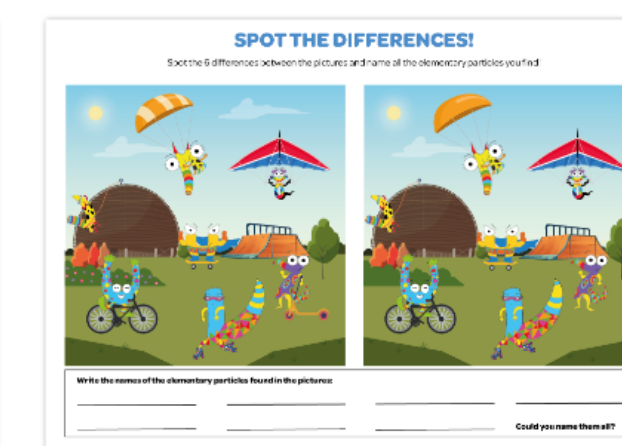


Label the Detector

Download in English, French, Spanish, German,  
Italian, Portuguese, Chinese



Make your own Standard Model

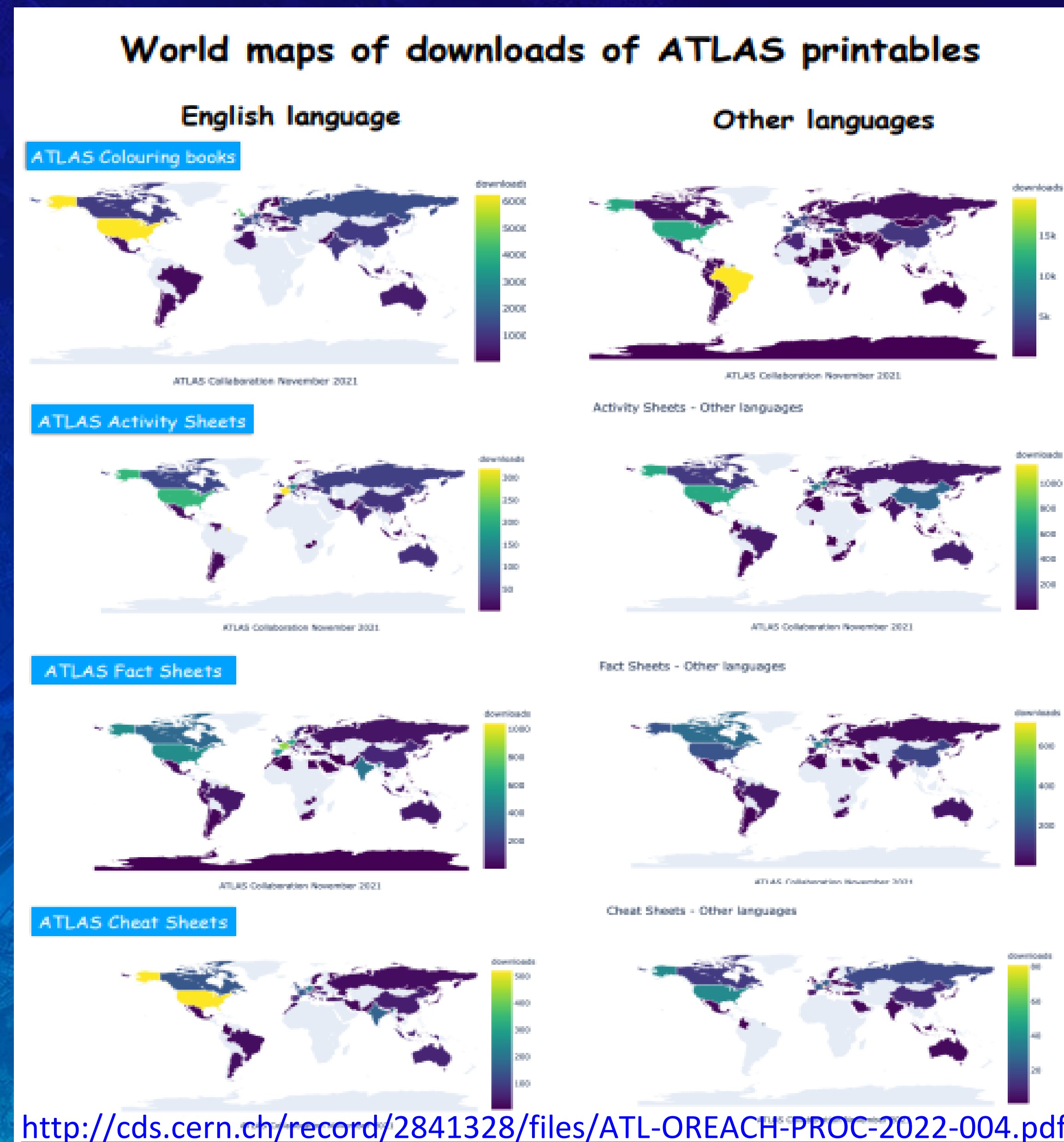


Spot the Differences



## MULTILINGUALISM

- CERN & ATLAS guided tours offered in ~30 languages.
- ATLAS International MasterClasses offered in 13 languages: English, French, German, Italian, Spanish, Portuguese, Greek, Norwegian, Polish, Slovak, Czech, Danish, Turkish.
- Outreach events organized in different languages by regional research groups & individual ATLAS members from/in different countries.

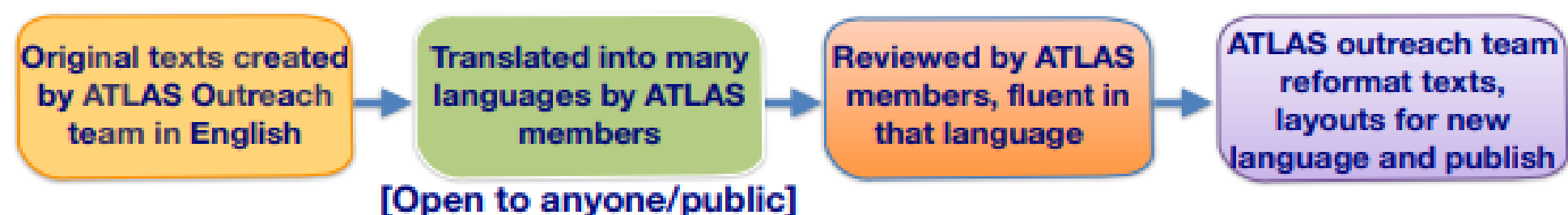




## MULTILINGUALISM

- ATLAS educational material (written and oral) is provided in many different languages.

### Translations of educational materials

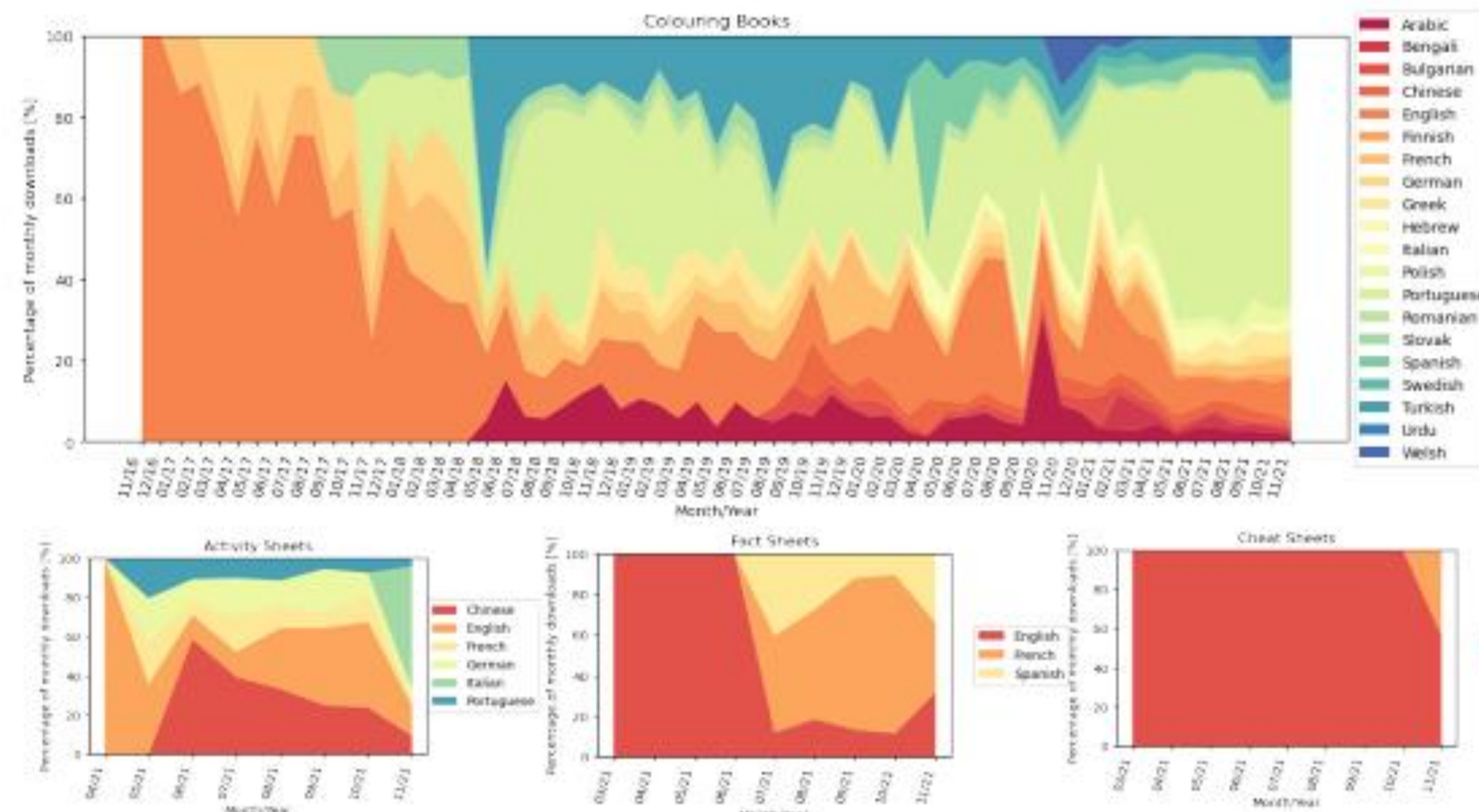


Educational materials	Publication time	No. of languages	Languages
 ATLAS Colouring book	November 2016	21	English, French, German, Spanish, Italian, Portuguese, Welsh, Romanian, Slovak, Ukrainian, Greek, Bulgarian, Russian, Hebrew, Polish, Swedish, Turkish, Urdu, Arabic, Bengali, Chinese
 ATLAS Particles of the Universe	January 2020	11	English, French, German, Spanish, Italian, Greek, Chinese, Polish, Portuguese, Finnish, Urdu
 ATLAS Activity Sheets (6)	April 2021	7	English, Spanish, French, Italian, German, Portuguese, Chinese
 ATLAS Fact Sheets (10)	March 2021	4	English, Spanish, French, Italian
 ATLAS Cheat Sheets (3)	March 2021	3	English, Spanish, French
 Guide for Parents and Teachers	February 2022	2	English, Portuguese

Examples of ATLAS printable materials

### Monthly data on translated ATLAS materials

Downloads of the ATLAS printable in different languages as a function of time :





## Conclusion

The ATLAS Outreach has been putting a lot of effort in engaging the classroom through:

- ATLAS On-site Visits
- ATLAS Virtual Visits
- International MasterClasses
- Printables (Cheat sheets, Fact sheets & Activity books)
- Multilingualism (activities & printables offered in many languages and in/to many countries)

Get in touch with Outreach Coordinators Darren+Dilia:

◦ [atlas-outreach-coordination@cern.ch](mailto:atlas-outreach-coordination@cern.ch)

**WE ARE ALSO INTERESTED IN HEARING ABOUT  
YOUR IDEAS/PROJECTS!**



DARREN



DILIA



KATARINA