Introduction to CERN and Physics Programs

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Chulalongkorn U., CMS Collaboration
5 May 2022

To download the talk:

https://twiki.cern.ch/twiki/bin/view/Main/PhatSrimanobhasTeaching

Quiz-0:

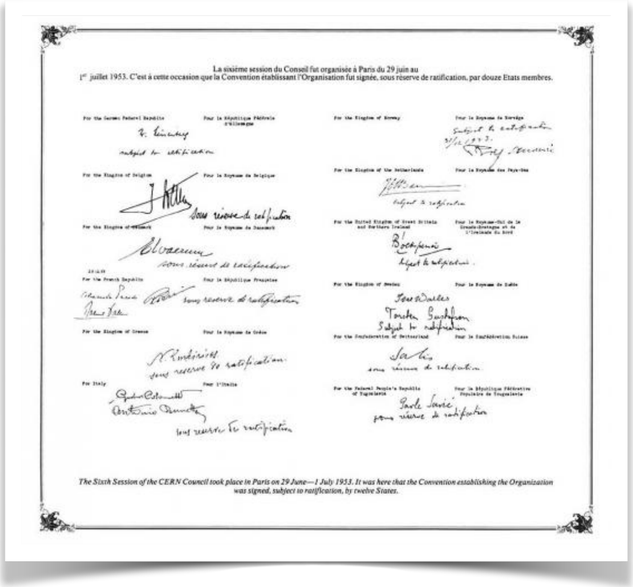
What is the detector shown in the background of this slide?

[ ] ALICE
[ ] ATLAS
[ ] CDF
[ ] CMS
[ ] D0
[ ] LHCb

[Link]

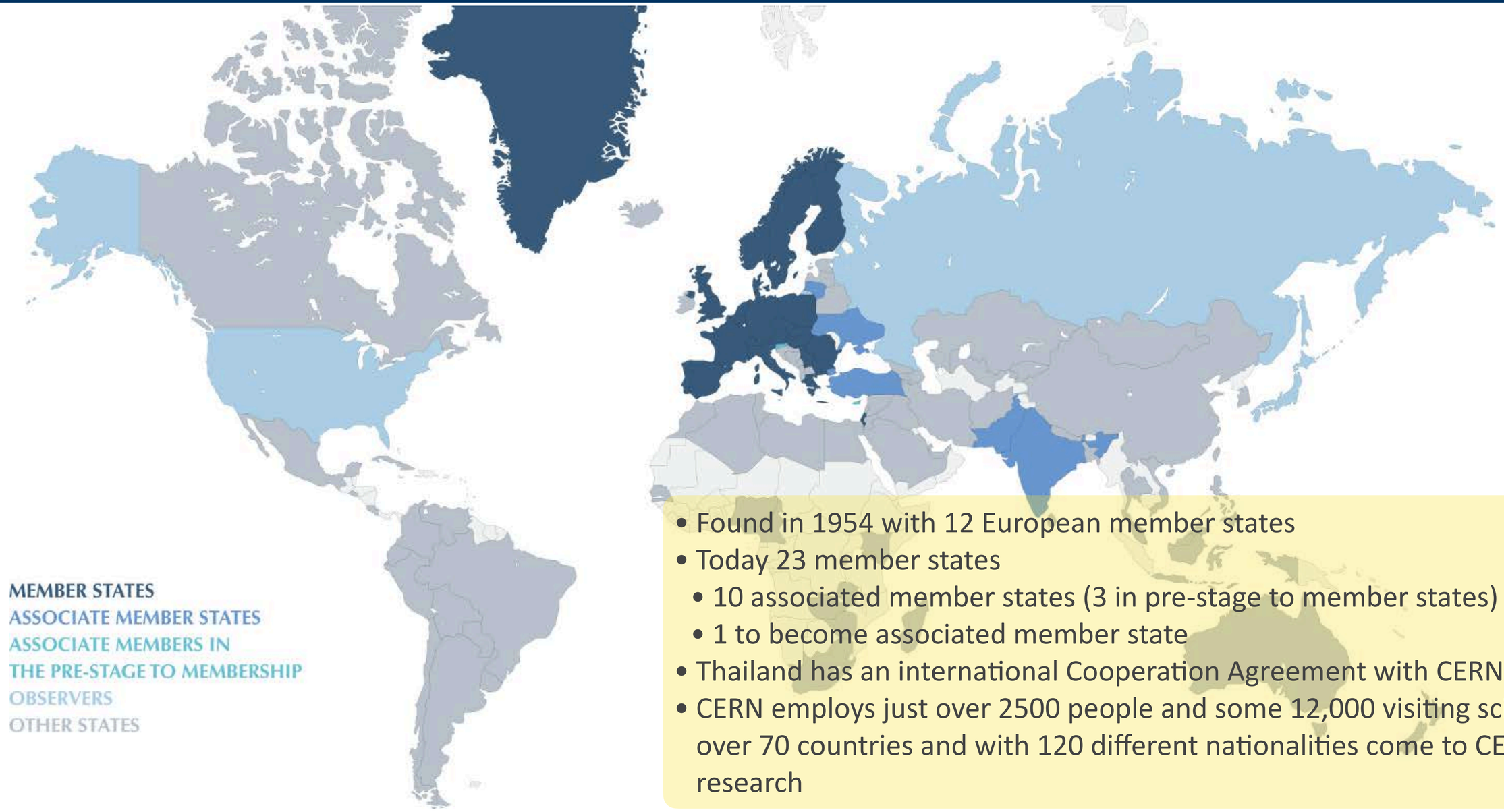
CERN: Conseil Européen pour la Recherche Nucléaire

- At the end of the Second World War, European science was no longer world-class.
- A handful of visionary scientists, including *Raoul Dautry, Pierre Auger, Lew Kowarski, Edoardo Amaldi, Niels Bohr*, imagined creating a **European atomic physics laboratory**.
- *Louis de Broglie* put forward the first official proposal for the creation of a European laboratory at the European Cultural Conference, Lausanne on 9 Dec 1949.
- At the fifth UNESCO General Conference, held in Florence in June 1950, where American physicist and Nobel laureate *Isidor Rabi* tabled a resolution authorizing UNESCO to "assist and encourage the formation of regional research laboratories in order to increase international scientific collaboration…"
- Geneva was selected as the site for the CERN.

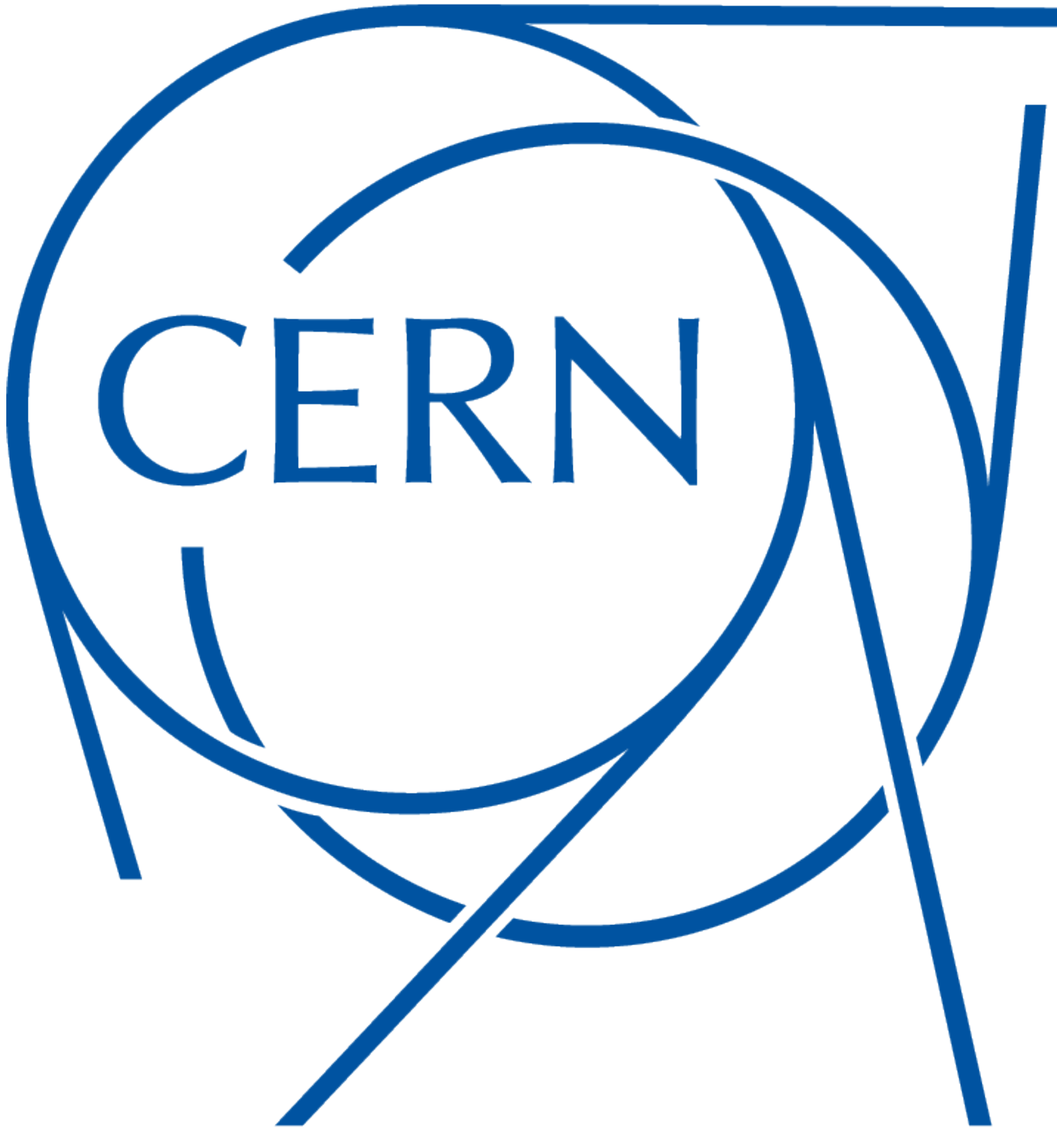

La sixième session du Conseil fut organisée à Paris du 29 juin au 1er juillet 1953. C'est à cette occasion que la Convention établissant l'Organisation fut signée, sous réserve de ratification, par douze Etats membres.

The Sixth Session of the CERN Council took place in Paris on 29 June—1 July 1953. It was here that the Convention establishing the Organization was signed, subject to ratification, by twelve States.

CERN: Conseil Européen pour la Recherche Nucléaire



- Found in 1954 with 12 European member states
- Today 23 member states
  - 10 associated member states (3 in pre-stage to member states)
  - 1 to become associated member state
- Thailand has an international Cooperation Agreement with CERN since 2018
- CERN employs just over 2500 people and some 12,000 visiting scientists from over 70 countries and with 120 different nationalities come to CERN for their research



CERN Missions

Research
Seeking and finding answers to questions about the Universe

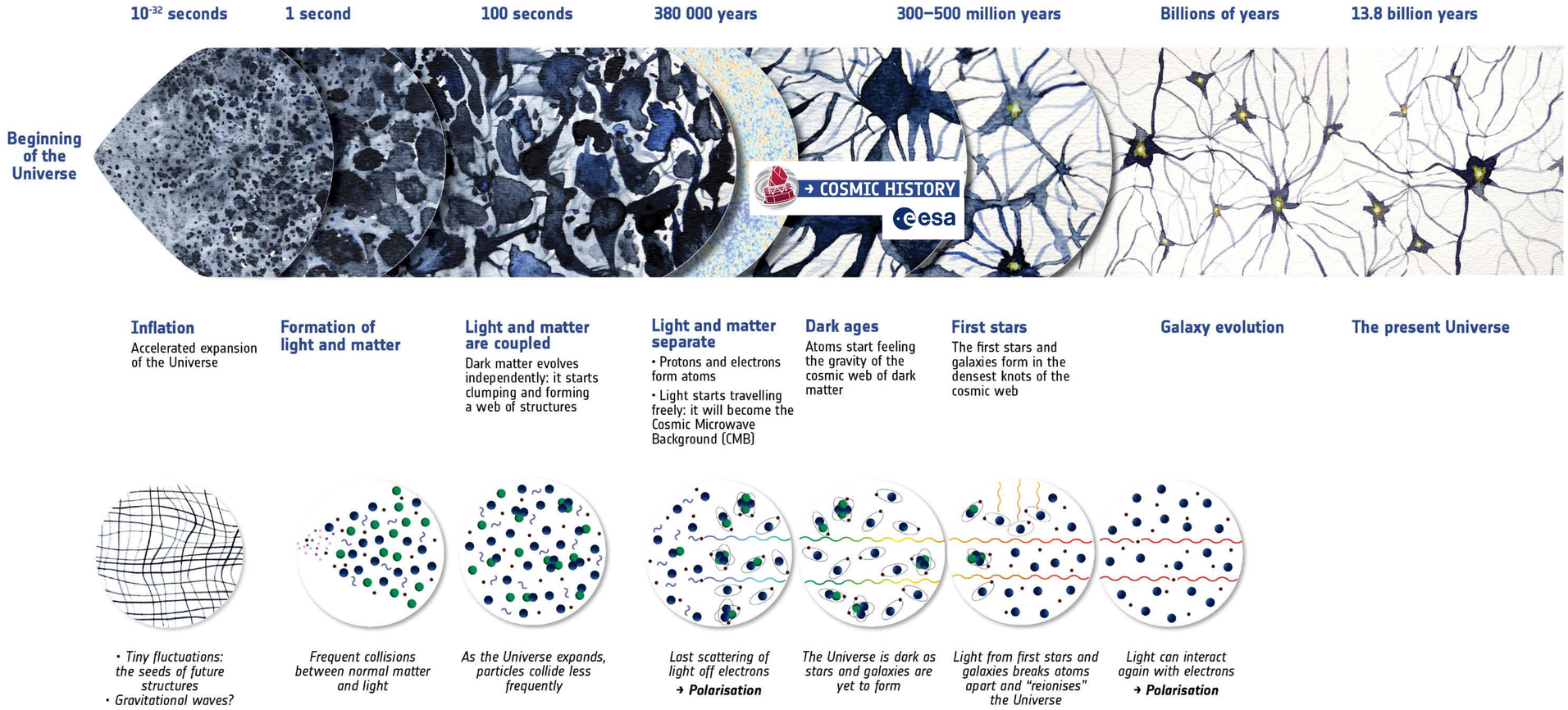
Technology
Advancing the frontiers of technology

Education
Training the scientists of tomorrow

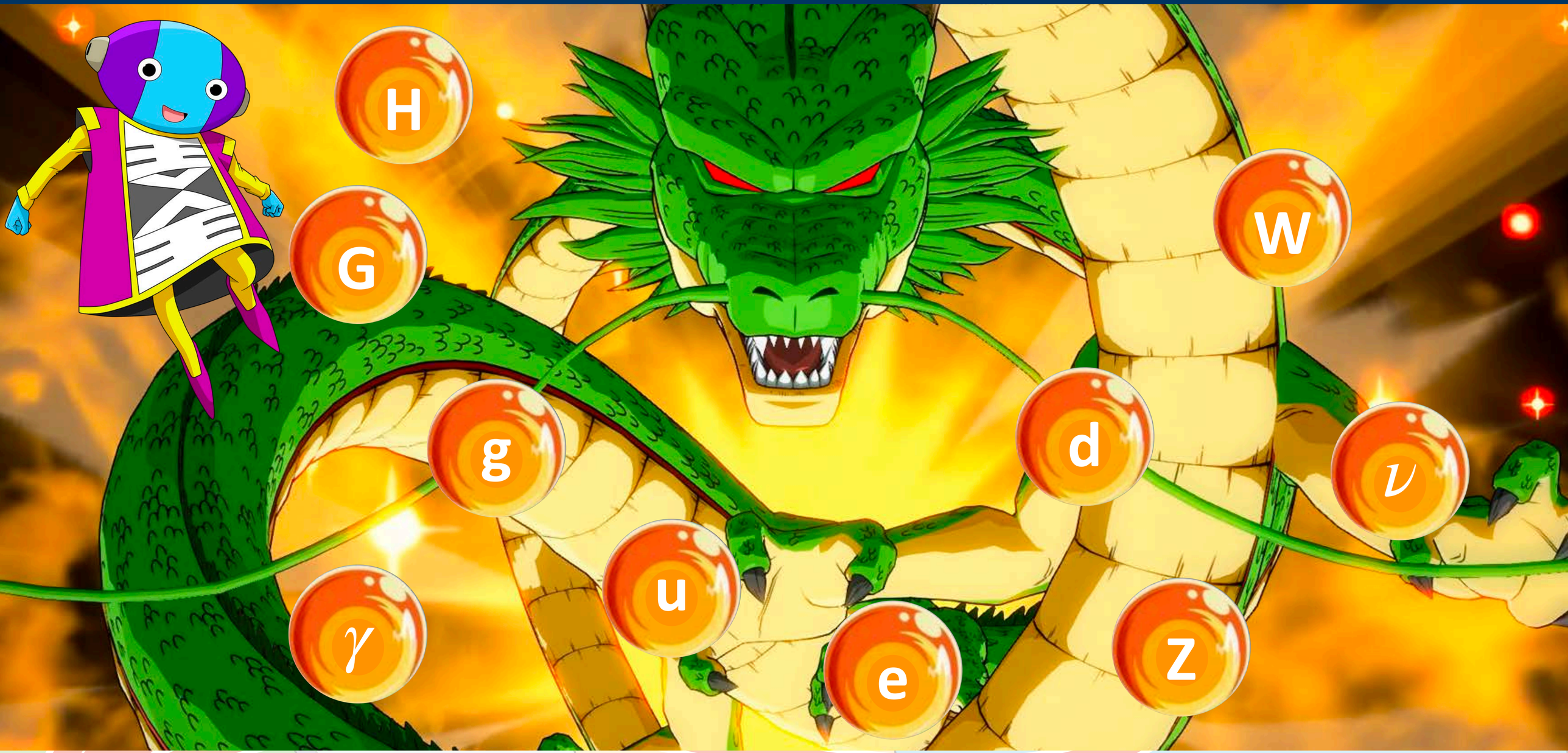
Collaborating
Bringing nations together through science

Where do we come from? What are we? Where are we going?

At CERN, the world's largest and most complex scientific instruments are used to study the basic constituents of matter — the fundamental particles. By studying what happens when these particles collide, physicists learn about the laws of nature.



Known universe



Quiz-1:

The particles carrying the strong force are the

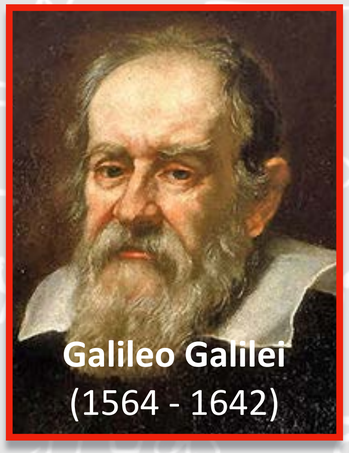
[ ] gluons
[ ] Ju-on
[ ] photons
[ ] gravitons
[ ] W and Z bosons
[ ] axions

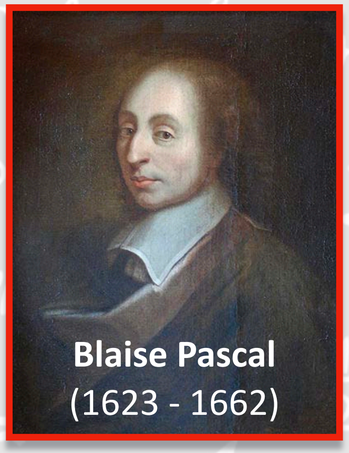
[Link]

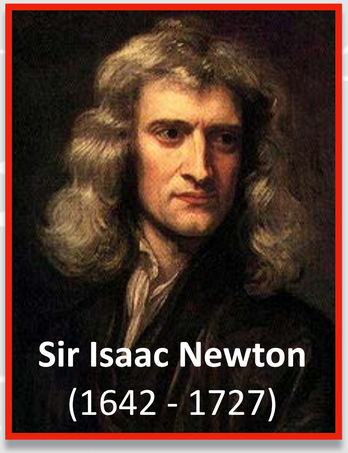
Physics from beginning ...

Classical physics team

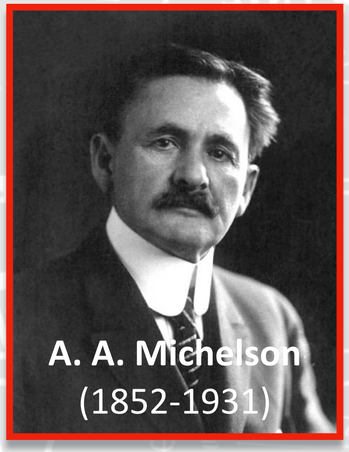

Johannes Kepler
(1571 - 1630)

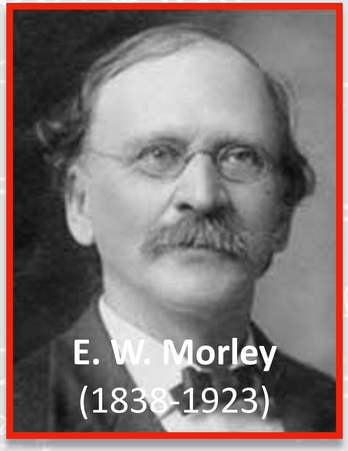

Galileo Galilei
(1564 - 1642)

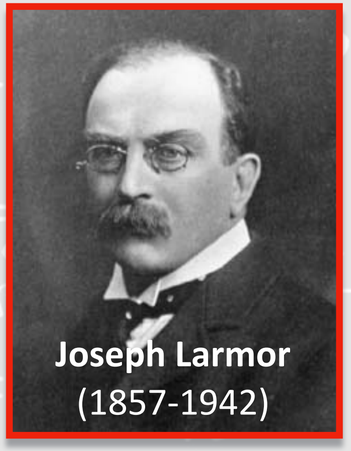

Blaise Pascal
(1623 - 1662)


Sir Isaac Newton
(1642 - 1727)

Aether team

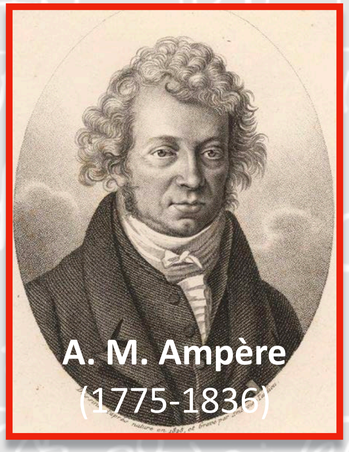

A. A. Michelson
(1852-1931)

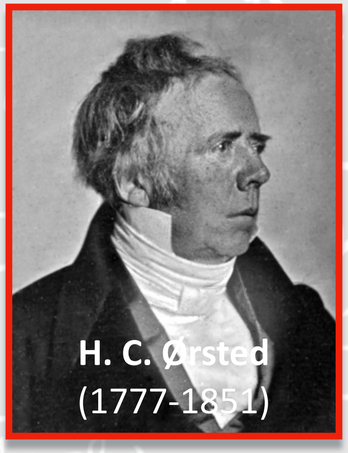

E. W. Morley
(1838-1923)

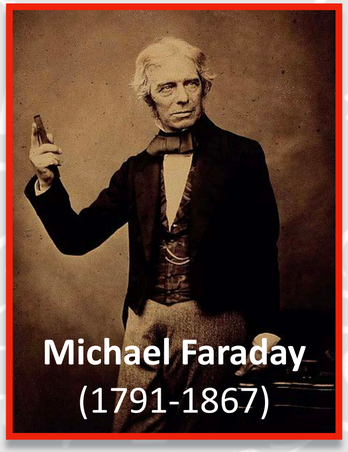

Joseph Larmor
(1857-1942)

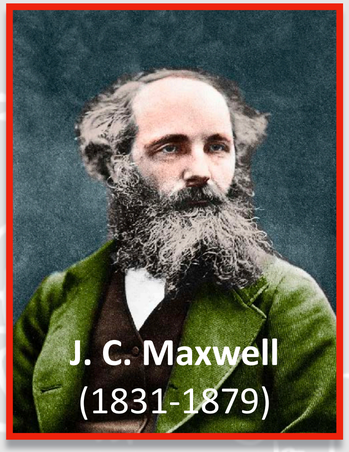
Electromagnetism team


J.C.F. Gauss
(1777 - 1855)


A. M. Ampère
(1775-1836)

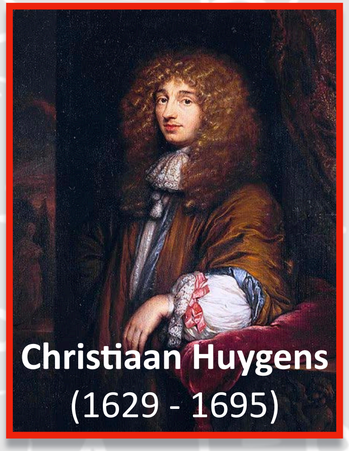

H. C. Ørsted
(1777-1851)


Michael Faraday
(1791-1867)


J. C. Maxwell
(1831-1879)

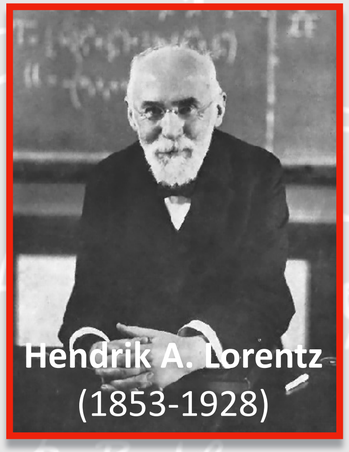
c Team

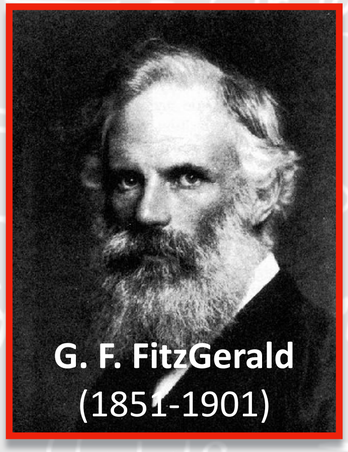

Ole Rømer
(1644 - 1710)

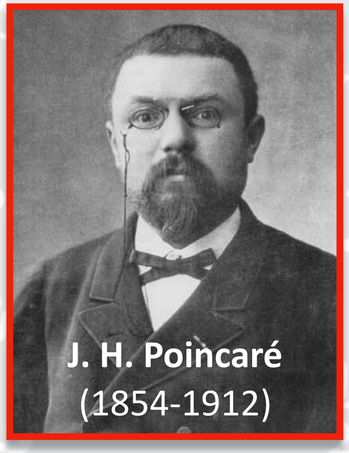

Christiaan Huygens
(1629 - 1695)

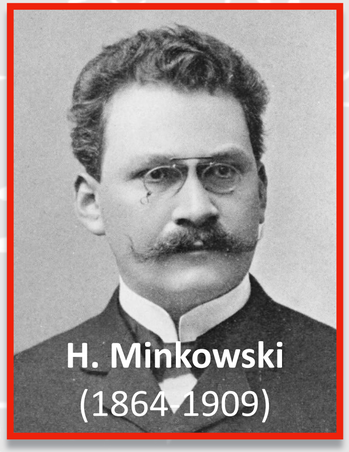
Physics from beginning ...

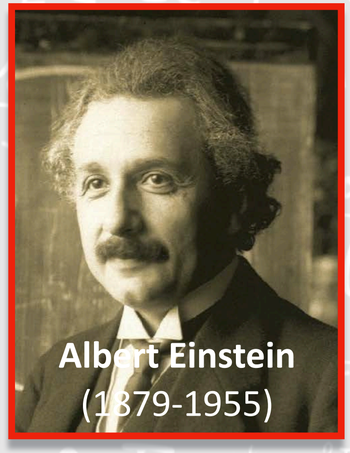
Modern relativity team


Hendrik A. Lorentz
(1853-1928)

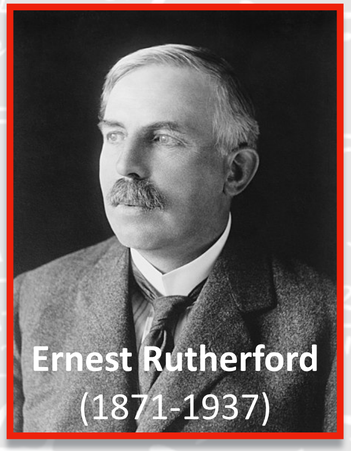

G. F. FitzGerald
(1851-1901)

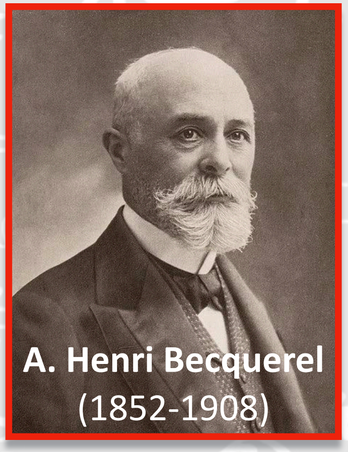

J. H. Poincaré
(1854-1912)


H. Minkowski
(1864-1909)

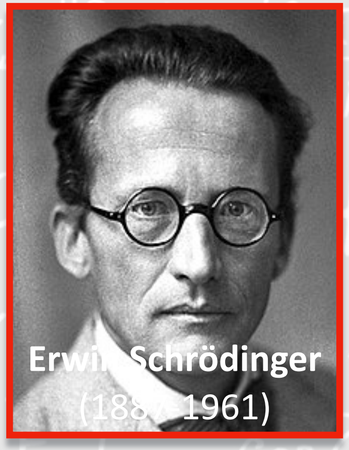

Albert Einstein
(1879-1955)

Activity team

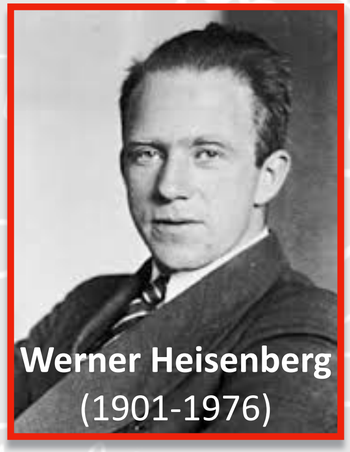

Ernest Rutherford
(1871-1937)


A. Henri Becquerel
(1852-1908)

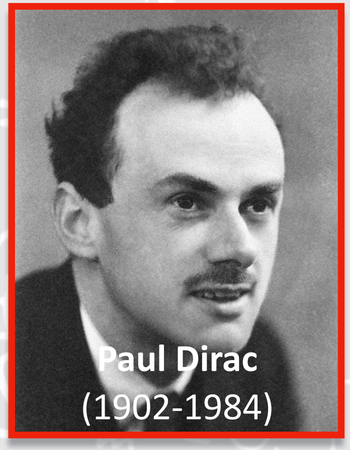
Quantum team

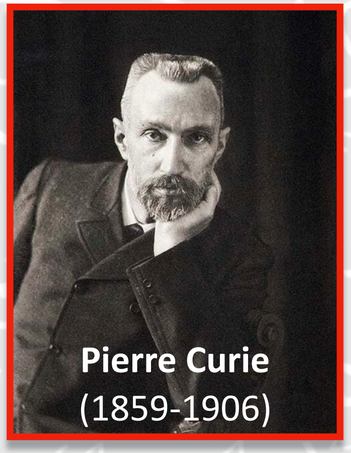

Erwin Schrödinger
(1887-1961)

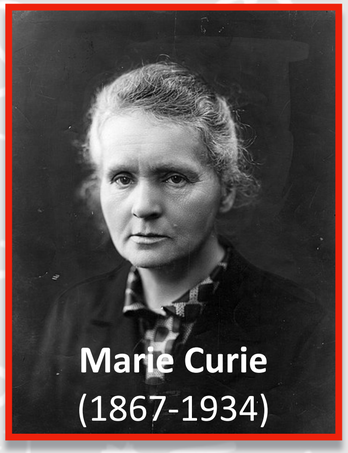

Max Born
(1882-1970)


Werner Heisenberg
(1901-1976)

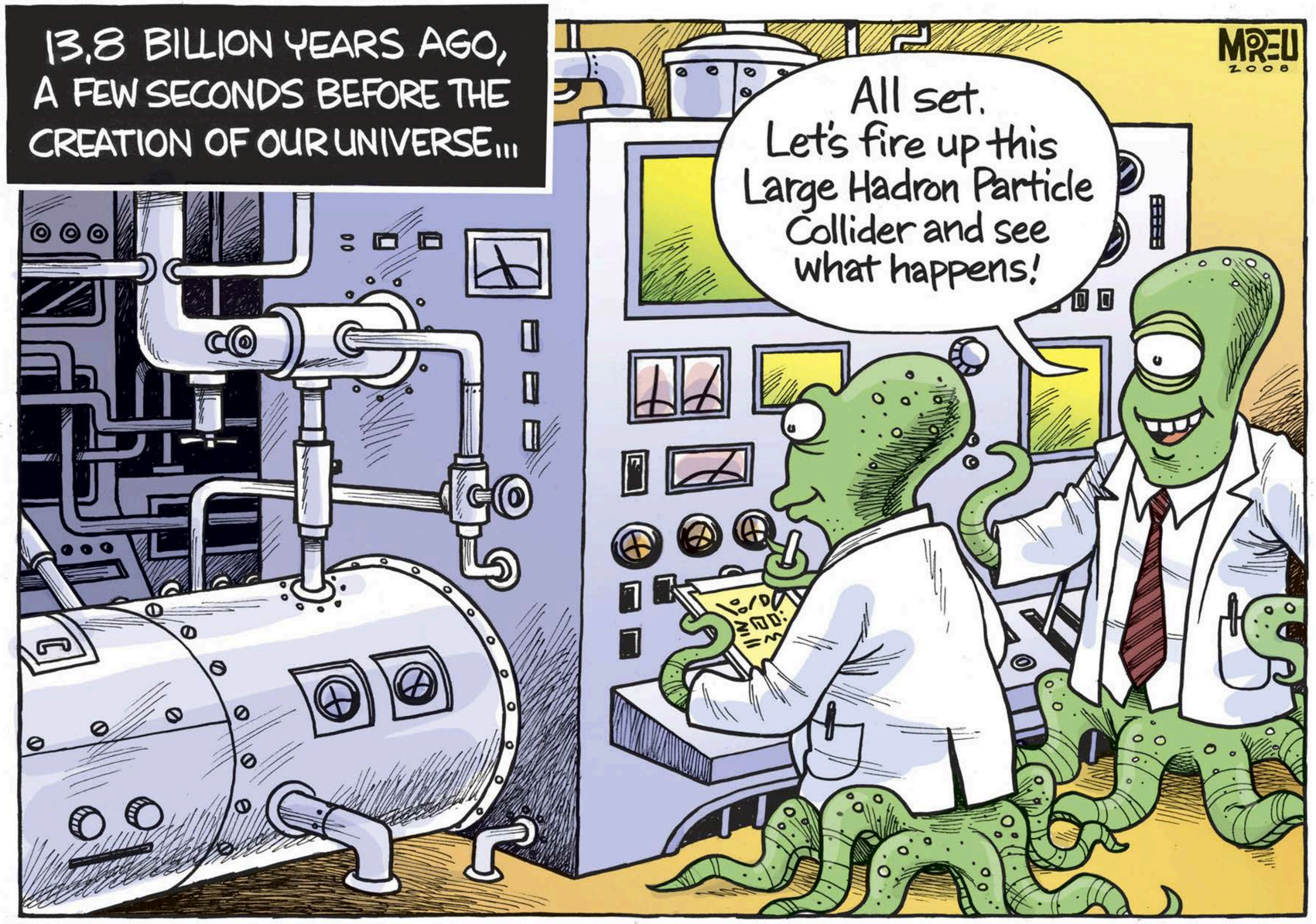

Wolfgang Pauli
(1900-1958)


Paul Dirac
(1902-1984)


Pierre Curie
(1859-1906)


Marie Curie
(1867-1934)

What are we looking for?



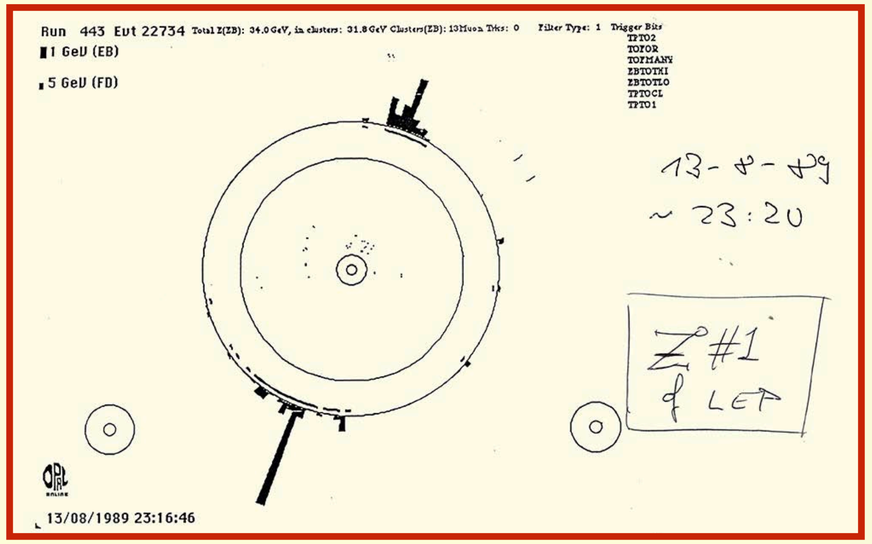
Basic research in the field of experimental and theoretical particle physics, finding out what the Universe is made of and how it works.

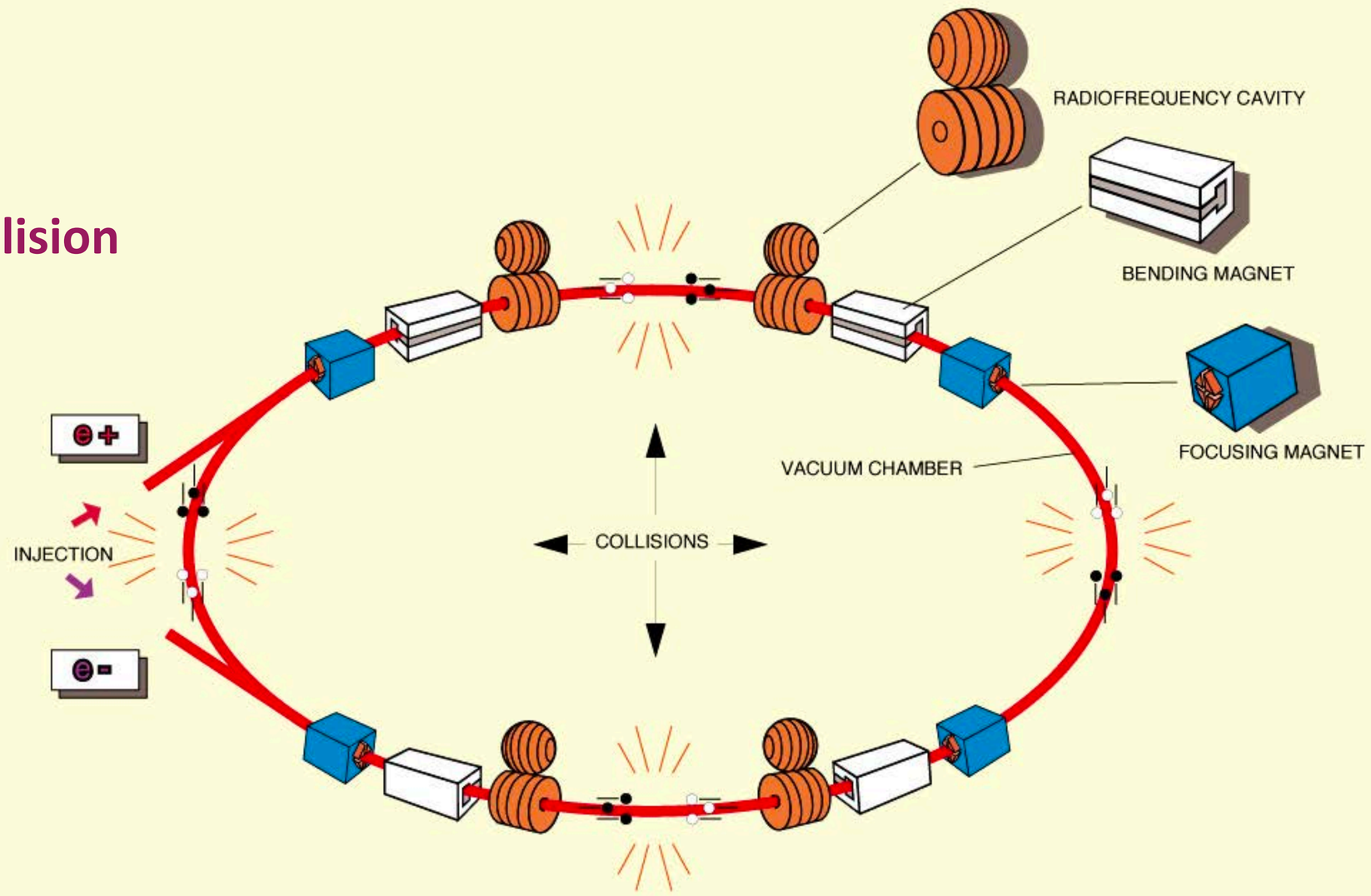
Accelerator is our tool to find answers

Electron mass = 0.511 MeV/c^2

Z-boson mass = 91.18 GeV/c^2

How does very small particle collision create heavy particle?

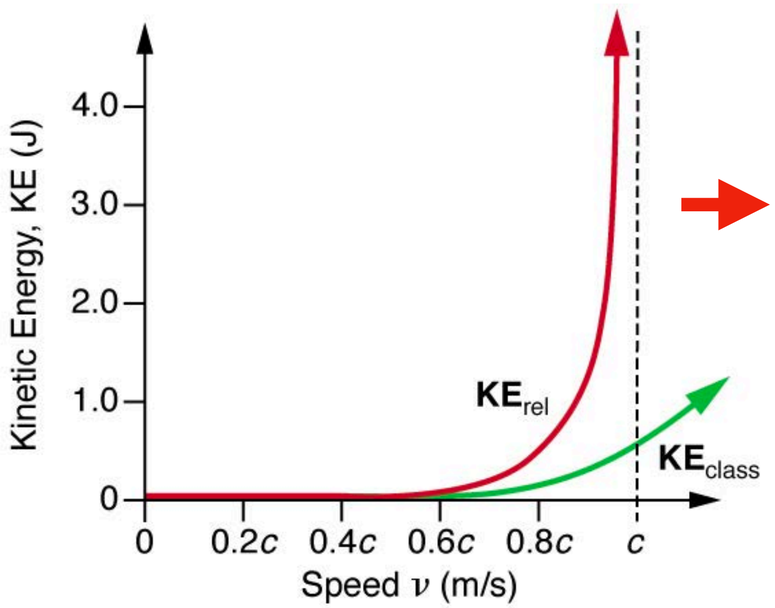




The OPAL logbook entry for the first Z boson seen at LEP, recorded late on 13 August 1989.
Credit: CERN [Link]

CERN AC - E509

Accelerator is our tool to find answers



Increase K.E. of particle

- Particle speed has limit to the speed of light but kinetic energy and momentum have not

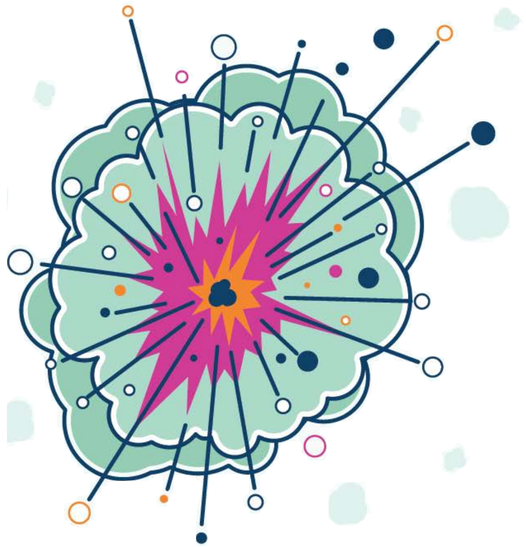
Use high momentum particle to

- create matter by collision

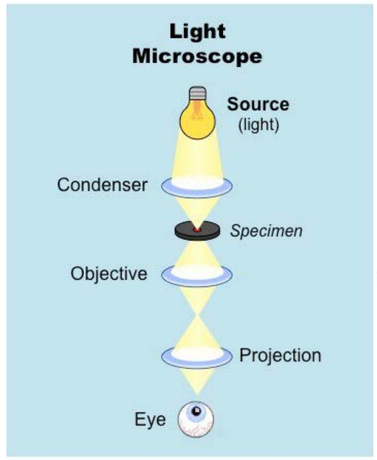
$$E^2 = p^2c^2 + m^2c^4$$

- probe insight in particle structure

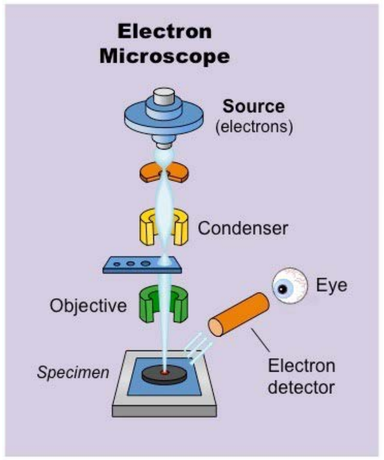
$$\lambda = h/p$$

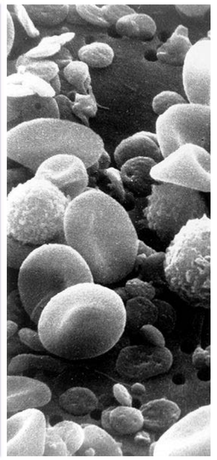


Visible light
400-500 nm

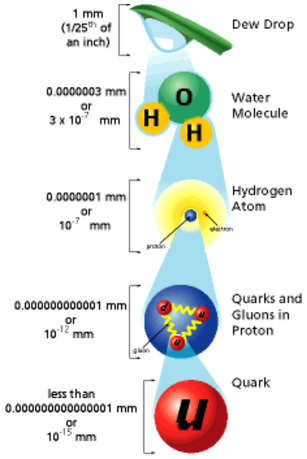


X-Ray
0.01-10 nm





Particle Accelerator
<0.01 nm



Quiz-2:

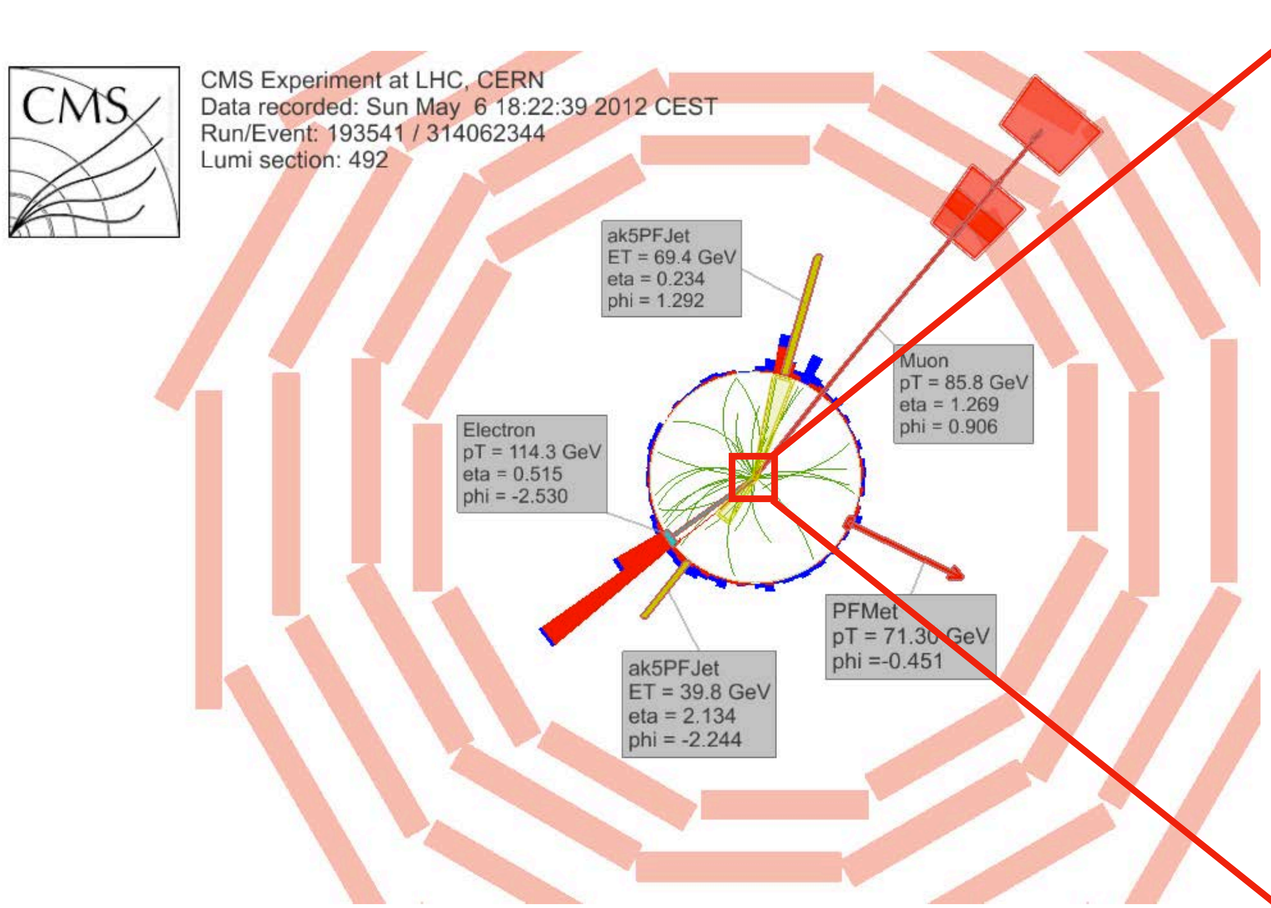
Will a massless particle ($m = 0$) traveling with speed = $0.99c$ have a momentum?

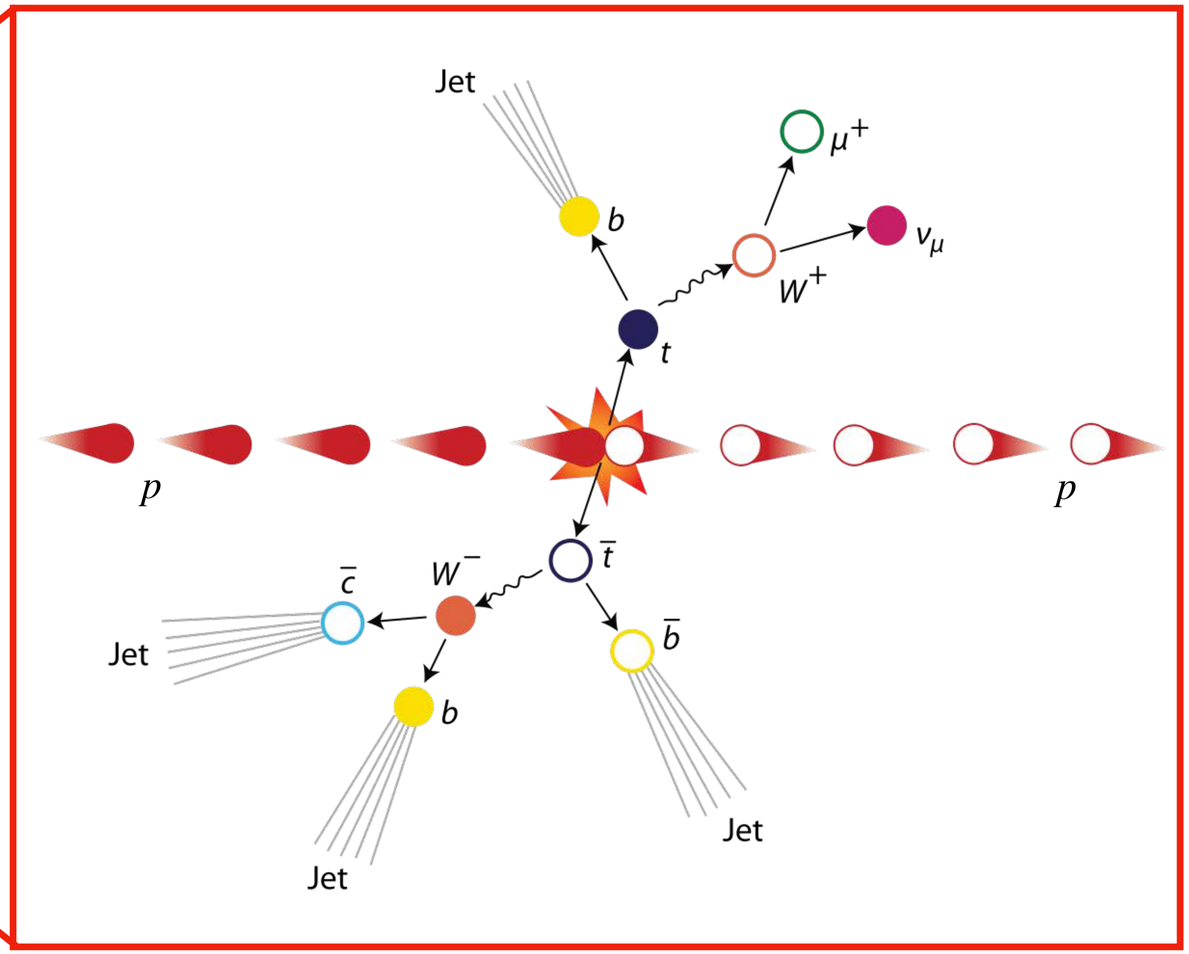
[ ] Yes

[ ] No

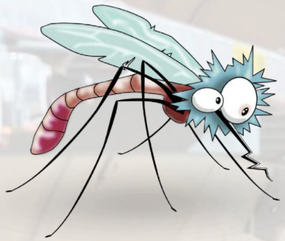
[Link]

From collision to detection





Quiz-3:



Calculate the kinetic energy of a mosquito of 60 mg flying at 20 cm/s.

[ ] 0.8×10^{-3} J

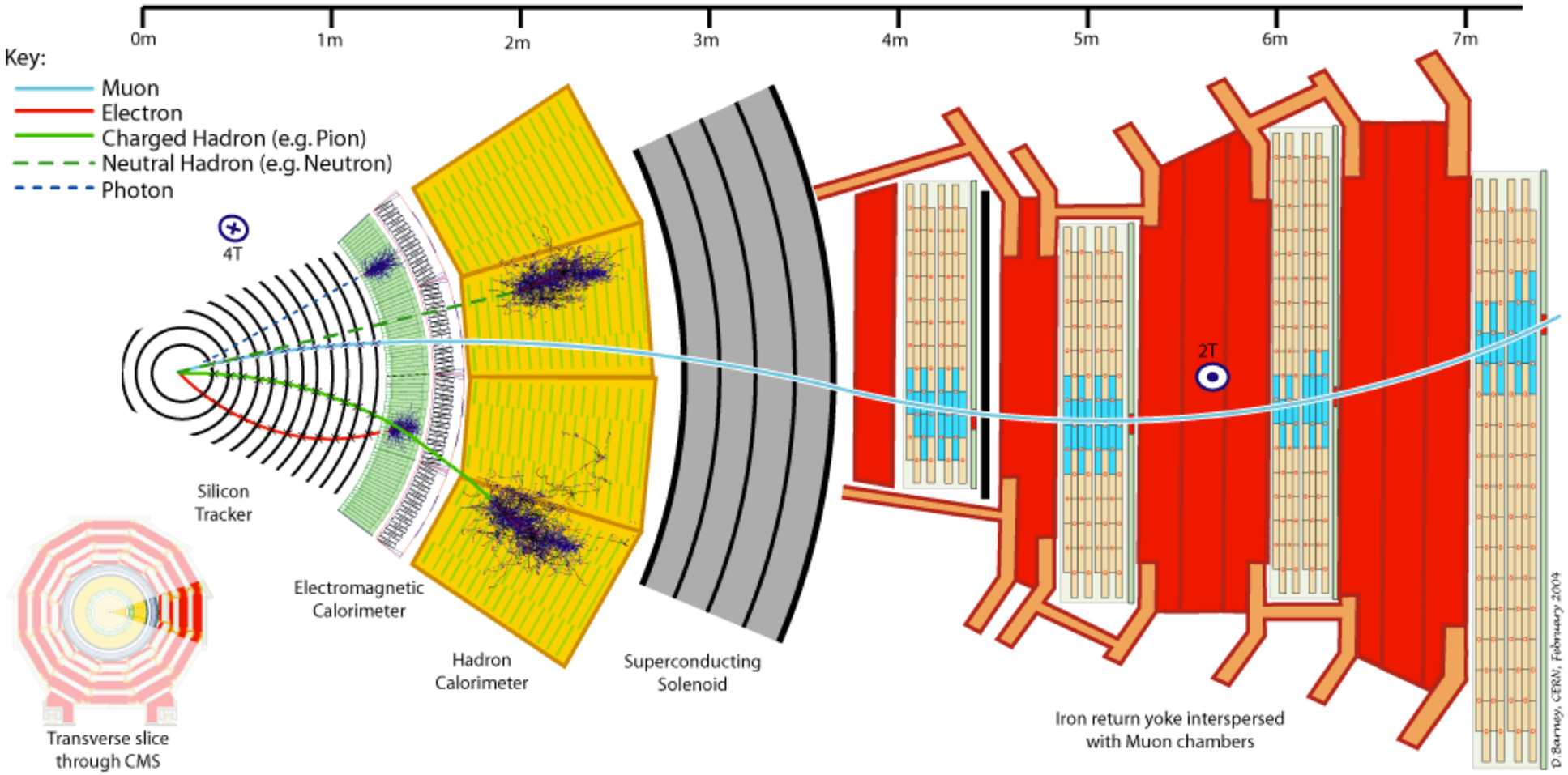
[ ] 0.8×10^{-6} J

[ ] 1.2×10^{-3} J

[ ] 1.2×10^{-6} J

[Link]

then particle detection, identification



Aim: to detect as many of the stable and long-lived particles produced in a particle collision.

Need to measure: charge, mass, energy, direction.

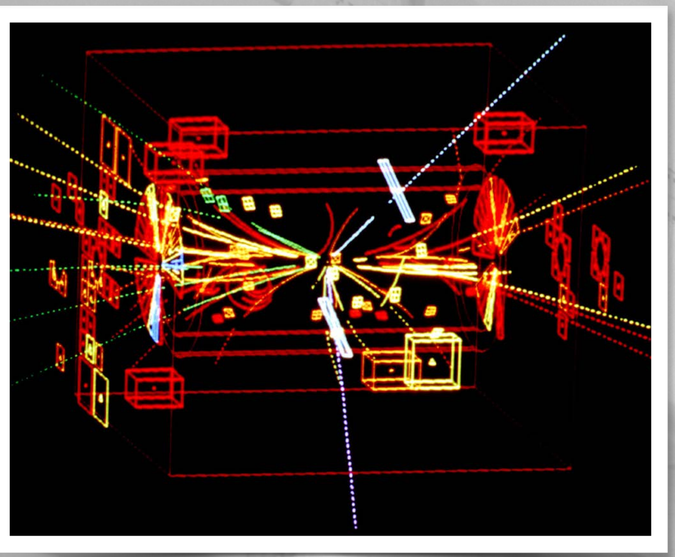
Quiz-4:

Our detector shows a signal only in the hadronic calorimeter (no signal in the tracker, electromagnetic calorimeter or muon chambers). Therefore, this signal is most likely

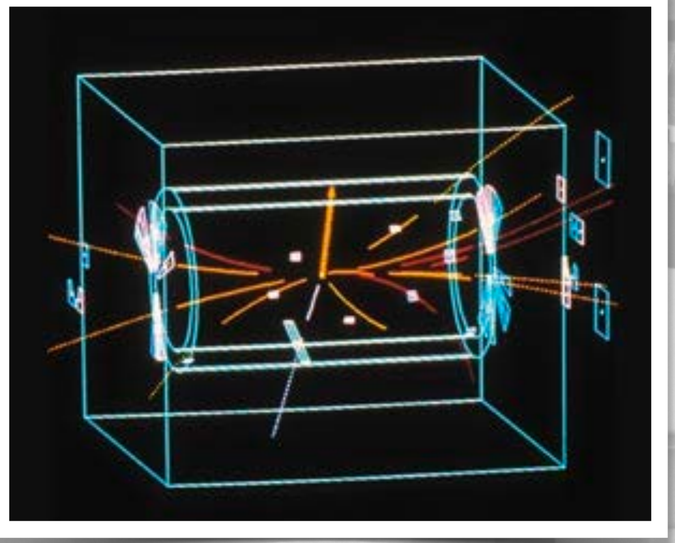
[ ] Electron
[ ] Photon
[ ] Neutron
[ ] Muon

[Link]

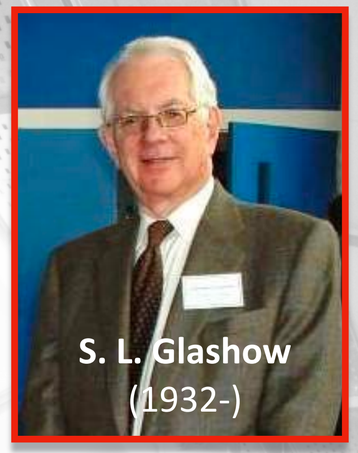
17 June 1976, SPS ... plan changed to $p\bar{p}$ collider ... discovery

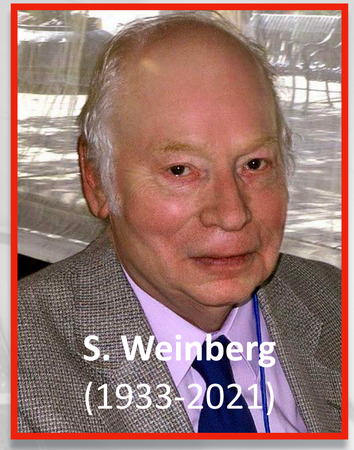


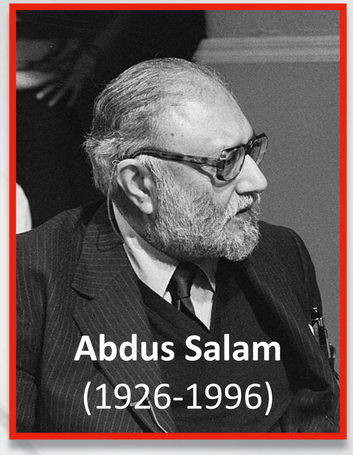
30 April 1983, Image taken by the UA1 which later confirmed to be Z candidate decays to electron-positron pair



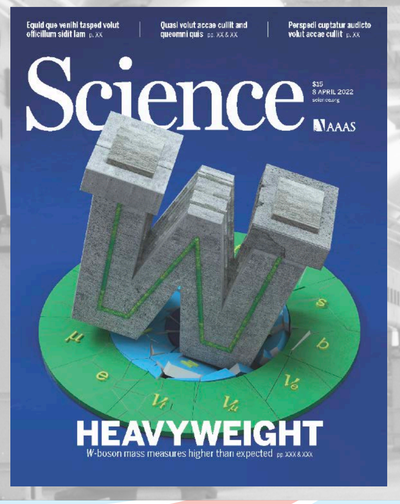
UA1 detected the W candidate event with electron and high missing energy

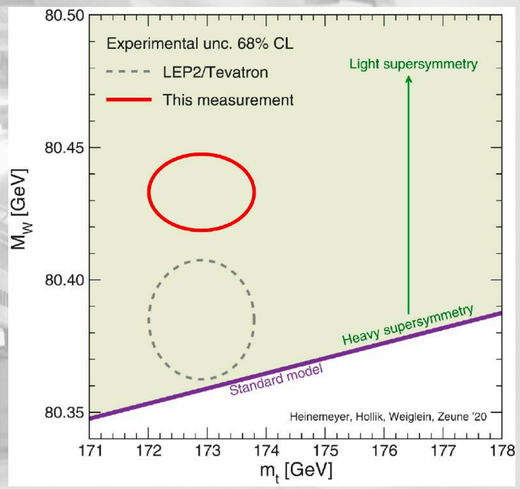






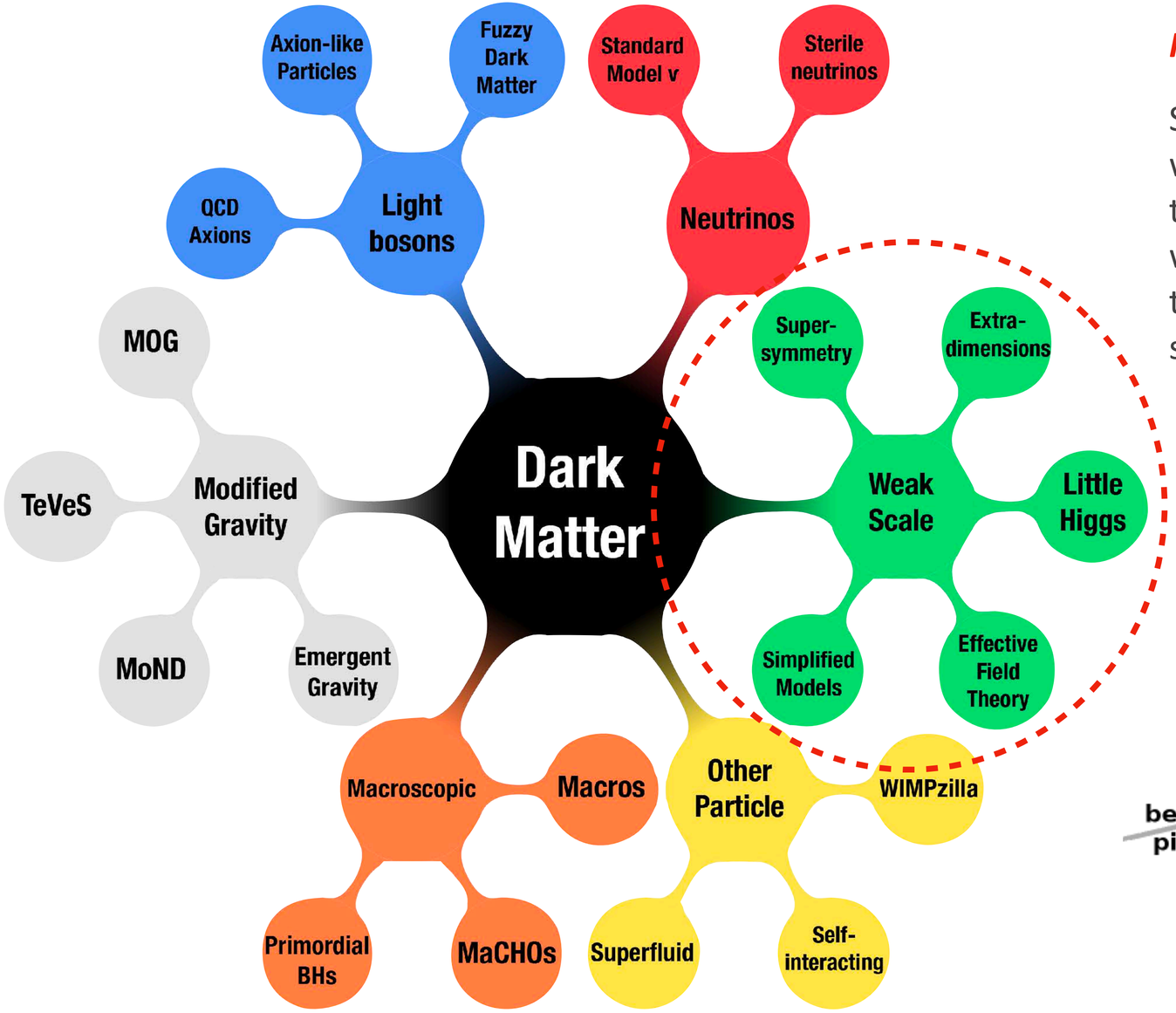
Around 1968, theorists came up with the electroweak theory, which unified electromagnetism and weak interactions. The theory postulated the existence of W and Z bosons. CERN decided to modify SPS to SppS.





W mass is still in discussion.

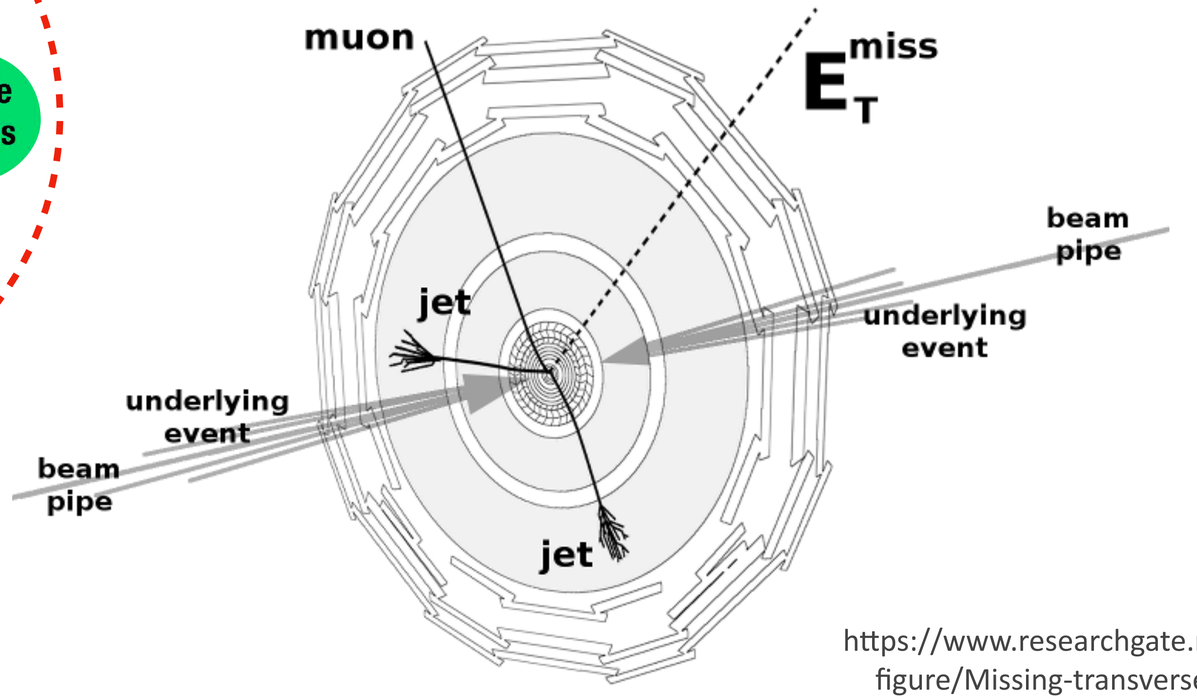
Search for dark matter



https://home.cern/news/series/lhc-physics-ten/breaking-new-ground-search-dark-matter

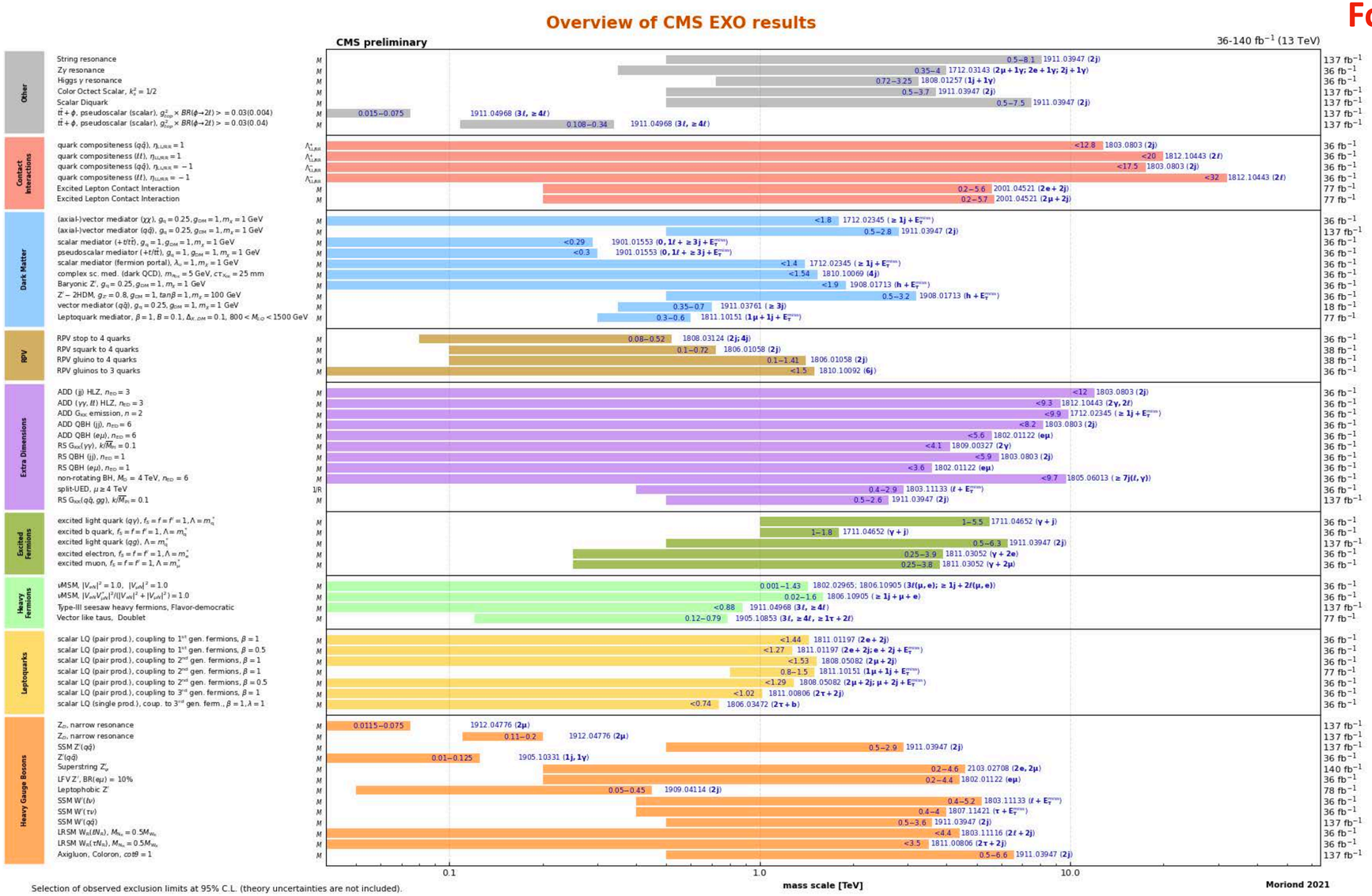
How do we search for dark matter at the collider?

Since the dark matter does not interact to the material in the way we know (e.g. without electromagnetic interaction), so we assume that if it is produced at the LHC, it will leave from our detector without making a signal (energy loss) to the sensitive regions of the detector. Missing (transverse) momentum is the basis of search at the LHC.



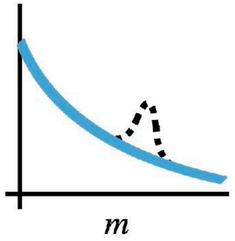
https://www.researchgate.net/figure/Missing-transverse-momentum_fig2_331397740

Search for new things, you need to understand well *known* things



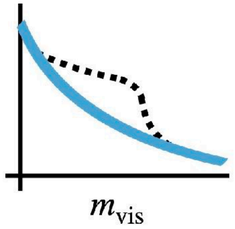
Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included).

For exotic searches, we normally look for



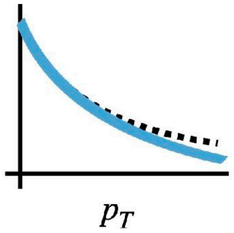
Bump(s), Resonant

Di-Higgs interpretation, Z', ...



Semi-resonant, end-point

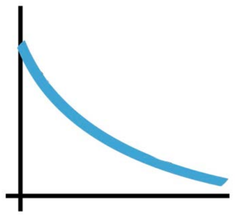
Heavy charged bosons, ...



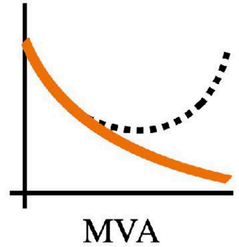
Non-resonant, Tail

Dark matter, Extra dimensions,...

We need

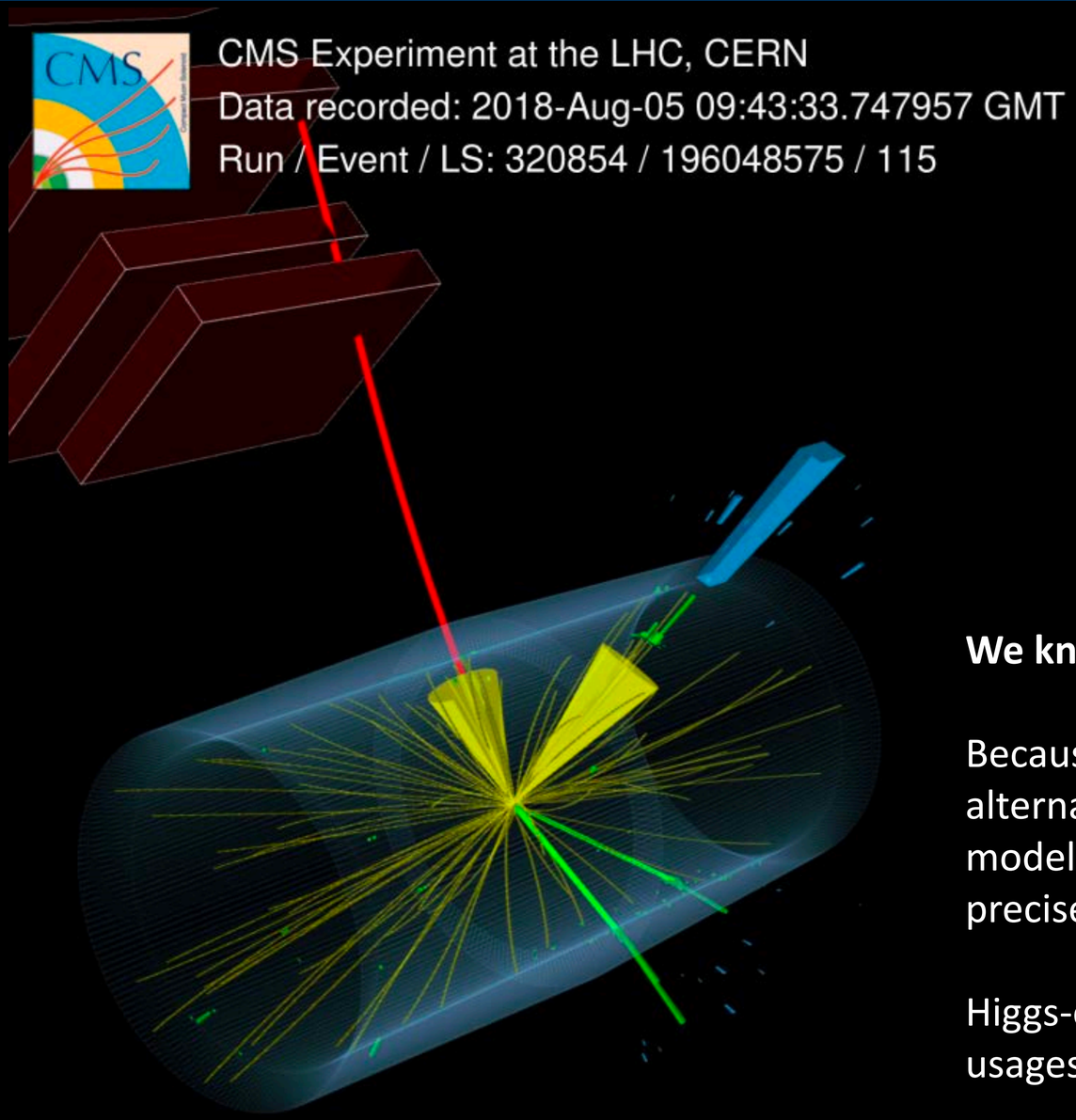


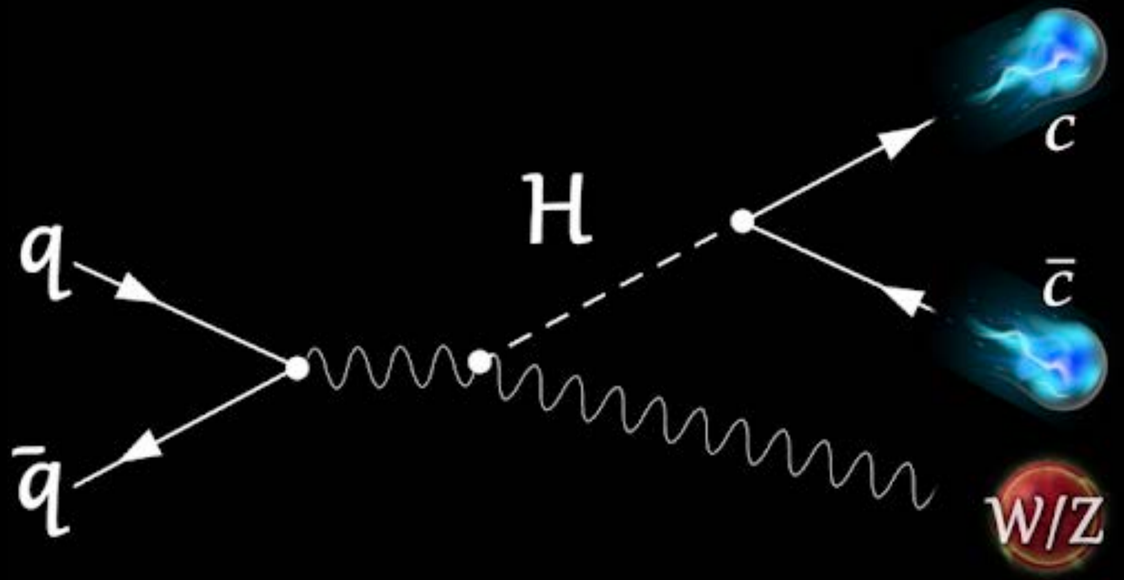
Well understand bkg



Powerful tools for analyze structure, discriminator

Higgs ... from *search* to *precision measurement*





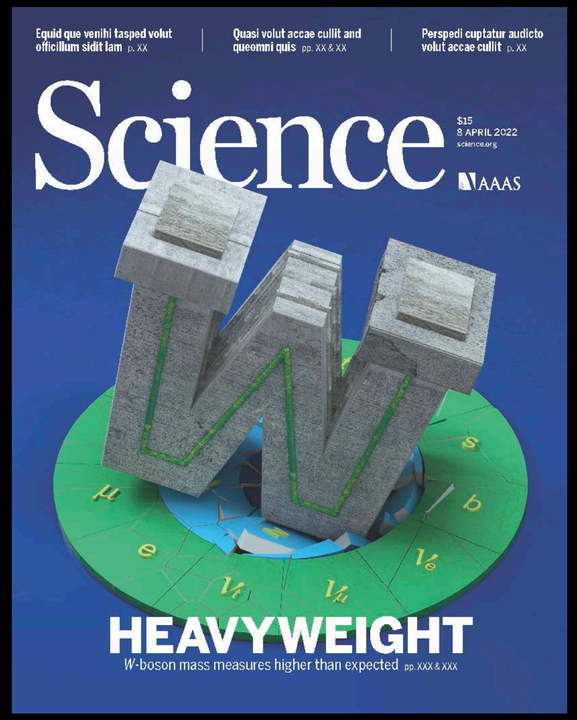
We know that Higgs is there, why do we need precise measurements?

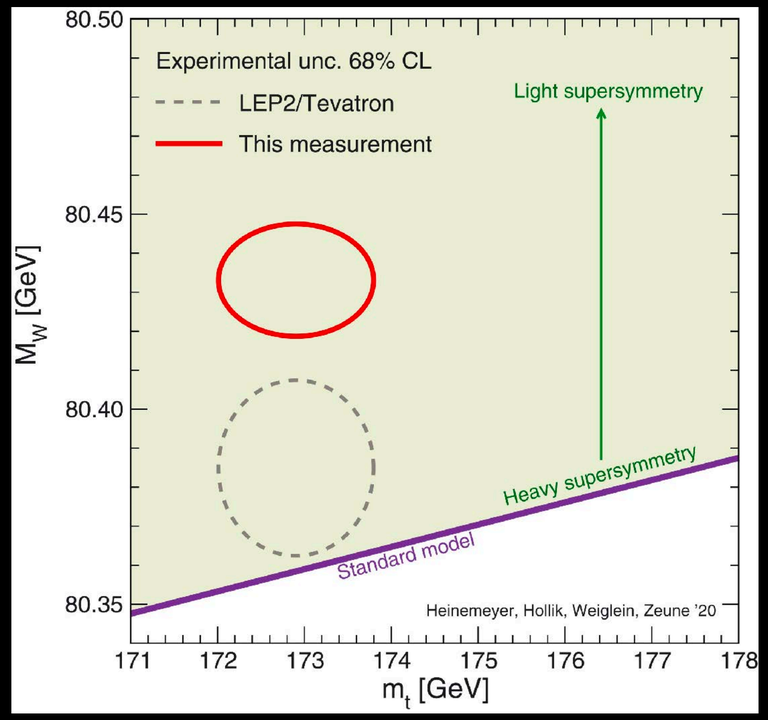
Because the lack of direct observations of new particles at the LHC!, we need an alternative approach which we consider that BSM physics interfere with standard model particles and subsequently leave an imprint on their properties. With precise measurement, we may see hint(s) of new physics.

Higgs-charm coupling challenge: Improve identification algorithms by innovative usages of deep learning techniques. [See detail about the analysis here]

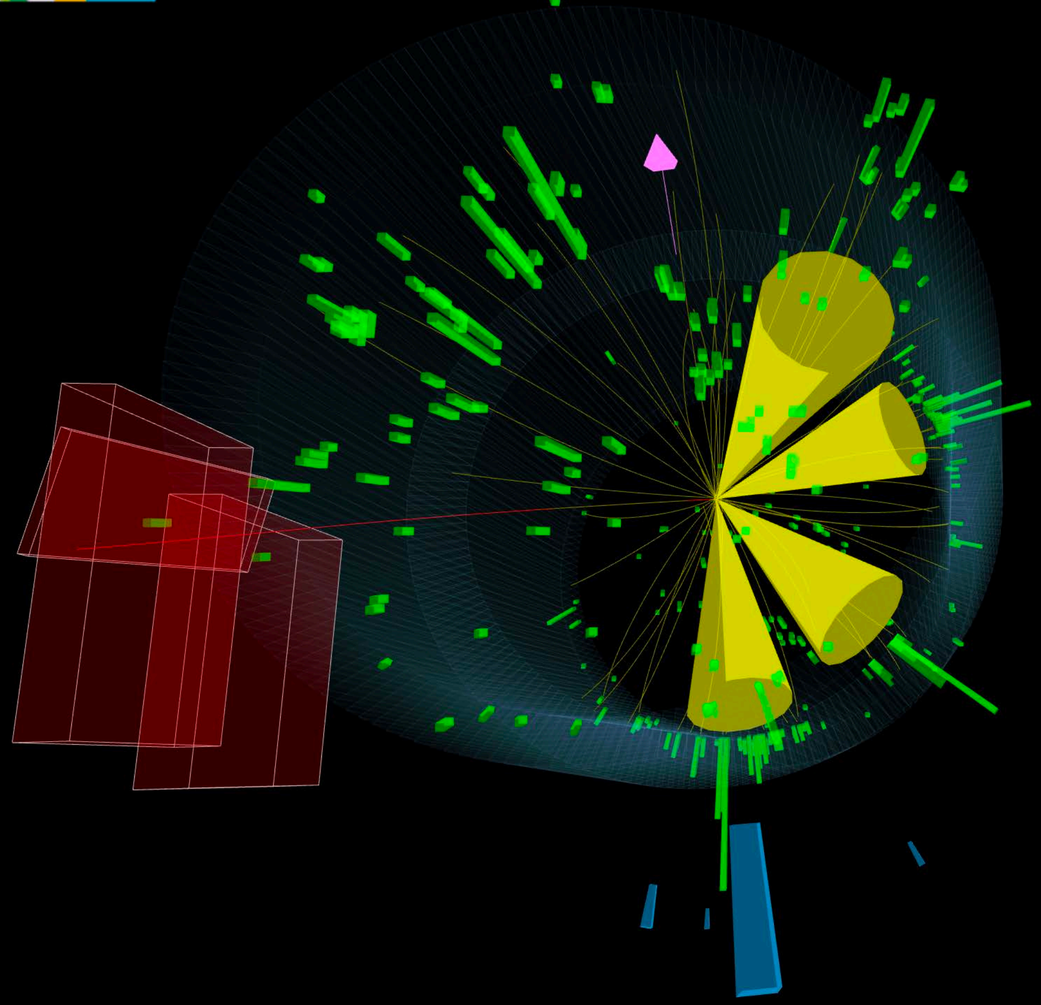
Top quark ... a tool for discoveries

- Discover in 1995 by CDF and D0 at Tevatron
- To predict the top quark mass, need to know accurately the W boson and Higgs boson masses
- Consequently, use top and Higgs masses to produce W boson mass ... reported on 7 April 2022 by CDF that W boson mass extracted from data taken at the Tevatron ***(2002-2011)***





CMS Experiment at the LHC, CERN
Data recorded: 2016-Aug-17 08:01:23.065024 GMT
Run / Event / LS: 278969 / 229126383 / 184



Quiz-5:

How do we see “quarks” in a detector?

[ ] Not at all

[ ] As two individual straight tracks in opposite directions

[ ] By their characteristic spiral trajectory

[ ] Via “jets” of hadrons they generate

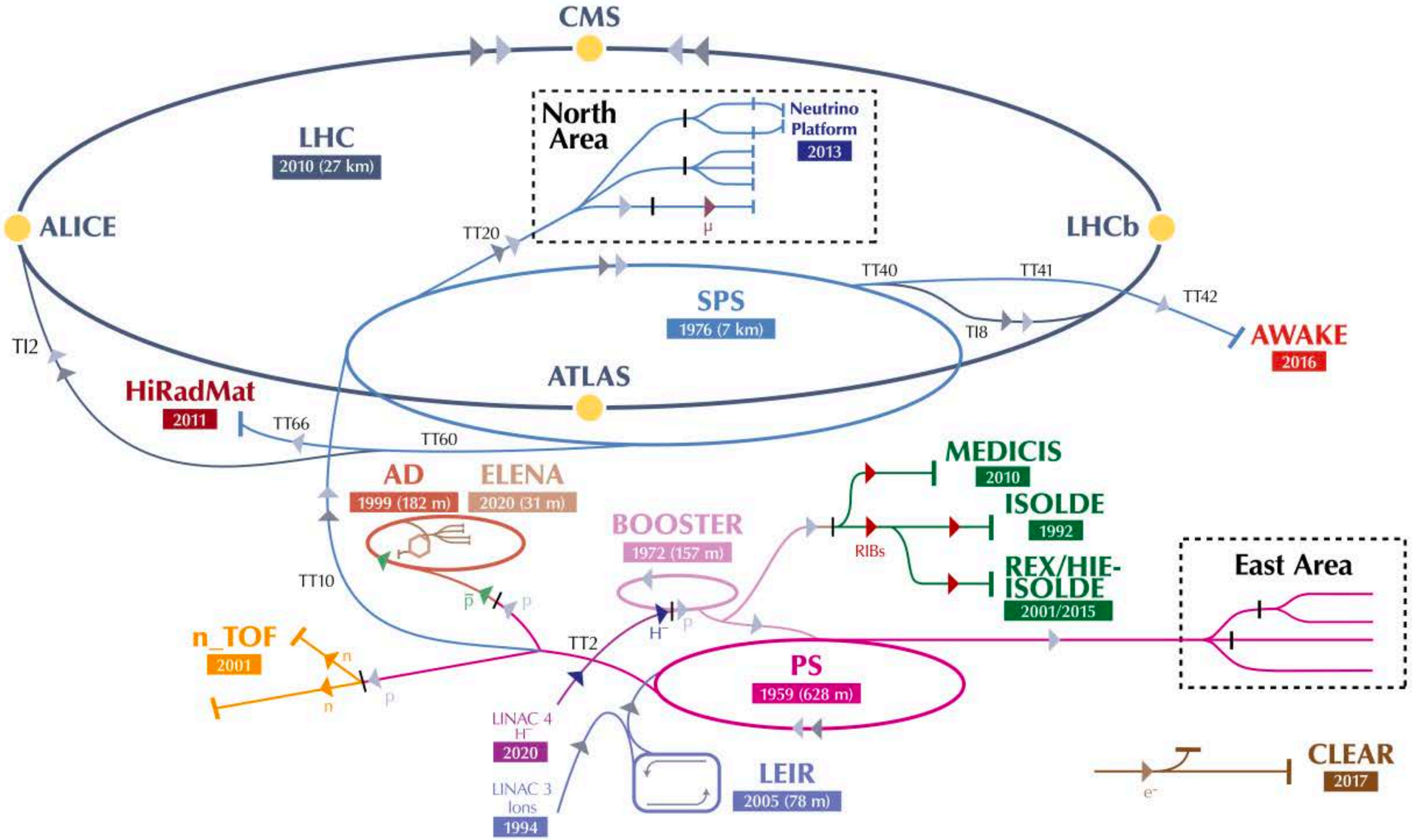
[Link]

Goals of today high energy particle physics

The SM is one of the most successful models in physics, but *is it enough?*

- **SM tells you how, but not why:**
  - Families – 3 families of quark/lepton
  - Number of parameters
- **Some phenomenon not explained by the SM:**
  - Gravity – not explained, why so weak?, SM incompatible with general relativity
  - Dark Matter & Dark Energy – accounts for 95% mass of universe but not included in SM
  - Matter/anti-matter asymmetry – SM does not explain the amount of matter/ anti-matter asymmetry at Big Bang

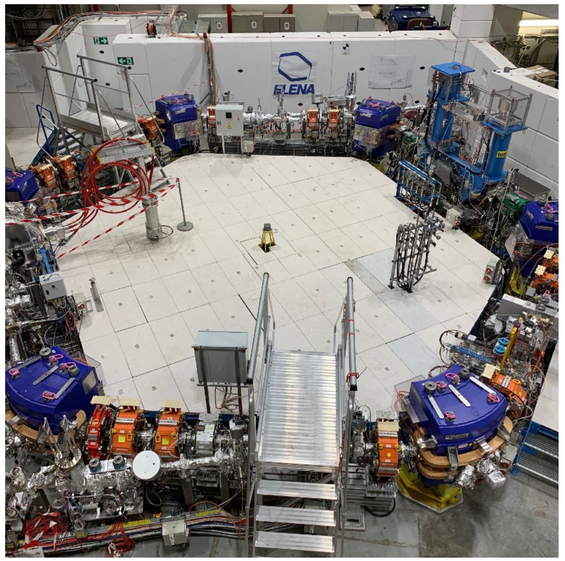
CERN accelerator complex: Not only LHC



Not only accelerate, but also decelerate

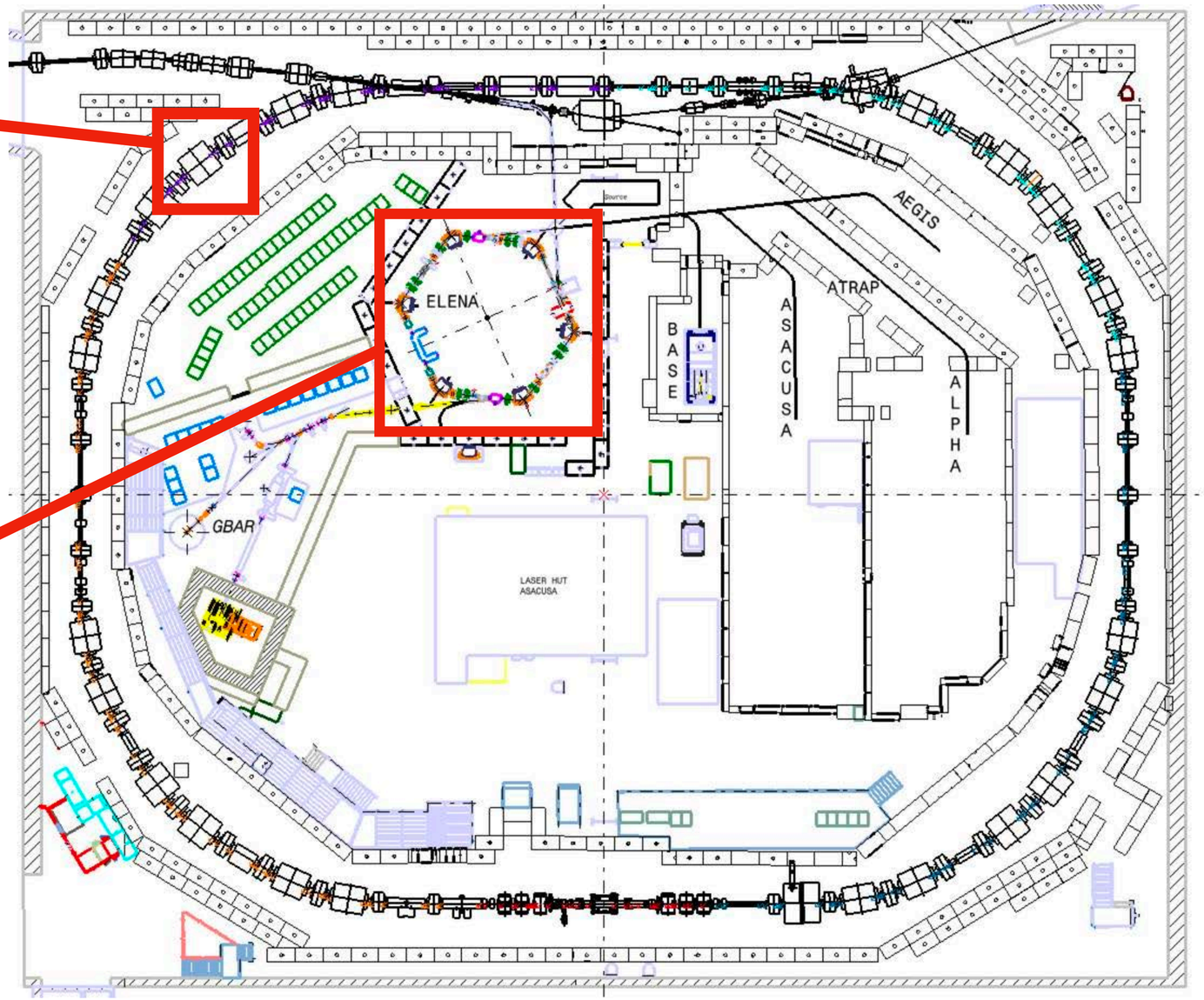
Antiproton Decelerator (AD)

A machine that produces low-energy antiprotons for studies of antimatter, and also creates anti-atoms.



Extra Low ENergy Antiproton (ELENA)

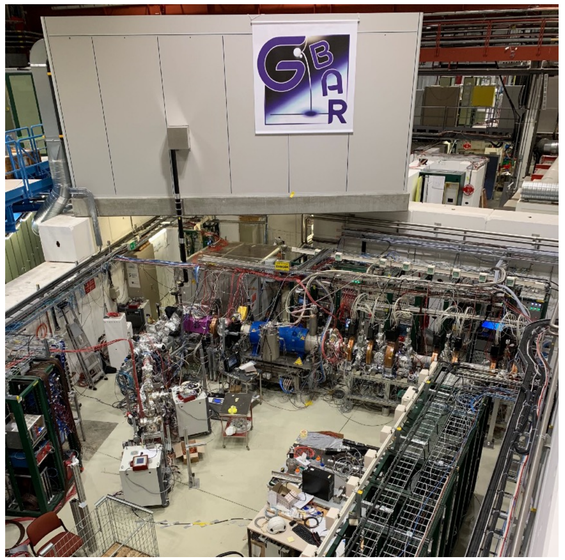
A machine to slow more the antiprotons from AD. This is to improve the efficiency of the experiments



To study anti-matter

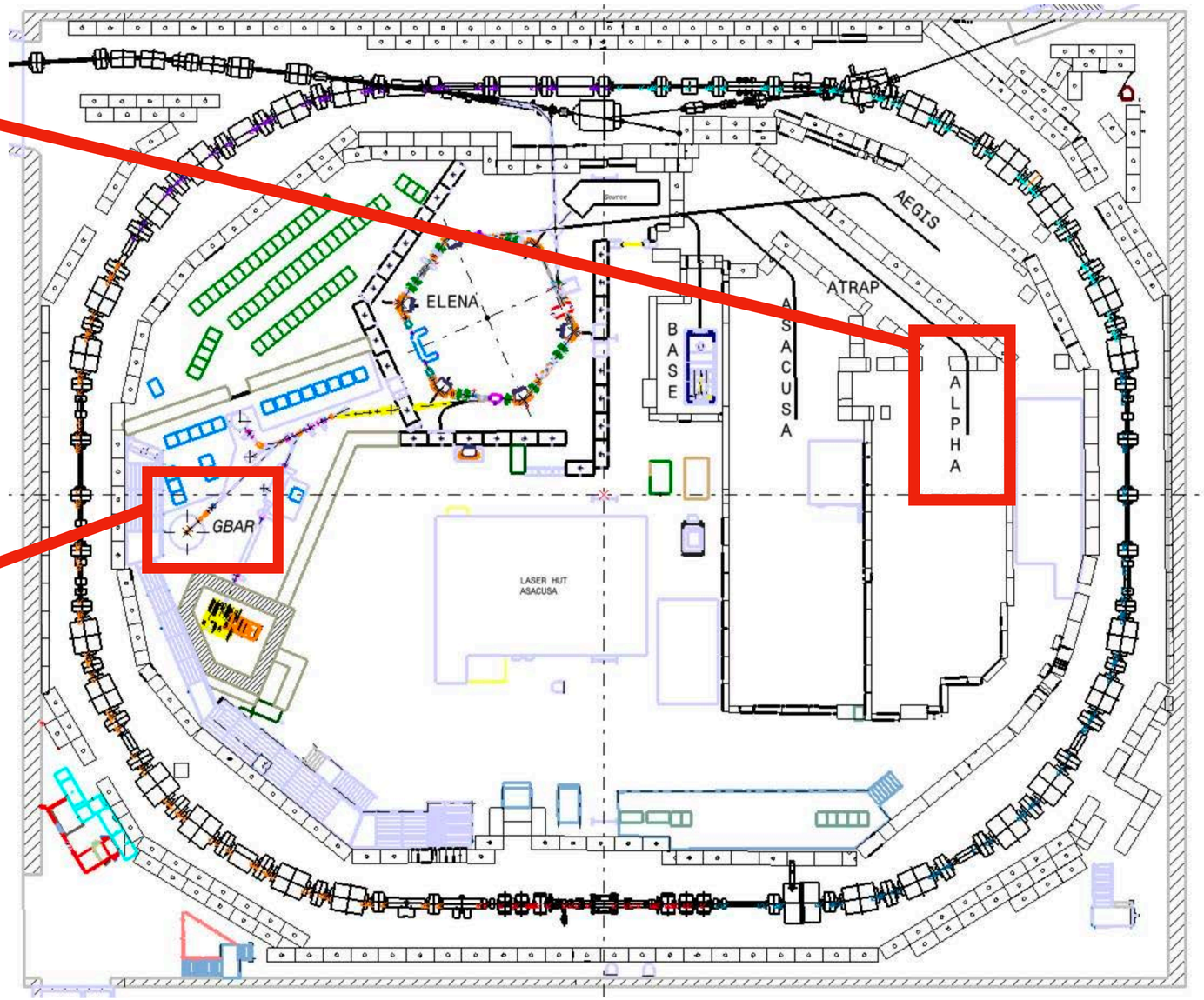
Antihydrogen Laser Physics Apparatus (ALPHA)

create, capture and then cool anti-hydrogen to use for experiment

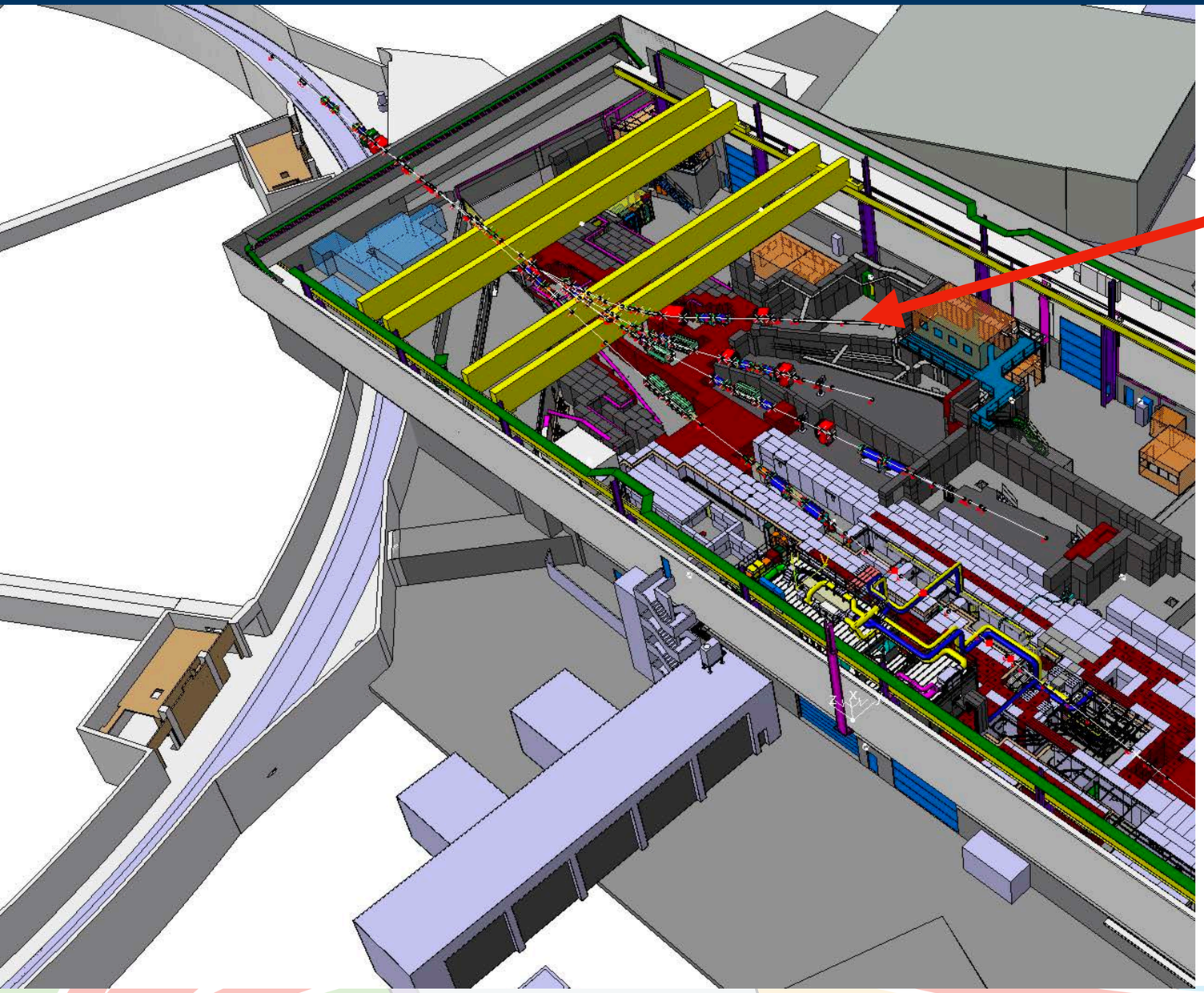


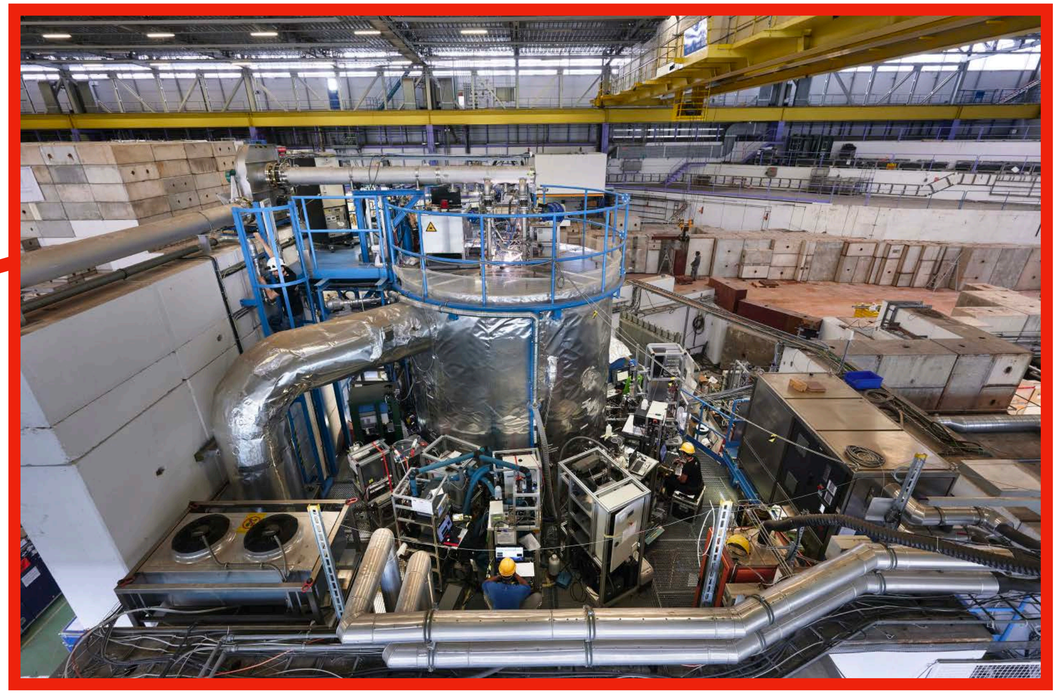
Gravitational Behaviour of Antimatter at Rest (GBAR)

Study different behavior of hydrogen/anti-hydrogen under gravity (free fall)



To study links between cosmic rays and cloud formation

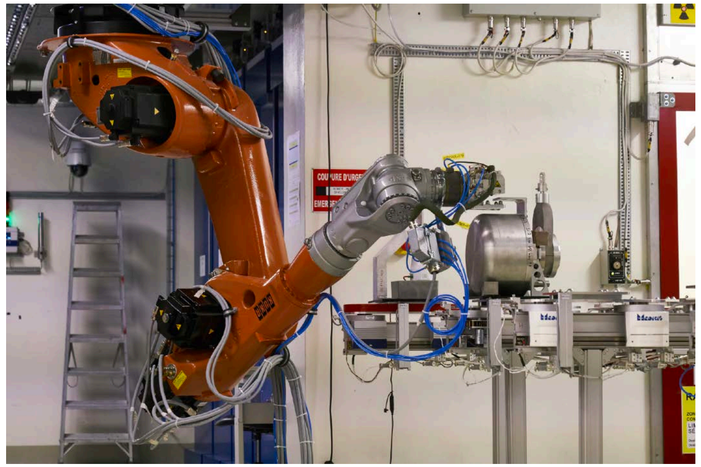




CLOUD

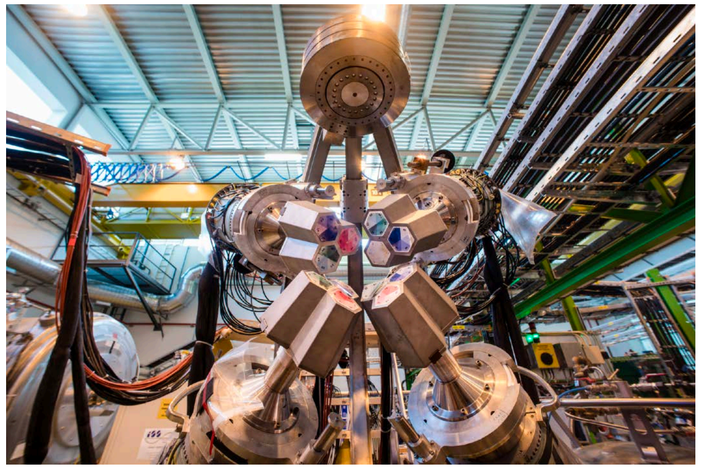
Could there be a link between galactic cosmic rays and cloud formation? An experiment at CERN is using the cleanest box in the world to find out.

To study on radioisotopes and applications, e.g. medical applications



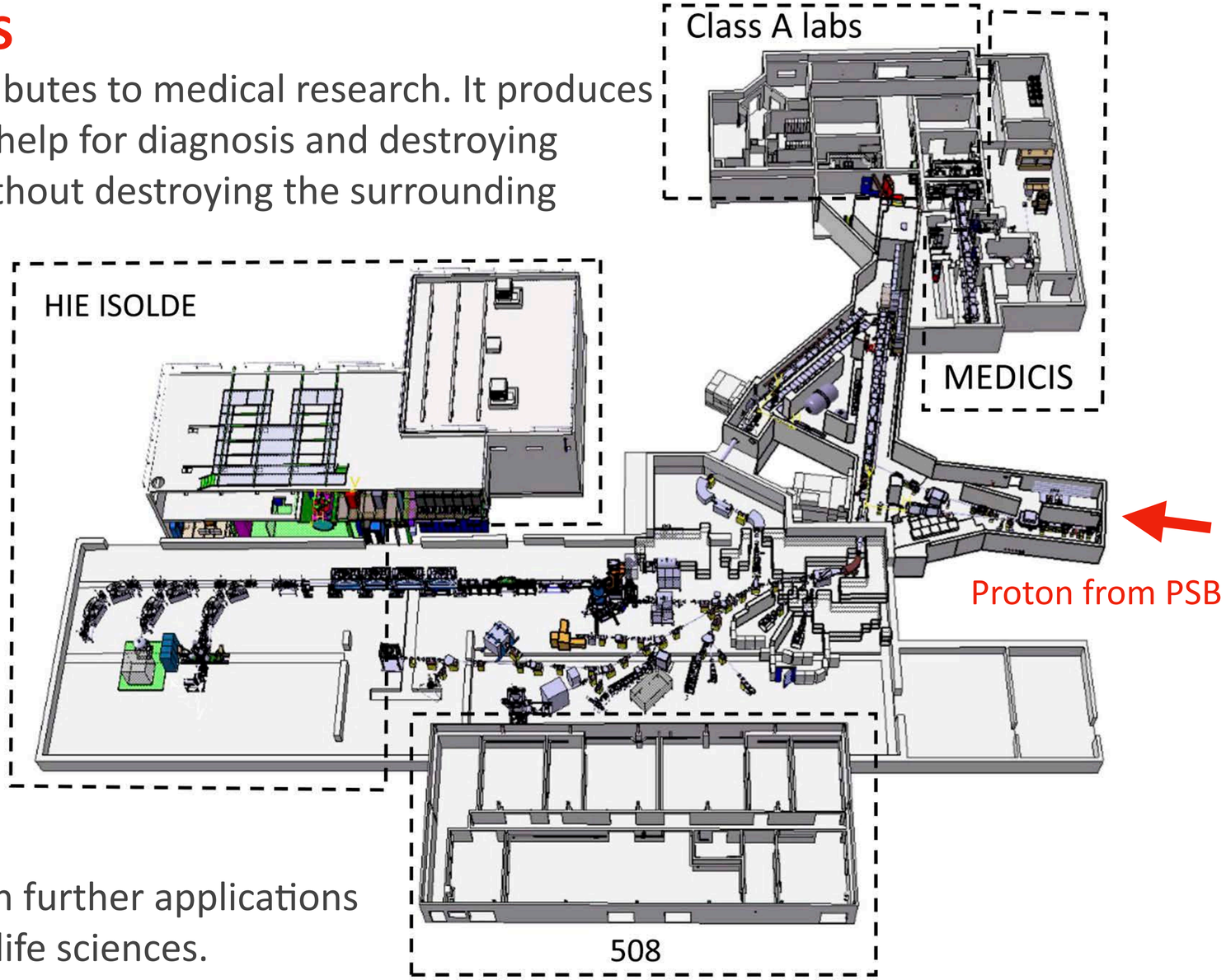
CERN MEDICIS

The facility contributes to medical research. It produces radioisotopes to help for diagnosis and destroying diseased cells without destroying the surrounding healthy tissue.



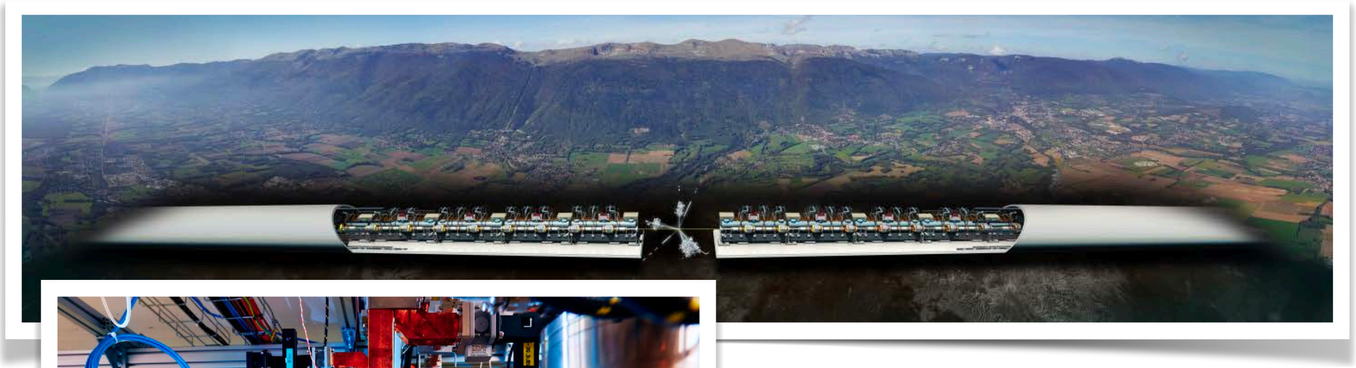
ISOLDE

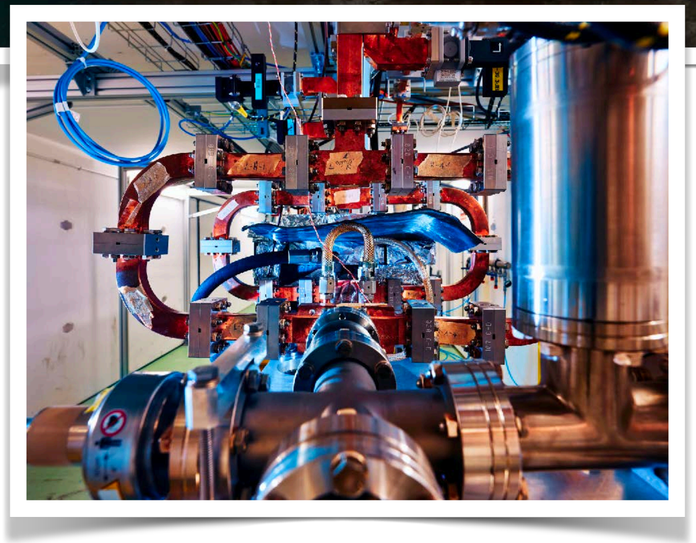
ISOLDE studies the properties of atomic nuclei, with further applications in fundamental studies, astrophysics, material and life sciences.



Blue skies research ... not with imaginations/ideas

[Wikipedia] **Blue skies research** (also called blue sky science) is scientific research in domains where "real-world" applications are not immediately apparent. It has been defined as "research without a clear goal"[1] and "curiosity-driven science". It is sometimes used interchangeably with the term "basic research".



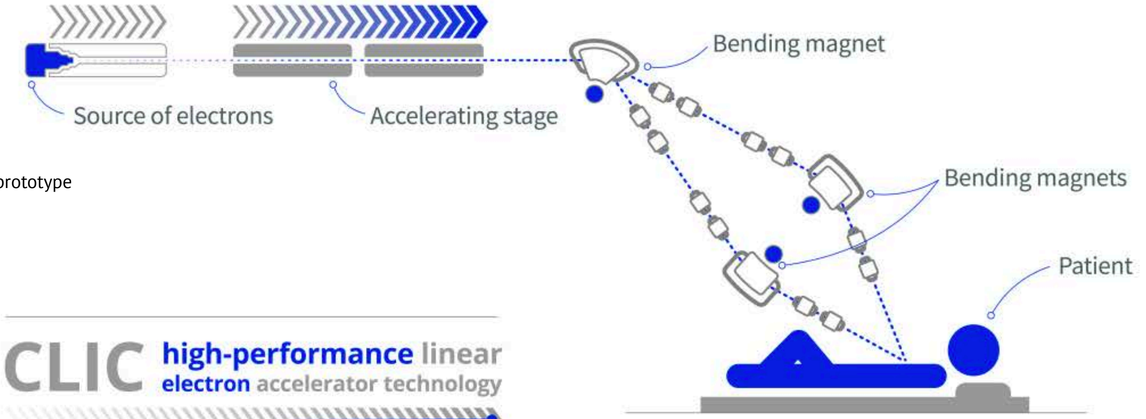


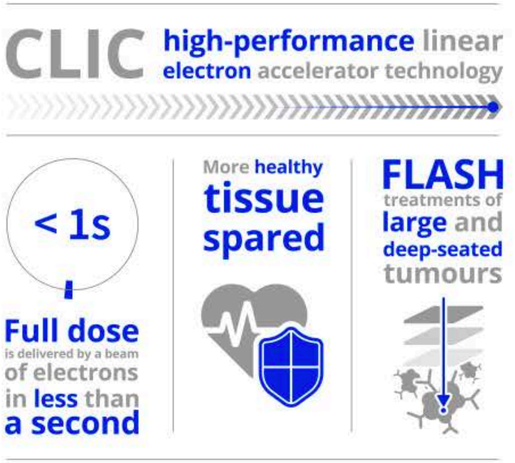
CLIC prototype

Views of Compact Linear Collider (CLIC) prototype

To design and construction of an innovative radiotherapy facility for cancer treatment for FLASH radiotherapy with electrons. The machine uses CLIC (Compact Linear Collider) accelerator technology to accelerate electrons to treat tumours up to 15 to 20 cm in depth.

Compact Linear Collider (CLIC)

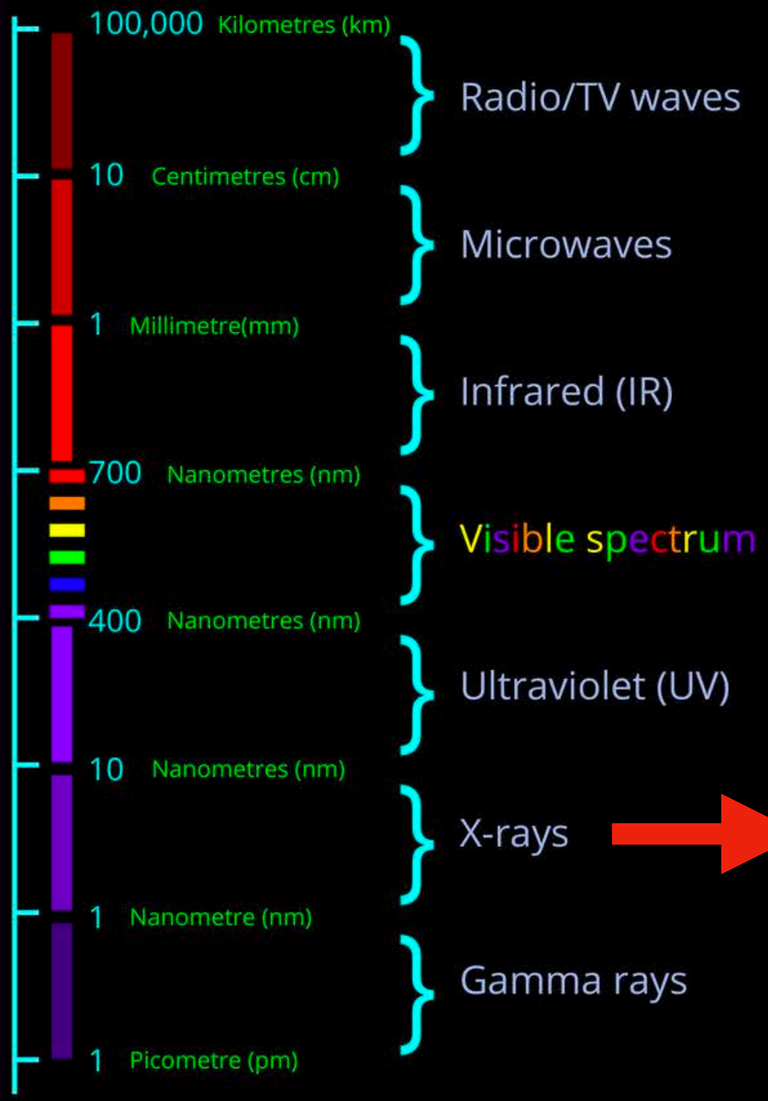


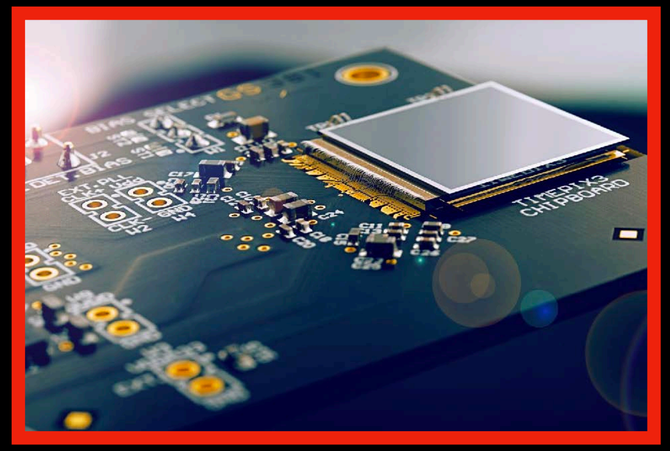


Innovative Radiation Therapy with Electrons

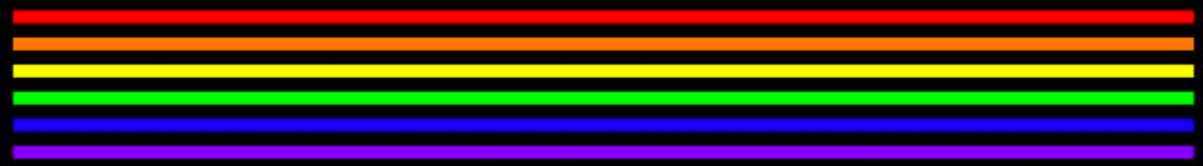
https://cds.cern.ch/record/2728727

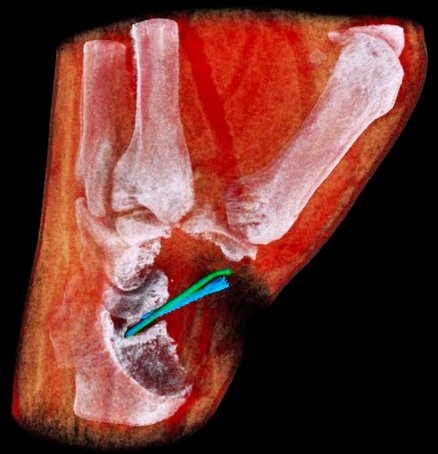
Blue skies research ... not with imaginations/ideas





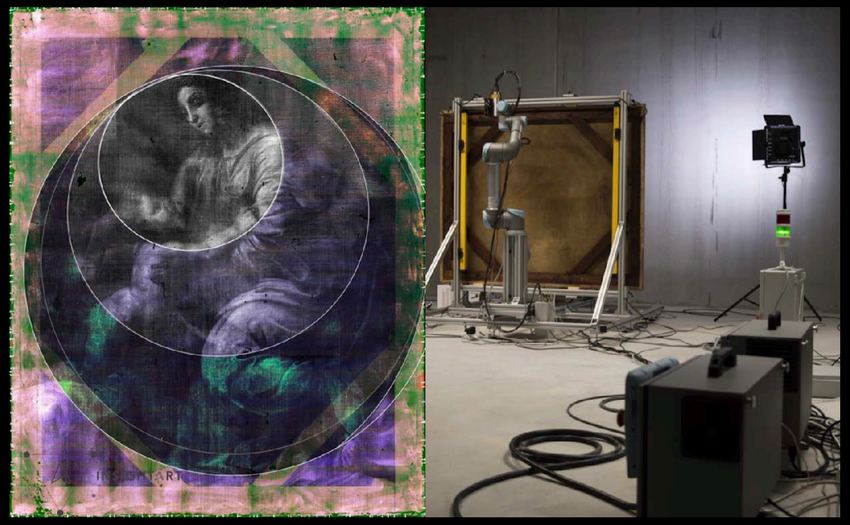
Medipix3; a CMOS pixel detector readout chip designed to be connected to a segmented semiconductor sensor.



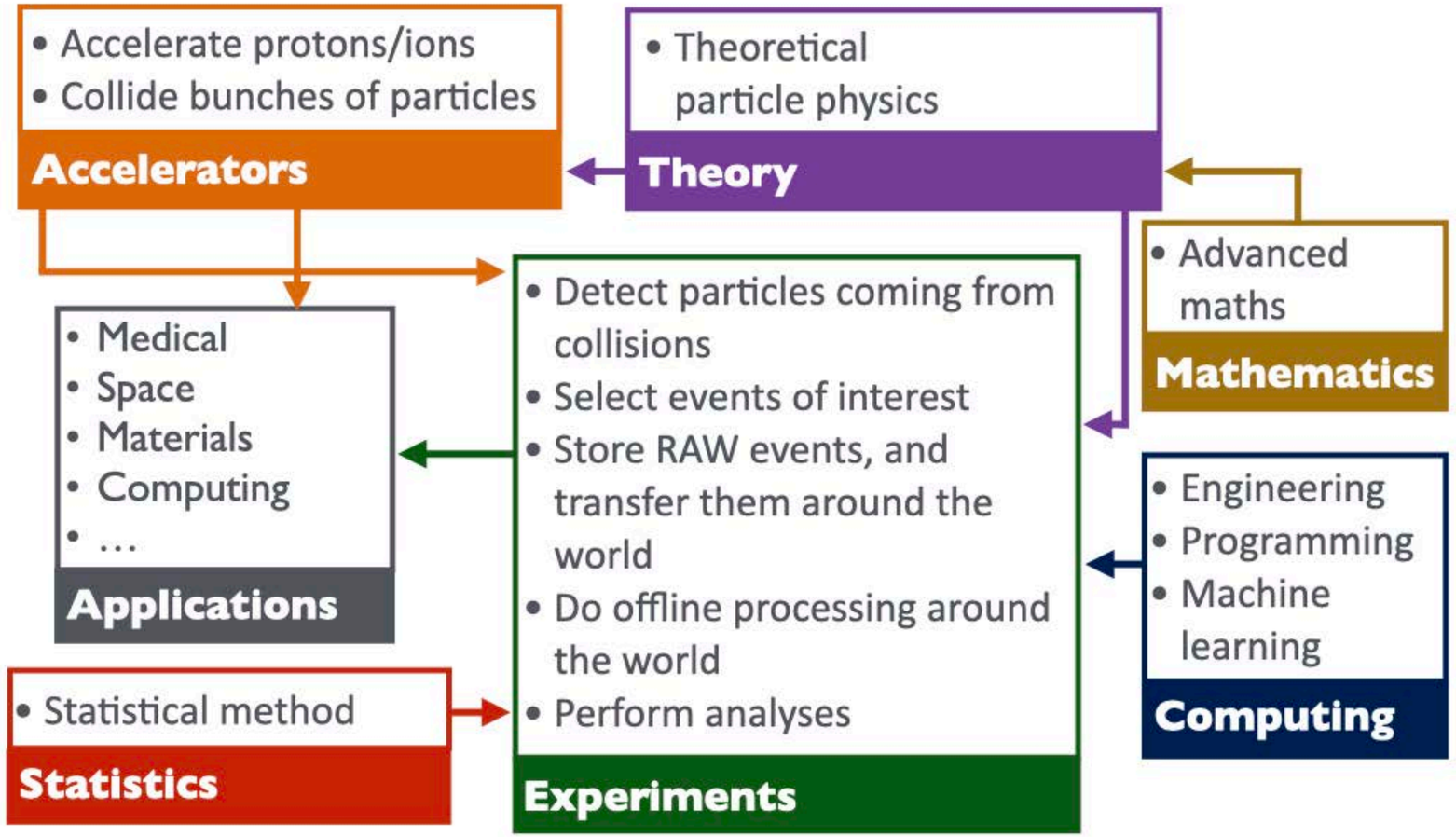


3D colour human X-ray, clinical trial

High resolution spectroscopic radiography



Middle income trap ... how to leave?

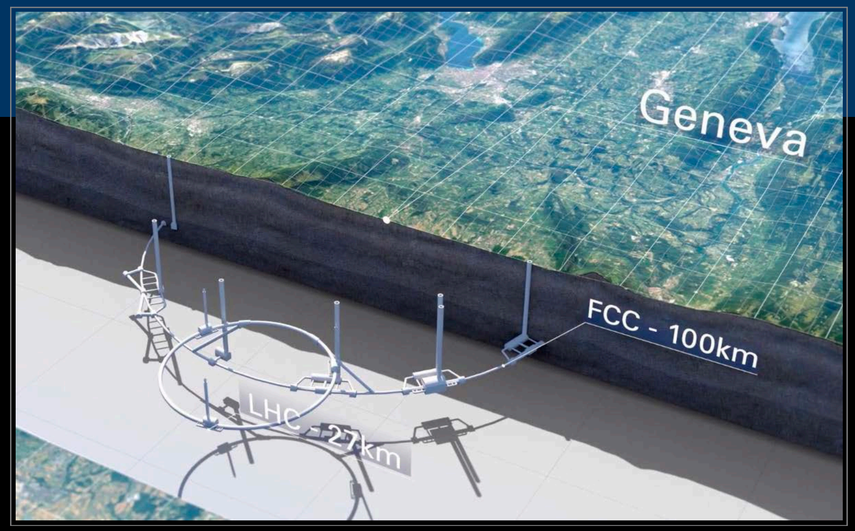


Example of HEP work space ... which can drive economics

Big game that need to play together with funding agencies, decision makers, government, and private sectors, to drive country for our bright future.

The report said that physics-based industries produce 16 per cent of business revenue in the EU, about €4.4 trillion per year, a €1 trillion increase since 2010. Two thirds of that revenue was generated in just four countries: Germany, the UK, France, and Italy. In Germany (contribute ~29%), physics-based industries accounted for more than 53.4 per cent of exports.

Beyond LHC



- **Future Circular Collider (FCC)**
  Circumference: 90 -100 km
  Energy: 100 TeV (pp) 90-350 GeV (e^+e^-)
- **Large Hadron Collider (LHC)**
  Large Electron-Positron Collider (LEP)
  Circumference: 27 km
  Energy: 14 TeV (pp) 209 GeV (e^+e^-)
- **Tevatron**
  Circumference: 6.2 km
  Energy: 2 TeV ($p\bar{p}$)

Learn about CERN with high school physics and a little beyond ...

How to study the following topics?

ฟิสิกส์อะตอม

- สมมติฐานของพลังค์และทฤษฎีอะตอมของโบร์
- ปรากฏการณ์โฟโตอิเล็กทริก
- ทวิภาวะของคลื่นและอนุภาค

ฟิสิกส์นิวเคลียร์และฟิสิกส์อนุภาค

- เสถียรภาพของนิวเคลียส
- กัมมันตภาพรังสี
- ปฏิกิริยานิวเคลียร์และพลังงานนิวเคลียร์
- ประโยชน์และการป้องกันอันตรายจากรังสี
- ฟิสิกส์อนุภาค