



Chula
Chulalongkorn University



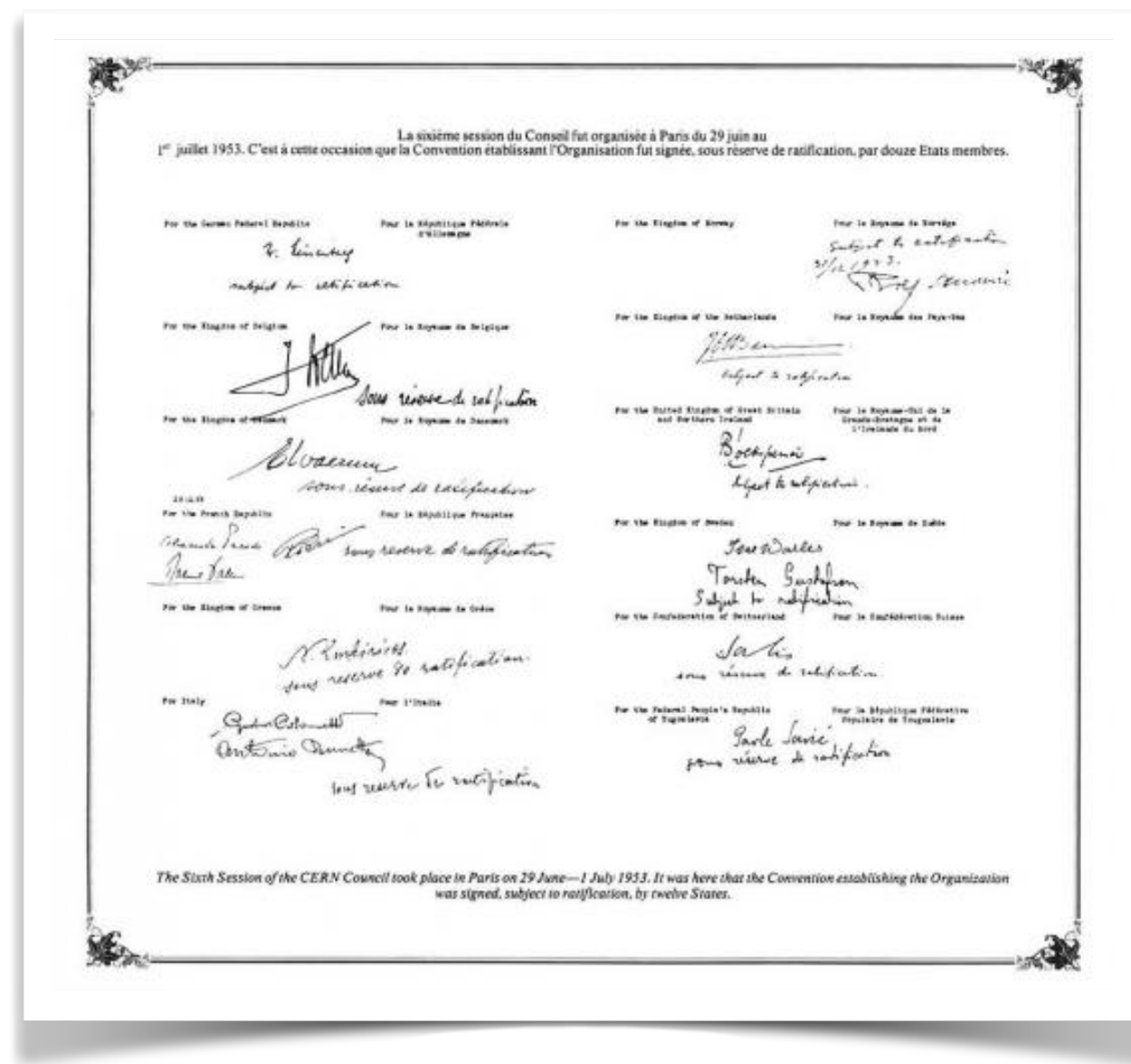
Introduction to CERN and High Energy Particle Physics Programs

N. SRIMANOBHAS,
Chulalongkorn U. (TH), CMS Collaboration
29 April 2023

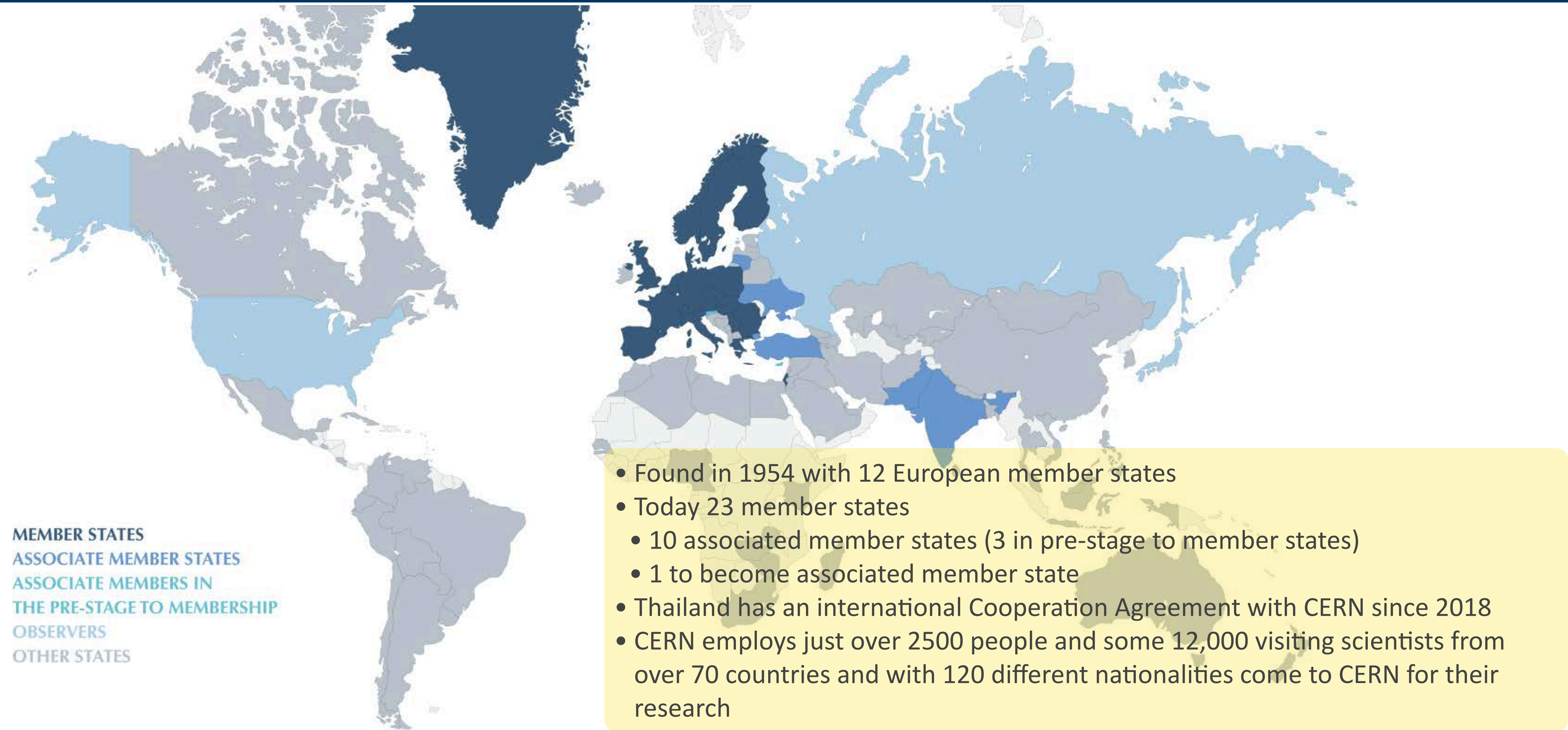


CERN: Conseil Européen pour la Recherche Nucléaire

- 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.

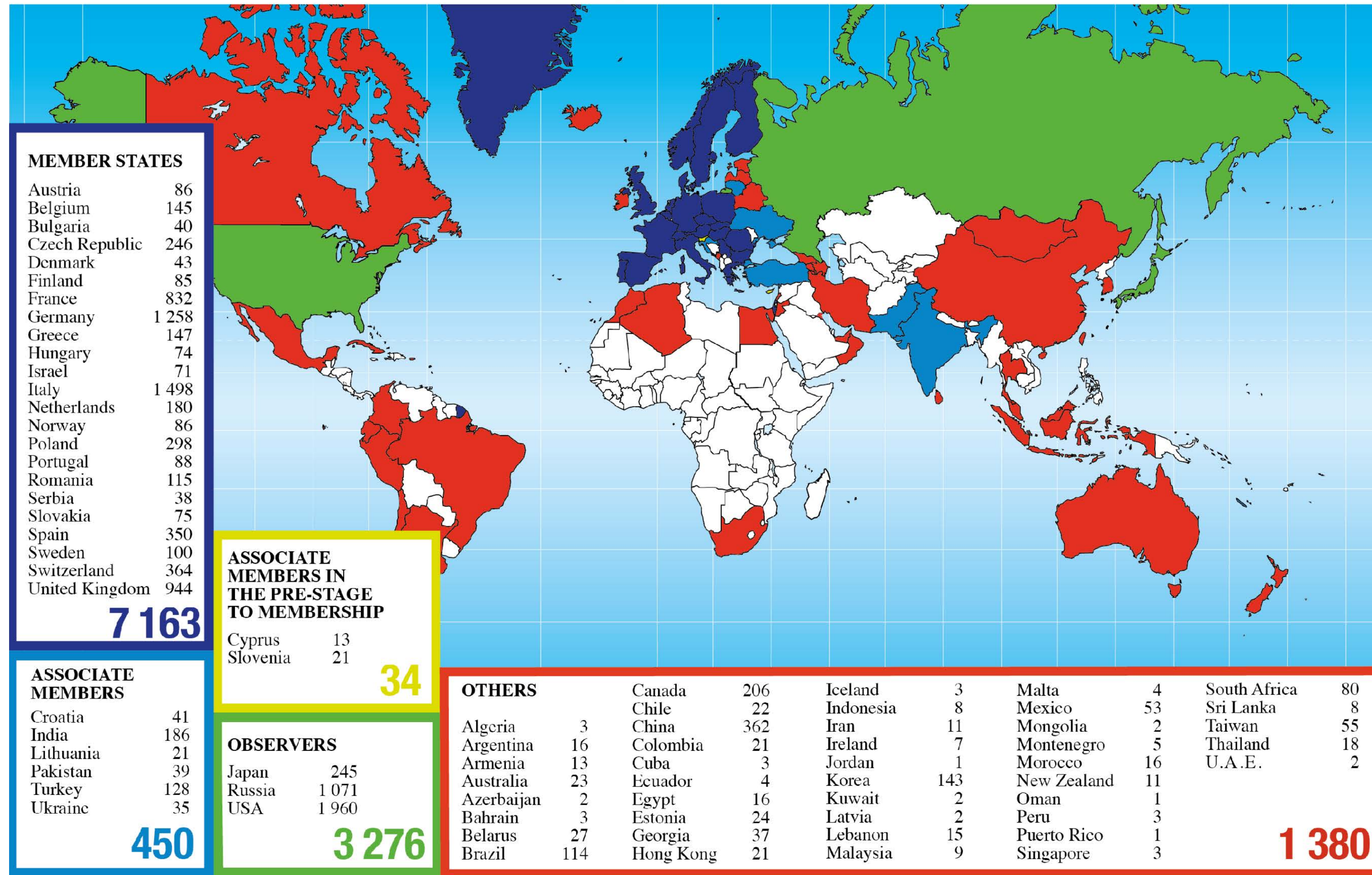


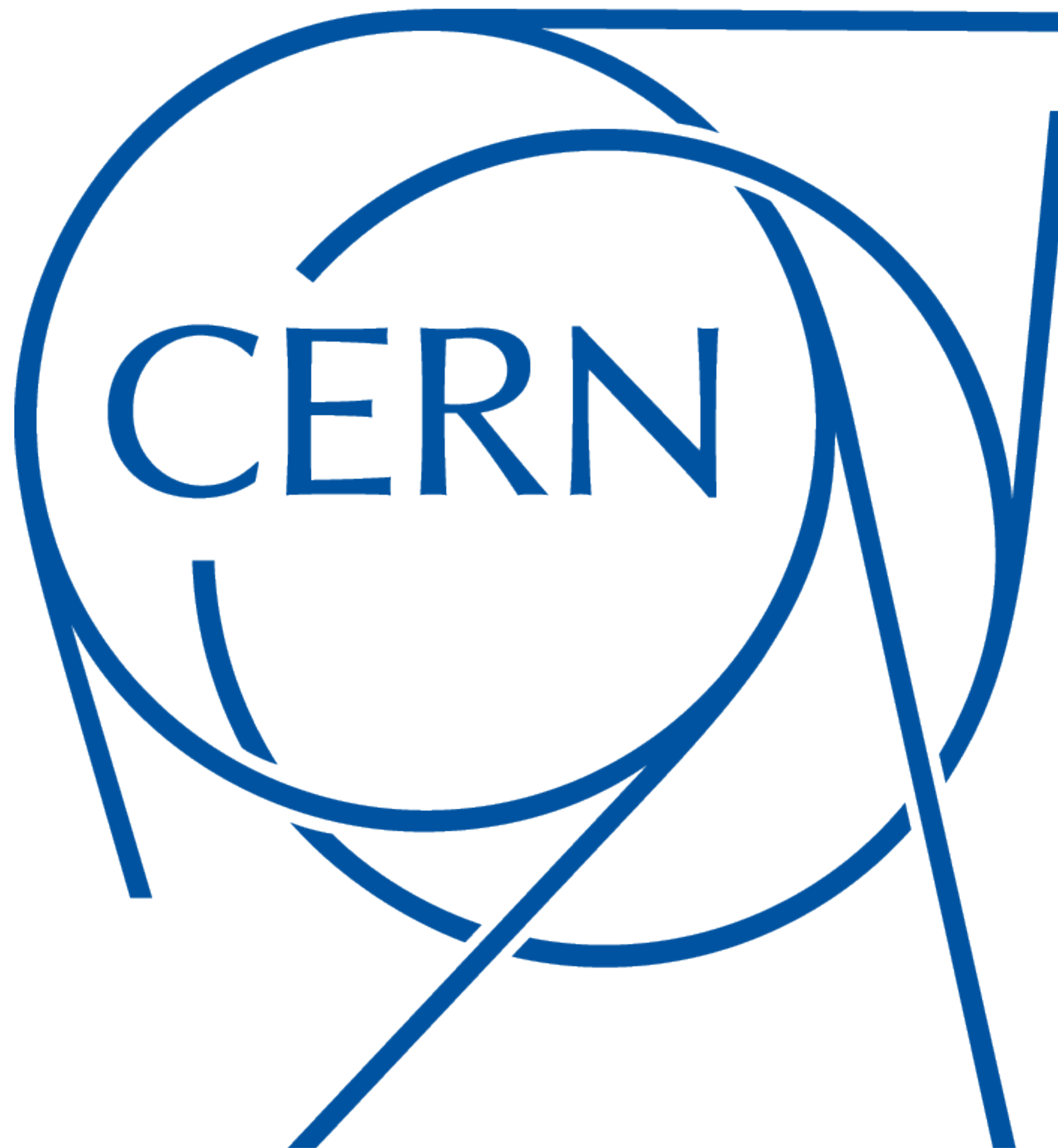
CERN: Conseil Européen pour la Recherche Nucléaire



CERN: Conseil Européen pour la Recherche Nucléaire

Distribution of All CERN Users by Location of Institute on 27 January 2020





CERN Missions

Research

Seeking and finding answers to questions about the Universe

Technology

Advancing the frontiers of technology

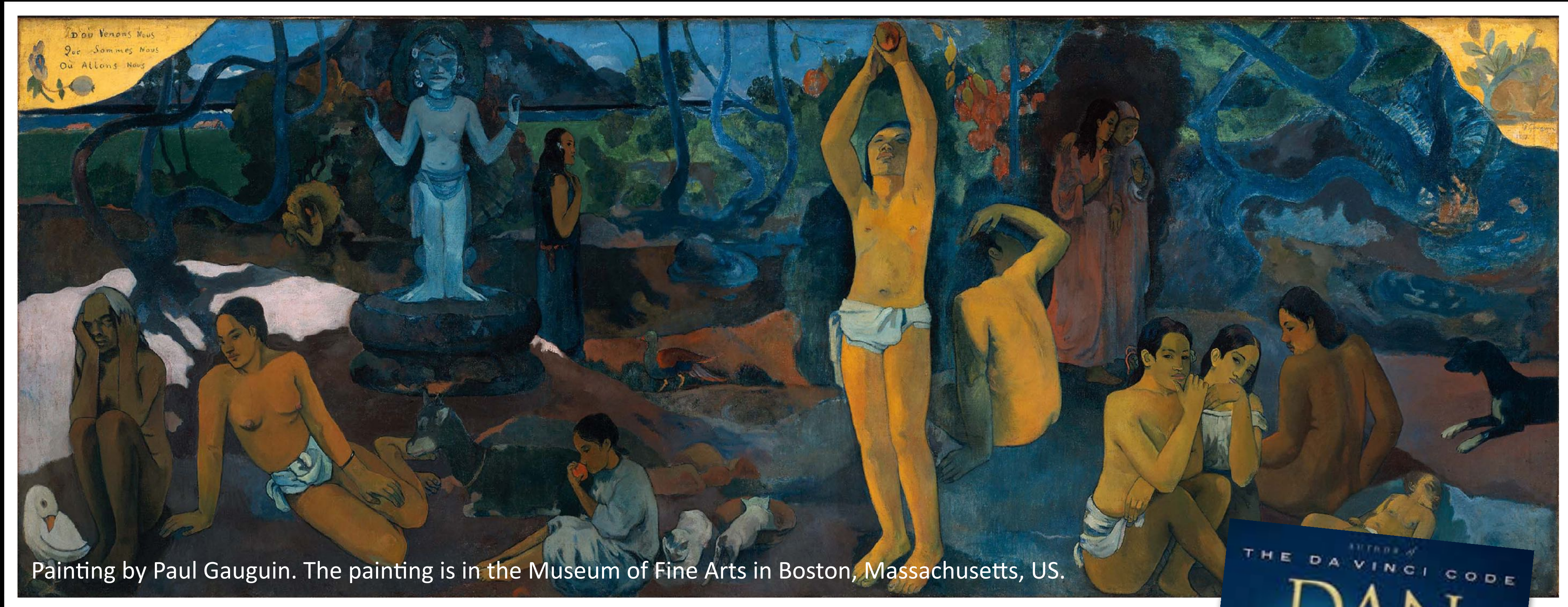
Education

Training the scientists of tomorrow

Collaborating

Bringing nations together through science

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



Painting by Paul Gauguin. The painting is in the Museum of Fine Arts in Boston, Massachusetts, US.

Where Do We Come From? What Are We? Where Are We Going?
Note that this painting should be read from right to left.

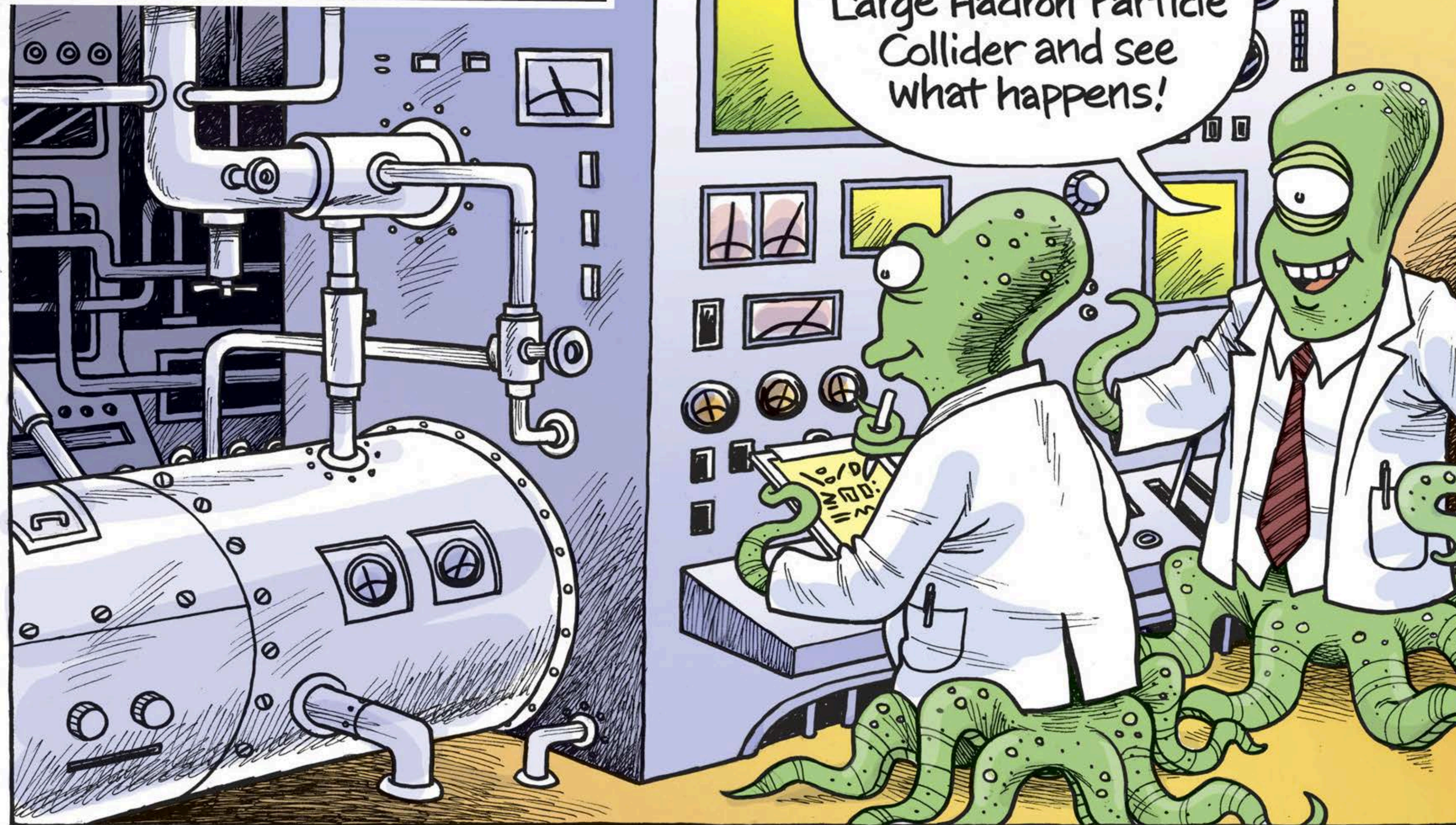


Paul Gauguin
1848 - 1903



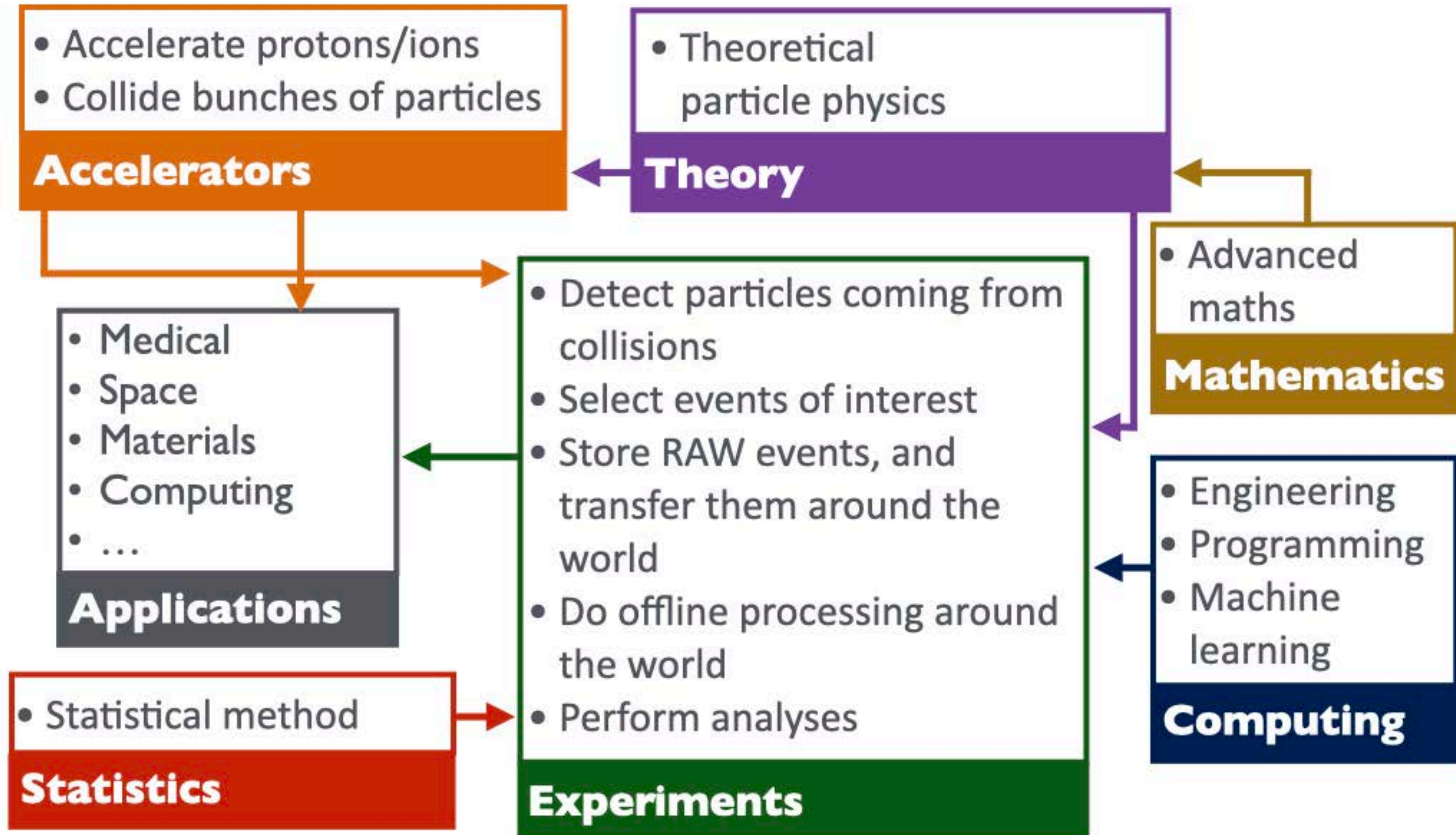
What are we looking for?

13,8 BILLION YEARS AGO,
A FEW SECONDS BEFORE THE
CREATION OF OUR UNIVERSE...

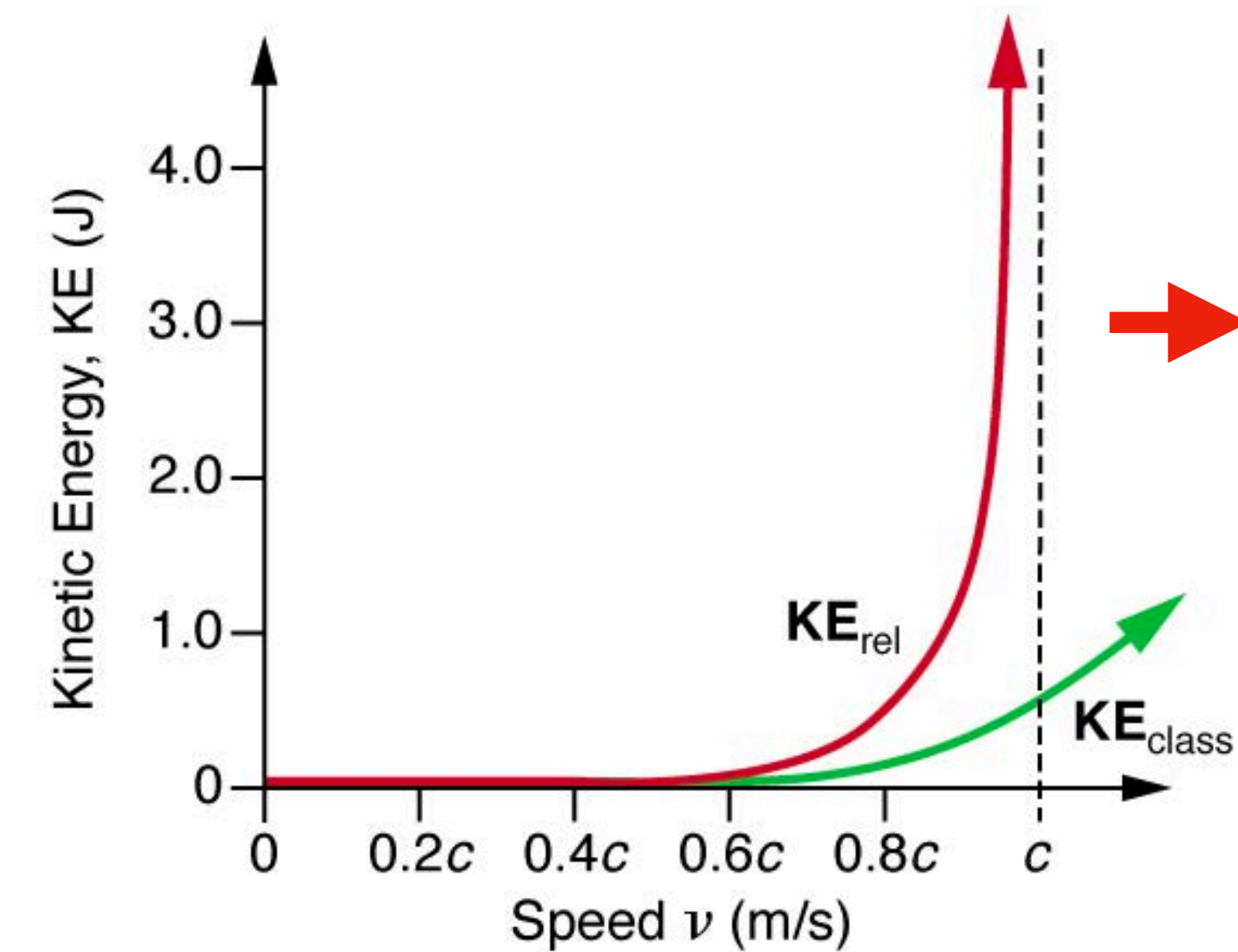


Basic research in the field of experimental and theoretical particle physics, finding out what the Universe is made of and how it works.

What do you learn in this workshop?



Accelerator is our tool to find answers

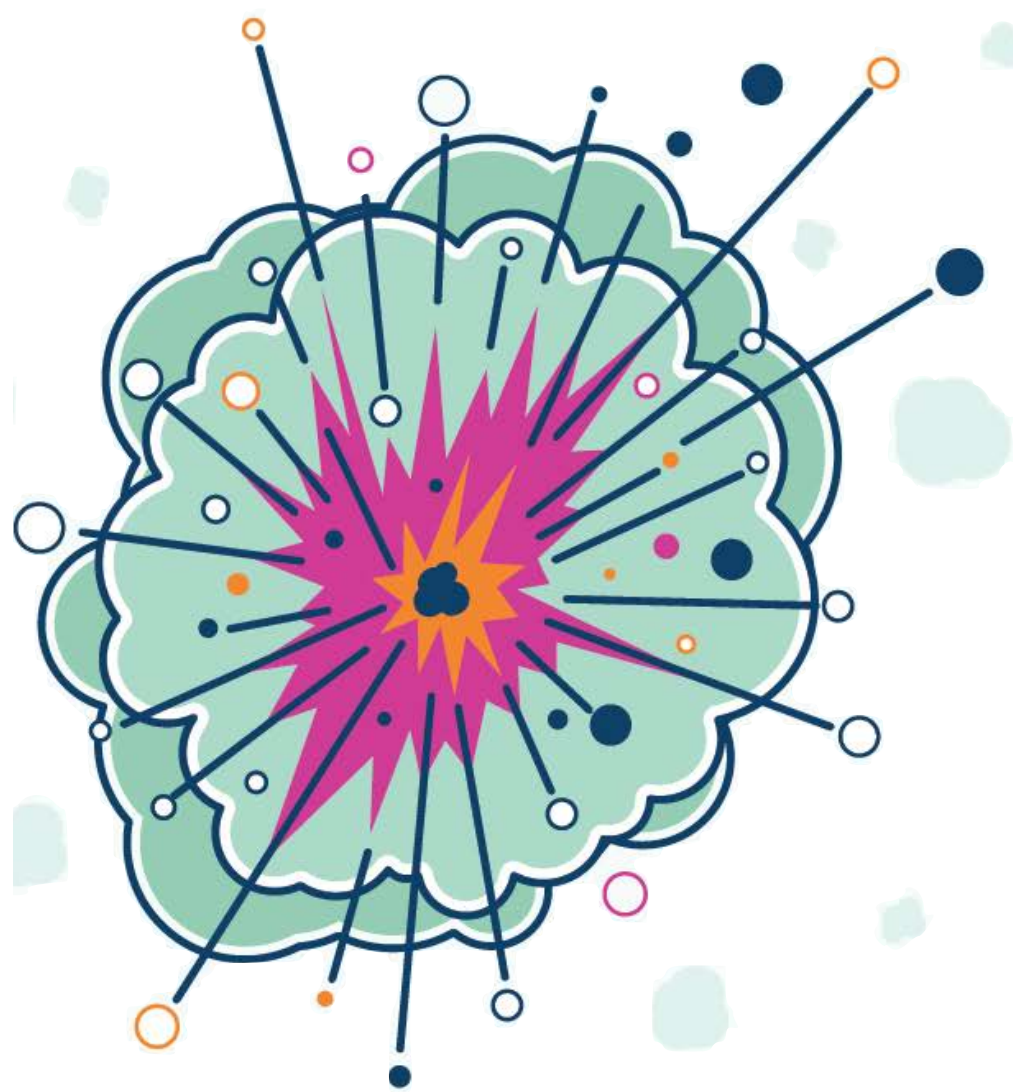


Increase K.E. of particle

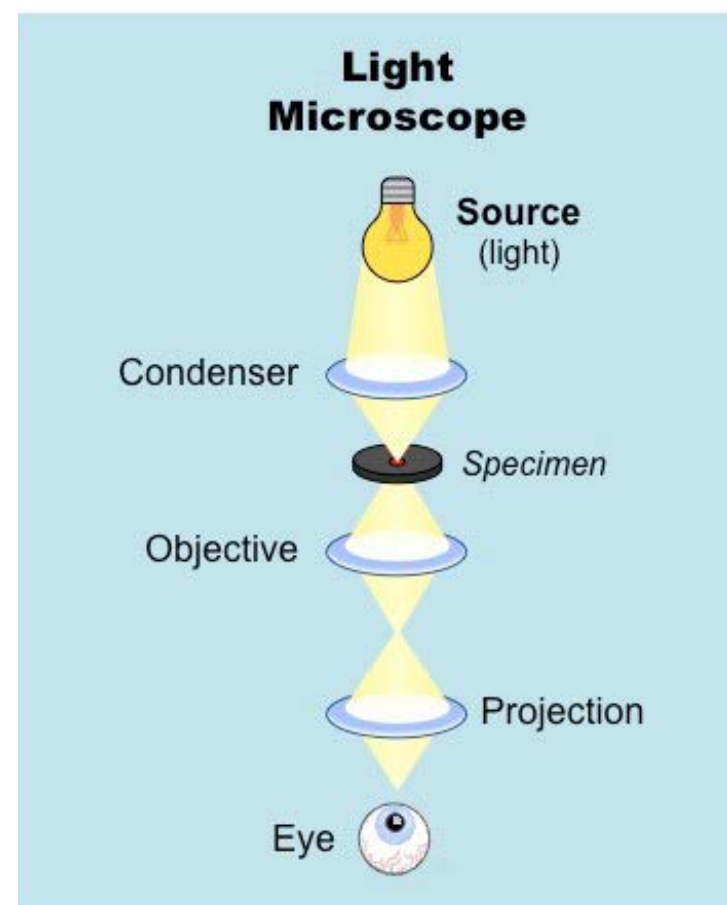
- Particle speed has limit to the speed of light but kinetic energy and momentum have not

Use high momentum particle to

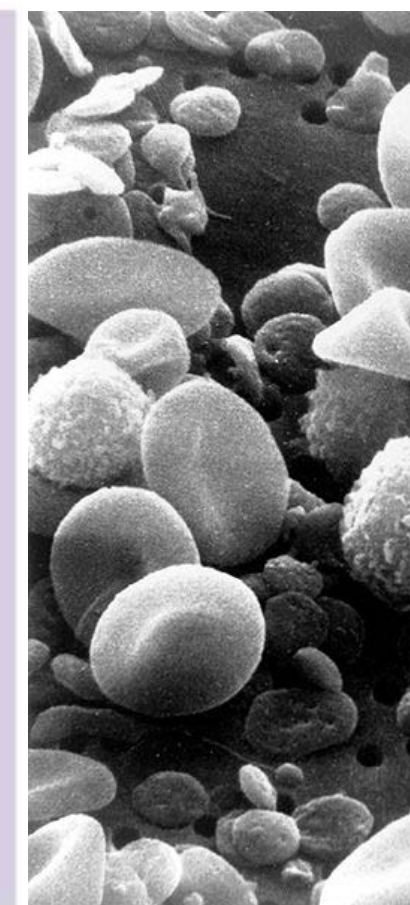
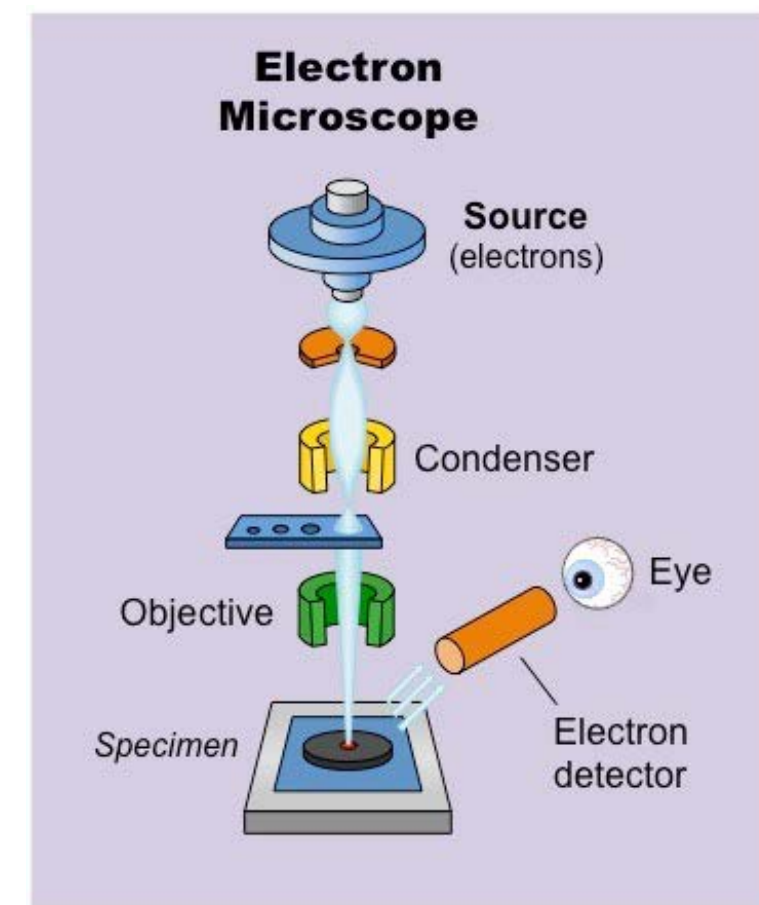
- create matter by collision
 - probe insight in particle structure
- $$E^2 = p^2c^2 + m^2c^4$$
- $$\lambda = h/p$$



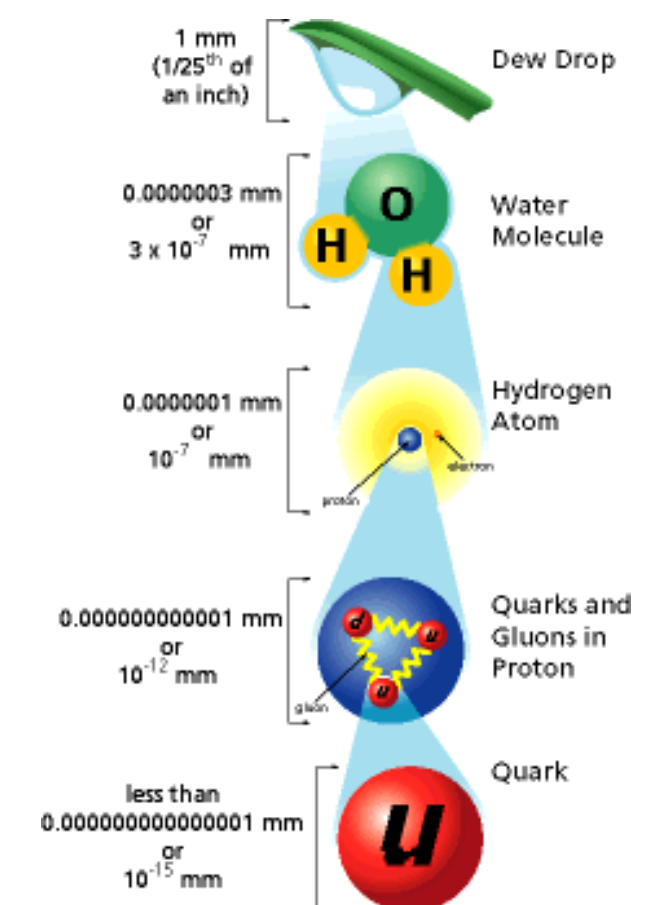
Visible light 400-500 nm



X-Ray 0.01-10 nm



Particle Accelerator <0.01 nm

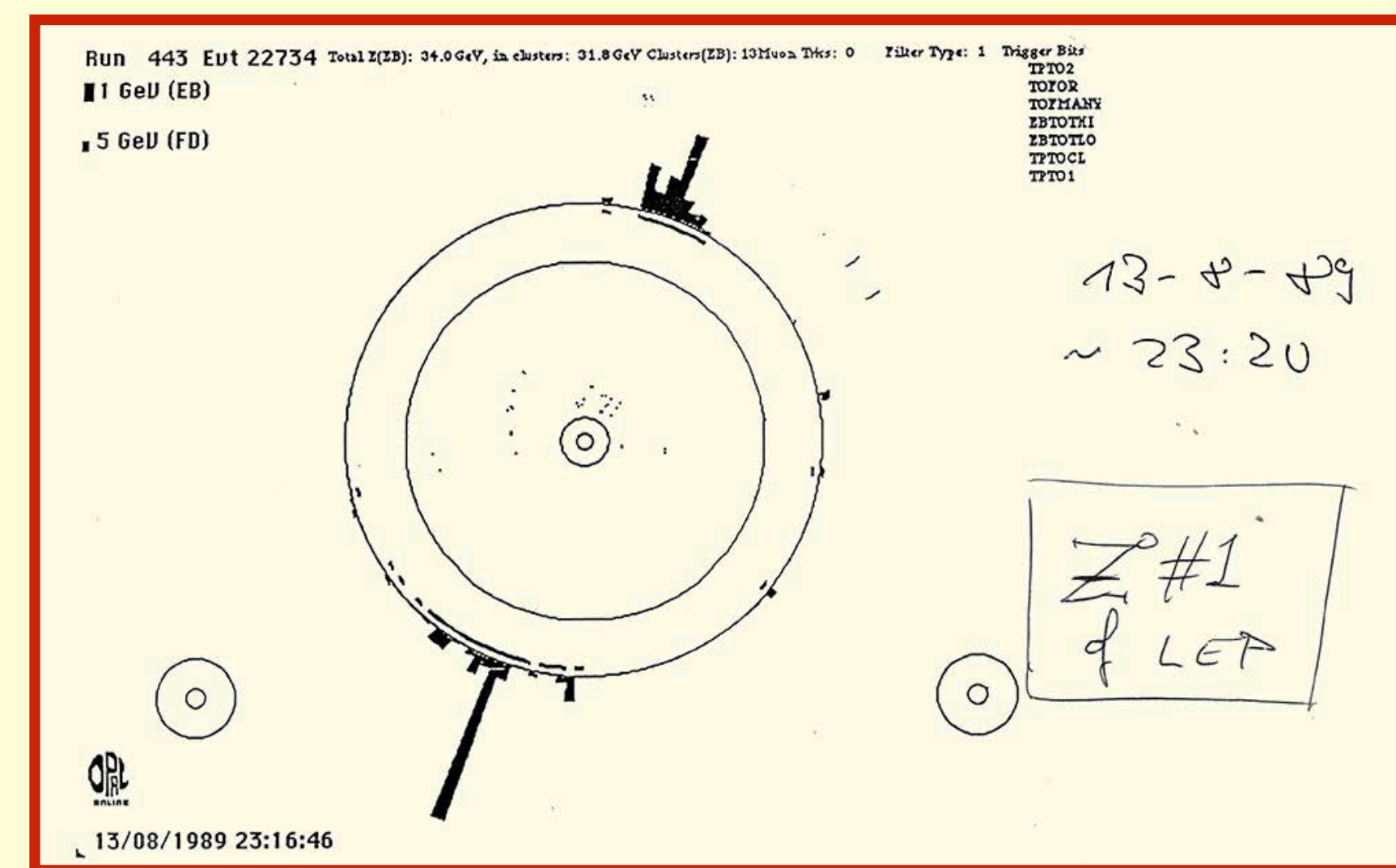
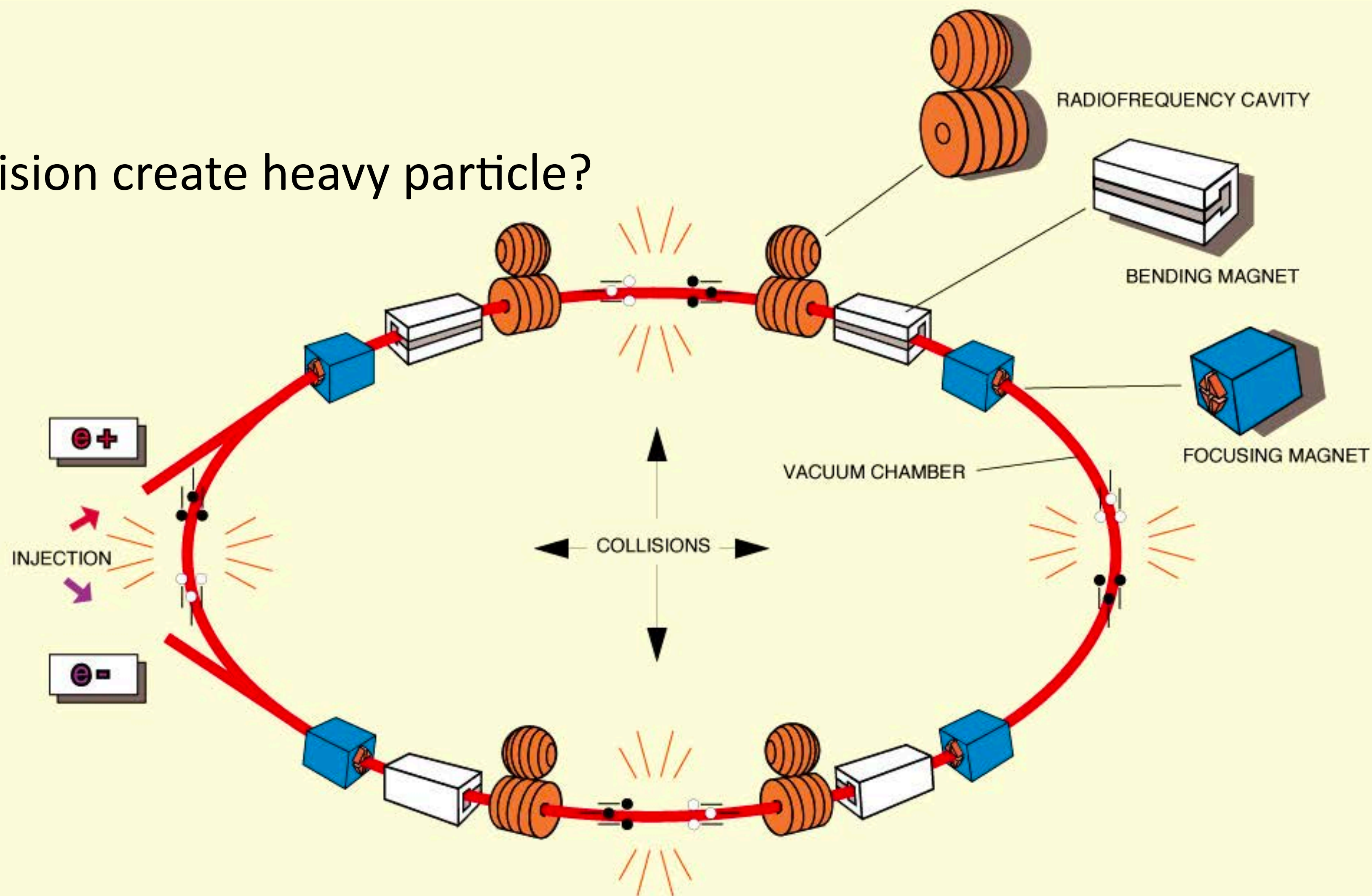


Accelerator is our tool to find answers

Electron mass = $0.511 \text{ MeV}/c^2$

Z-boson mass = $91.18 \text{ GeV}/c^2$

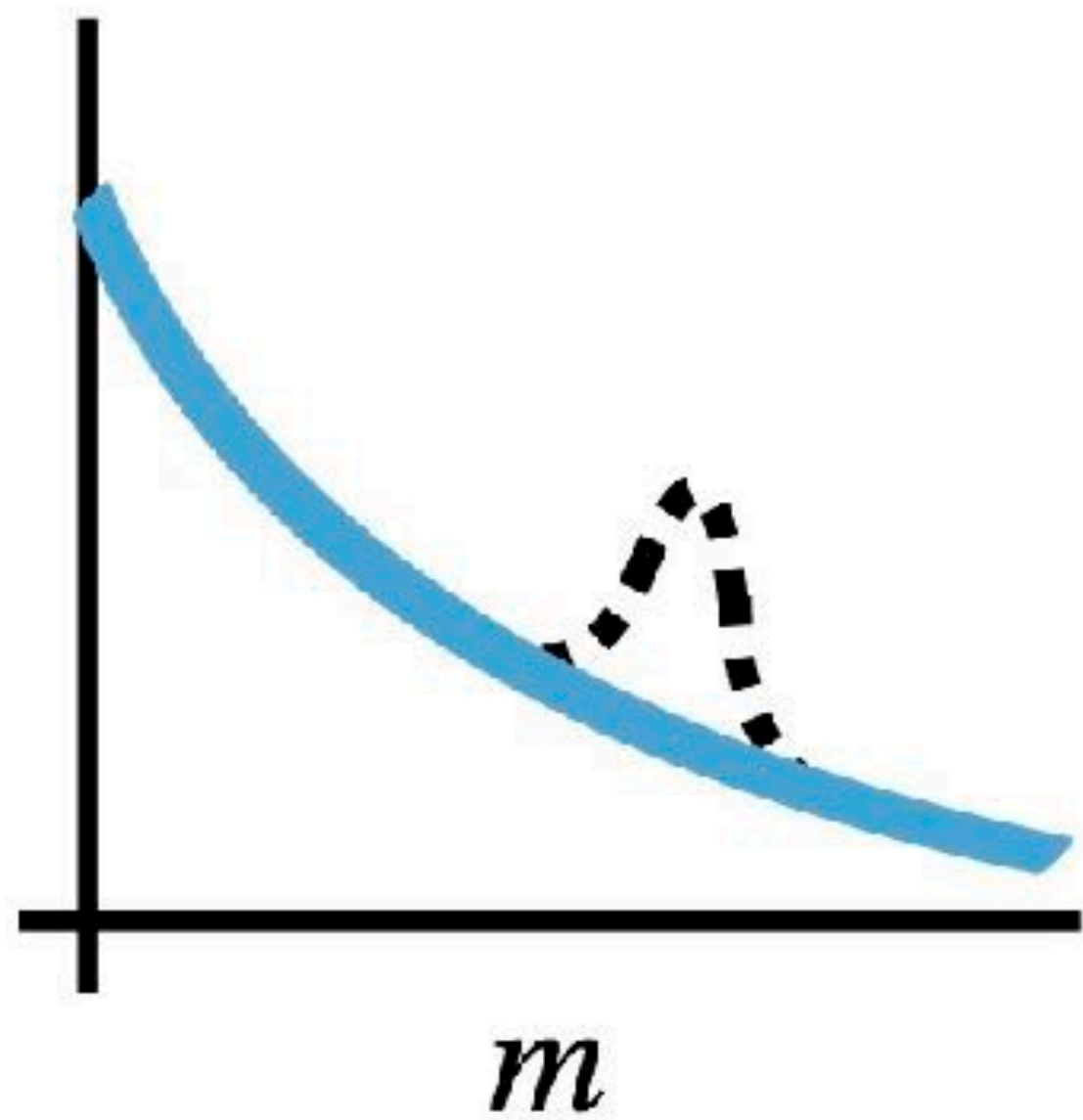
How does very small particle collision create heavy particle?



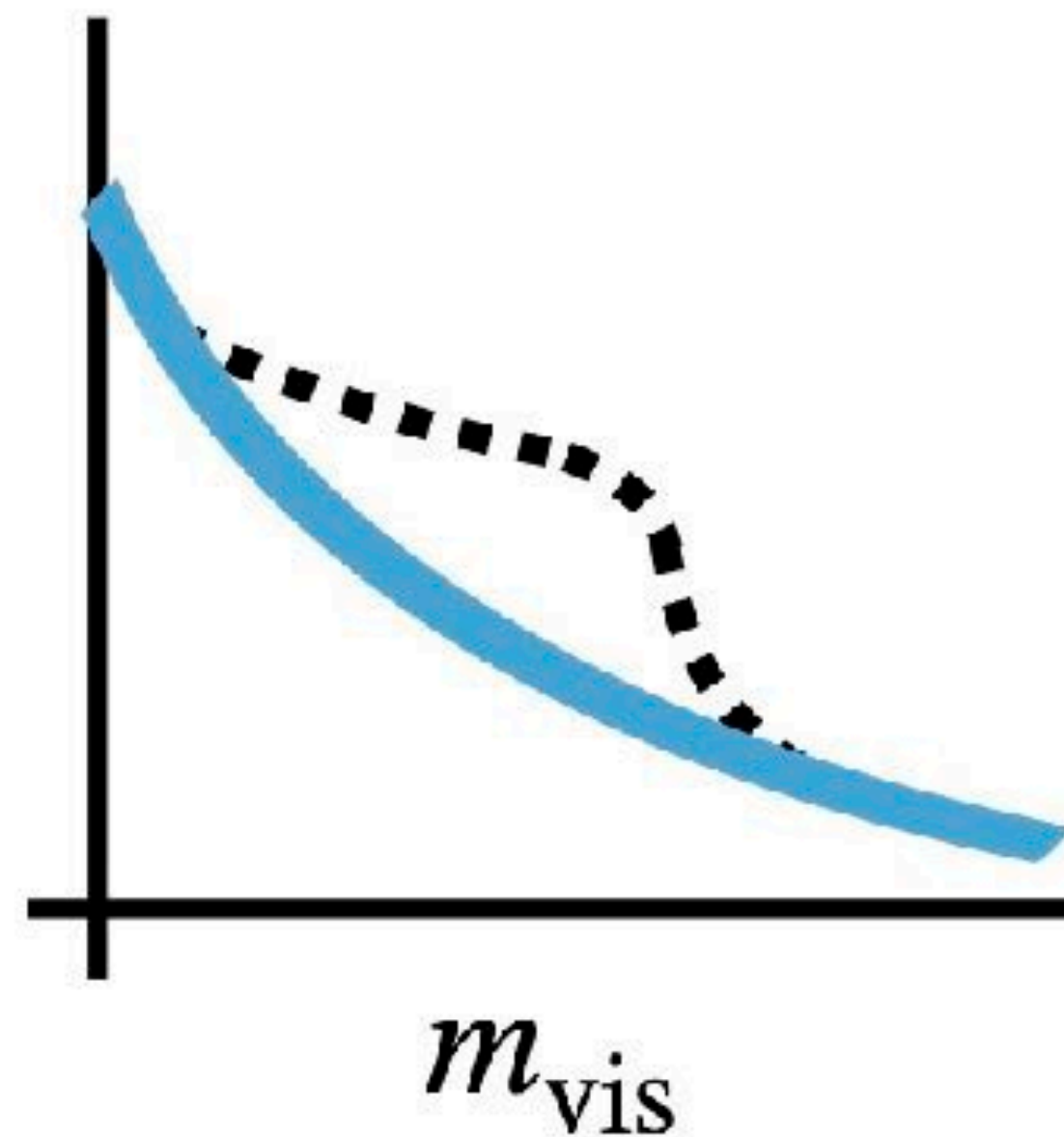
The OPAL logbook entry for the first Z boson seen at LEP, recorded late on 13 August 1989.

Credit: CERN [\[Link\]](#)

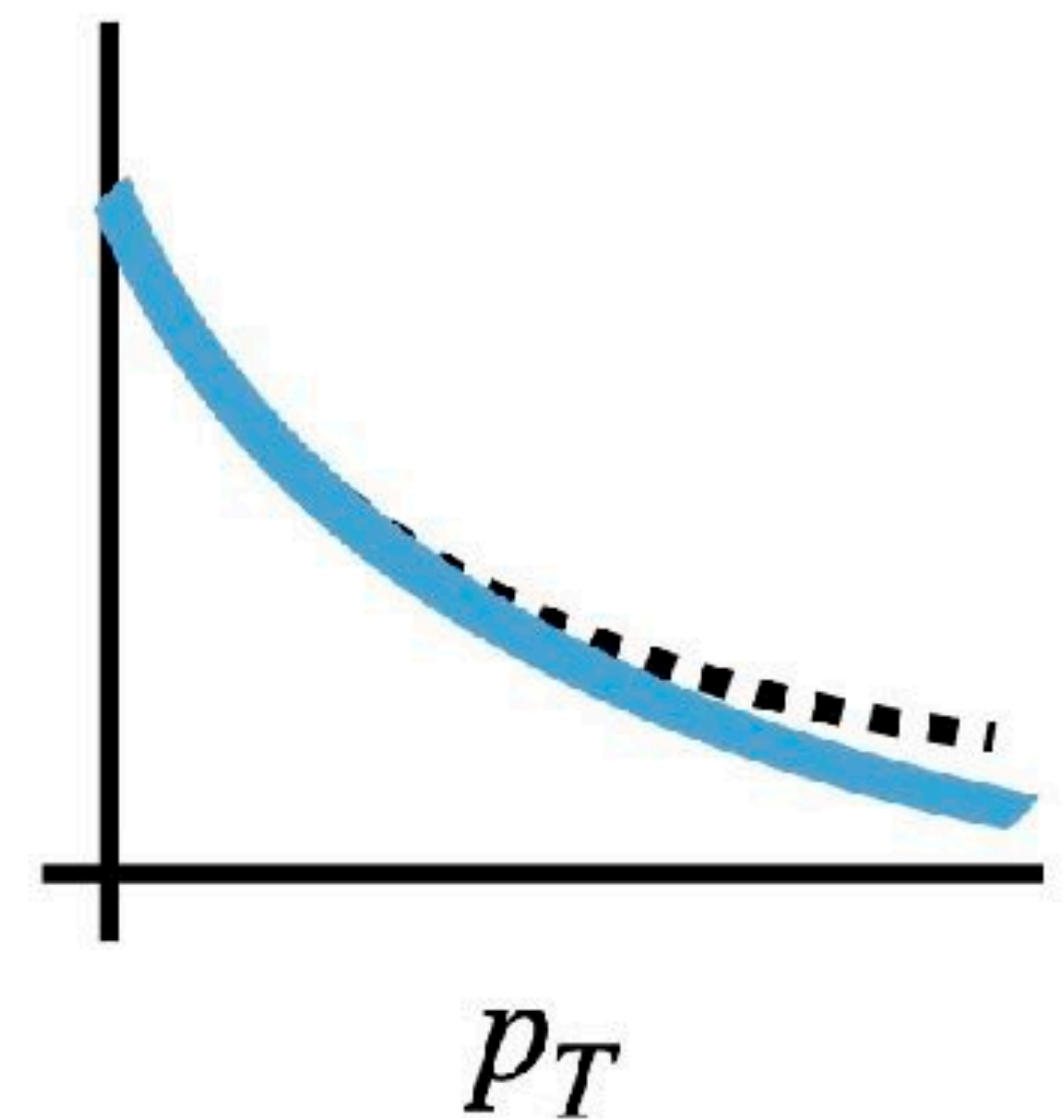
Searching for new physics



Bump(s), Resonant
Di-Higgs interpretation,
 Z' , ...

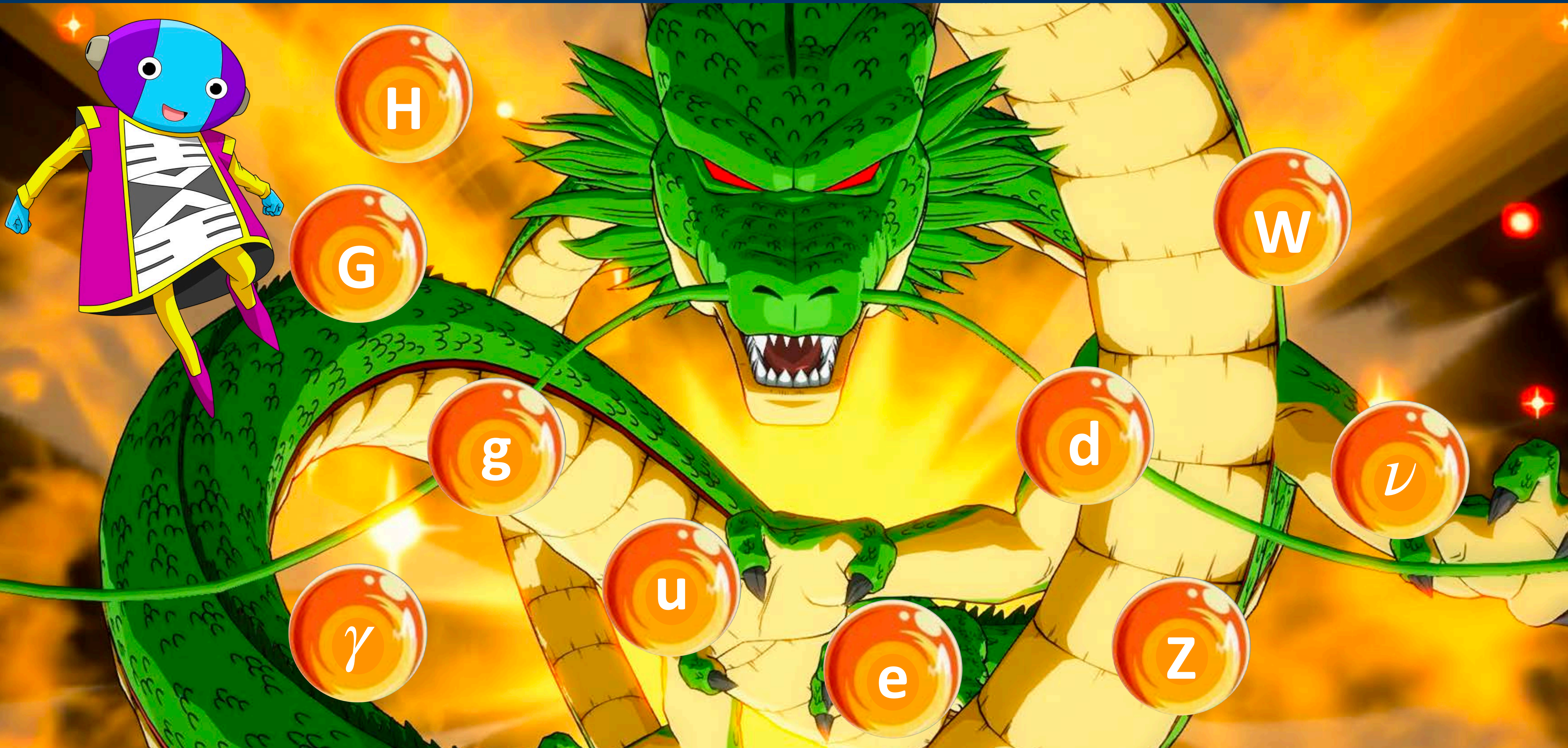


Semi-resonant, end-point
Heavy charged bosons,
...



Non-resonant, Tail
Dark matter,
Extra dimensions,...

Known universe's ingredients



Known universe's ingredients

Everything around us (the whole periodic table) is made up of the **first three particles (u-quark, d-quark and electron)**. But somehow nature

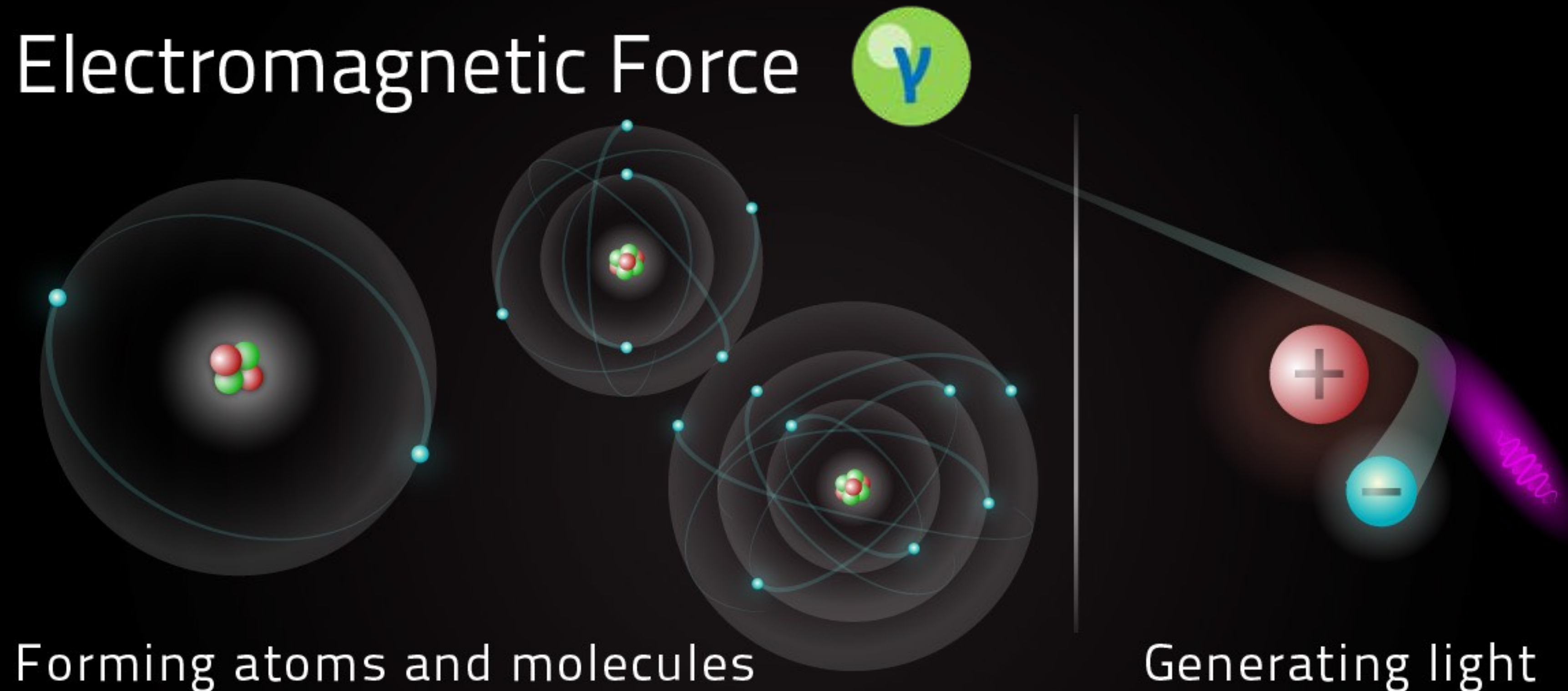
- supplies us with two extra families that are very much heavier,
- doesn't allow us to see free quarks (or maybe we don't see it yet),
 - group of 3 quarks: **Baryon** (e.g. proton),
 - quark-antiquark pairs: **Meson** (e.g. pion),
- describes interactions between these particles by **three (out of four) fundamental forces**.



This is so simple, compared to Periodic Table in Chemistry, or Biological taxonomy!



Electromagnetic force



Forming atoms and molecules

The electromagnetic force pulls negatively charged electrons into bound orbits around positively charged nuclei to form atoms and molecules. As a gas cools, electrons will find their way into the presence of atomic nuclei. Larger nuclei with a greater positive charge pull in more electrons until atoms and molecules have a balance of charges.

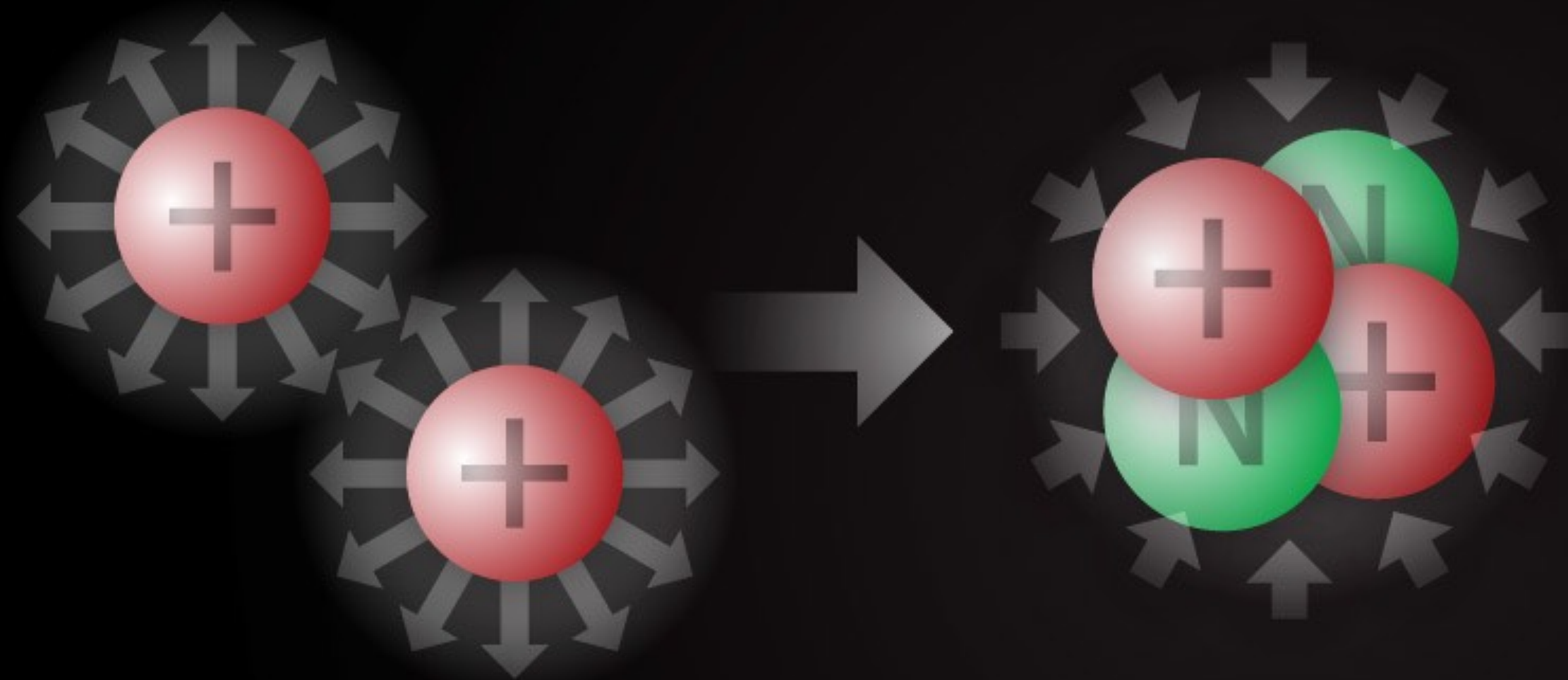
Generating light

When a negative electron interacts with a positive proton, the electromagnetic force adds energy to the electron generating a photon.

<http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/03.html>

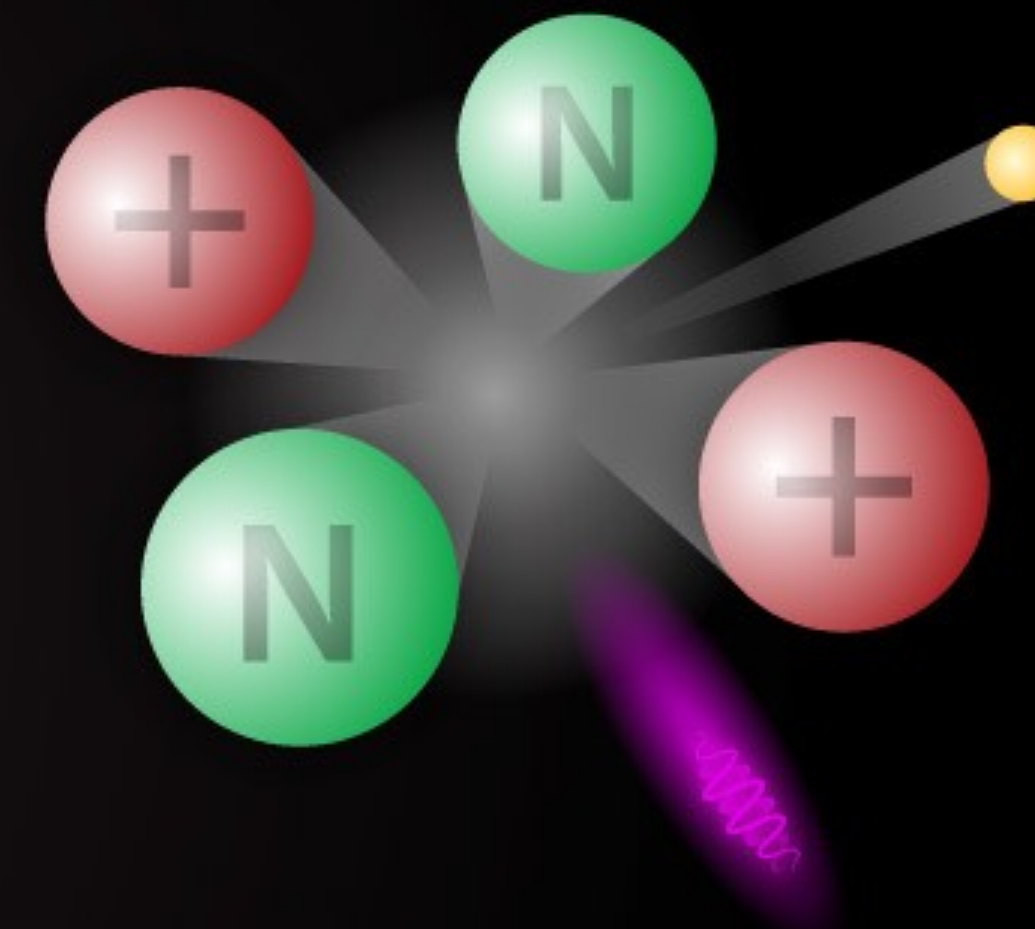
Strong nuclear force

Strong Nuclear Force



Binding protons in atomic nuclei

Positively charged particles naturally repel each other, it takes an extreme amount of force to hold protons together. The strong nuclear force overcomes the repulsion between protons to hold together atomic nuclei. Without the strong nuclear force, complex nuclei cannot form.



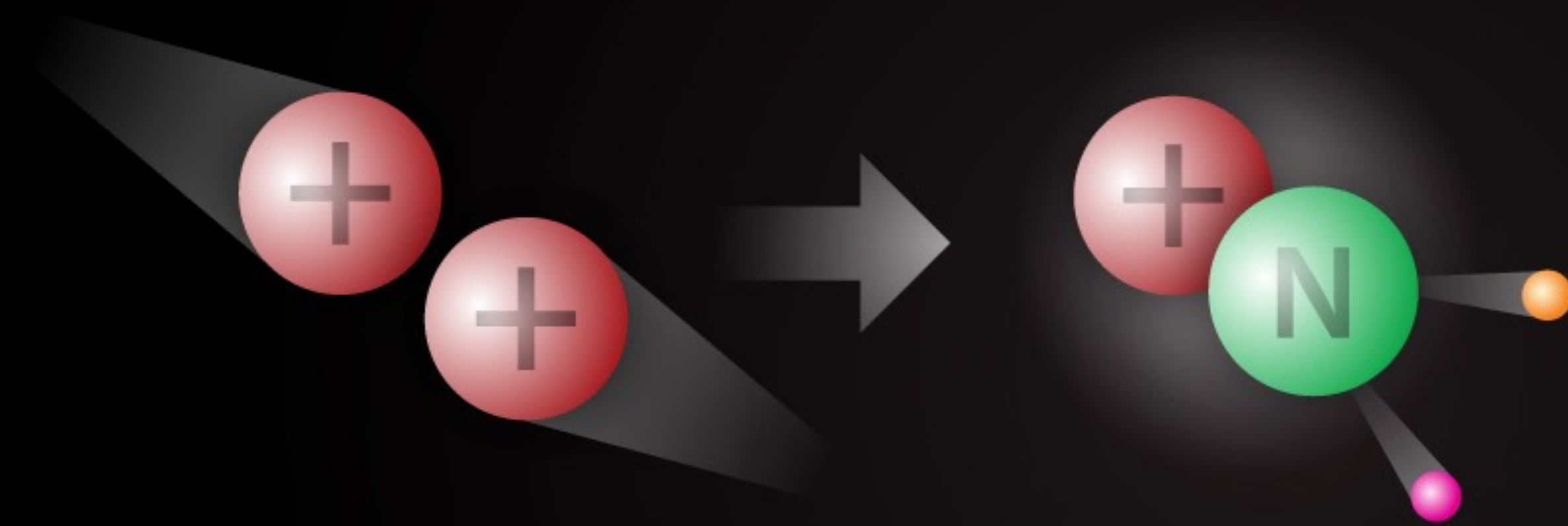
Breaking the bond

Enormous energy is released as gamma rays and neutrinos when the strong nuclear force is broken between protons and neutrons.

<http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/03.html>

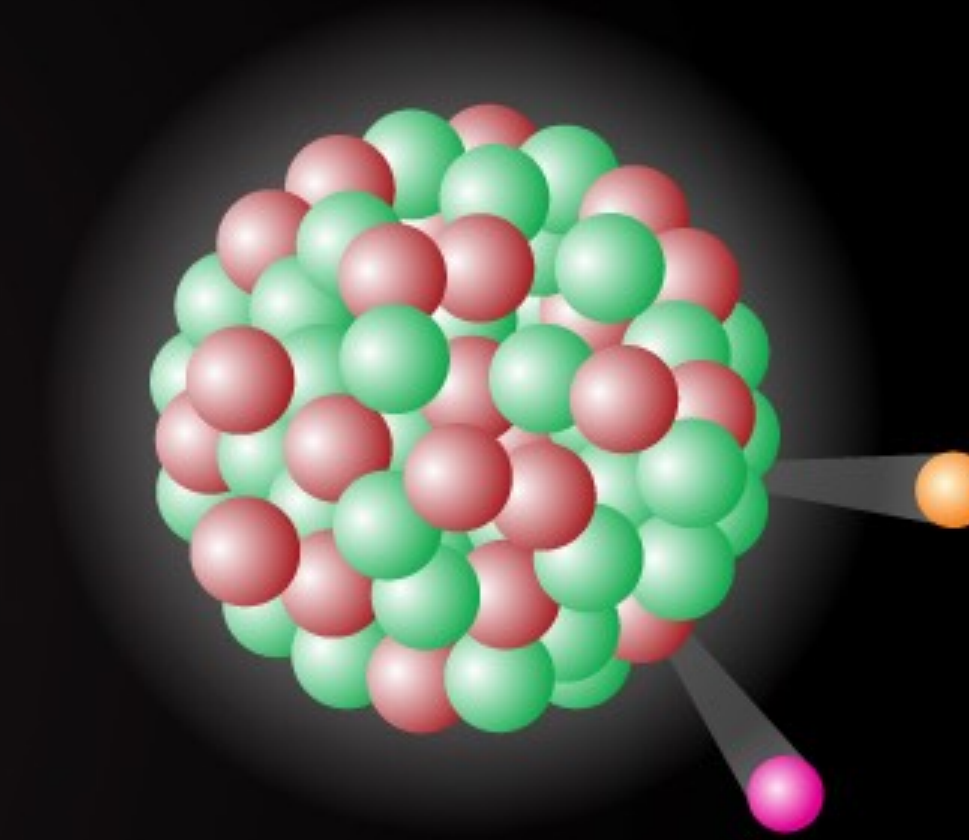
Weak nuclear force

Weak Nuclear Force Z^0 W^\pm



Converting protons into neutrons

When two protons collide and fuse, a disruption in the weak nuclear force emits a positron and neutrino, which converts one of the positively charged proton to a neutrally charged Neutron. Without the weak nuclear force converting protons into neutrons, certain complex nuclei cannot form.

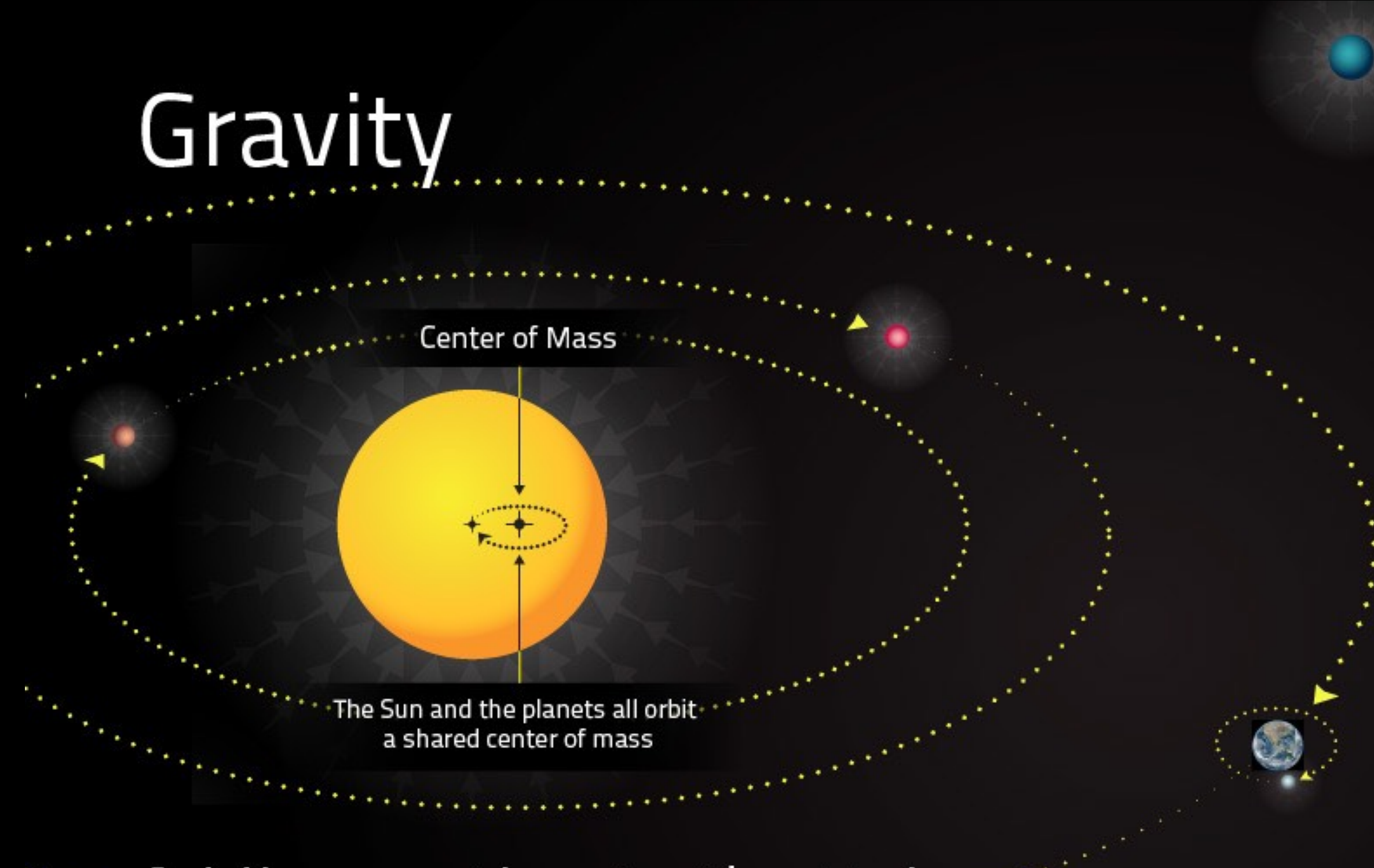


Releasing radiation

Heavy atoms have an imbalance of protons and neutrons, so the weak nuclear force converts protons to neutrons releasing radiation.

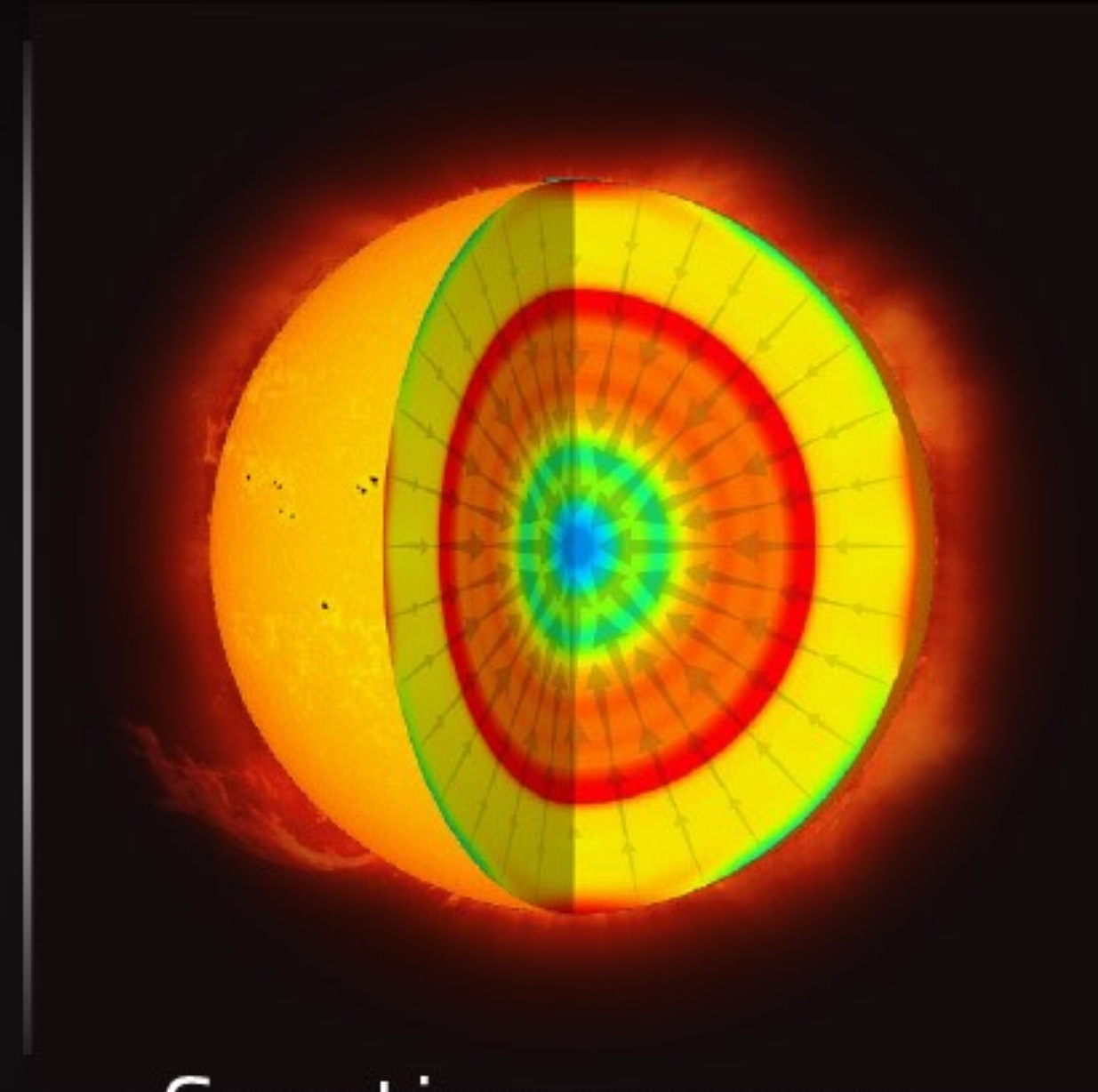
<http://ecup.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/03.html>

Gravity



Adding motion to the Universe

Gravity forms stars, planets, and moons, and forces these objects to spin on an axis and move along an orbital path. The planets appear to be orbiting the center of the Sun, but the Sun and planets all orbit a shared center of mass. Planets with enough mass can develop orbiting moons or rings of debris.



Creating energy

Gravity is the force that creates pressure and fusion energy in the core of stars allowing them to burn for millions of years.

<http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/03.html>

Goals of today high energy particle physics

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

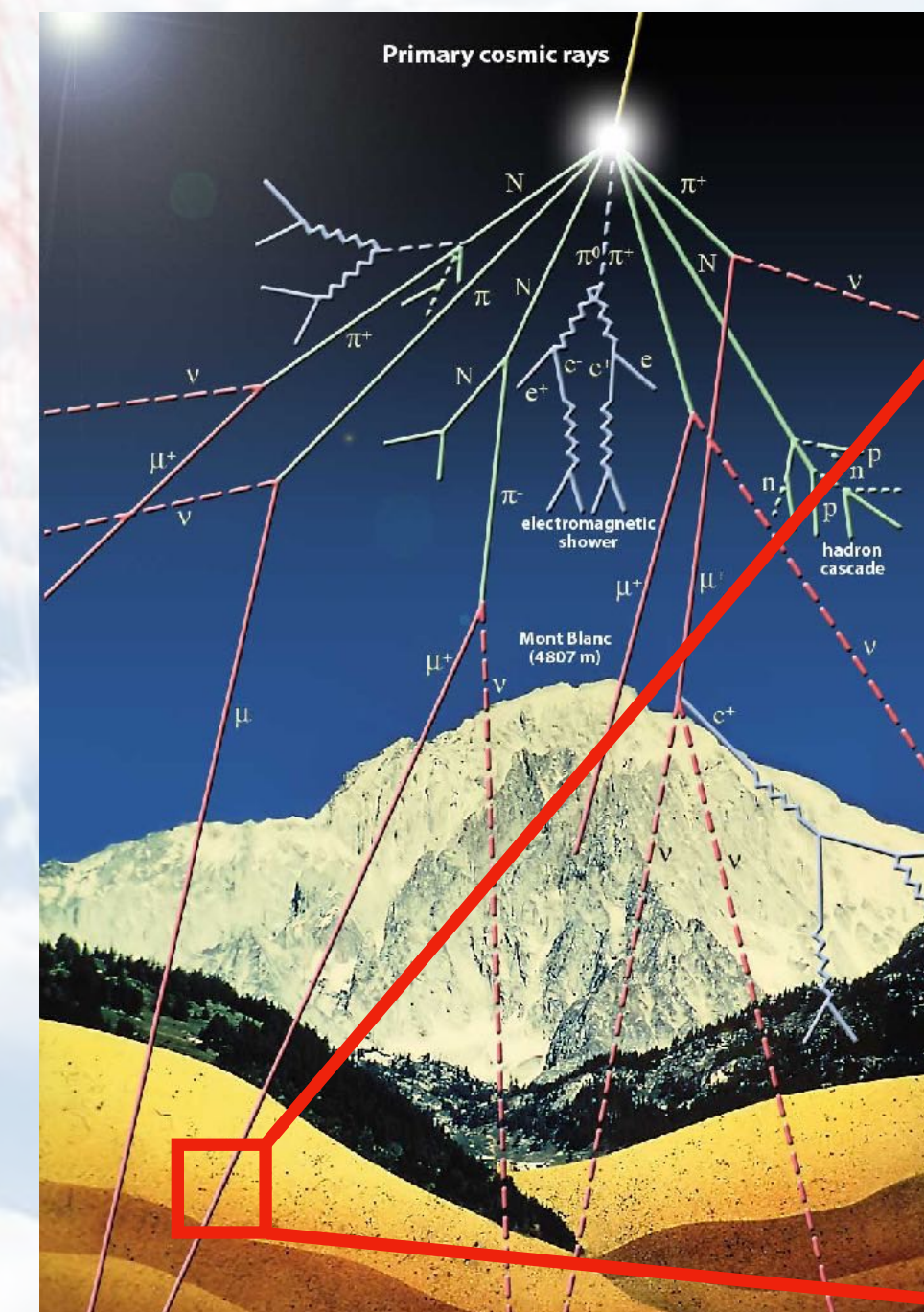
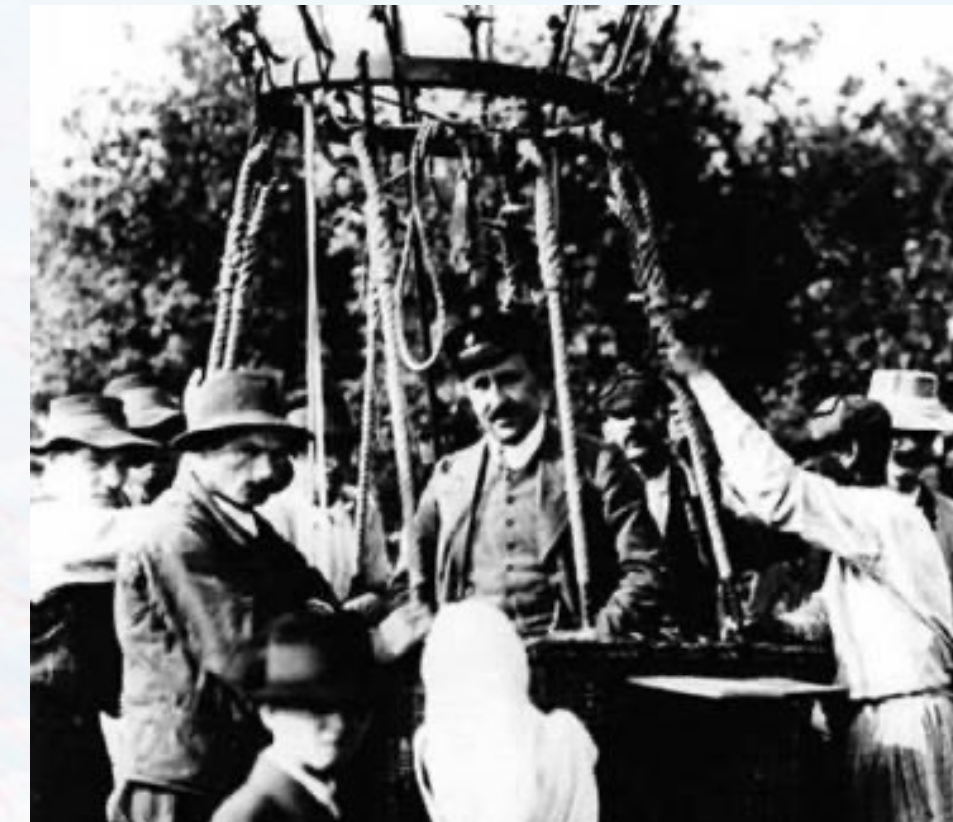
- **SM tells you how, but not why:**
 - Families – 3 families of quark/lepton
 - Number of parameters – 19 free parameters
- **Some phenomenon not explained by the SM:**
 - Gravity – not explained, why so weak?, SM incompatible with general relativity
 - Dark Matter & Dark Energy – accounts for 95% mass 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



Cosmic rays: Particles from outer space accelerators

In 1912, Austrian physicist **Victor Hess** took an ionization chamber aloft in balloon and measured background radiation. He found that from 2000 meters to 5300 meters the amount of radiation increased, indicating the radiation came from space (Hess ruled out the Sun as the radiation's source by making a balloon ascent during a near-total eclipse). He had discovered "**Cosmic Rays**".

Hess shared the 1936 Nobel prize in physics for his discovery, and cosmic rays have proved useful in physics experiments – including several at CERN – since. Cosmic-ray showers were found to contain many different types of particles. Accelerators study these particles in detail.



27 Jan 1971 ... the era of hadron collider has begun

https://www.reddit.com/r/CERN/comments/8xnwz1/the_map_of_cern_and_cutaway_illustration_of_lhcb/



A vacuum chamber where the proton beams collide in the ISR

<http://cds.cern.ch/record/41966>



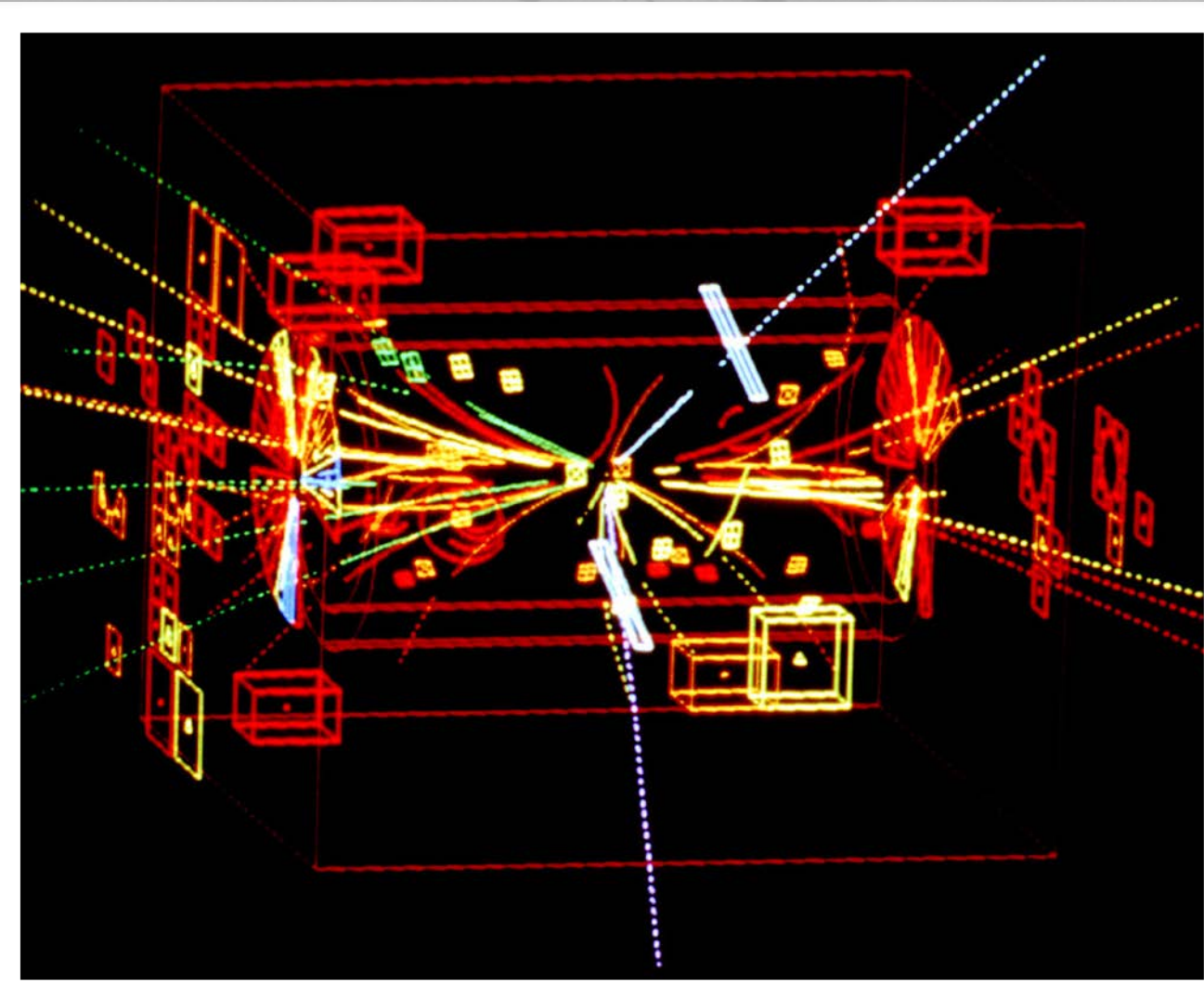
The CERN story on hadron collider started from here

On 27 January 1971, Kjell Johnsen, who led the construction team which built the Intersecting Storage Rings (ISR), announced that the first ever interactions from colliding protons had been recorded.

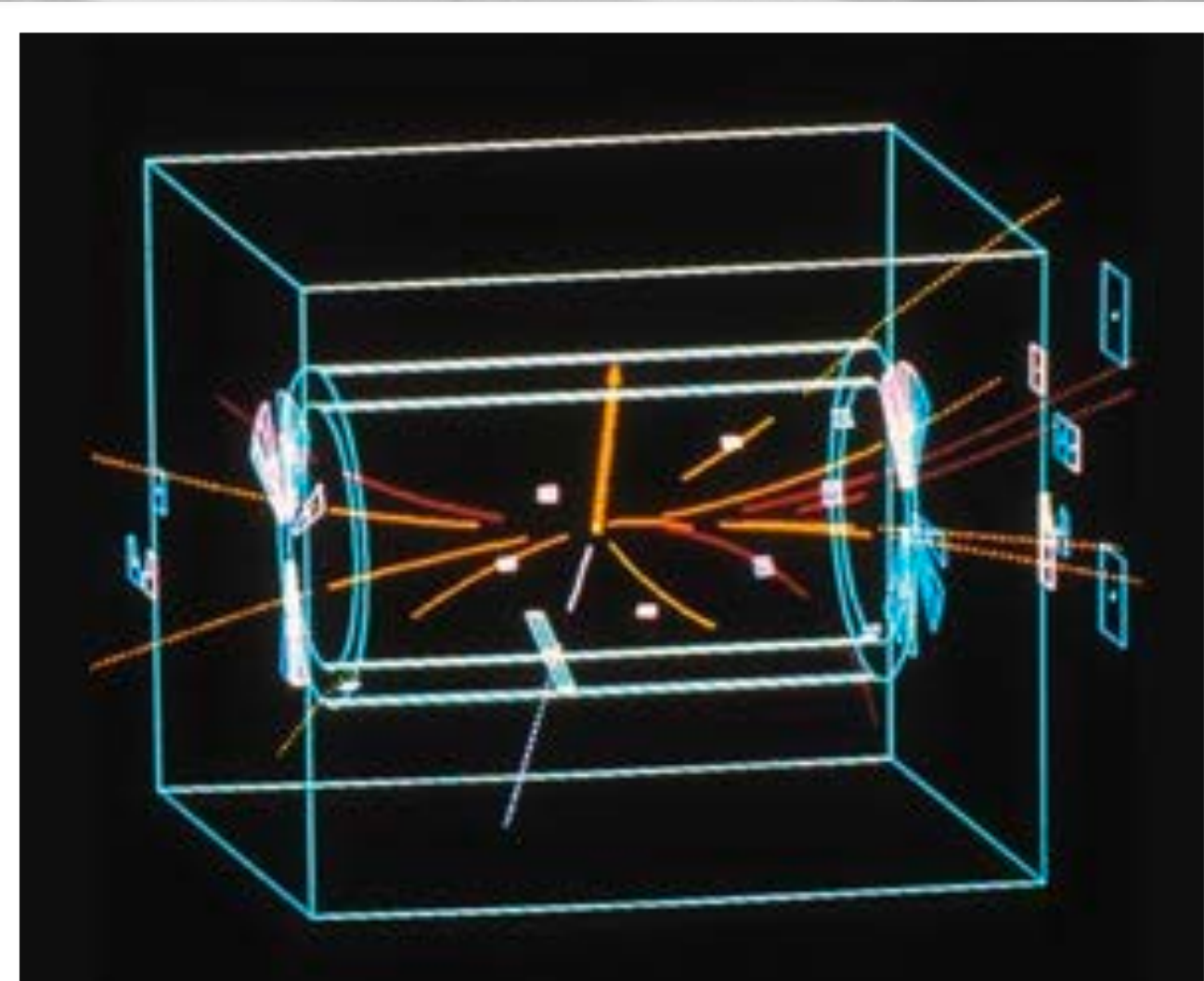
<http://cds.cern.ch/record/39571>



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



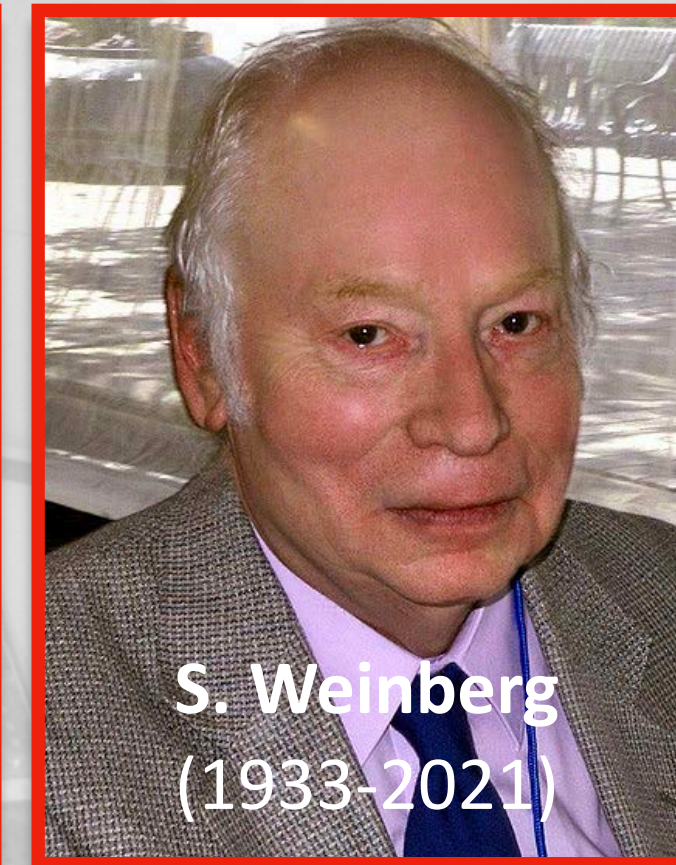
30 April 1983, Image taken by the UA1 which later confirmed to be Z candidate decays to electron-positron pair



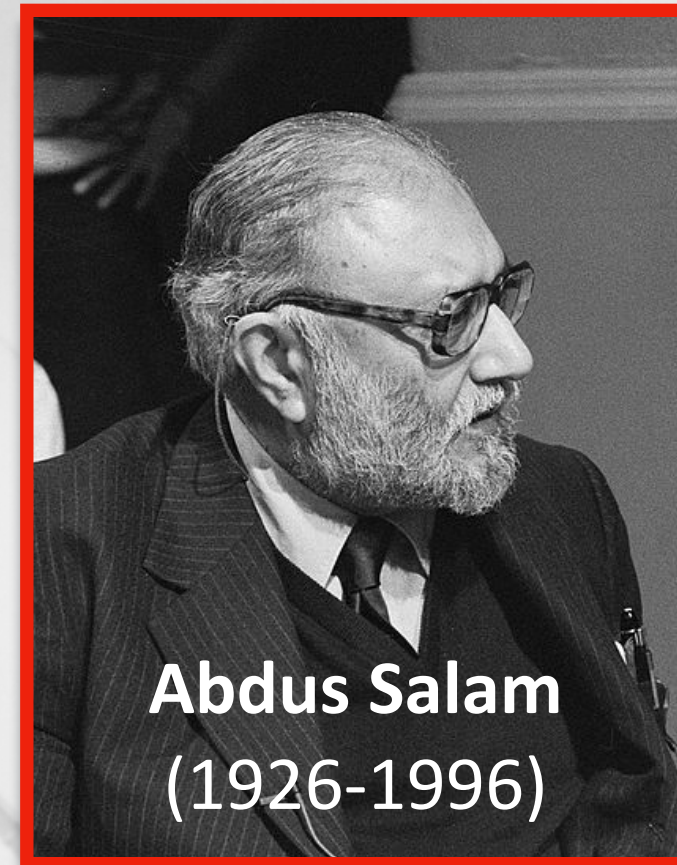
UA1 detected the W candidate event with electron and high missing energy



S. L. Glashow
(1932-)



S. Weinberg
(1933-2021)



Abdus Salam
(1926-1996)

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.

Large Hadron Collider



Timeline: Large Hadron Collider and CMS experiment

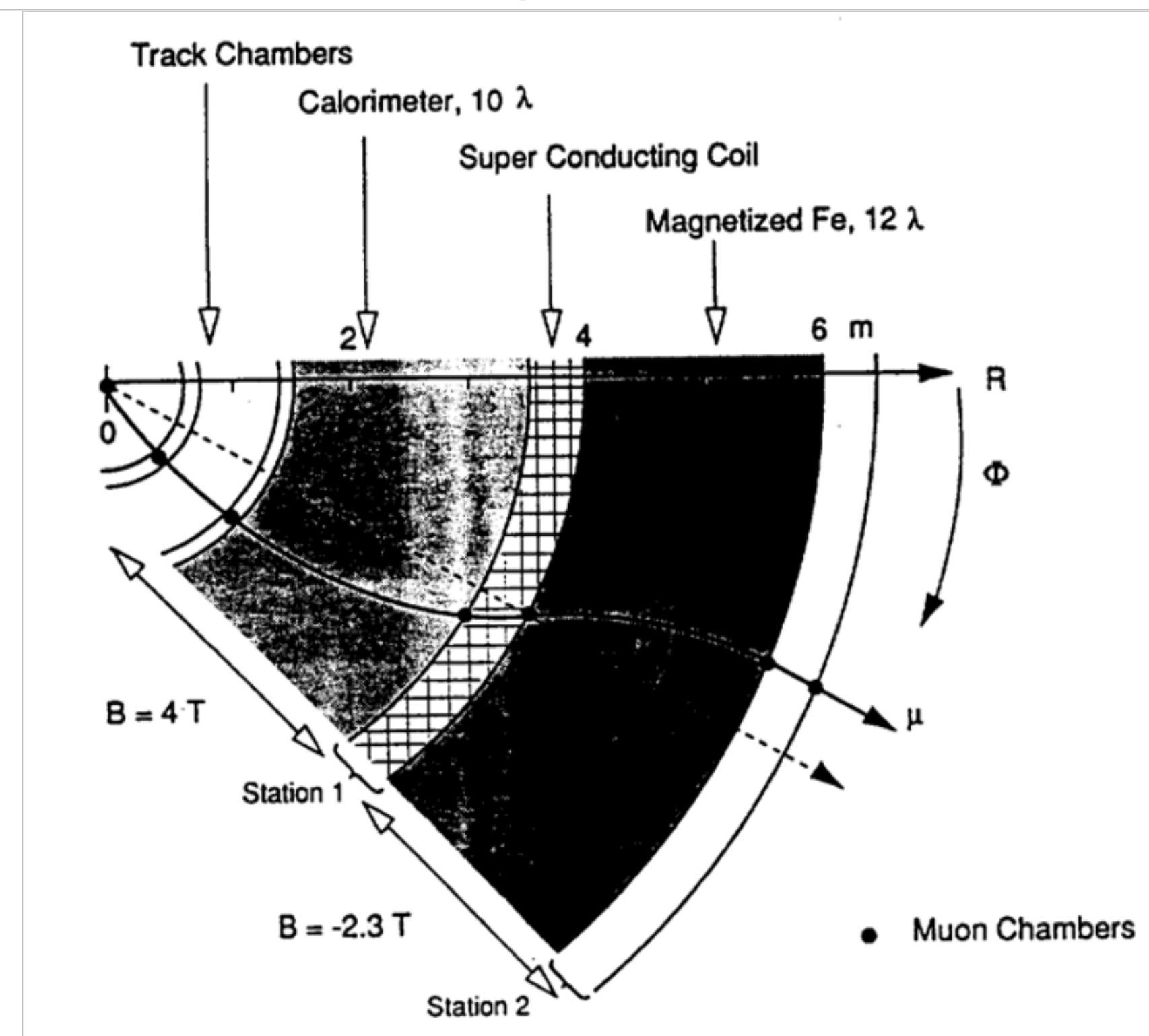
- 1984** Workshop on a Large Hadron Collider in the LEP tunnel, Lausanne
- 1987** CERN's "Long-Range Planning Committee" recommends Large Hadron Collider as the right choice for its future
- 1990** ECFA LHC Workshop, Aachen (physics and technologies)
- 1992** General Meeting on LHC Physics and Detectors, Evian les Bains, 4 EoI's presented.
- 1993** From three Letters of Intent (L3P, CMS, ATLAS), ATLAS and CMS selected by LHCC
- 1994** ATLAS and CMS Technical Proposals Approved
- 1996** Approval to move to Construction (materials cost of <475 MCHF1996)
- 1998** Memorandum of Understanding for Construction Signed
- 1998** Construction Begins (after approval of Technical Design Reports)
- 2000** Assembly begins of ATLAS and CMS (above ground). LEP closes
- 2008** ATLAS & CMS ready for First LHC Beams
- 2009** First proton-proton collisions
- 2012** A new heavy boson discovered with mass $\sim 130 \times$ mass of proton

Compact Muon Solenoid

M. Della Negra, K. Eggert, M. Lanzagorta, M. Pimiä, F. Szoncsó

presented by M. Pimiä

SEFT, University of Helsinki, Finland



Large Hadron Collider by numbers

27KM
(16 MILES)

IN CIRCUMFERENCE

1 PETABYTE-
PER-SECOND

IN RAW DATA GENERATED
BY LHC EXPERIMENTS

1 BILLION
COLLISIONS

OCCUR PER SECOND

100K
TIMES HOTTER THAN
THE SUN'S CORE,

HEAT GENERATED
BY COLLISIONS

<http://www.intelfreepress.com/news/cern-upgrades-data-center-and-restarts-large-hadron-collider/9819/>

99.
99999999%
SPEED OF LIGHT

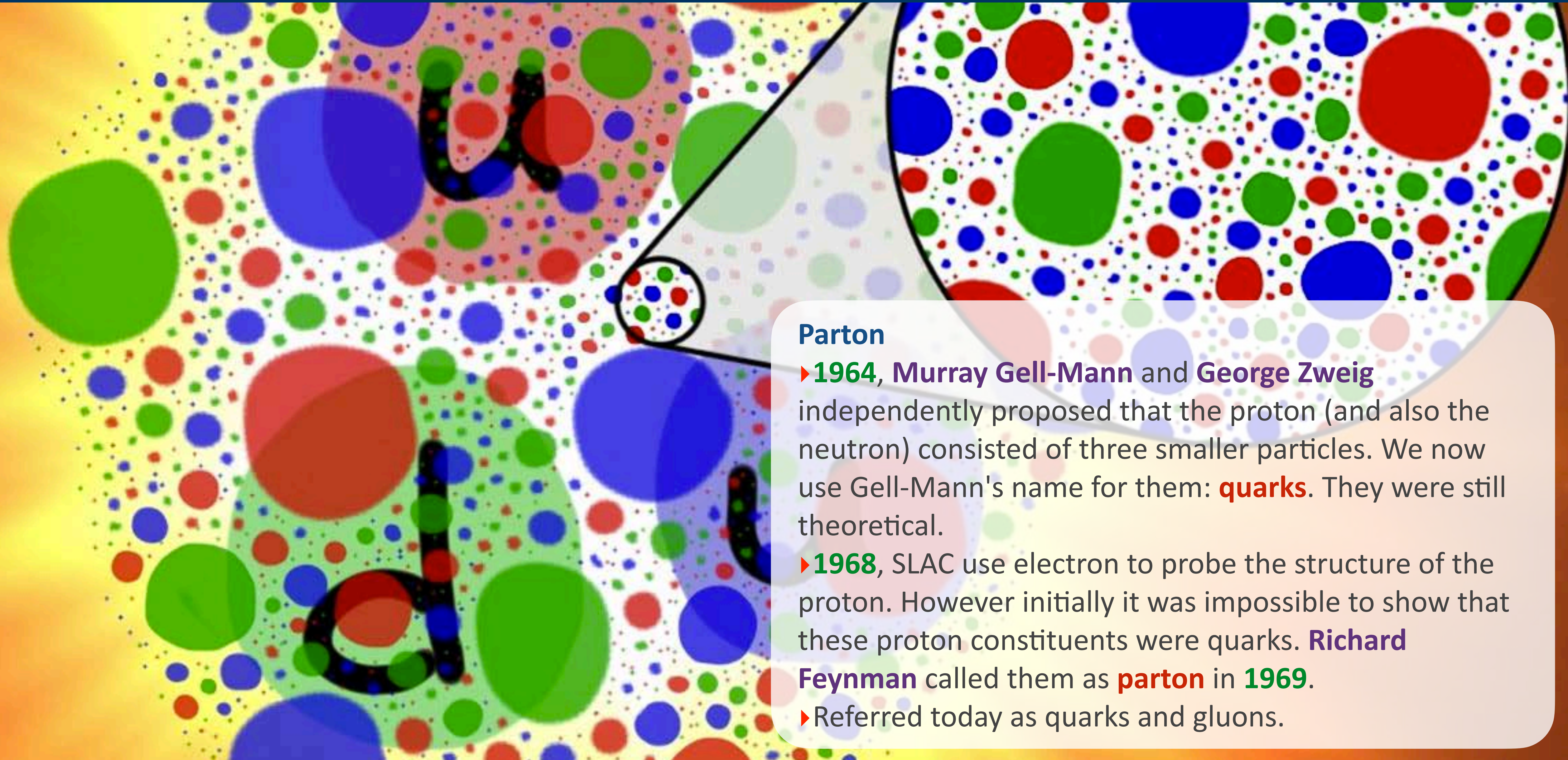
ACHIEVED BY PARTICLES

1.9 KELVIN
(-271.3 DEGREES
CELSIUS)

INTERNAL OPERATING
TEMPERATURE

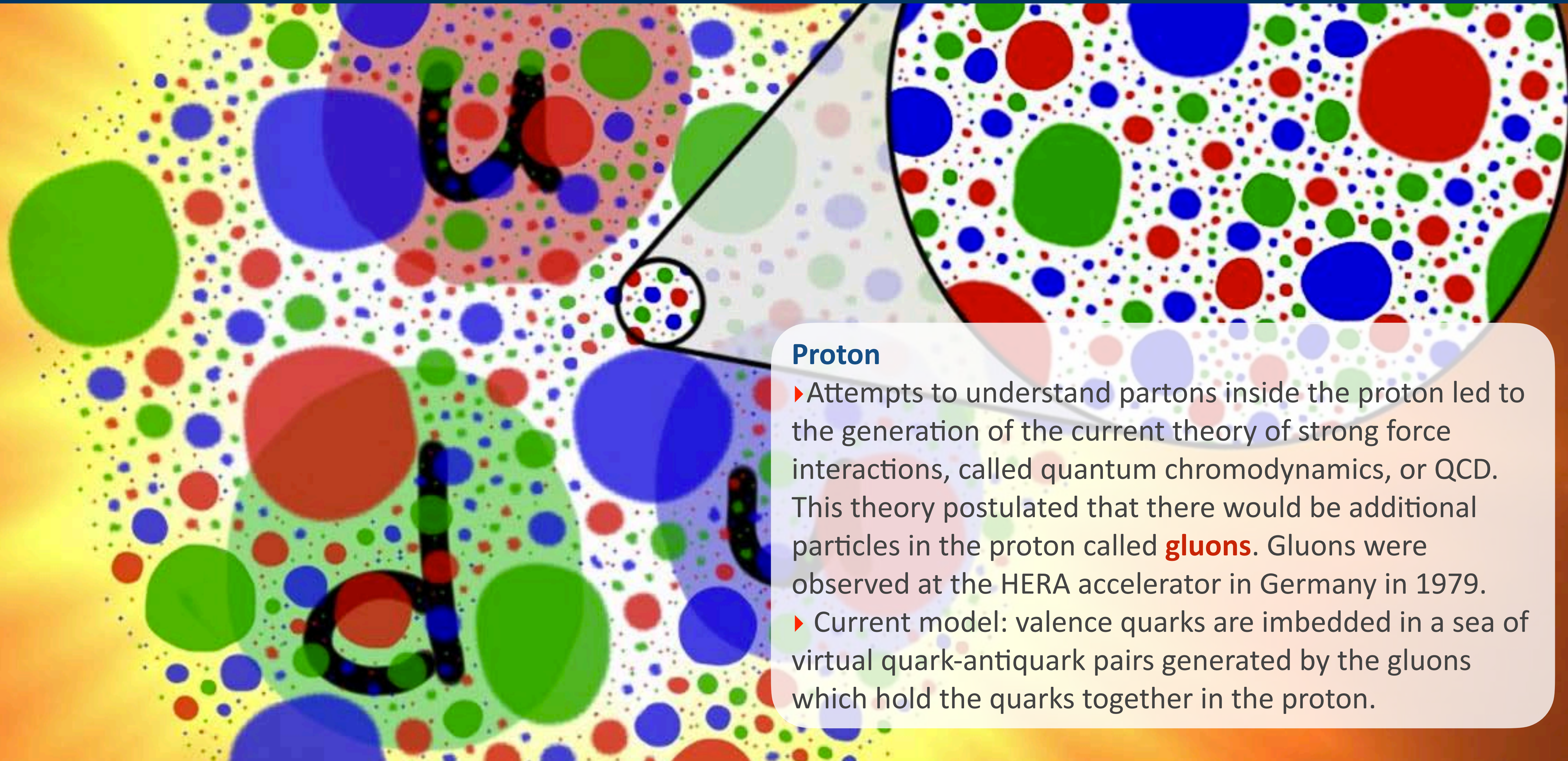
120,000
CORES RUNNING

CERN'S OPENSTACK CLOUD
ACROSS TWO DATA CENTERS



Parton

- ▶ **1964**, **Murray Gell-Mann** and **George Zweig** independently proposed that the proton (and also the neutron) consisted of three smaller particles. We now use Gell-Mann's name for them: **quarks**. They were still theoretical.
- ▶ **1968**, SLAC use electron to probe the structure of the proton. However initially it was impossible to show that these proton constituents were quarks. **Richard Feynman** called them as **parton** in **1969**.
- ▶ Referred today as quarks and gluons.

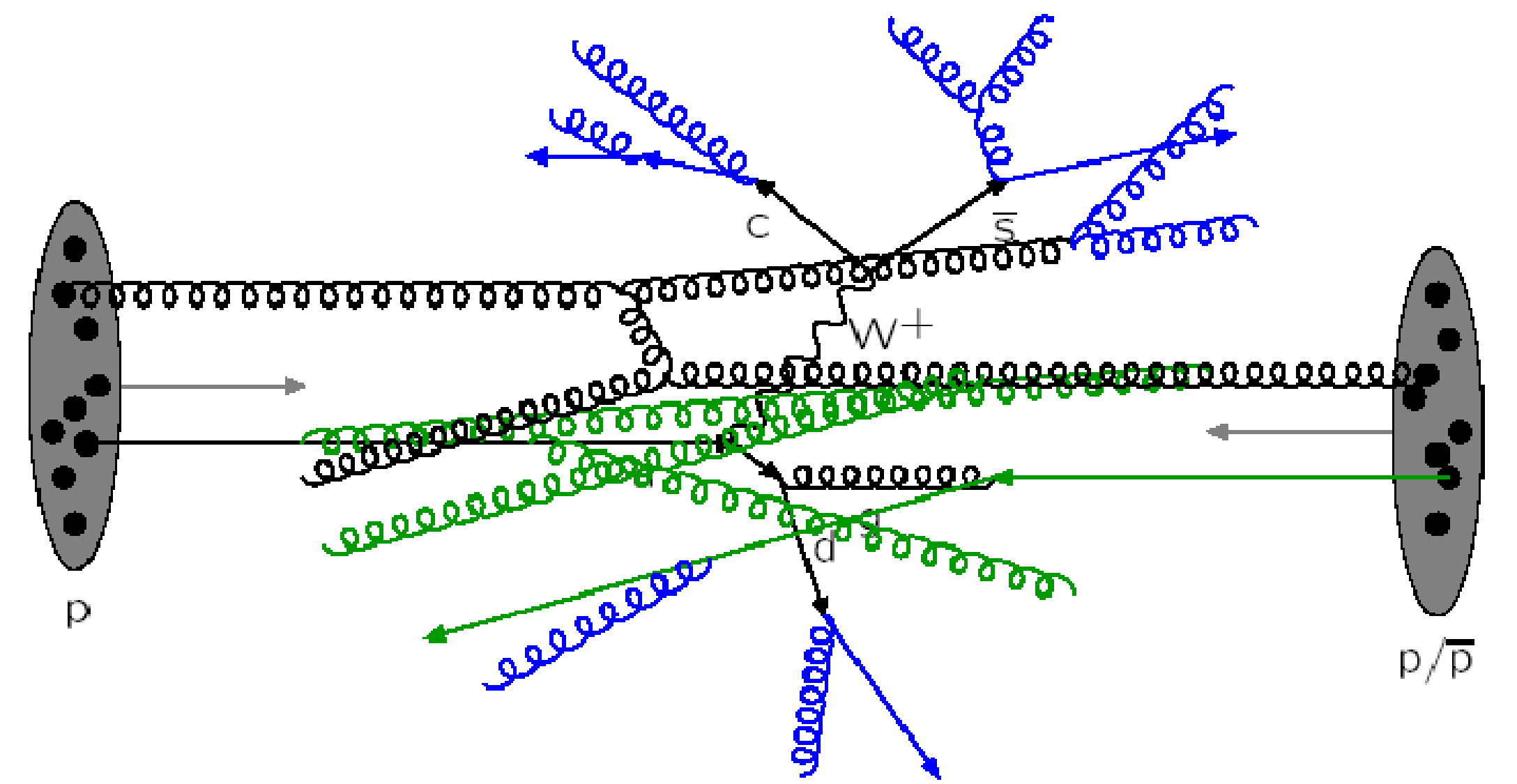
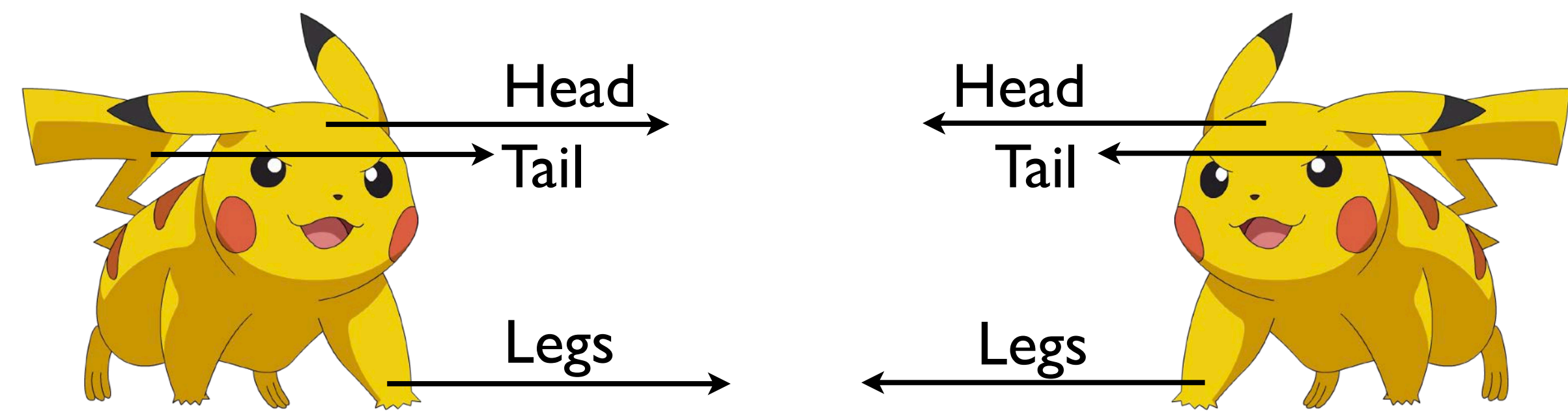


Proton

- ▶ Attempts to understand partons inside the proton led to the generation of the current theory of strong force interactions, called quantum chromodynamics, or QCD. This theory postulated that there would be additional particles in the proton called **gluons**. Gluons were observed at the HERA accelerator in Germany in 1979.
- ▶ Current model: valence quarks are imbedded in a sea of virtual quark-antiquark pairs generated by the gluons which hold the quarks together in the proton.

Proton collision

When “You” watch Pikachu fighting, you watch one-by-one interaction, i.e. Head-vs-Head, Tail-vs-Head, Head-vs-Leg, and then you are looking for the final result. This is the same case as proton interaction.



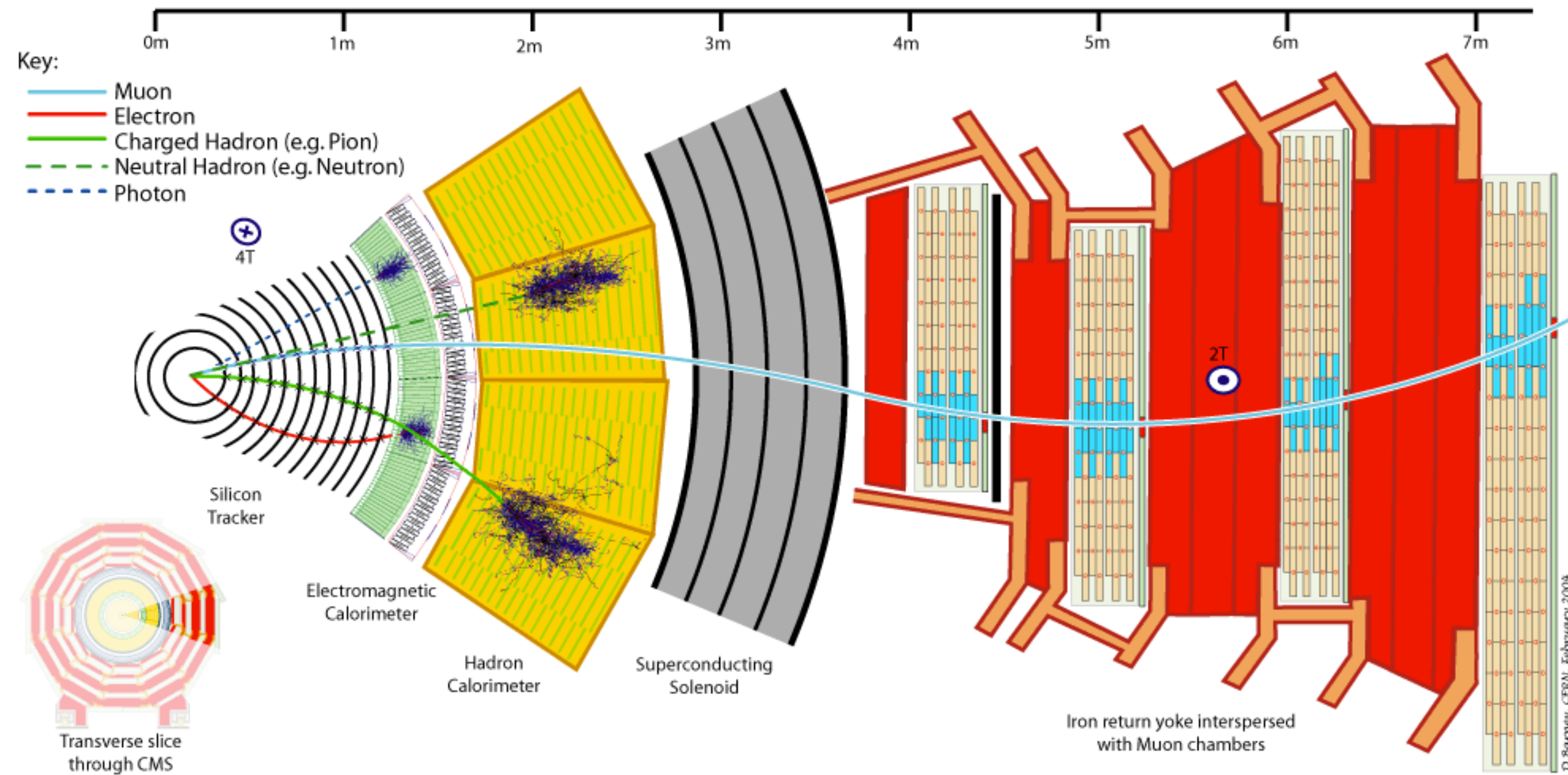
Particle detection

In experimental physics, a particle detector or radiation detector is an instrument used to detect, to track and to identify elementary particles by measuring one or more properties of them.

Particle detectors are devices producing an observable signal when they are crossed by a particle. Usually they are made by an active element (such that there is some interaction with the particle) and by a readout system (“forming” the signal and sending it to the data acquisition chain)

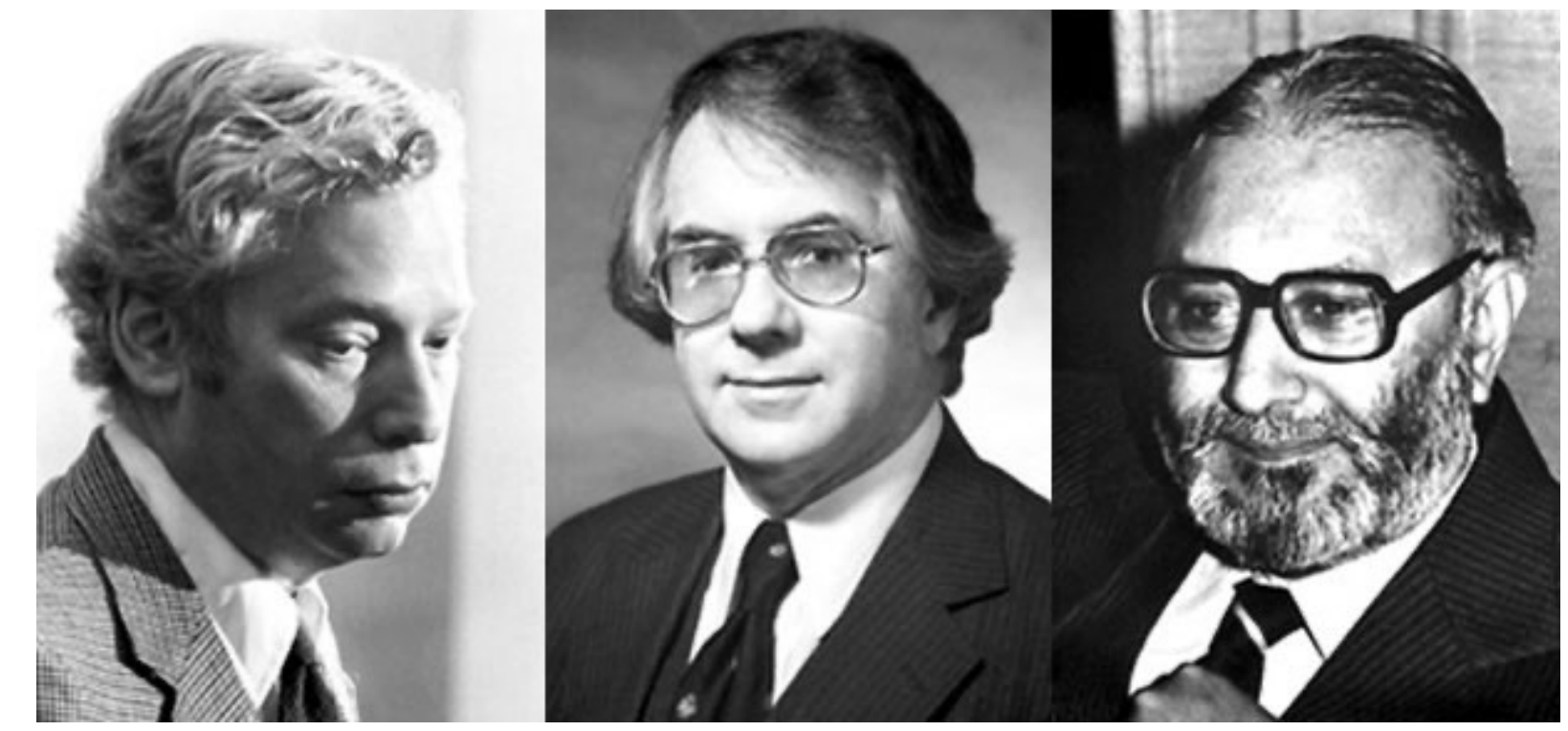
Aim: to detect as many of the stable and long-lived particles produced in a particle collision.

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



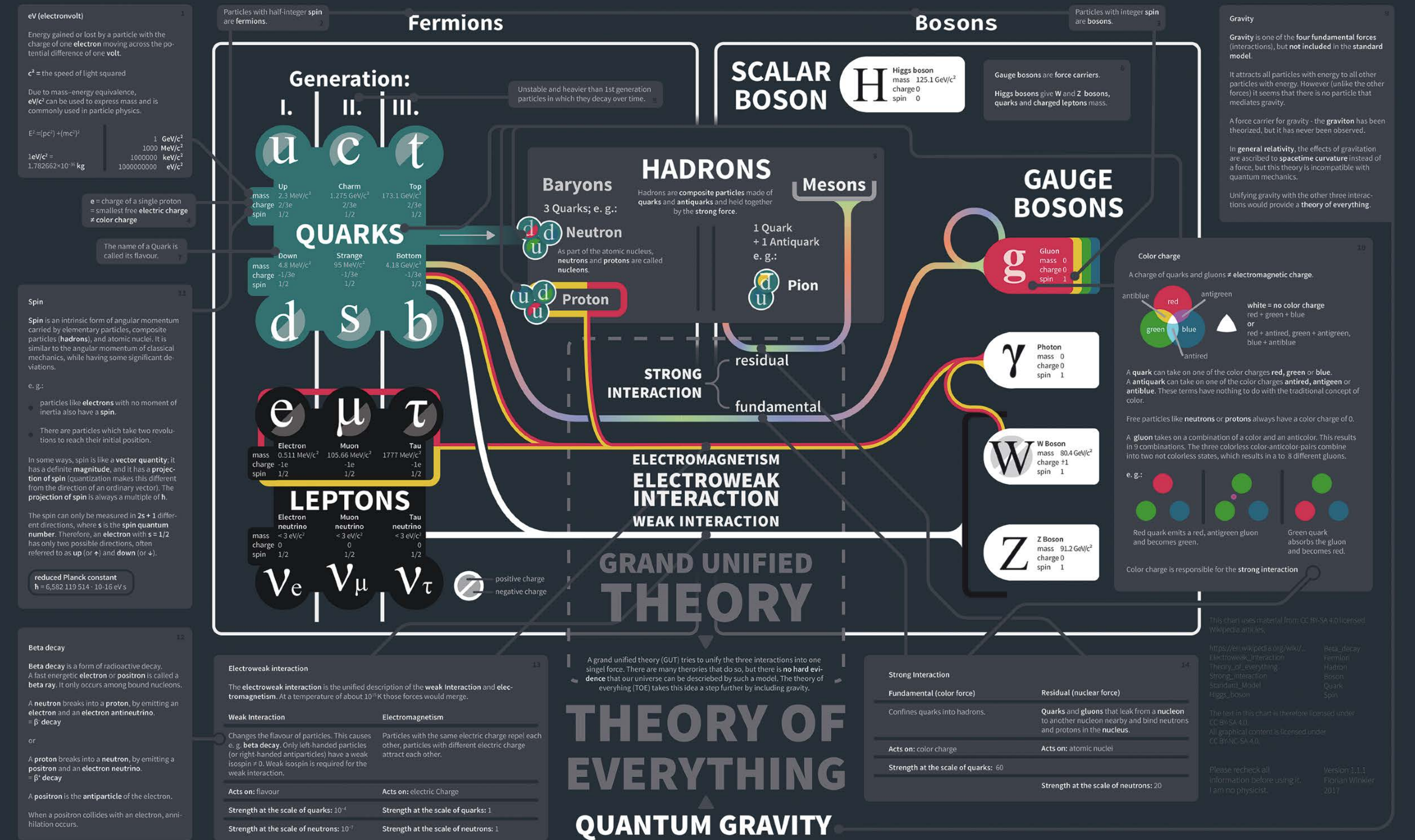
Standard Model

The Standard Model (SM) of particle physics is the theory describing three of the four known fundamental forces (the electromagnetic, weak, and strong interactions, and not including the gravitational force) in the universe, as well as classifying all known elementary particles.



Steven Weinberg Sheldon Glashow Abdus Salam

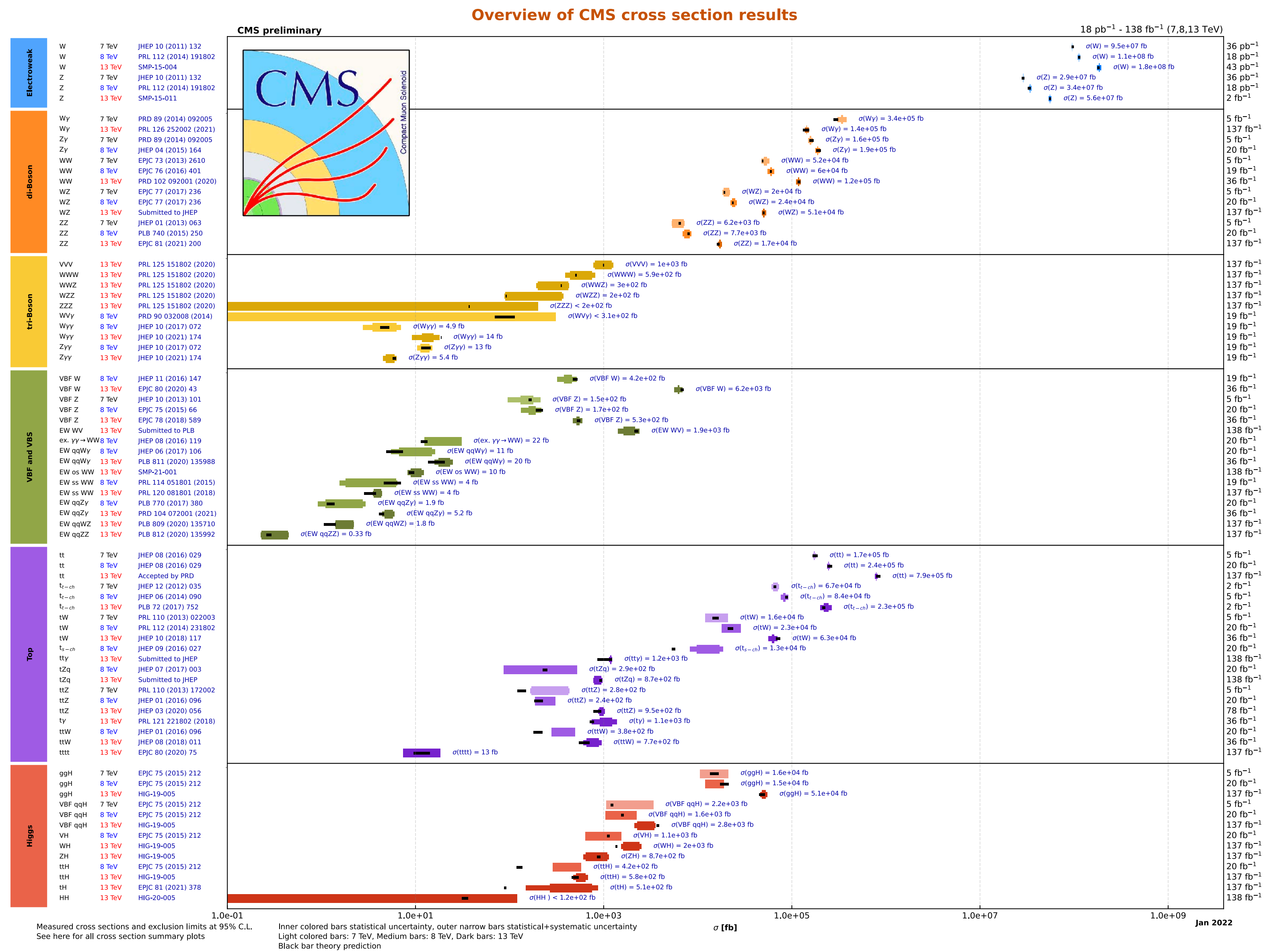
THE STANDARD MODEL OF PARTICLE PHYSICS



LHC with Standard Model

Since the 7 TeV data collection started in 2011, until now, LHC physics program shows that SM (still) works very well and Higgs (with mass 125 GeV) is there. However, one need to remember than studying known processes is very challenging:

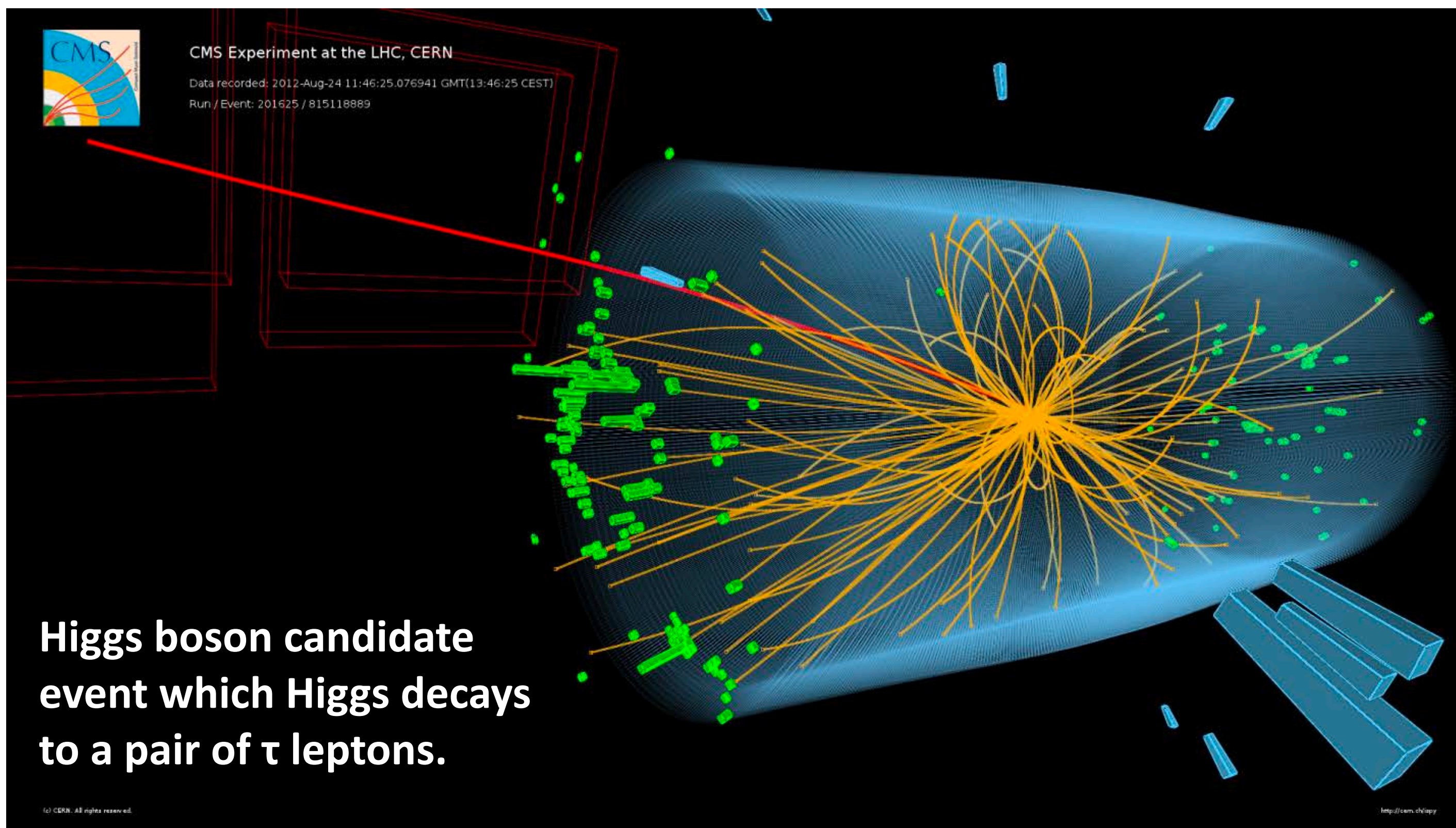
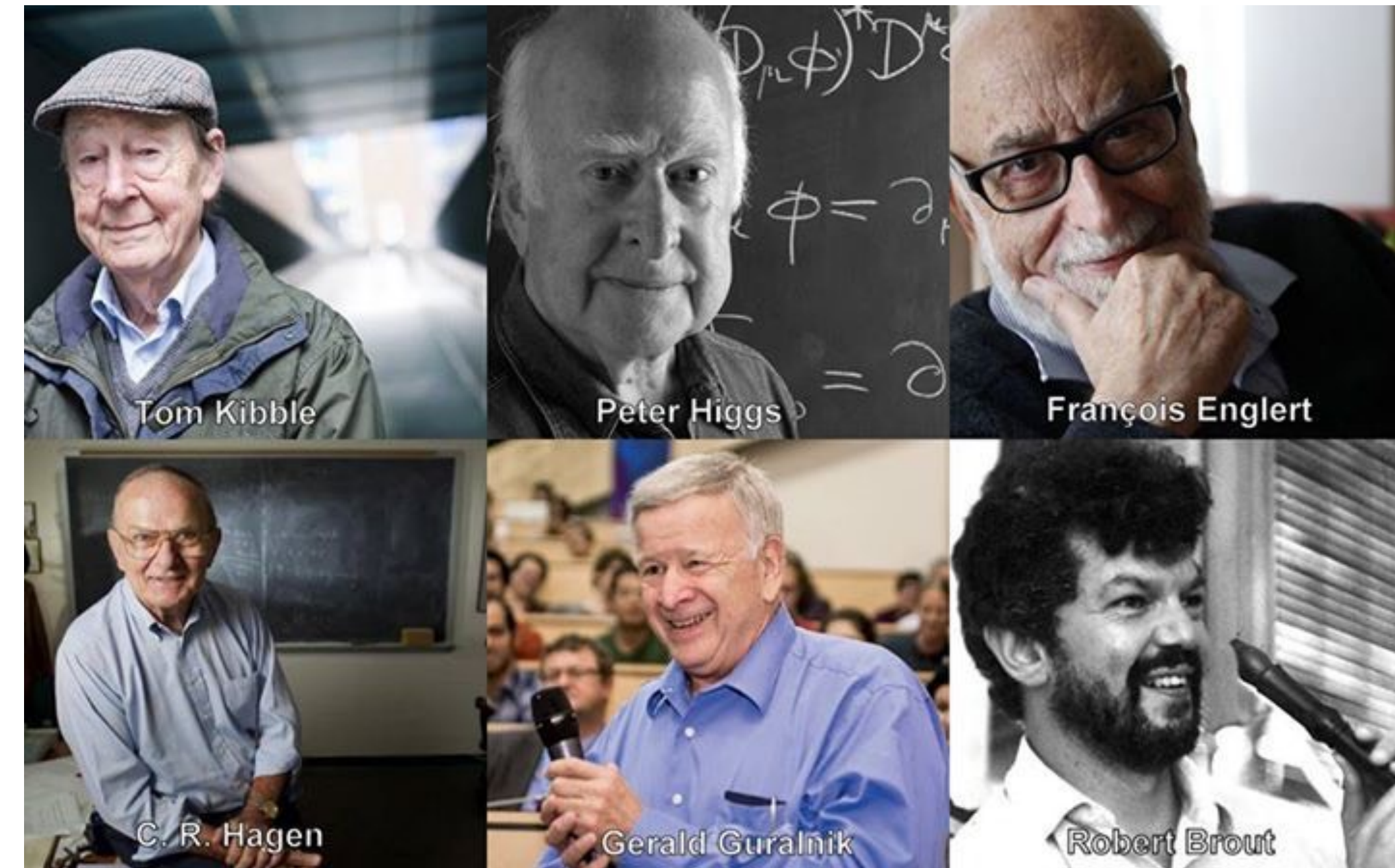
- Excellent performance and calibration
- Probe uncovered parameter space
- Try new techniques to enhance Signal/Background separation, i.e. new machine learning techniques



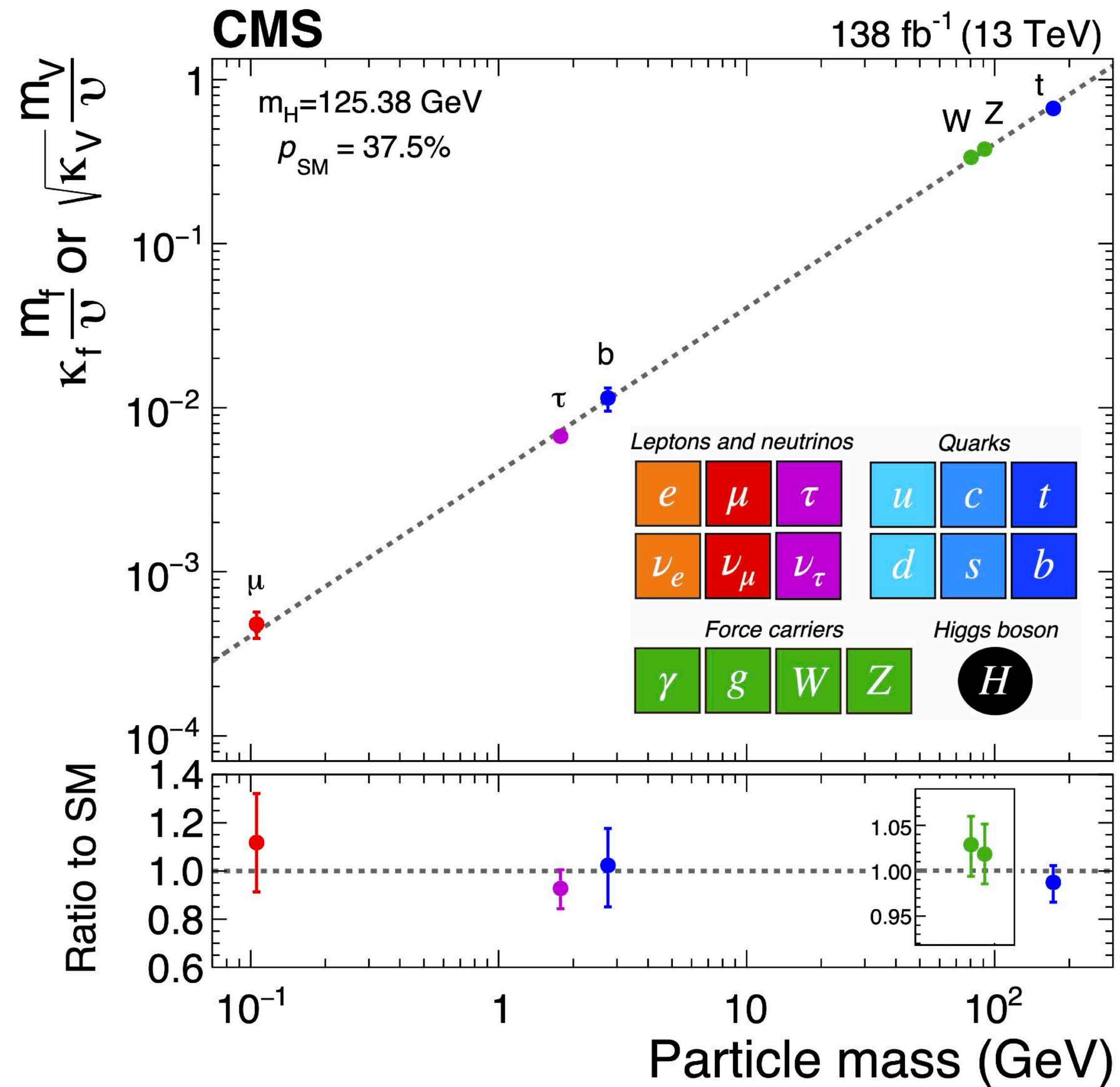
Mass of elementary particles?

One missing piece was the way to explain masses of elementary particles. In the mid 1960s, the mechanism to explain the mass generation came out by three independent groups,

- by **Robert Brout** and **François Englert** [Phys. Rev. Lett. 13, 321];
- by **Peter Higgs** [Phys. Rev. Lett. 13, 508];
- by **Gerald Guralnik**, **C. R. Hagen**, and **Tom Kibble** [Phys. Rev. Lett. 13, 585].



Mass of elementary particles?



The Higgs boson is predicted to couple to particles (or decay into them) with a strength depending on their masses in a well-defined way: the higher the mass, the stronger the coupling. The measurement of the many ways this Higgs boson decays and the measurement of its couplings to different particles, shown in the figure, provide a crucial test of the validity of existing theories.

All the measurements of the properties of the Higgs boson presently agree with the theoretical predictions within the measurement and prediction uncertainties.

[Link]

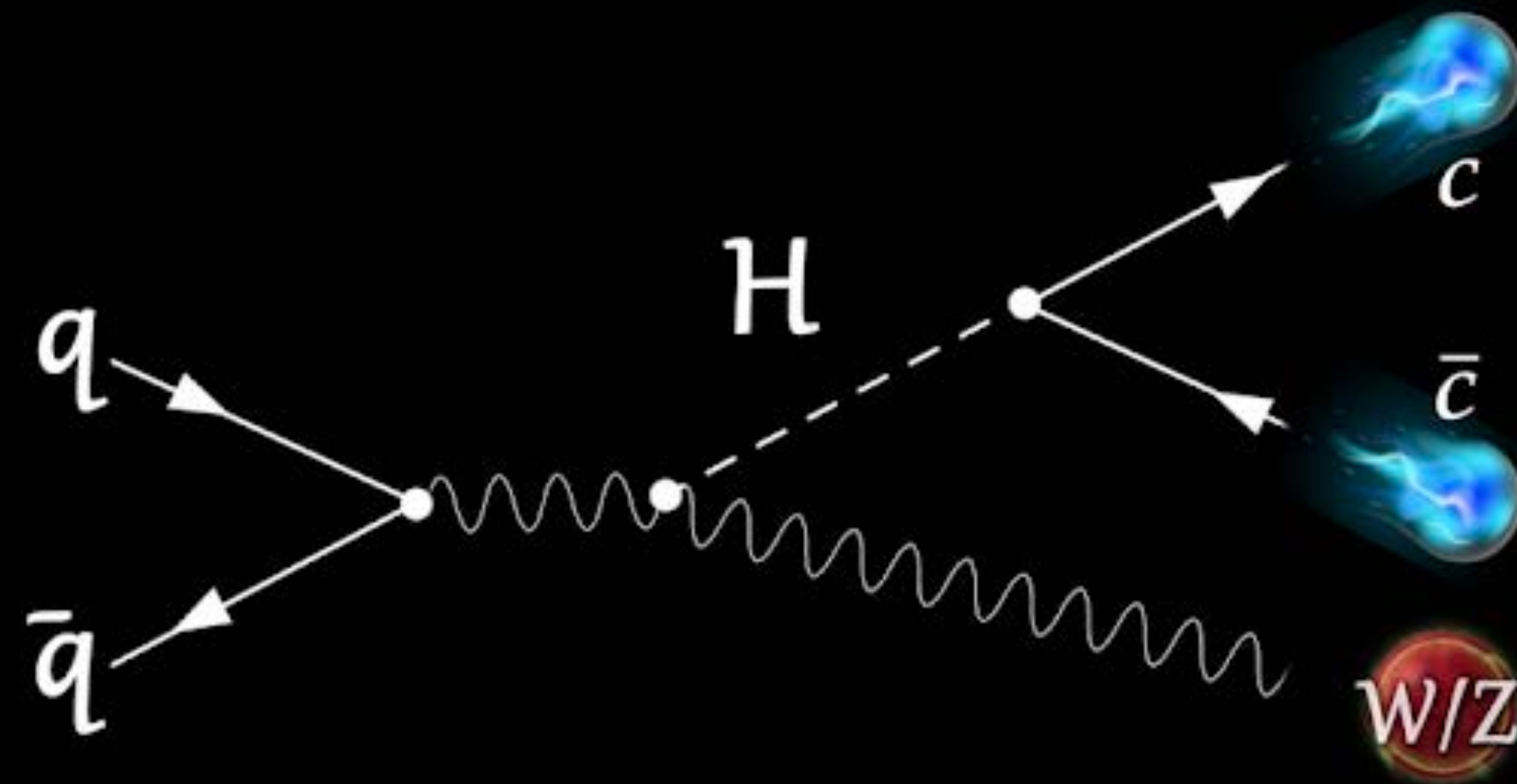
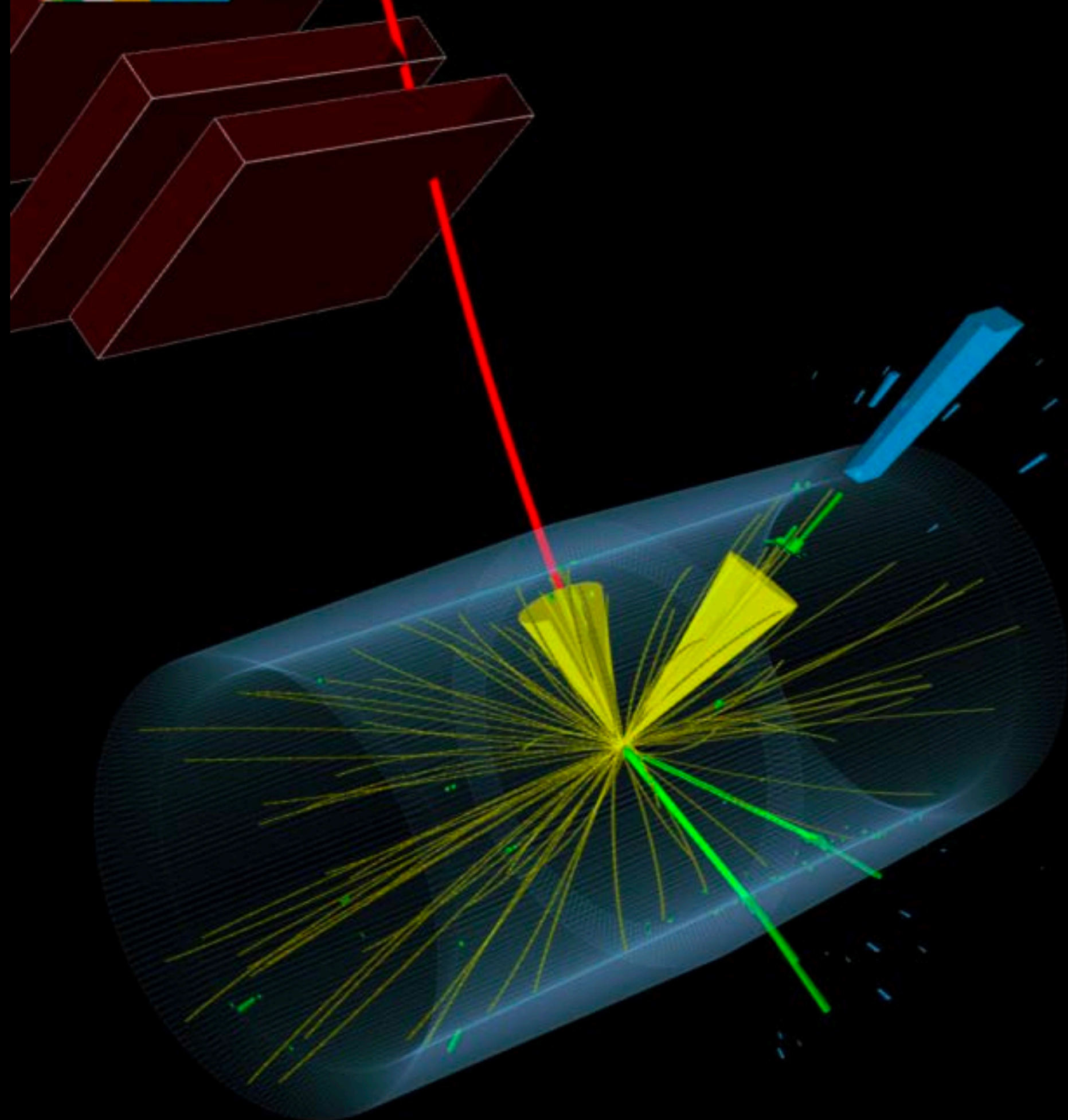
Higgs ... from *search* to *precision measurement*



CMS Experiment at the LHC, CERN

Data recorded: 2018-Aug-05 09:43:33.747957 GMT

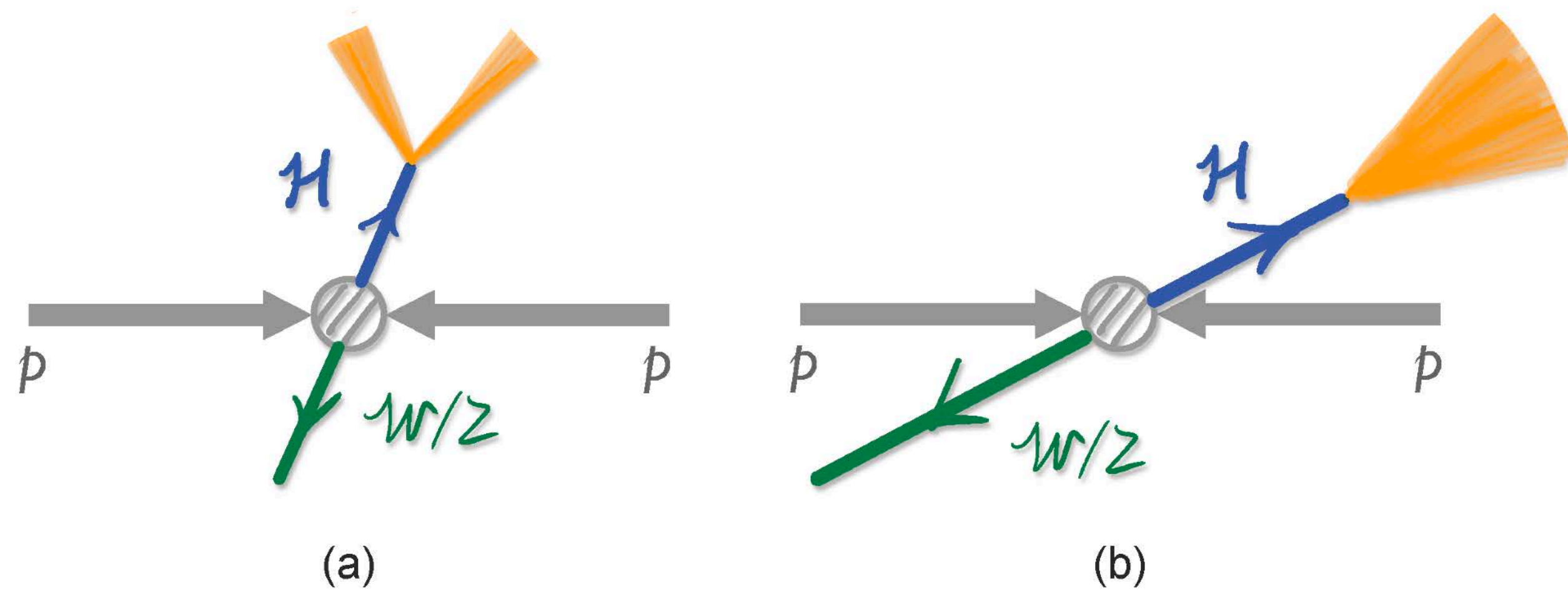
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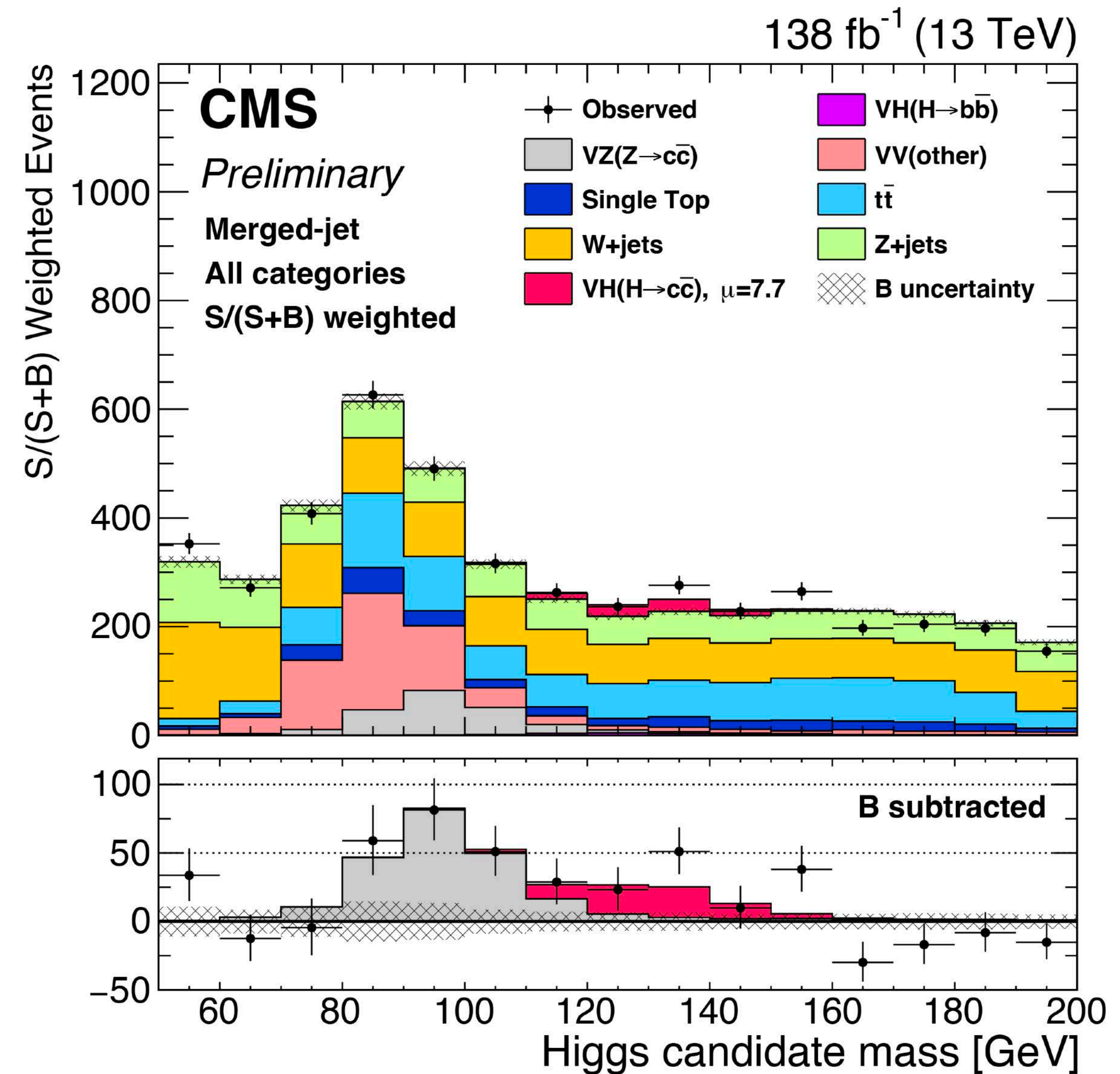
We know that Higgs is there, why do we need precise measurements?

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.

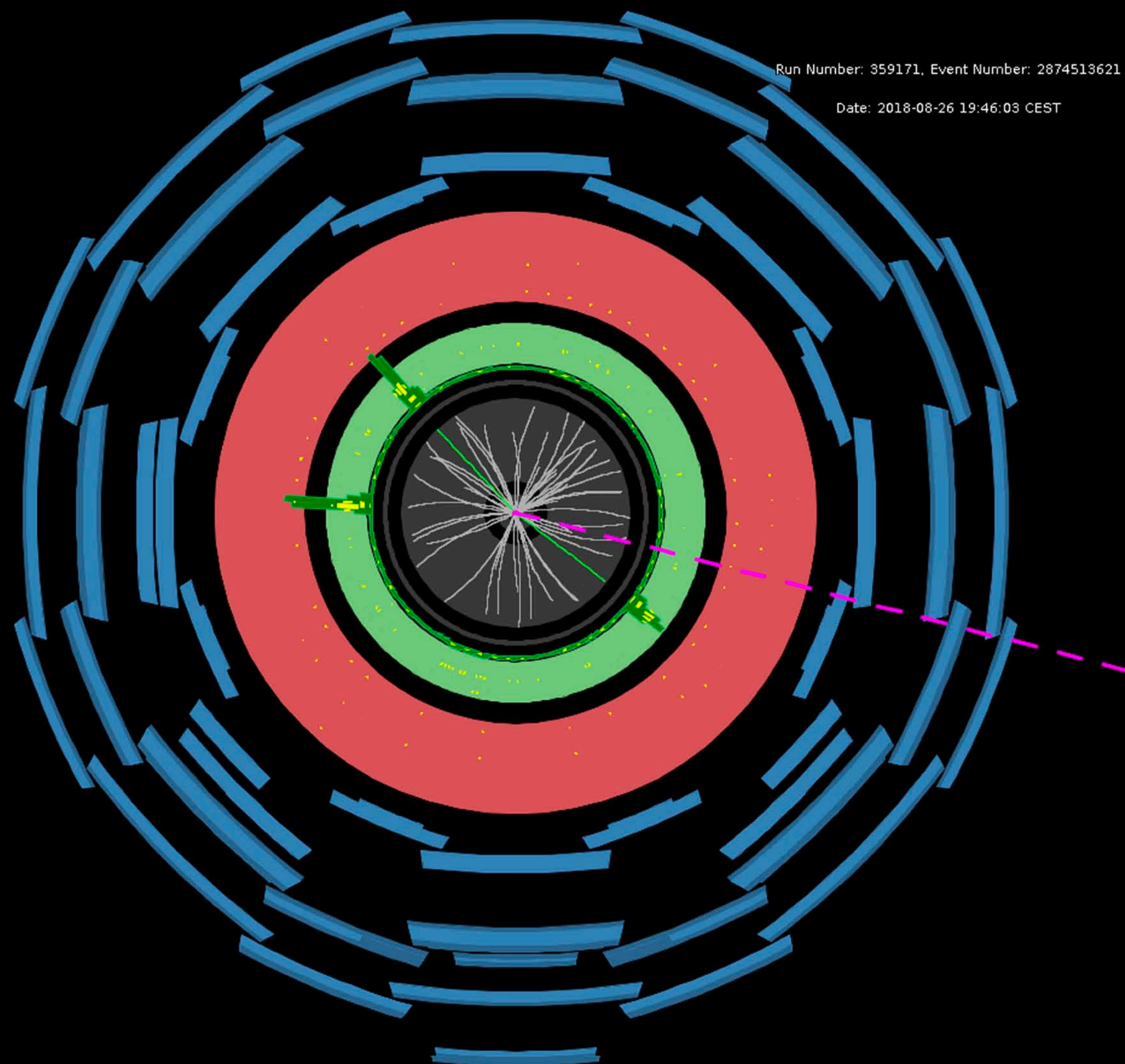
Higgs ... from *search* to *precision measurement*



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



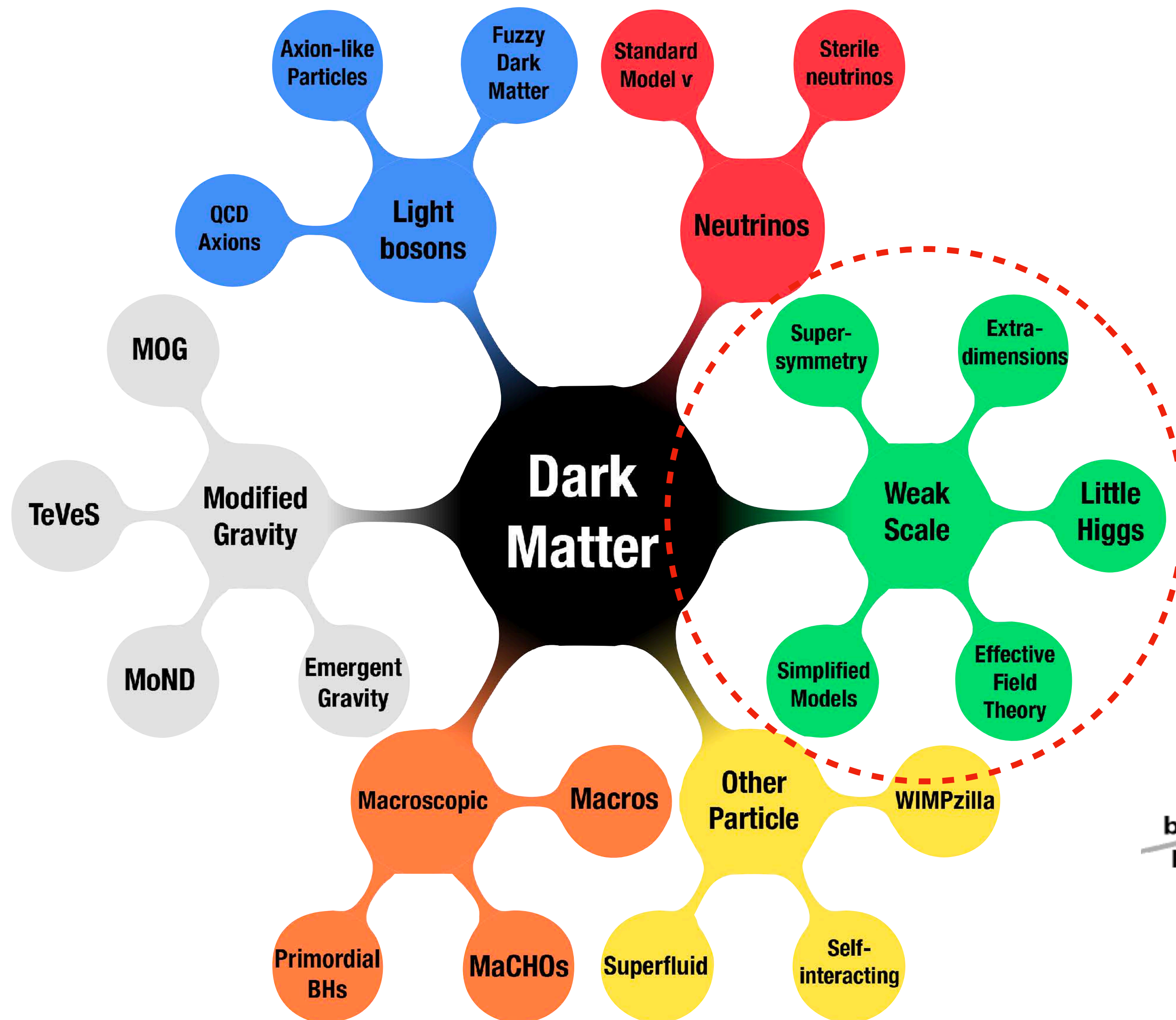
Higgs as a tool to search for the dark sector



- Dark matter might be part of a complex “dark sector” of particles beyond the Standard Model.
- Dark matter can have its own internal symmetry structure and interactions.
- Dark photon is a predicted mediator particle for interactions in this new sector.
- If dark photons interact with Standard Model particles, they could be produced in high-energy proton-proton collisions at the LHC and be detected by the LHC experiments.
- Looking for ZH production
 - Z decays to two leptons
 - H decays to photon and dark photon

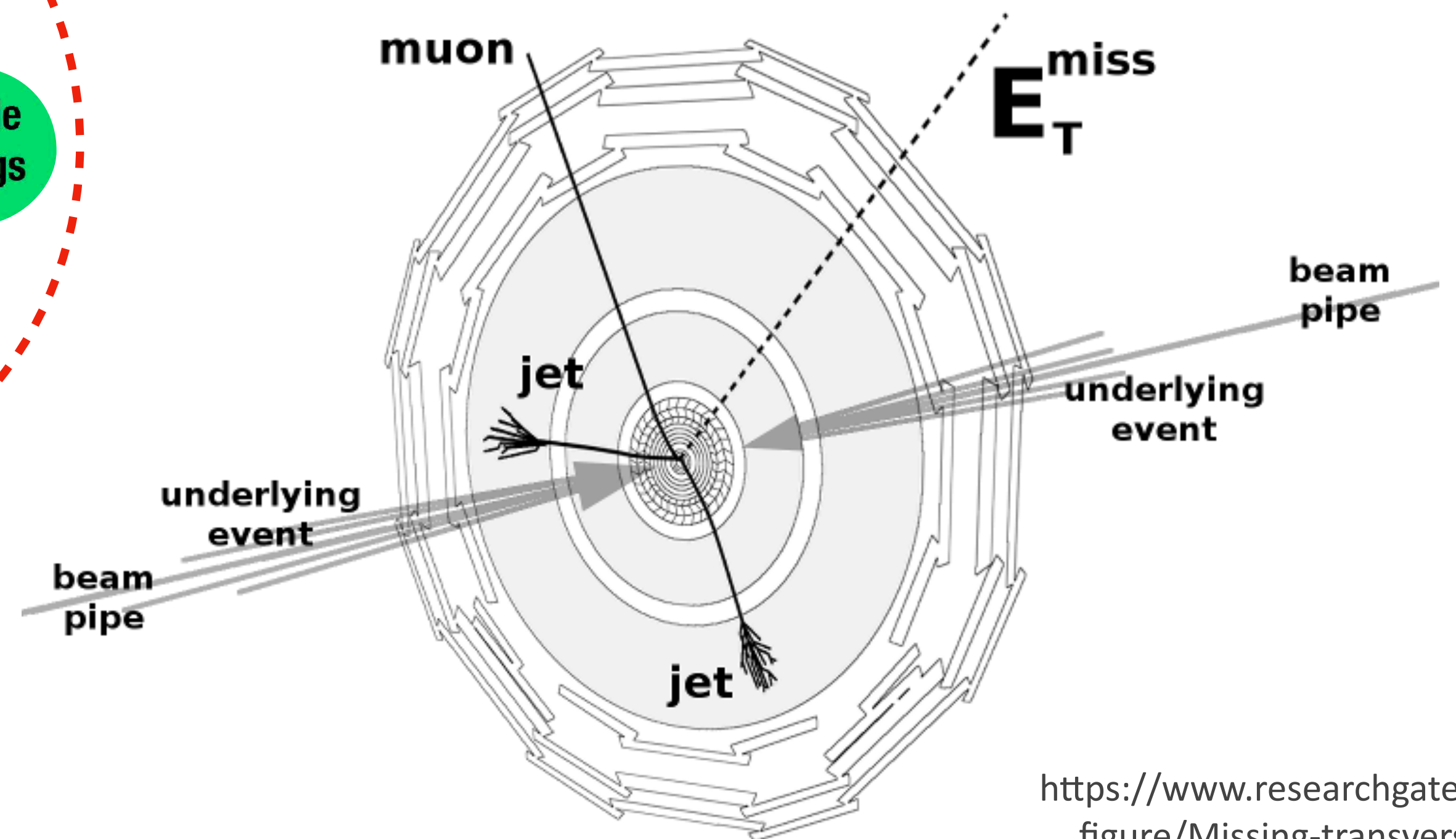
<https://atlas.cern/Updates/Briefing/Higgs-Dark-Photon>

Exotic searches: Dark Matter searches at collider



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

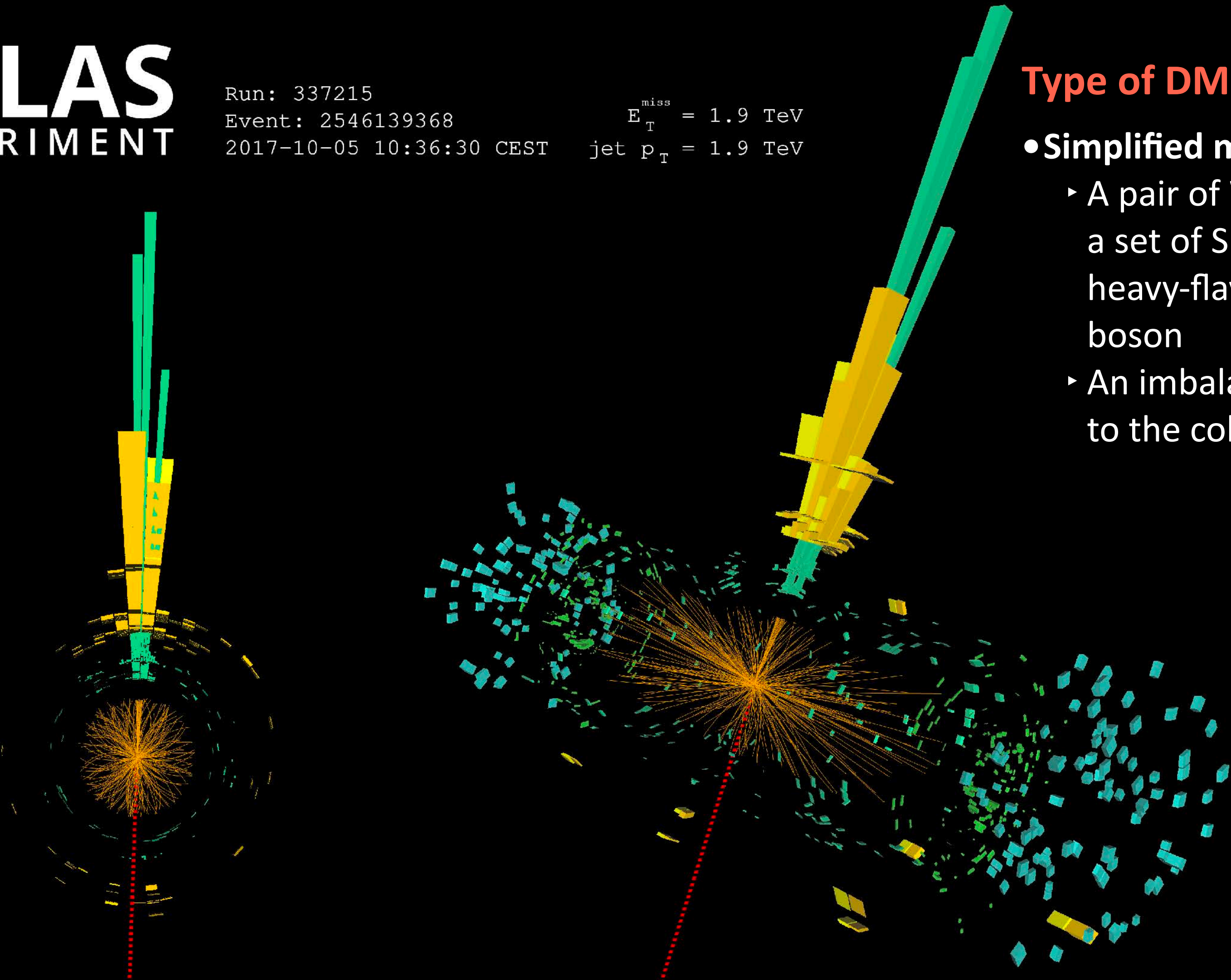
<https://home.cern/news/series/lhc-physics-ten/breaking-new-ground-search-dark-matter>

Exotic searches: ~~Darth Vader~~ Dark Matter



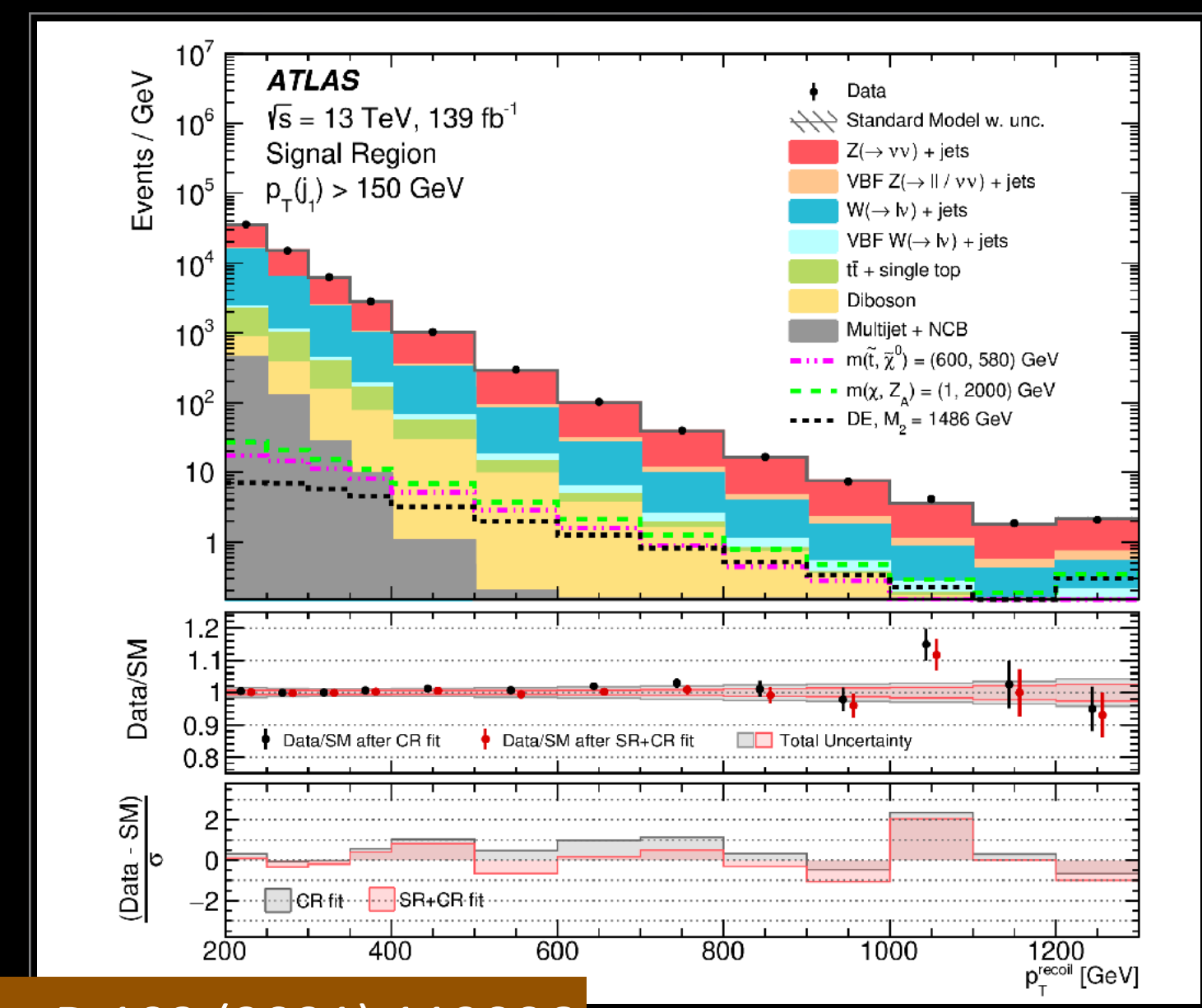
Run: 337215
 Event: 2546139368
 2017-10-05 10:36:30 CEST

$E_T^{miss} = 1.9 \text{ TeV}$
 jet $p_T = 1.9 \text{ TeV}$



Type of DM-candidate events we study at the colliders

- **Simplified models, one s-channel mediator (Mono-X)**
 - A pair of WIMPs that recoil against X (a visible SM particle, or a set of SM particles). Currently, X includes hadronic jet, heavy-flavor quarks, a photon, or a W or Z boson, even Higgs boson
 - An imbalance in the total momentum in the plane transverse to the colliding beams as reconstructed in the detector



Phys. Rev. D 103 (2021) 112006

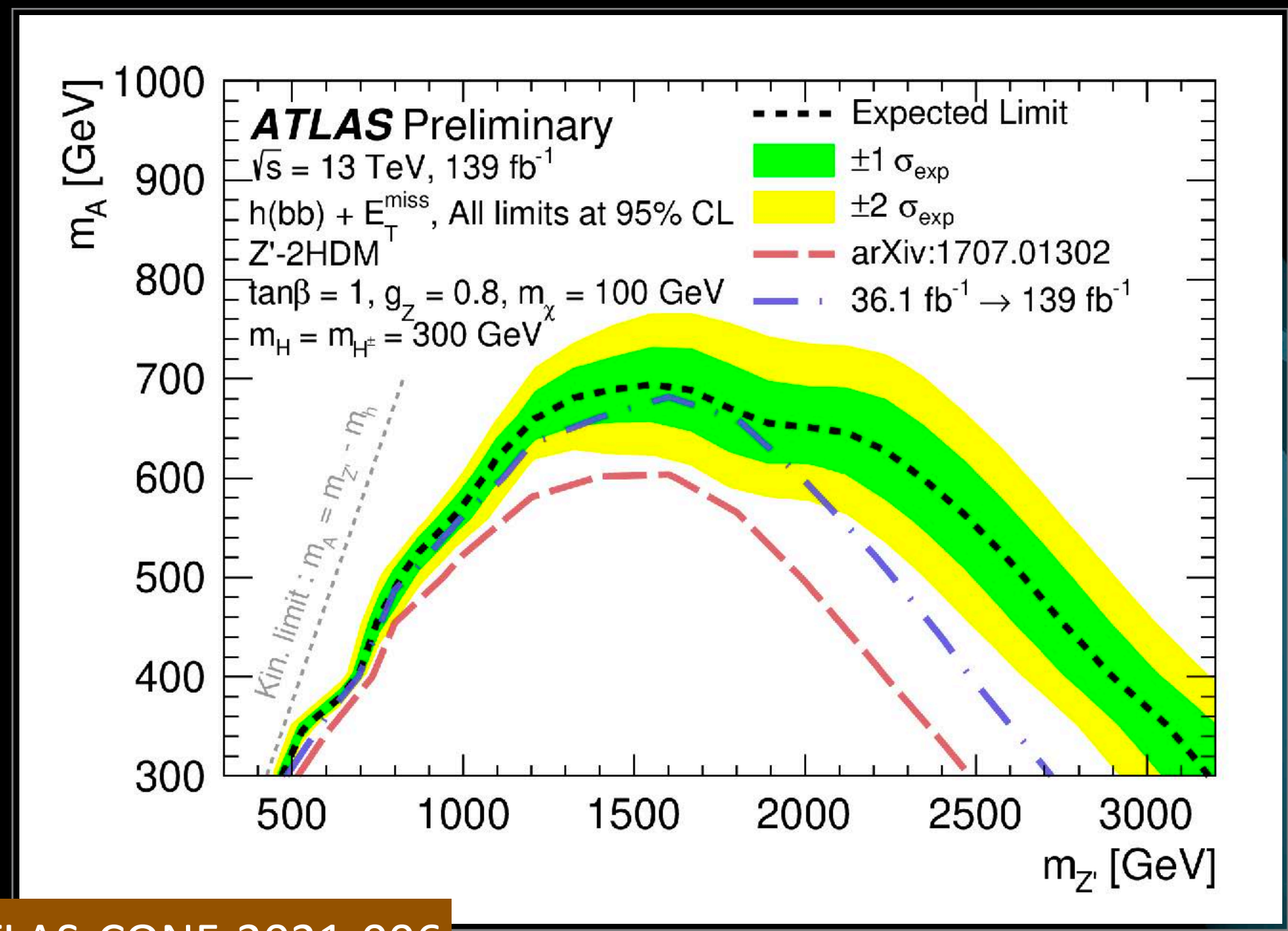
Exotic searches: ~~Darth Vader~~ Dark Matter



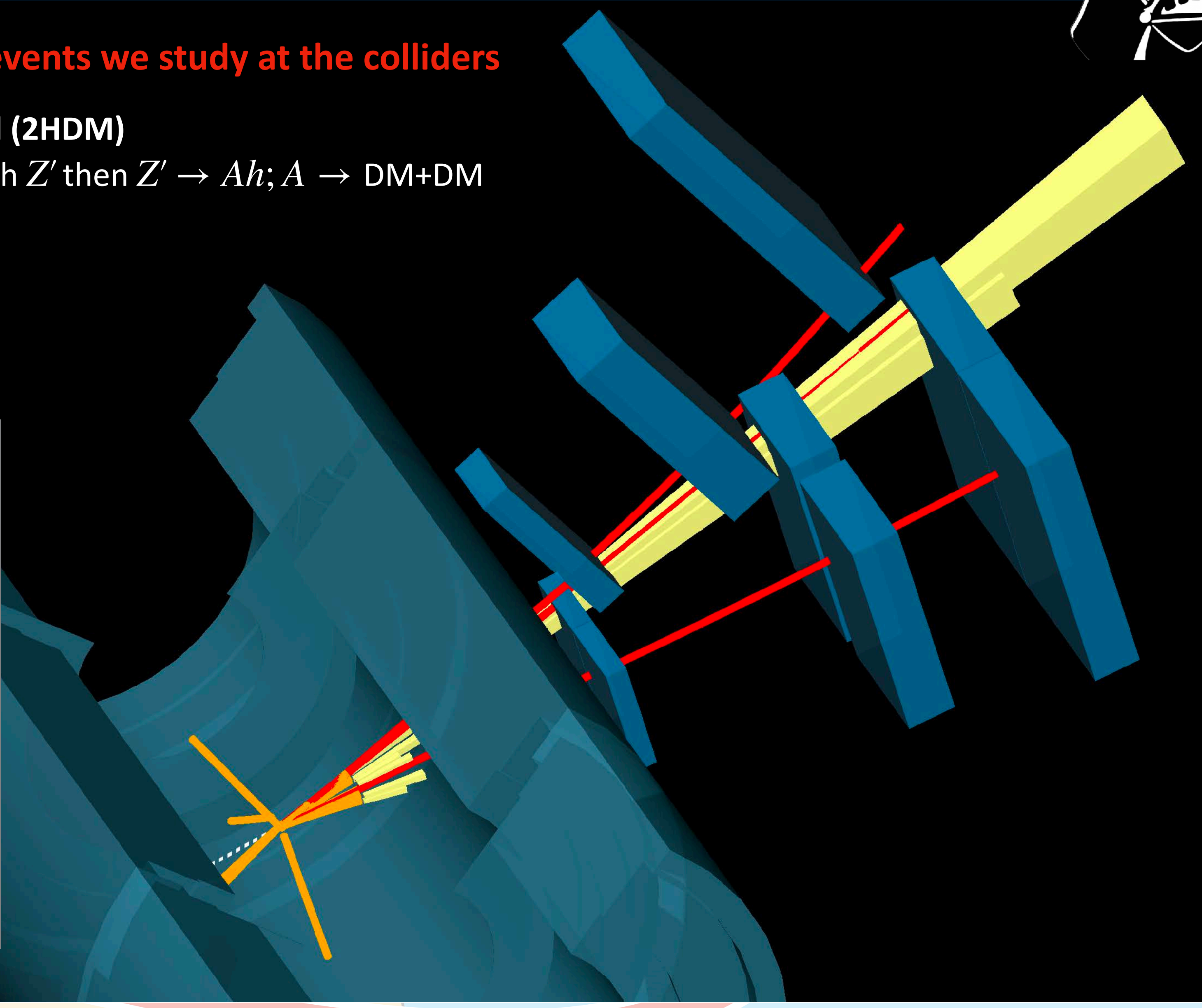
Run: 349309
Event: 769175011
2018-05-01 13:57:22 CEST

Type of DM-candidate events we study at the colliders

- two-Higgs-doublet model (2HDM)
 - Example: extension with Z' then $Z' \rightarrow Ah; A \rightarrow \text{DM}+\text{DM}$



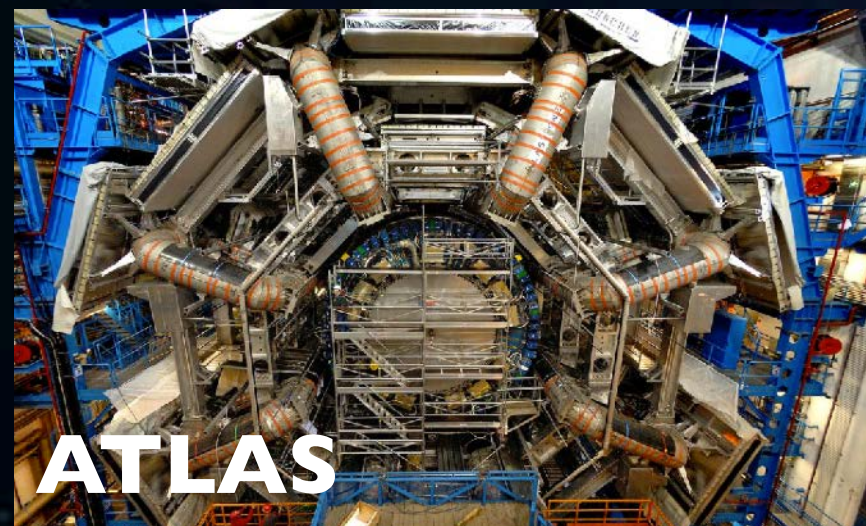
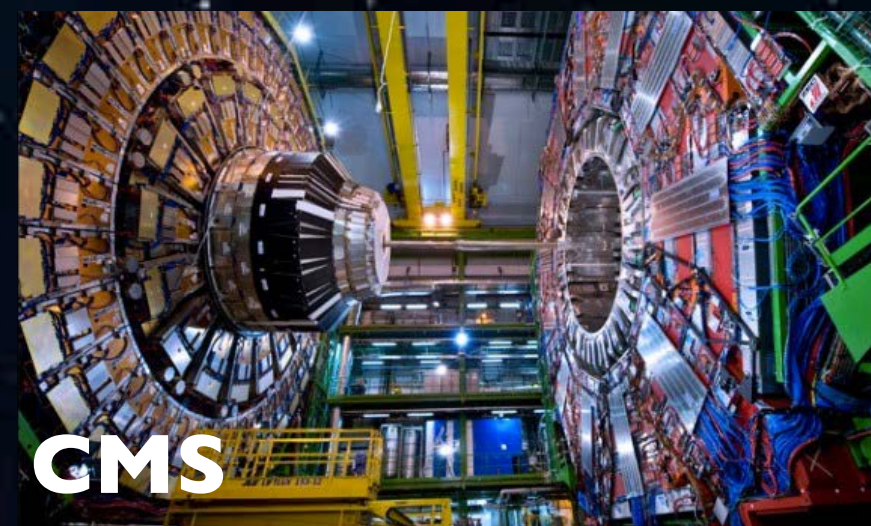
ATLAS-CONF-2021-006



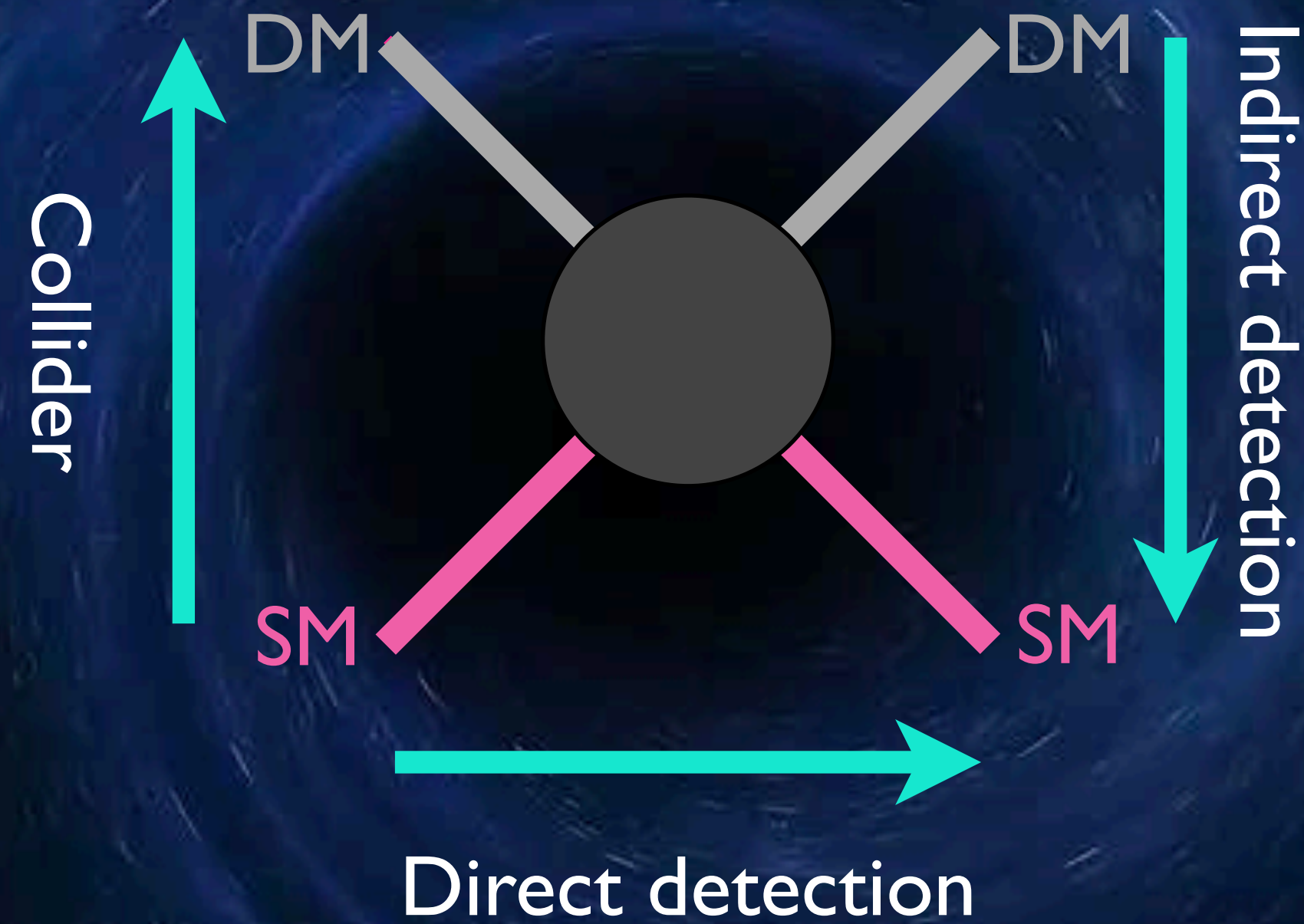
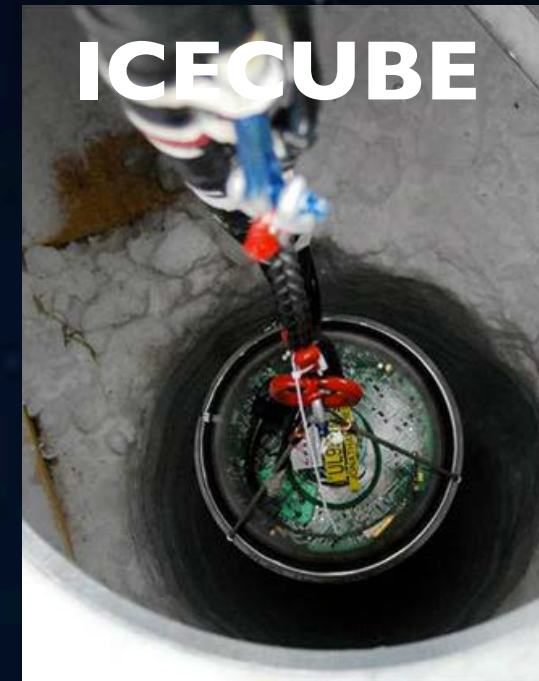
Dark matter searches

- Identify DM is one of the most important in physics.
- DM is likely to be (direct-)undetected particles.

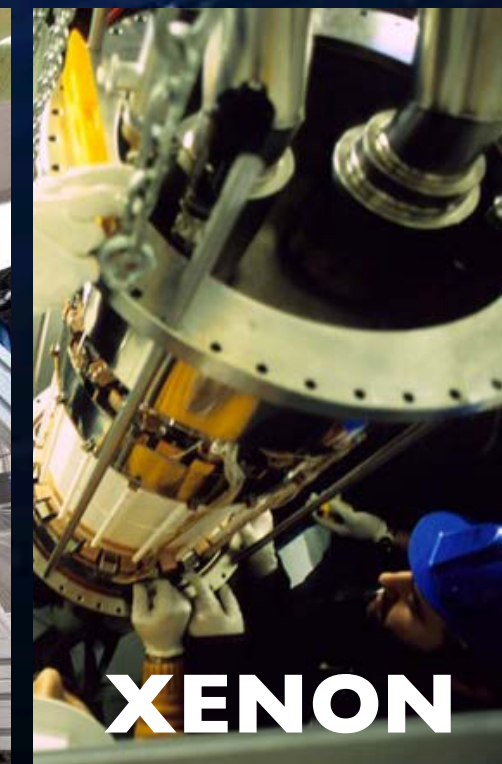
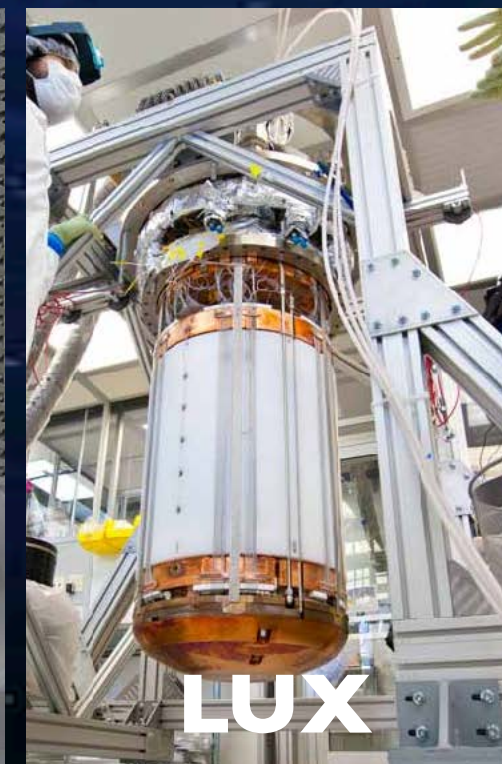
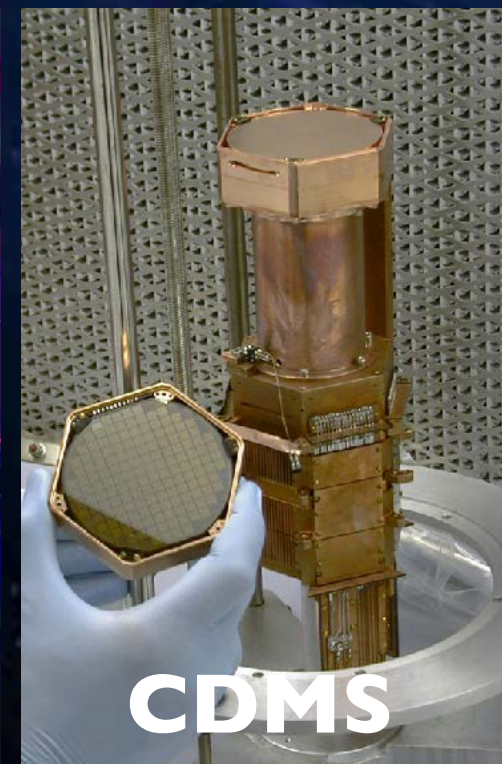
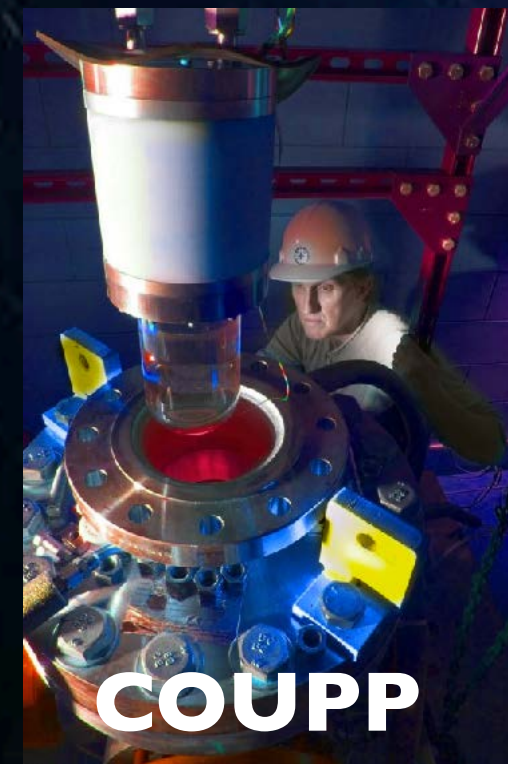
Laboratory production of DM particles



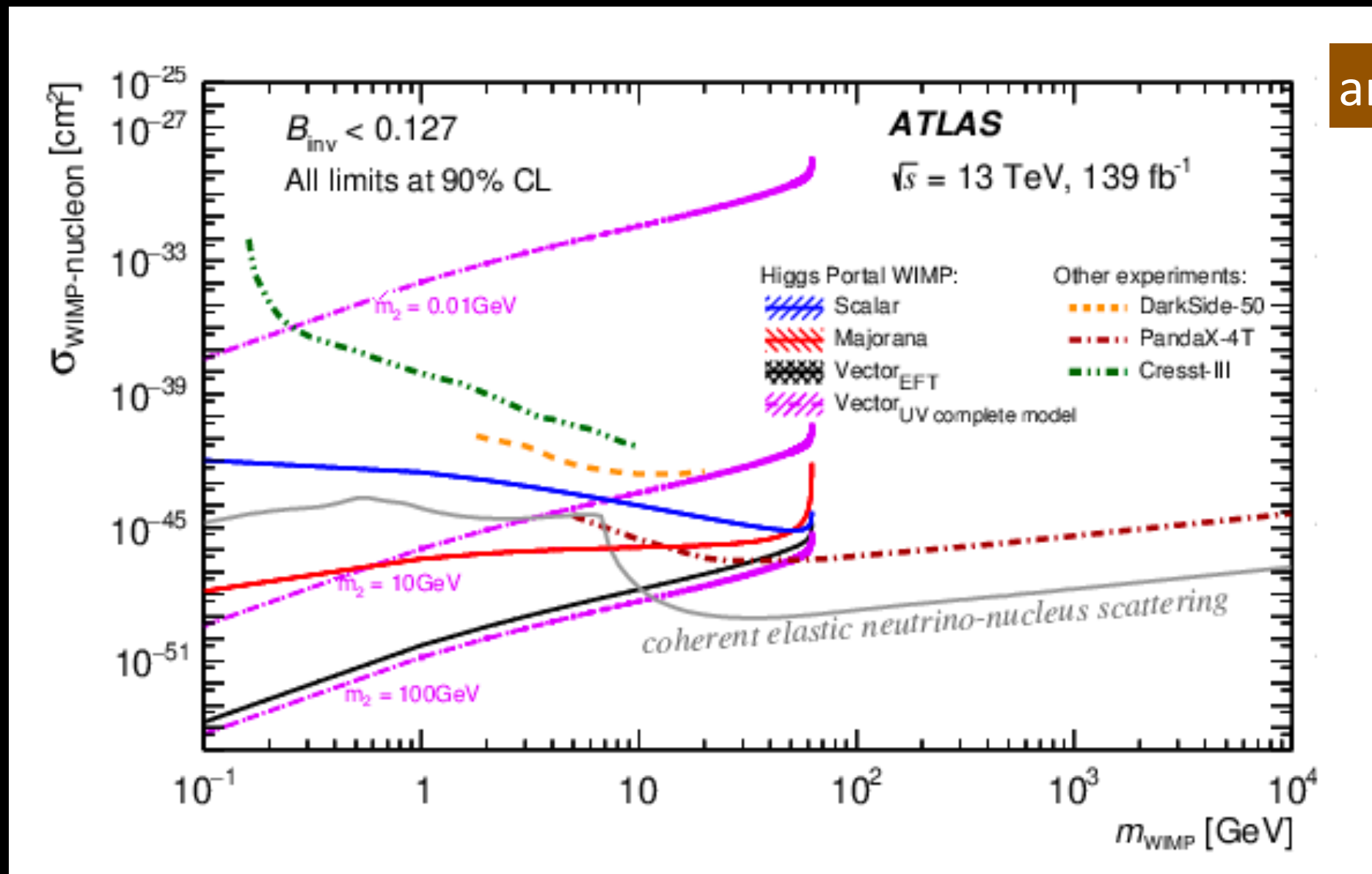
Observe DM annihilation products



Dark Matter-nucleus scattering

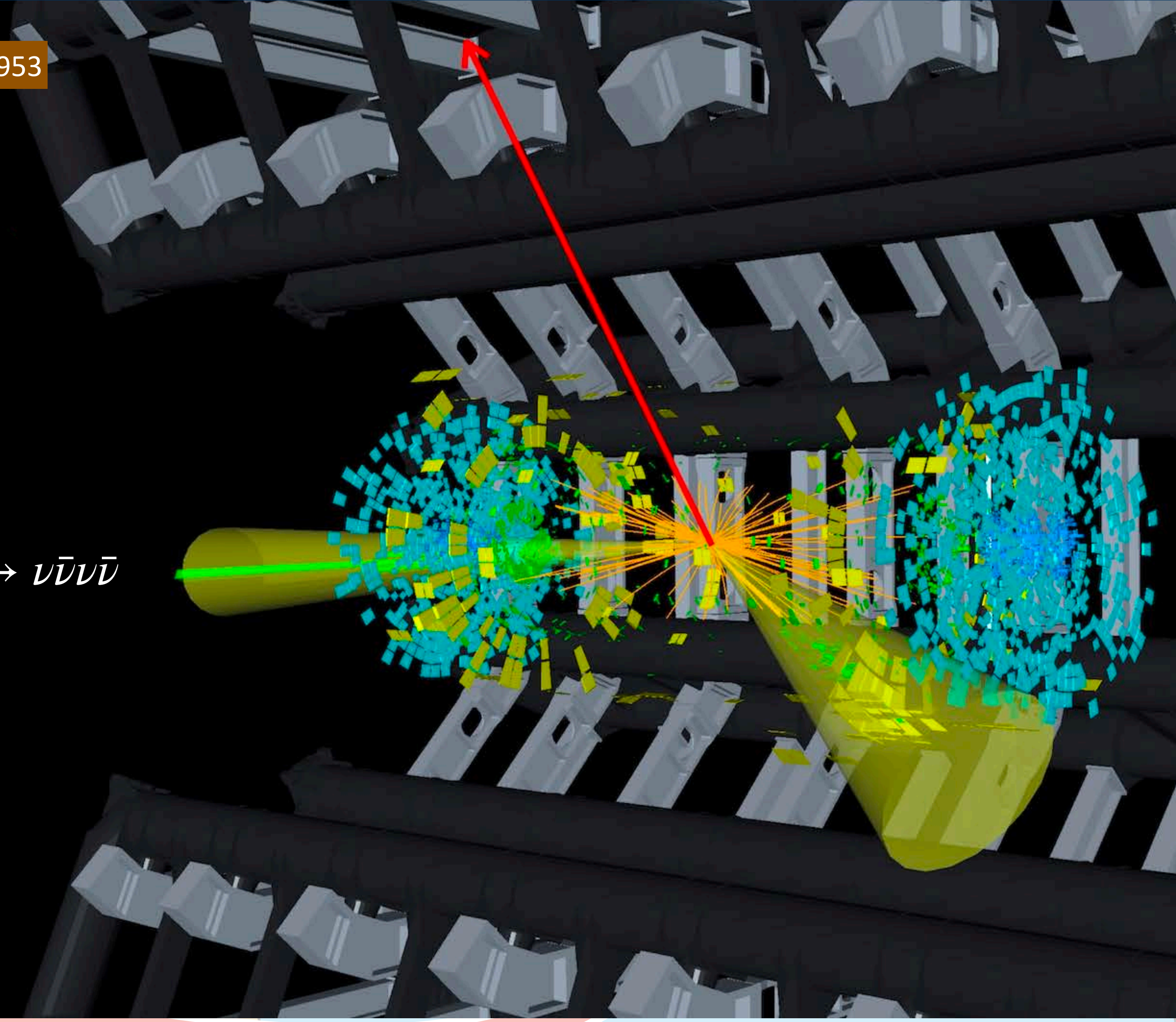


Invisible Higgs

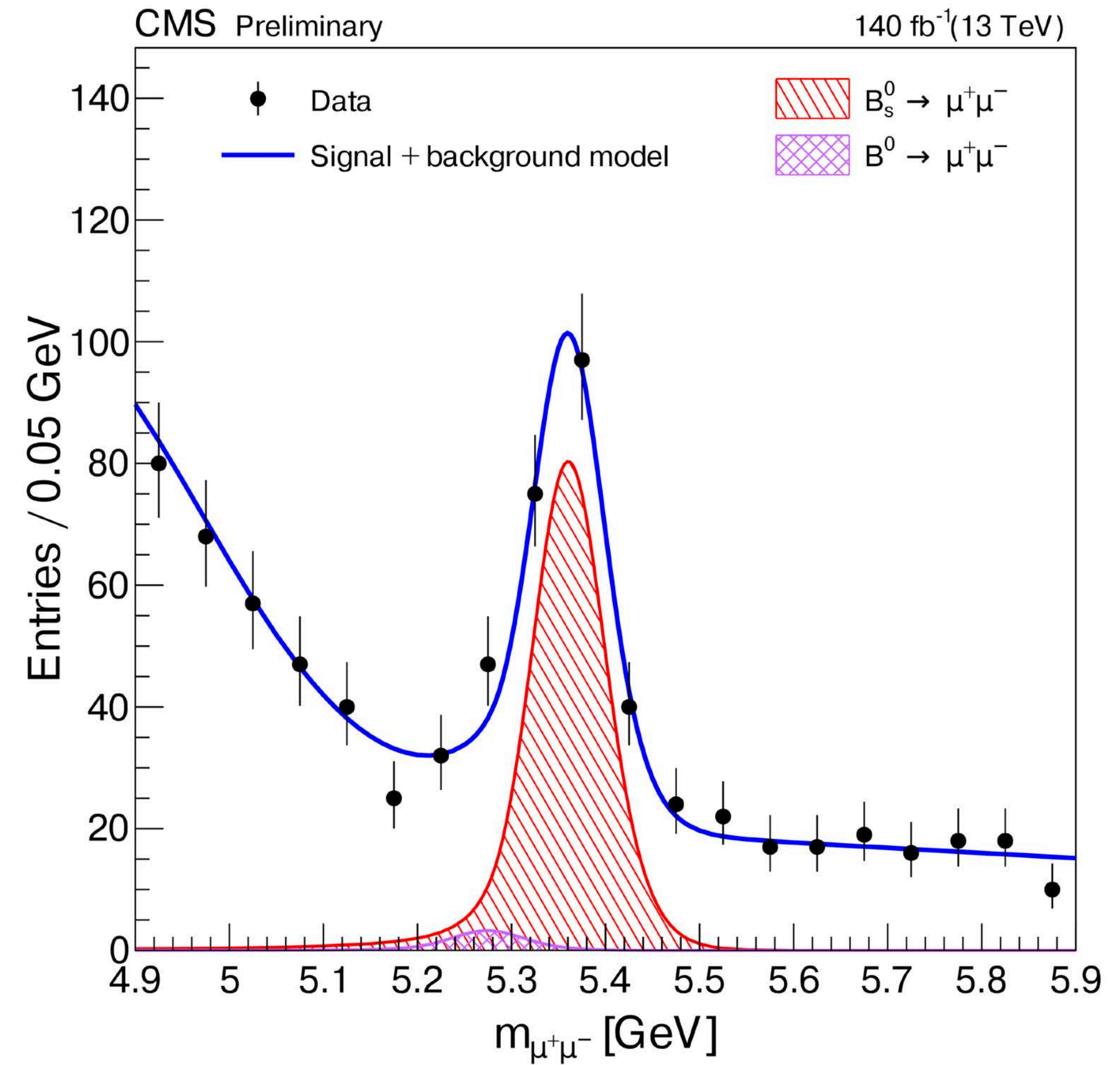
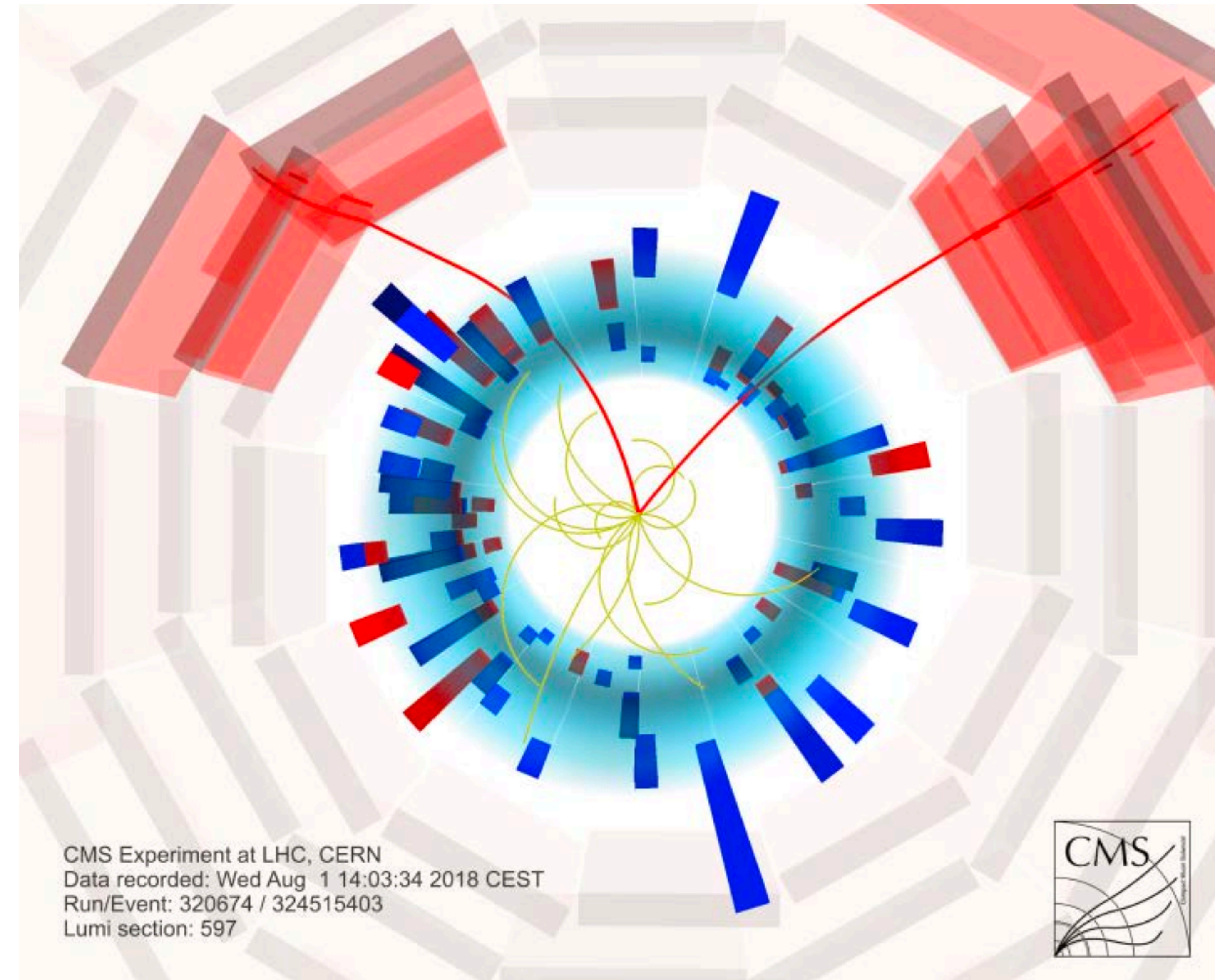


arXiv:2202.07953

- SM Higgs decay invisible, $H \rightarrow ZZ \rightarrow \nu\bar{\nu}\nu\bar{\nu}$
- DM model $H \rightarrow \chi\chi$

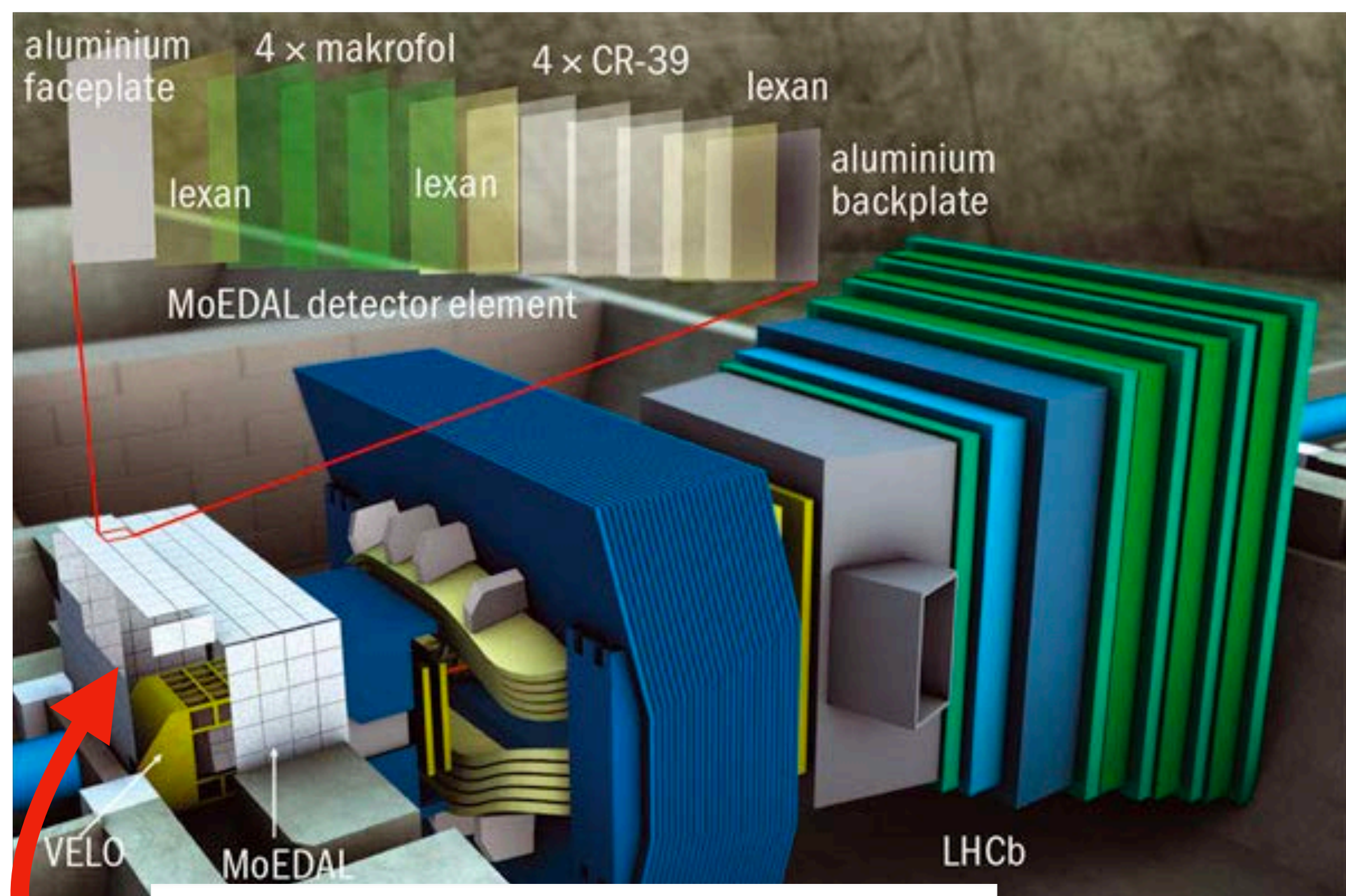


Rare process hunting



The motivation is to look for new particles that could lead to a large increase in this rare decay rate.

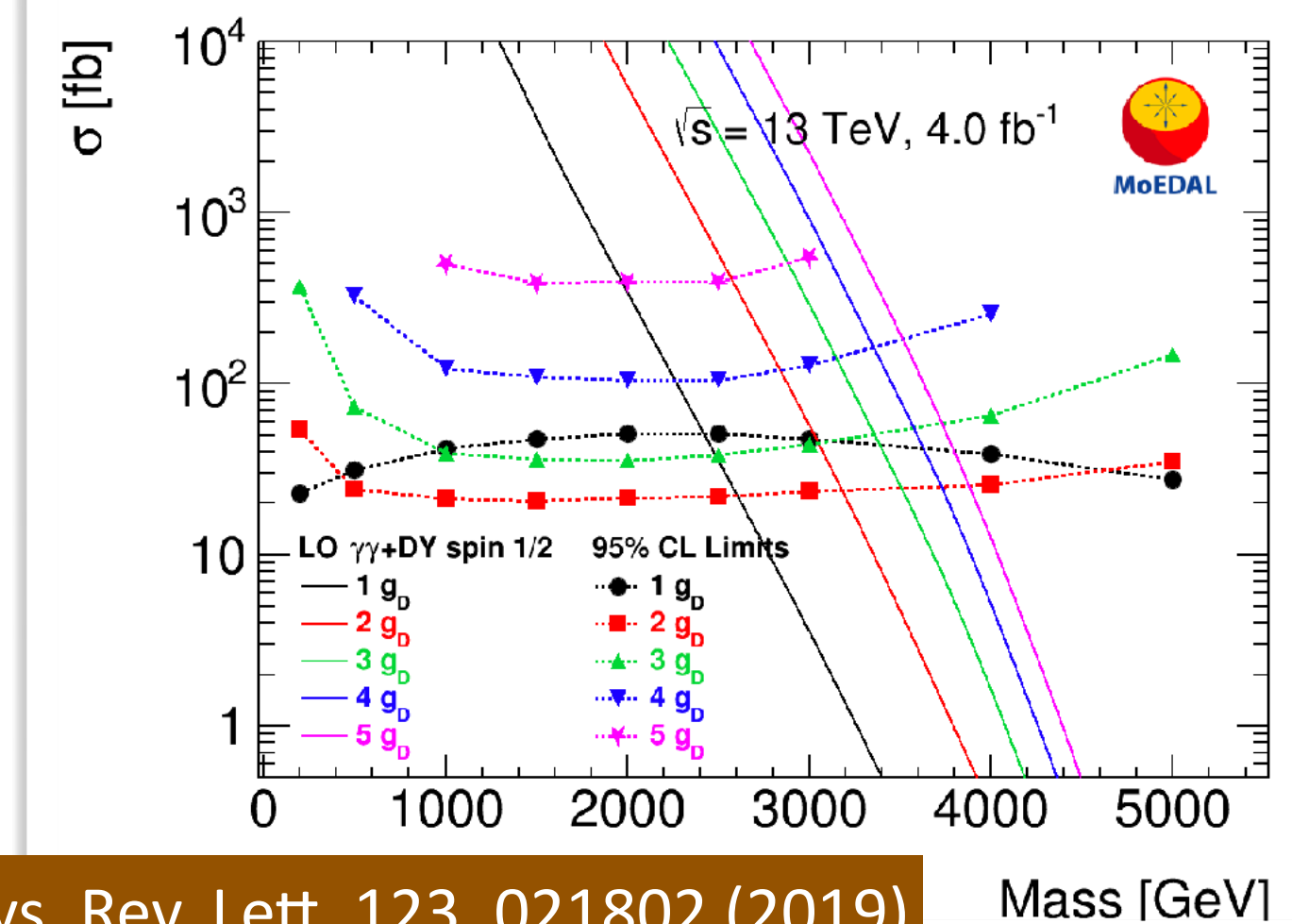
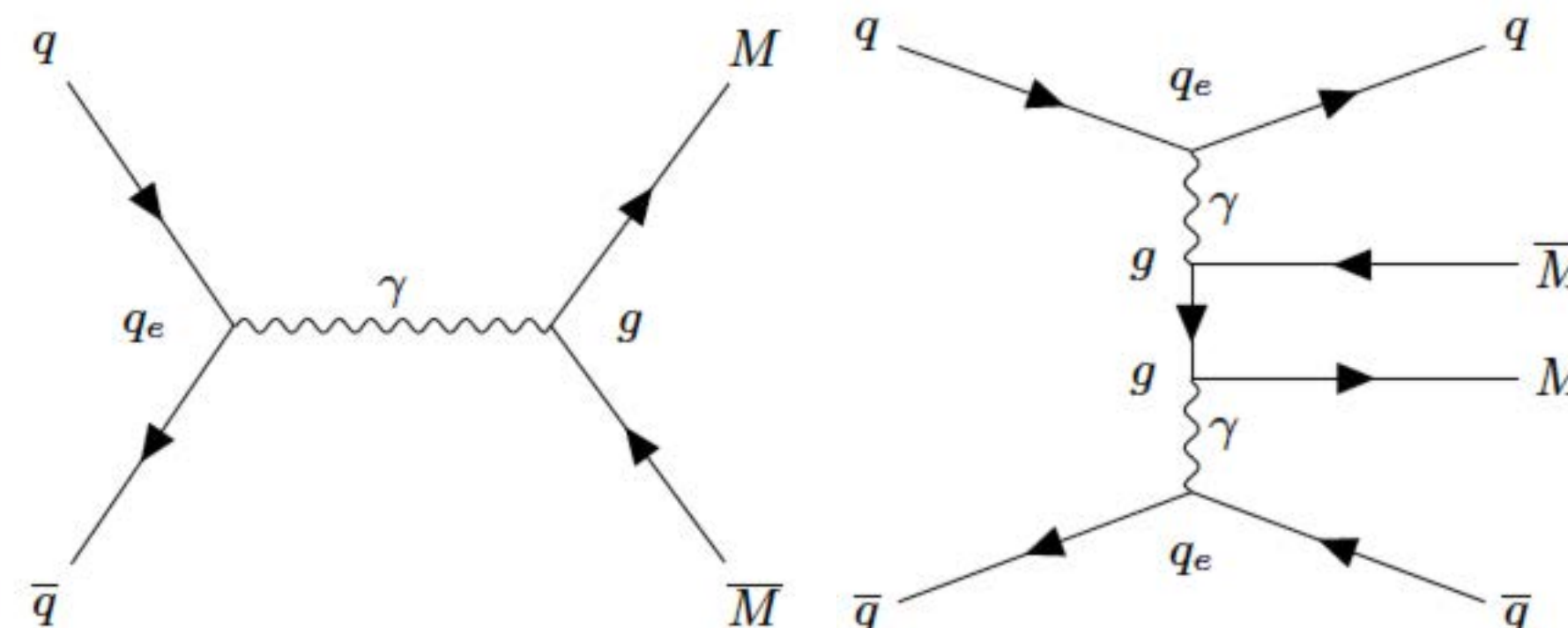
Small experiments but big Physics potentials at the LHC



MoEDAL (the Monopole and Exotics Detector At the LHC)

Physicists use the MoEDAL detector to search for a stable particle such as a magnetic monopole or a massive stable supersymmetric particle crossing through the plastic. MoEDAL detector is placed to the walls and ceiling of the cavern that houses the Vertex Locator (VELO) detector of the LHCb experiment. It consists of

- **plastic Nuclear Track Detectors (NTDs):** plastics to capture any signals from magnetic monopoles,
- **Magnetic Monopole Trapper (MMT):** roughly a ton of aluminium detectors that act as a trap for magnetic charge (trapping detectors),
- **Timepix Radiation Monitoring System:** an array of silicon pixel detectors used to monitor the experiment's environment in real time.



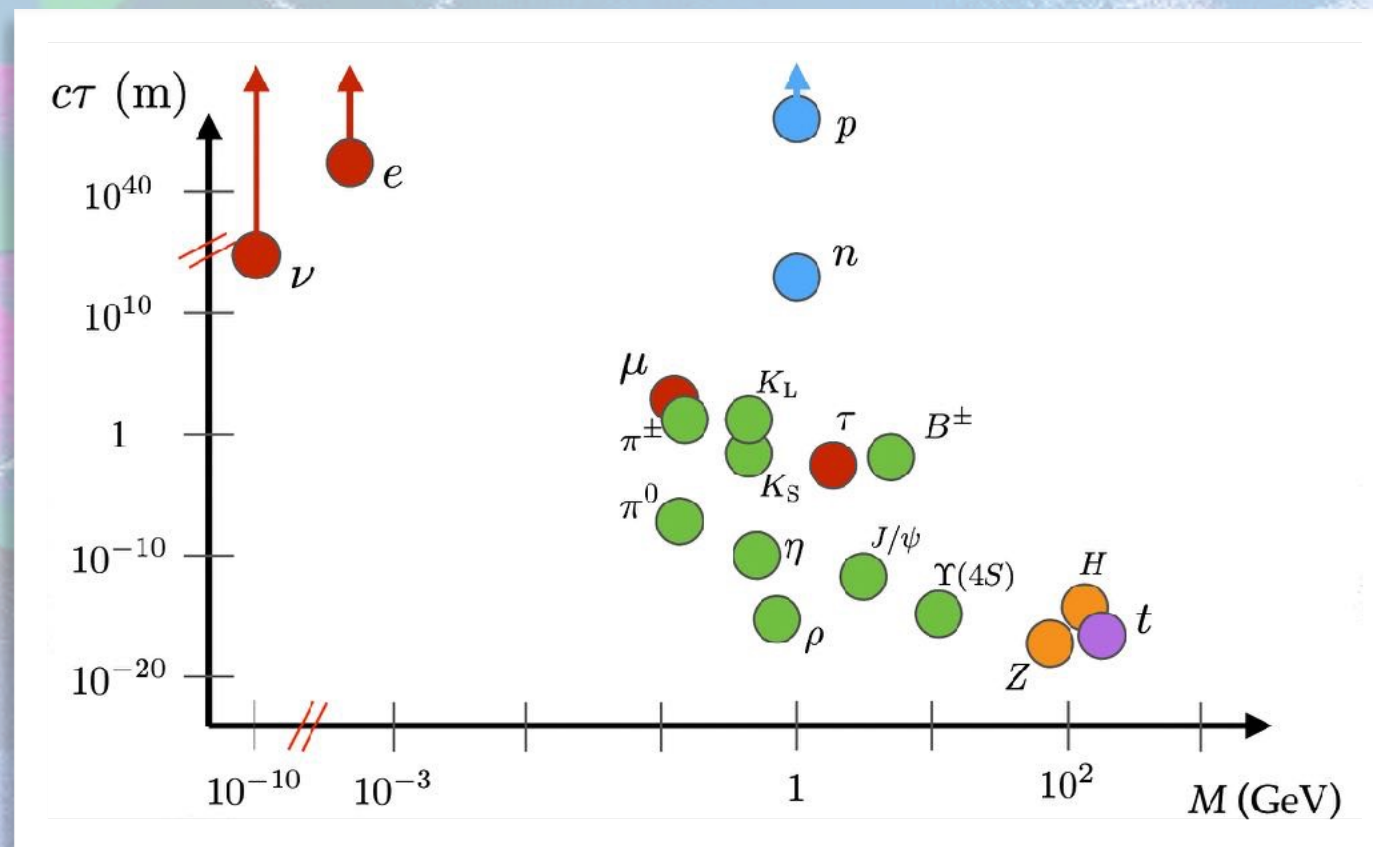
Phys. Rev. Lett. 123, 021802 (2019)

Mass [GeV]

Exotic searches: Long-lived particles

When produced particles will not decay immediately ...

In high energy particle physics experiments, physicists often assume that new *massive* particles produced in particle collisions would decay immediately, close to their points of origin, e.g. Higgs boson. However, we also know that there are particles which have long lifetimes, e.g. muons which can travel several kilometers (with the help of special relativity) before transforming into electrons and neutrinos.



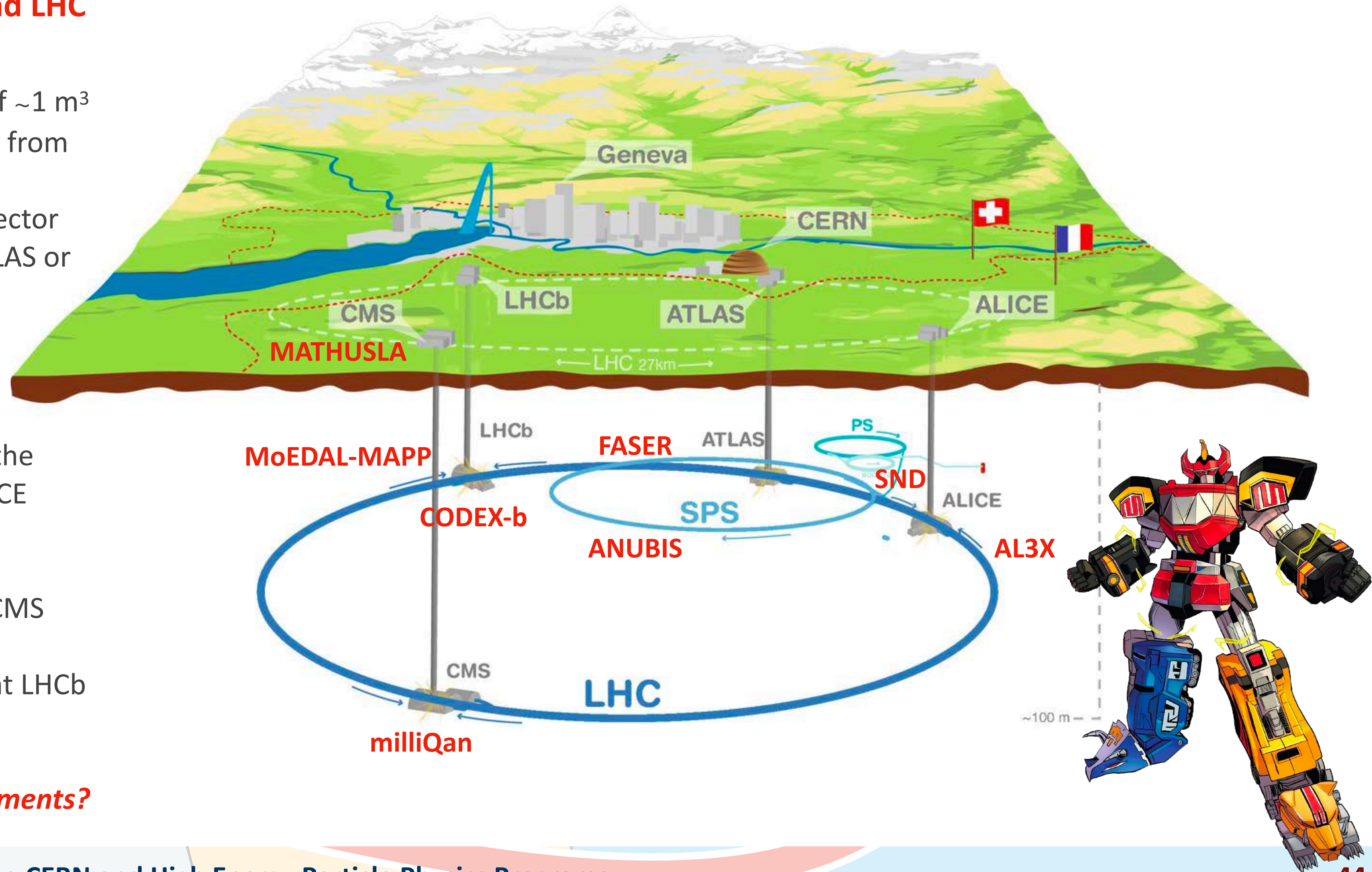
What if new particles we are hunting for has long lifetimes and traveled centimeters—even kilometers—before transforming into something physicists could detect?

<https://www.symmetrymagazine.org/article/long-lived-particles-get-their-moment>

Power Detector Rangers: To search for Long-lived particles

Several small experiments around LHC to search for LLPs

- **FASER** (Approved): with a volume of $\sim 1 \text{ m}^3$ will be installed 480 m downstream from the ATLAS interaction point
- **MATHUSLA**: large scale surface detector instrumenting $\sim 8 \times 10^5 \text{ m}^3$ above ATLAS or CMS
- **CODEX-b**: $\sim 10^3 \text{ m}^3$ detector to be installed in the LHCb cavern
- **AL3X** to use a cylindrical $\sim 900 \text{ m}^3$ detector inside the L3 magnet and the time-projection chamber of the ALICE experiment
- **MilliQan** to search for millicharged particles in the drainage gallery of CMS
- **MoEDAL** to look for highly ionizing particles like magnetic monopoles at LHCb alongside **MAPP**



.... Why do need need several experiments?

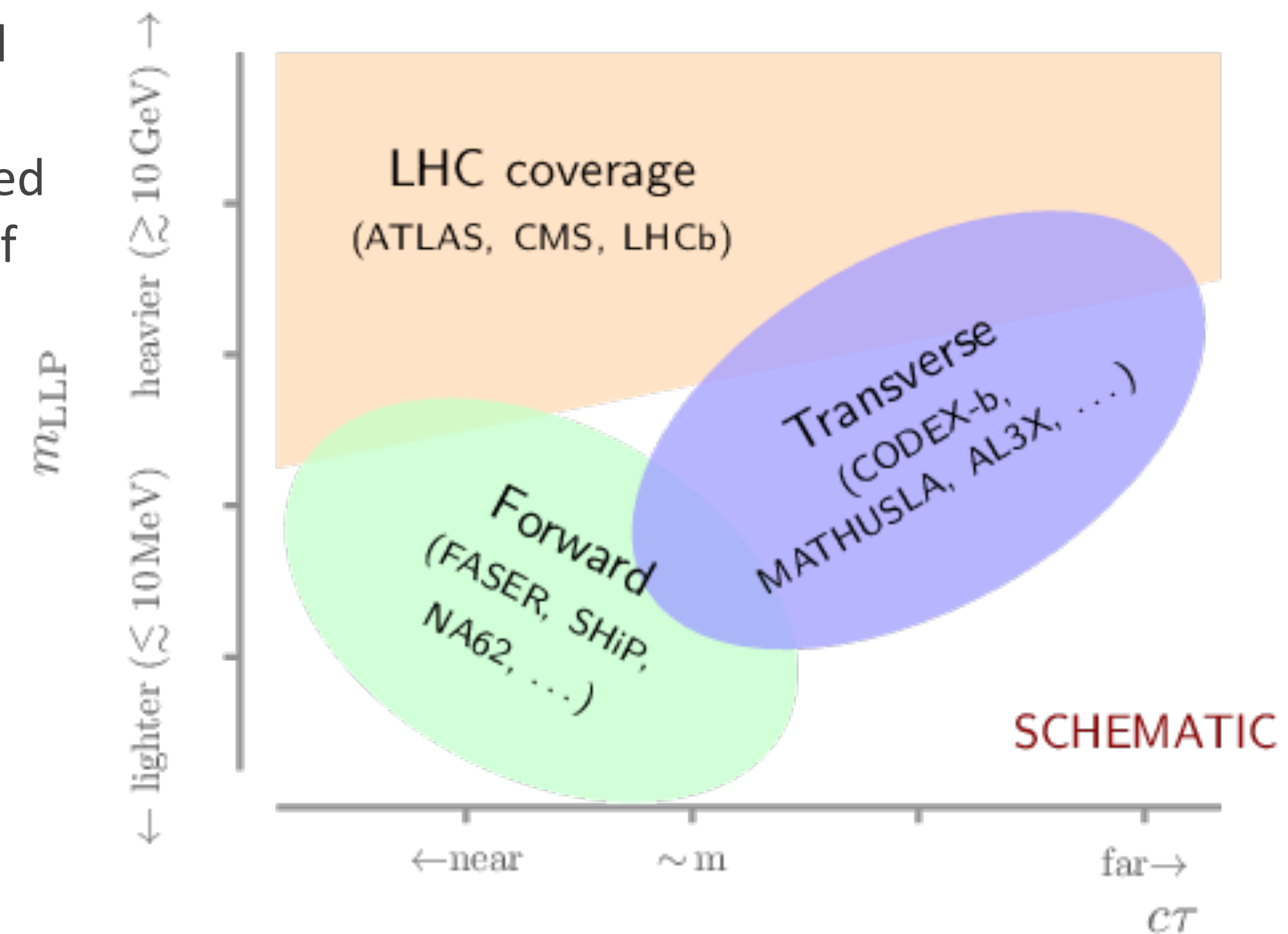
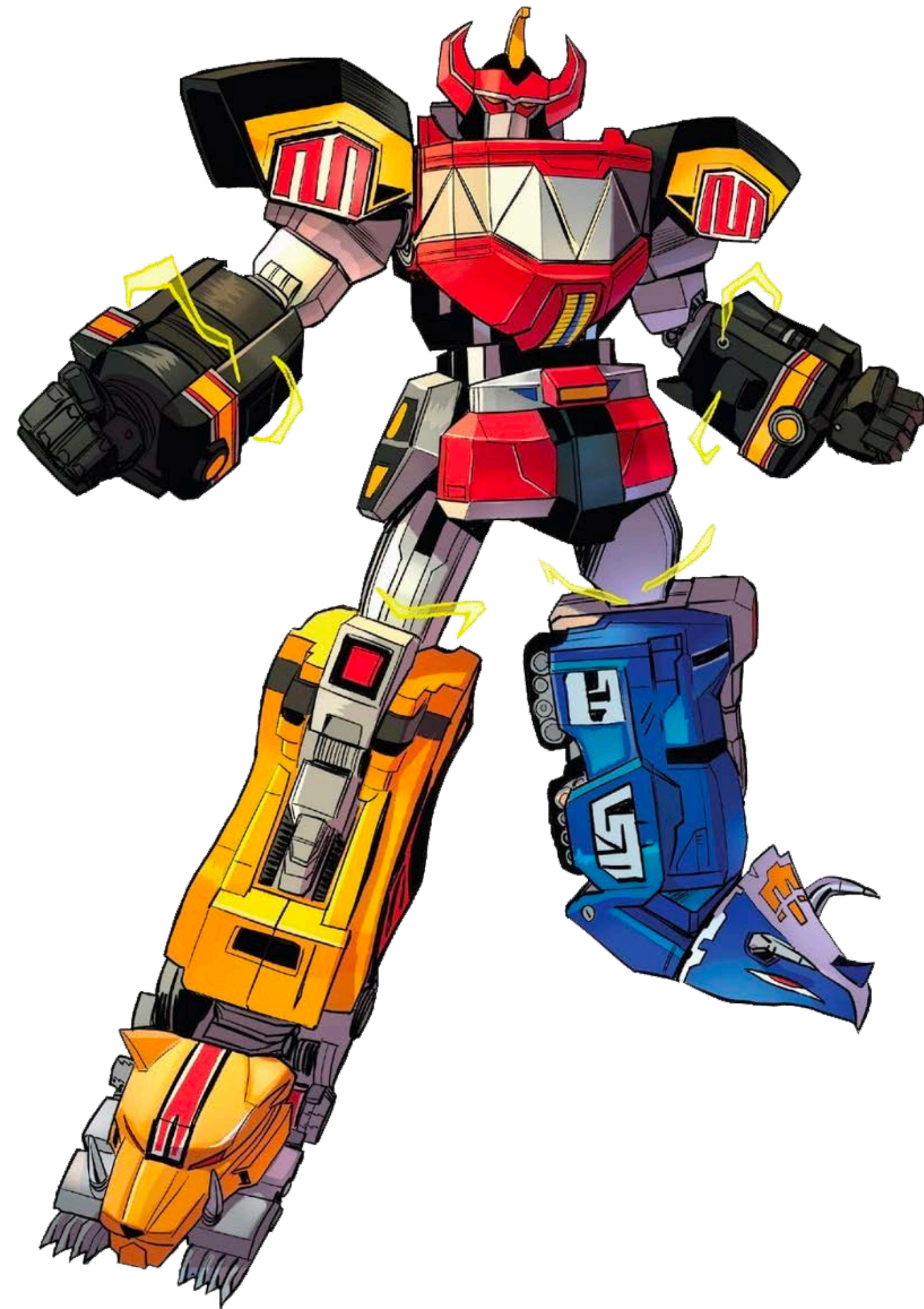
~~Power~~ Detector Rangers: To search for Long-lived particles

Why do we need detector rangers to search for LLP?

their masses ... don't know
their lifetimes ... don't know

Properties of LLPs may span many orders of magnitude. This makes us impossible from first principles to construct a single detector which would have the ultimate sensitivity to all possible LLP signatures. Multiple complementary experiments are necessary. **However, we still need to connect to main-big detector. Why?**

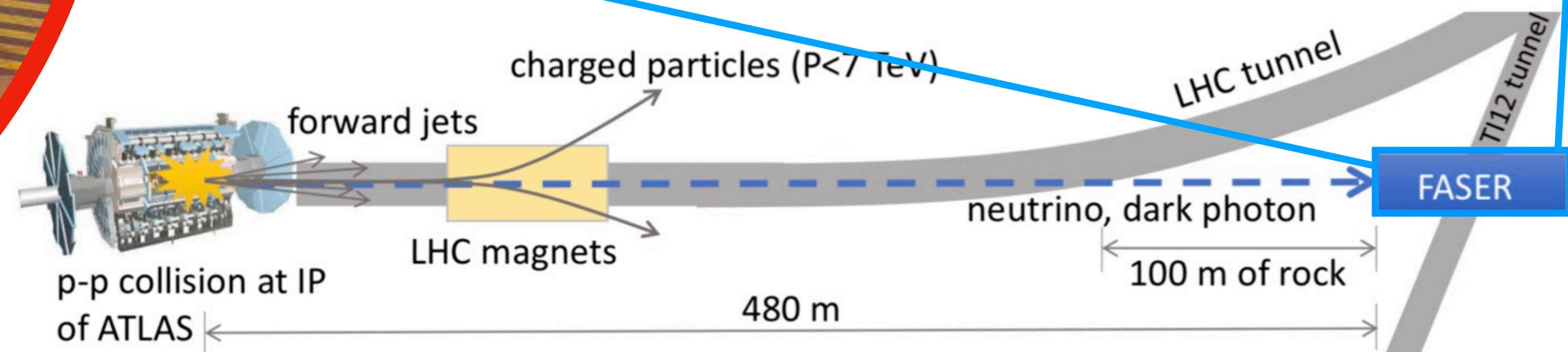
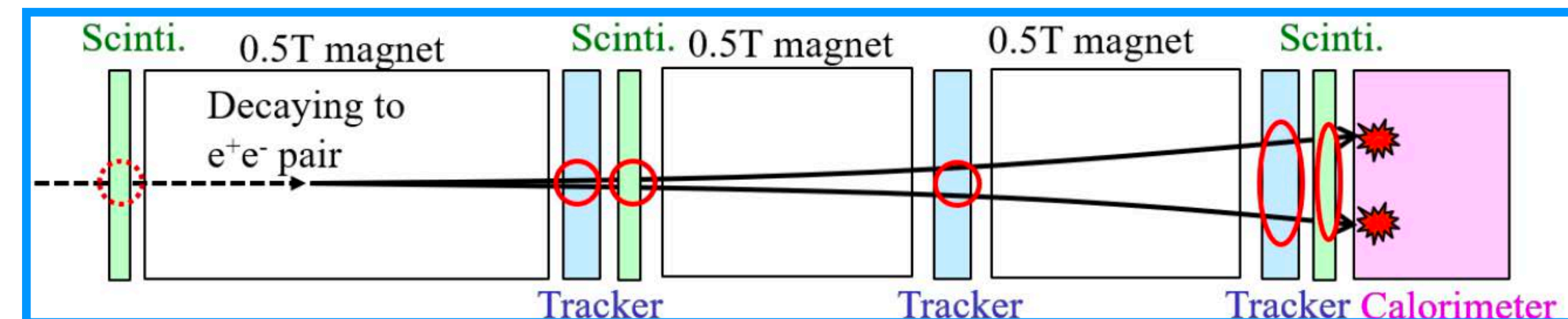
Because we assume that LLPs are produced at the four collision points of LHC. Information including timing can be obtained from big four experiment, to track events of interest.



ForwArd Search ExpeRiment (FASER)

Searches for new weakly-interacting light long-lived particles

- New particles produced in decays of light mesons
- Travel at \sim zero angle
- Escaping detection in ATLAS (for FASER)/CMS
- $pp \rightarrow X + LLP$, then LLP travels for $\sim 480\text{m}$, $LLP \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma, \dots$
 - Several models including dark photon, axion-like particles (ALPs), heavy neutral leptons (HNLs), and dark Higgs bosons



The Scattering and Neutrino Detector at the LHC (SND@LHC)

The SND@LHC is located underground close to the ATLAS experiment, in an unused tunnel that links the LHC to the Super Proton Synchrotron. Positioned slightly off the LHC's beamline, it will be able to detect neutrinos produced in the LHC collisions at small angles with respect to the beamline.

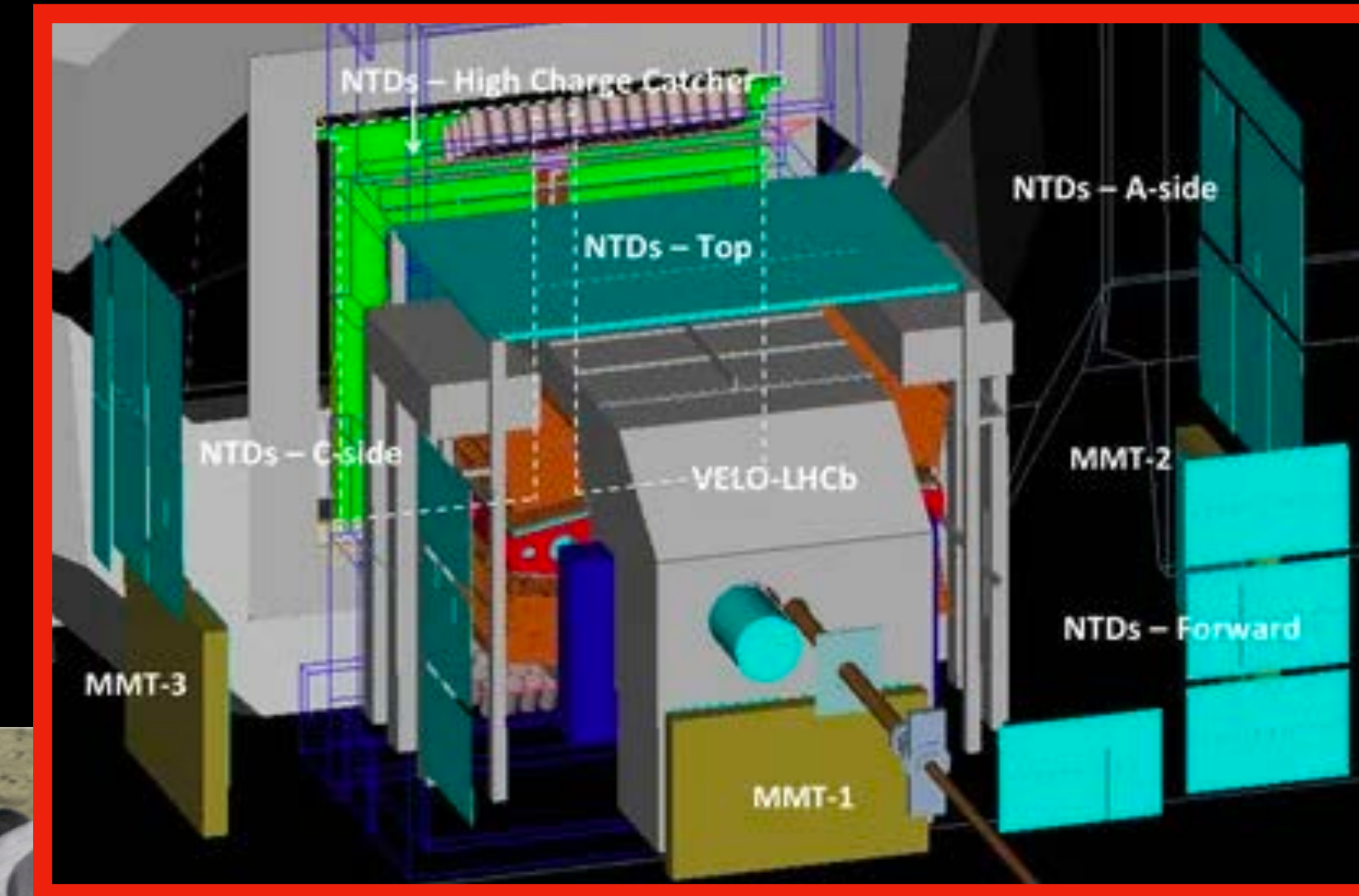
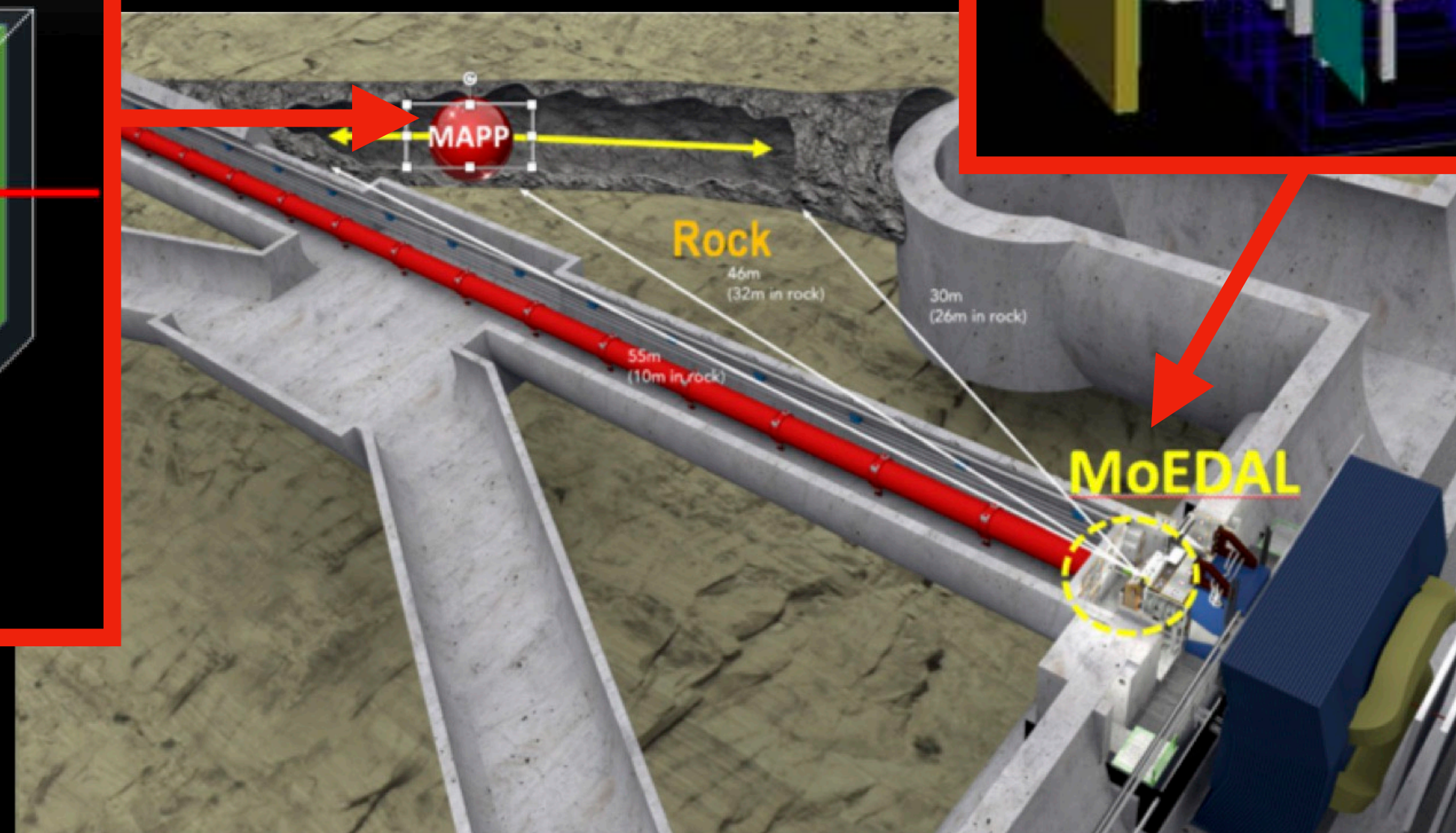
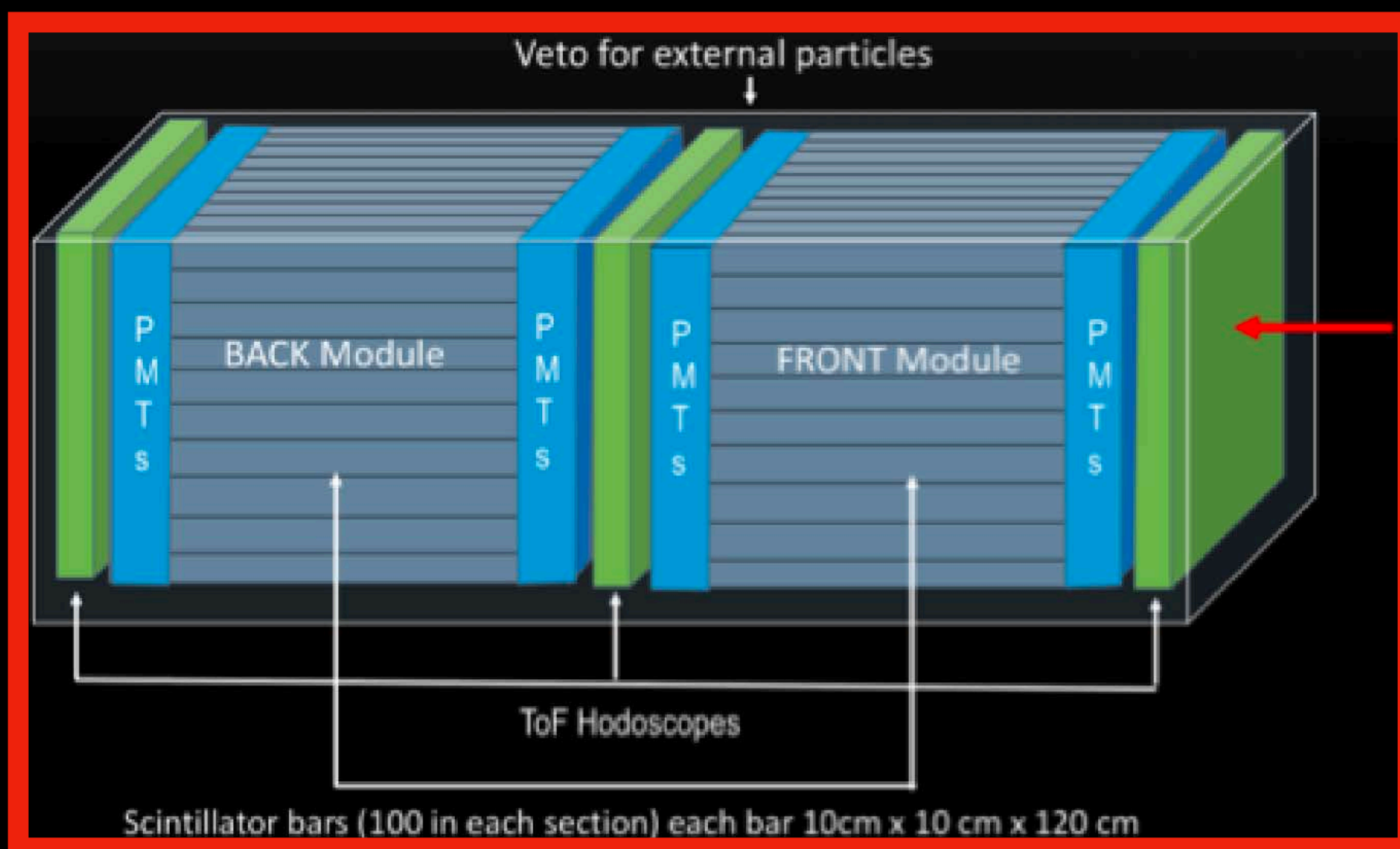
SND@LHC consists of a neutrino target followed downstream by a device to measure the neutrino energy and to detect muons (the heavier cousins of electrons) that are produced when neutrinos interact with the target.



MoEDAL Apparatus for Penetrating Particles (MAPP)

Several small experiments around LHC to search for LLPs

- For Phase-1 (LHC RUN-3): The baseline MoEDAL detector will be reinstalled and two MAPP sub detectors for two class of particles:
 - **MAPP-LLP**: nw pseudo-stable weakly interactive neutral particles with long lifetime
 - **MAPP-mQP**: mini-charged particle detector
- Positioned at an angle of 5-degree w.r.t. beam axis

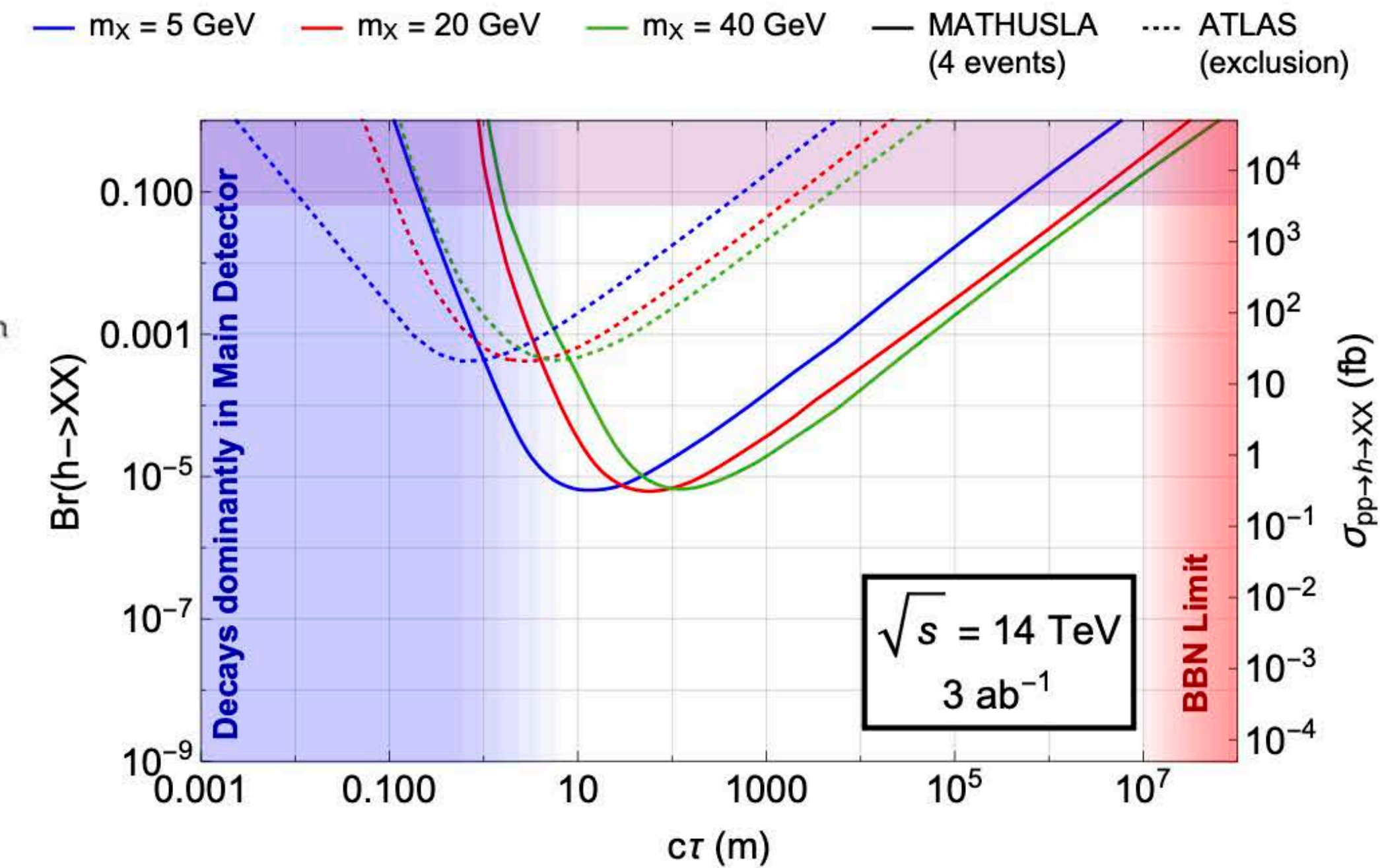
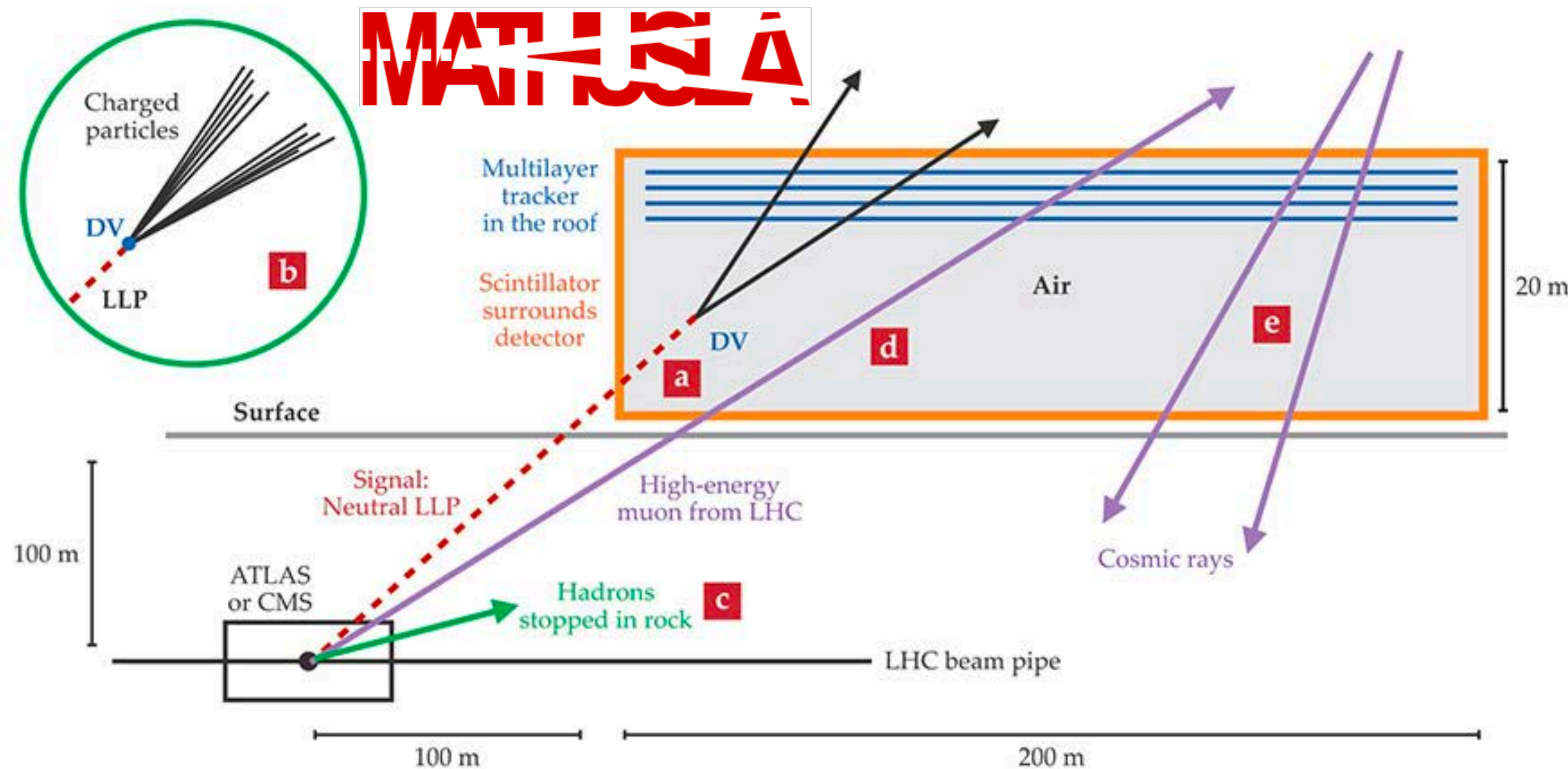


MAssive Timing Hodoscope for Ultra-Stable neutral pArticles (MATHUSLA)

Ultra-long-lived particles (ULLP), with surface detector

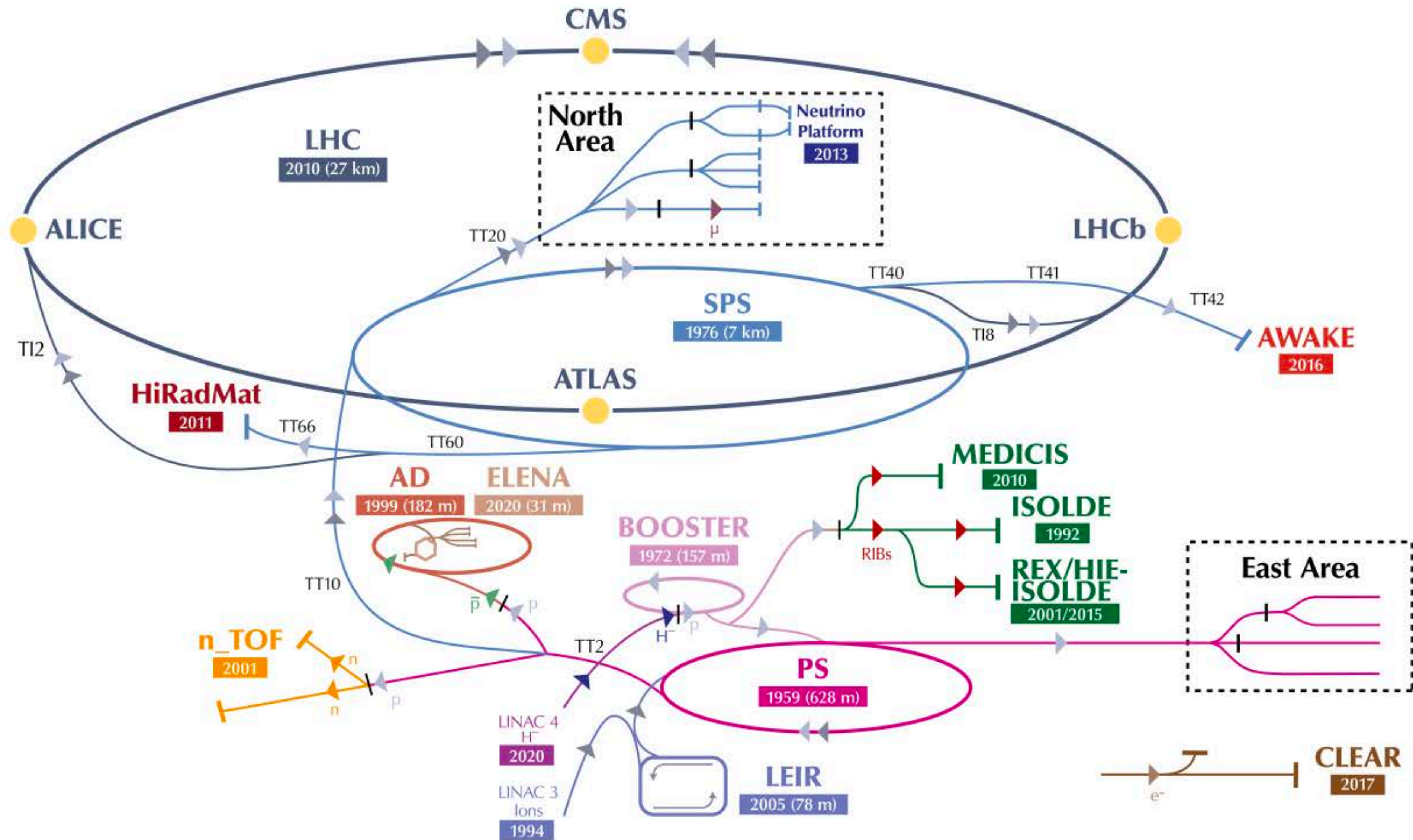
Requirement: New detector that minimizes background as much as possible; Maintain reasonably large radial detector size and solid angle coverage relative to the main interaction point (IP); Cheap. The proposal is to go for surface detector:

- ▶ No additional tunnel
- ▶ 100m of rock to protect radiation for LHC
- ▶ Background from cosmic muons which are rarely pointed towards IP. Mostly coming from the opposite direction (above instead of below)
- ▶ Decay volume filled with air with several detector layers for tracking



Physics Letter B 767 (2017) 29-36

CERN accelerator complex: Not only LHC

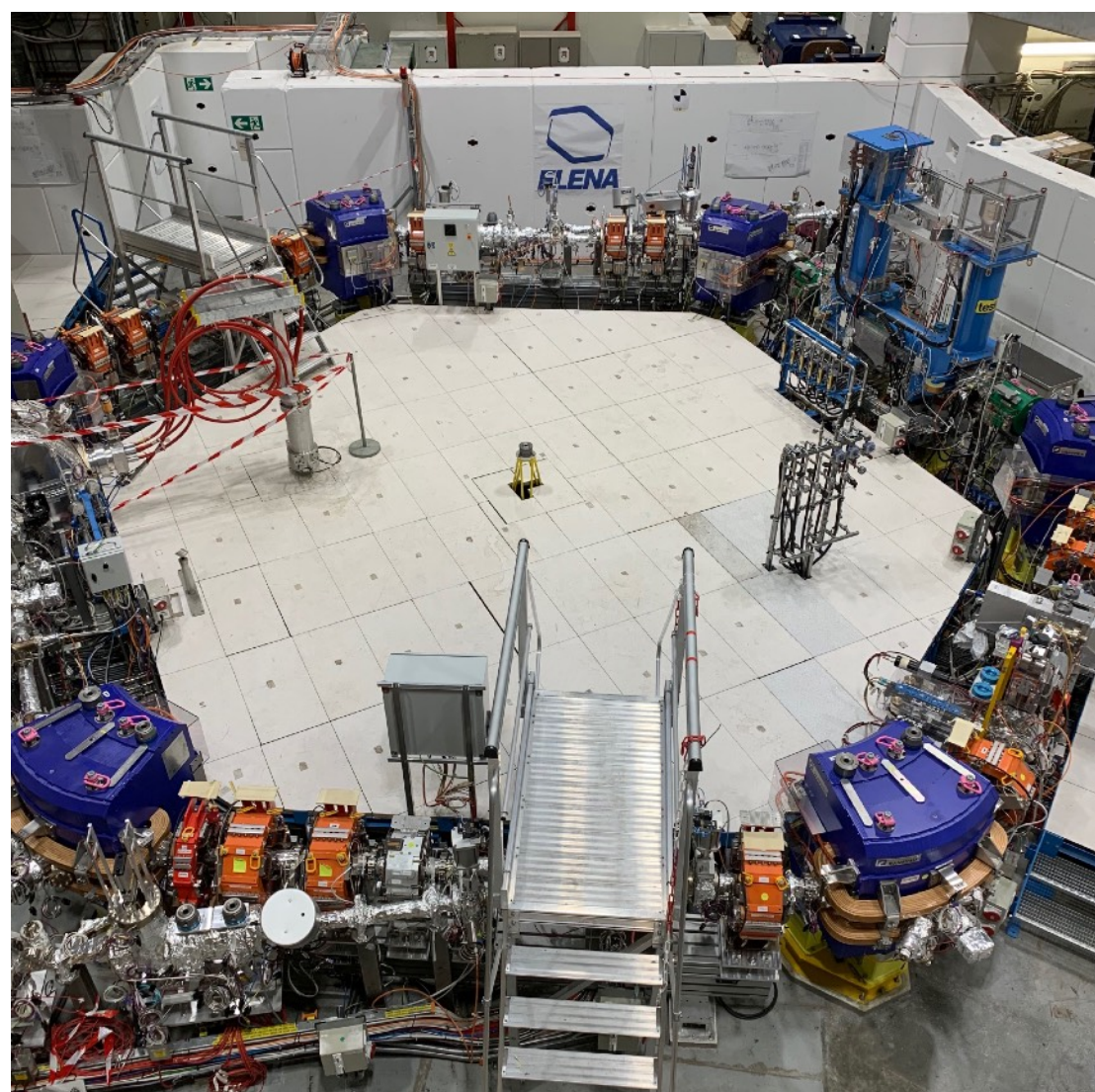


Not only accelerate, but also decelerate



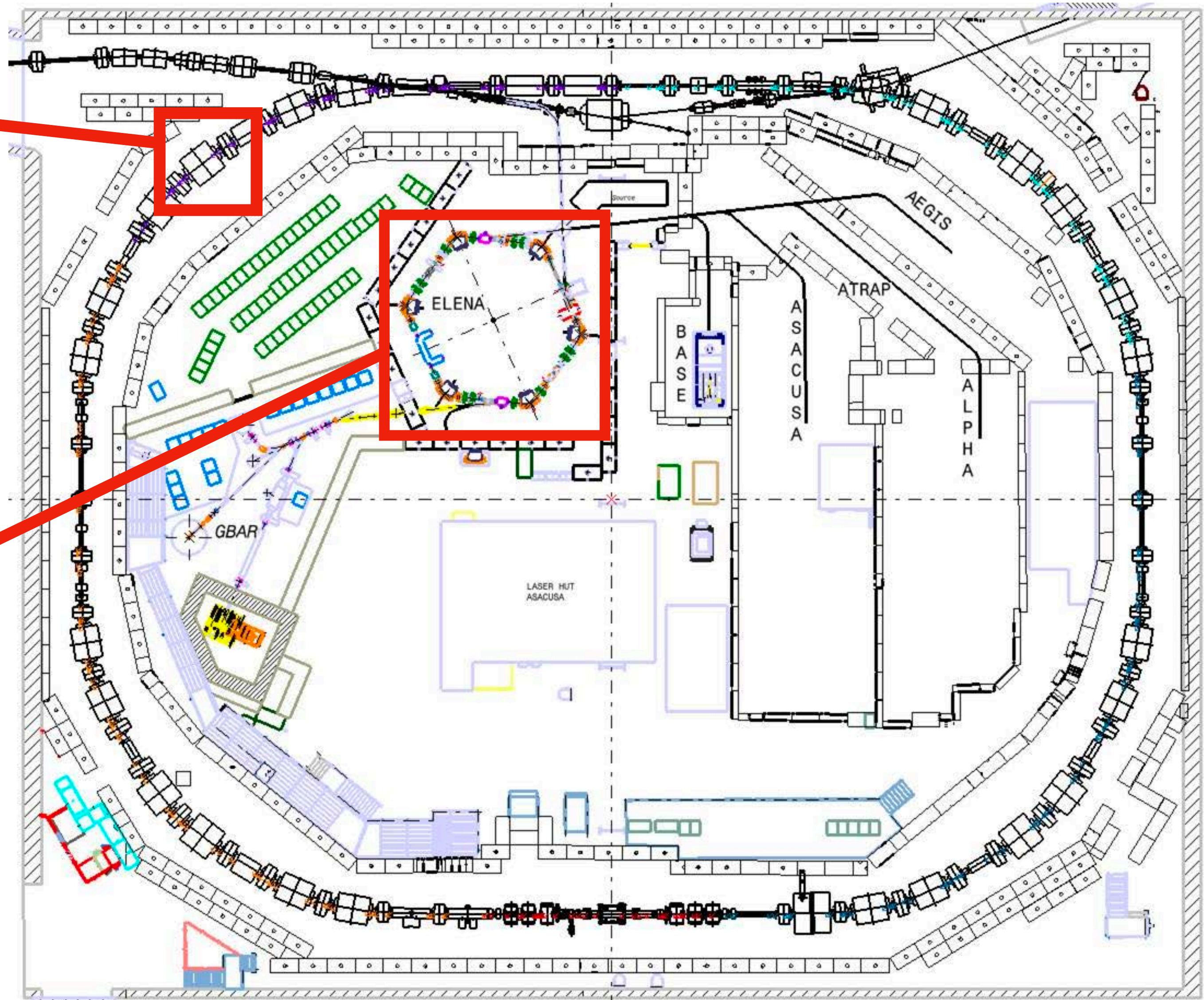
Antiproton Decelerator (AD)

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



Extra Low Energy Antiproton (ELENA)

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

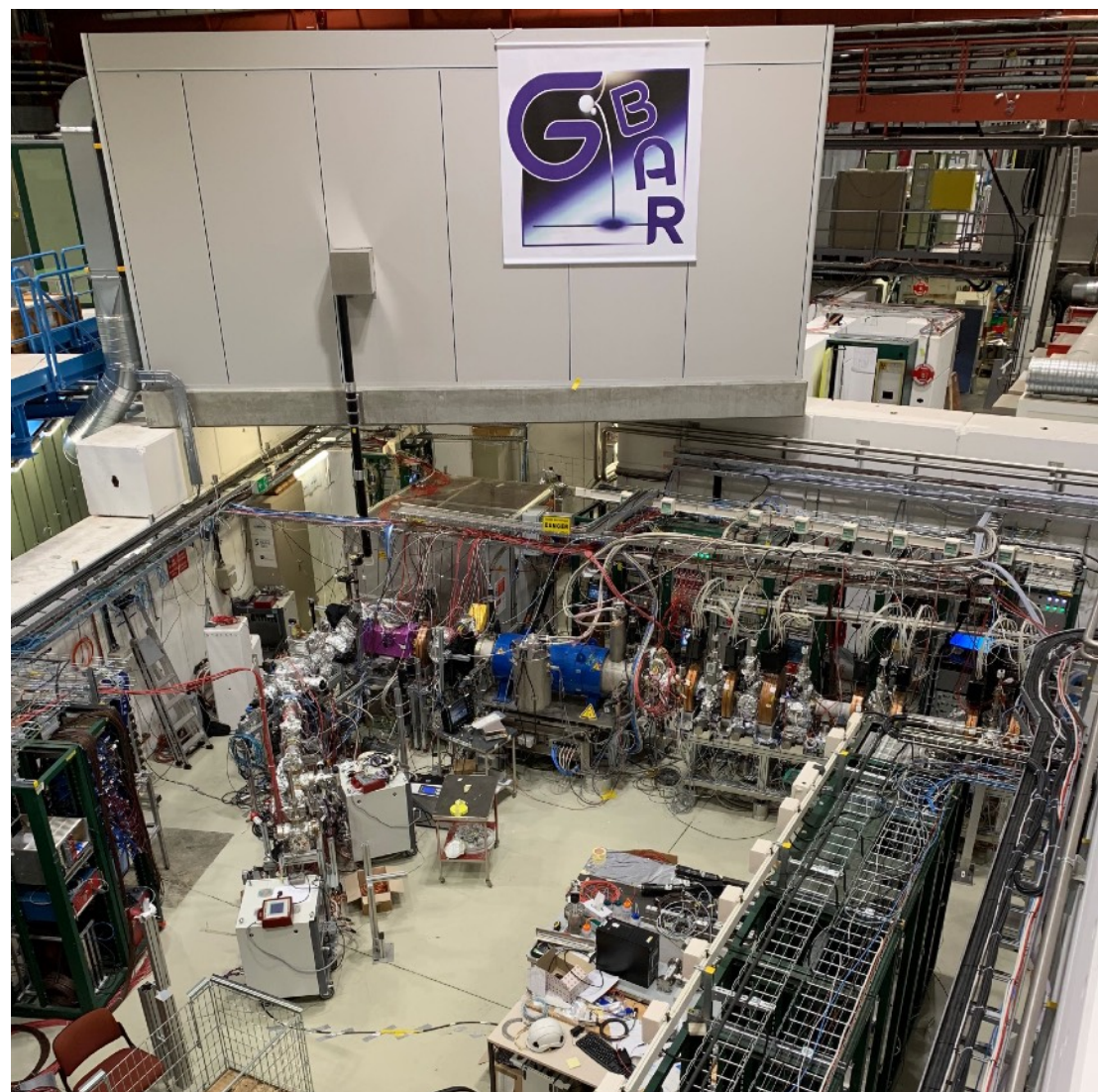


To study anti-matter



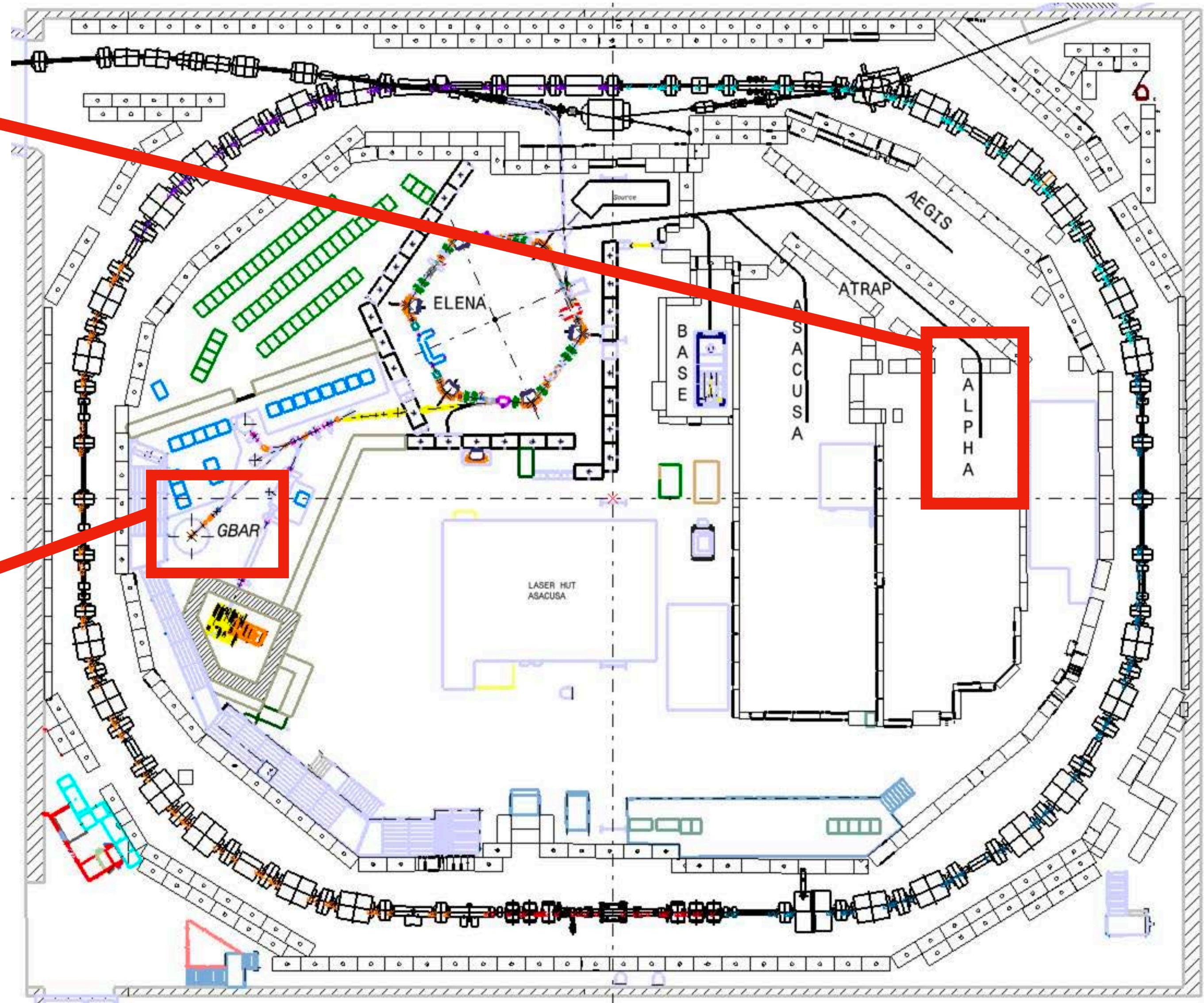
Antihydrogen Laser Physics Apparatus (ALPHA)

create, capture and then cool antihydrogen to use for experiment

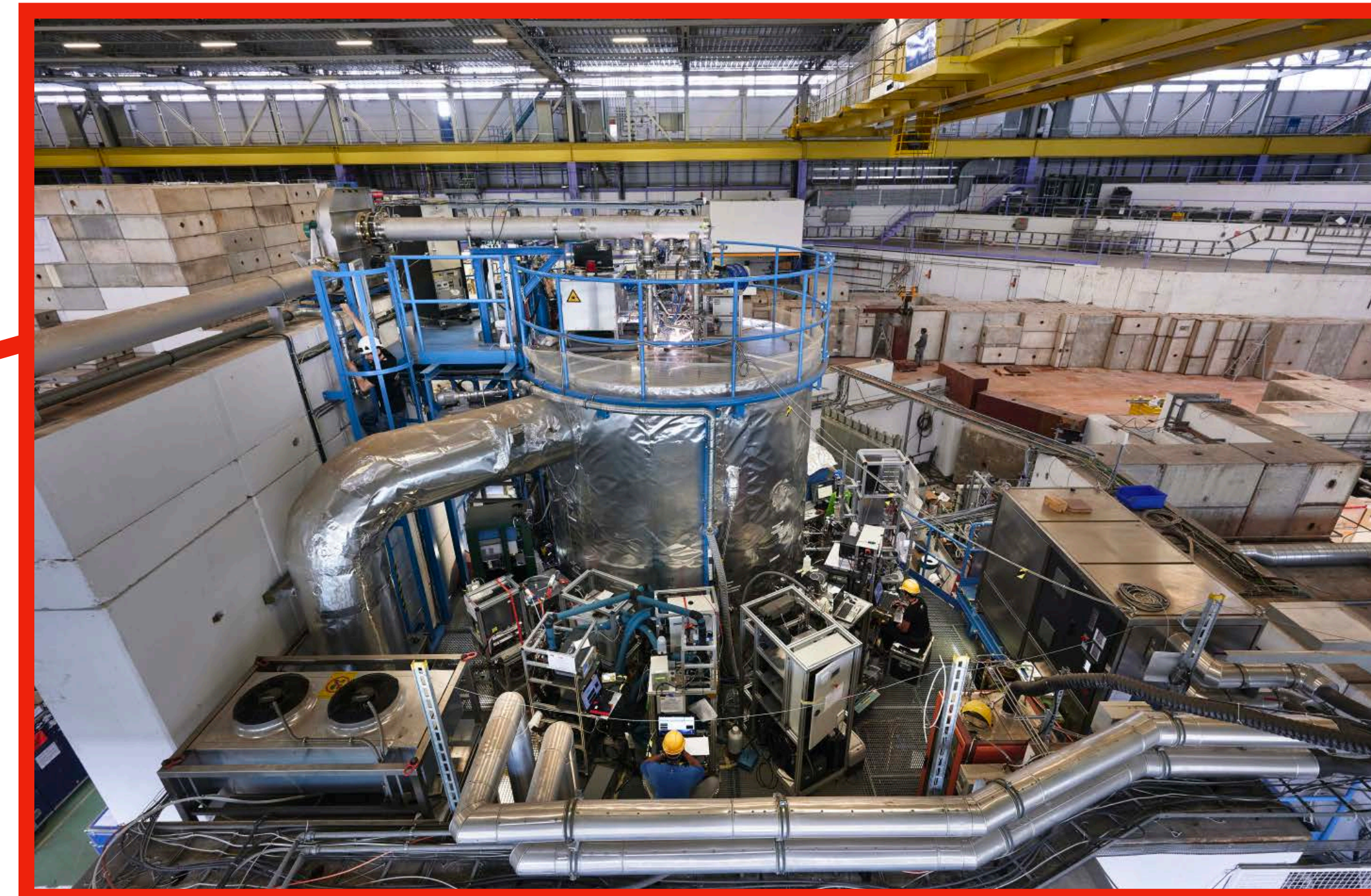
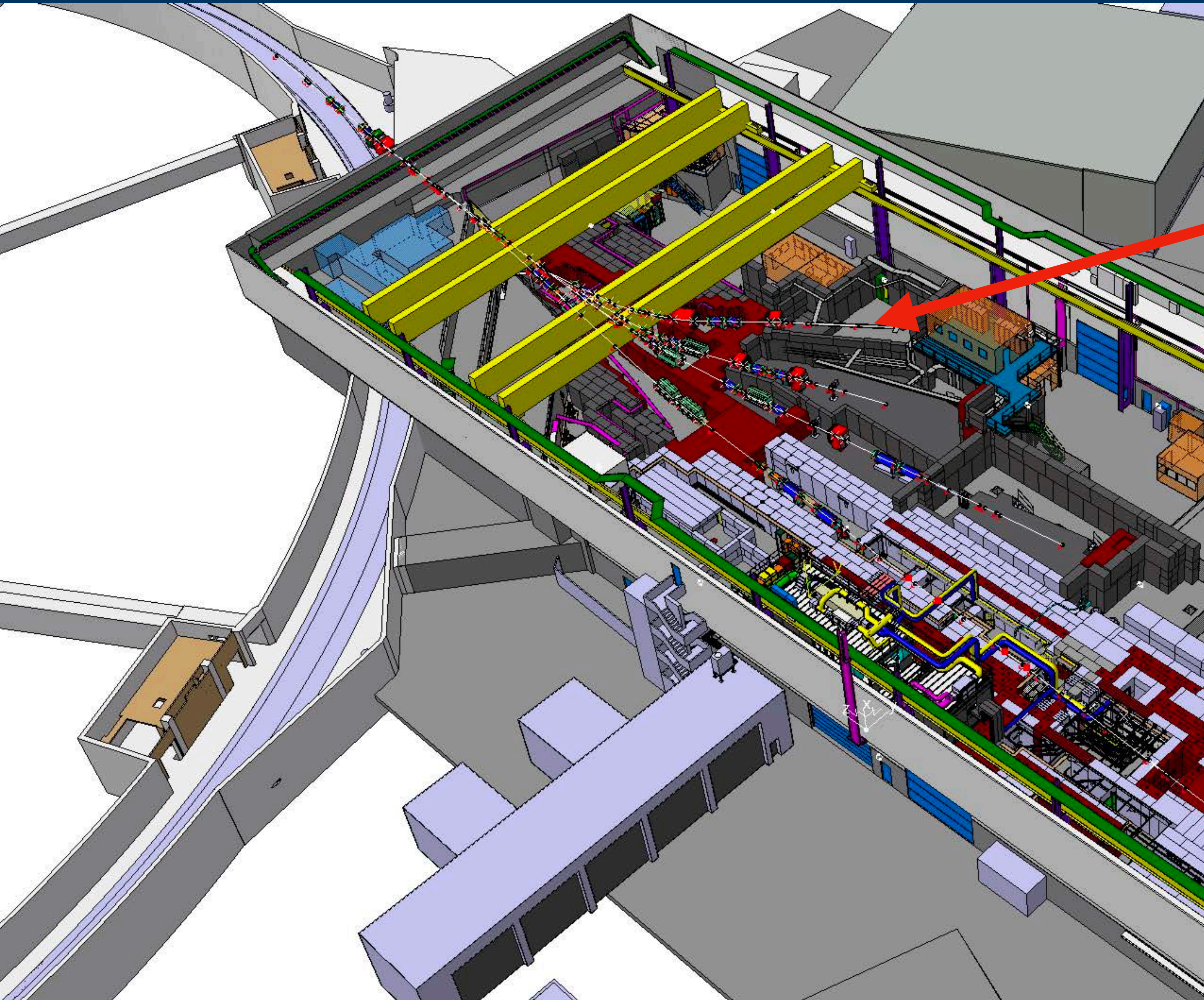


Gravitational Behaviour of Antimatter at Rest (GBAR)

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



To study links between cosmic rays and cloud formation



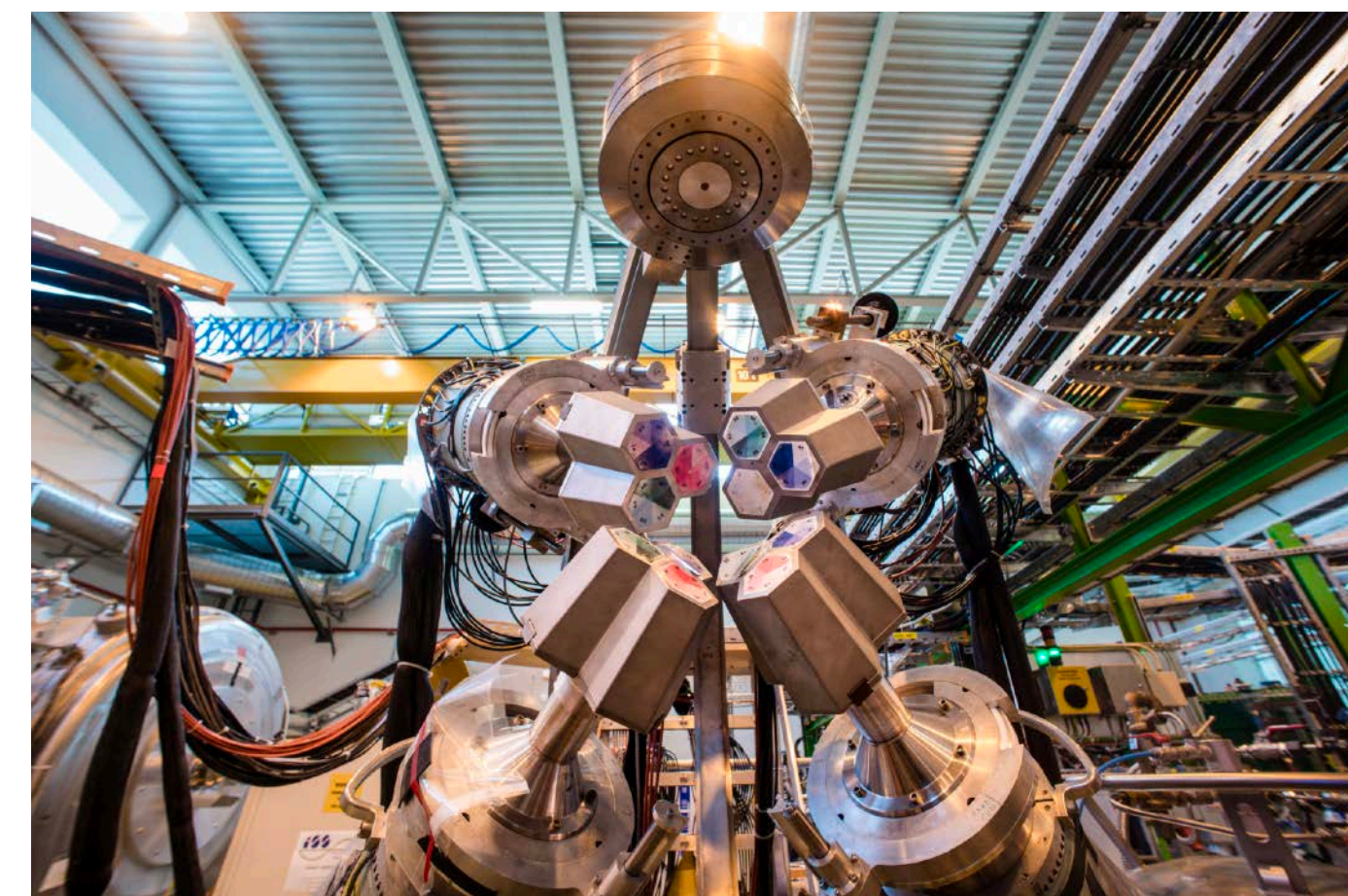
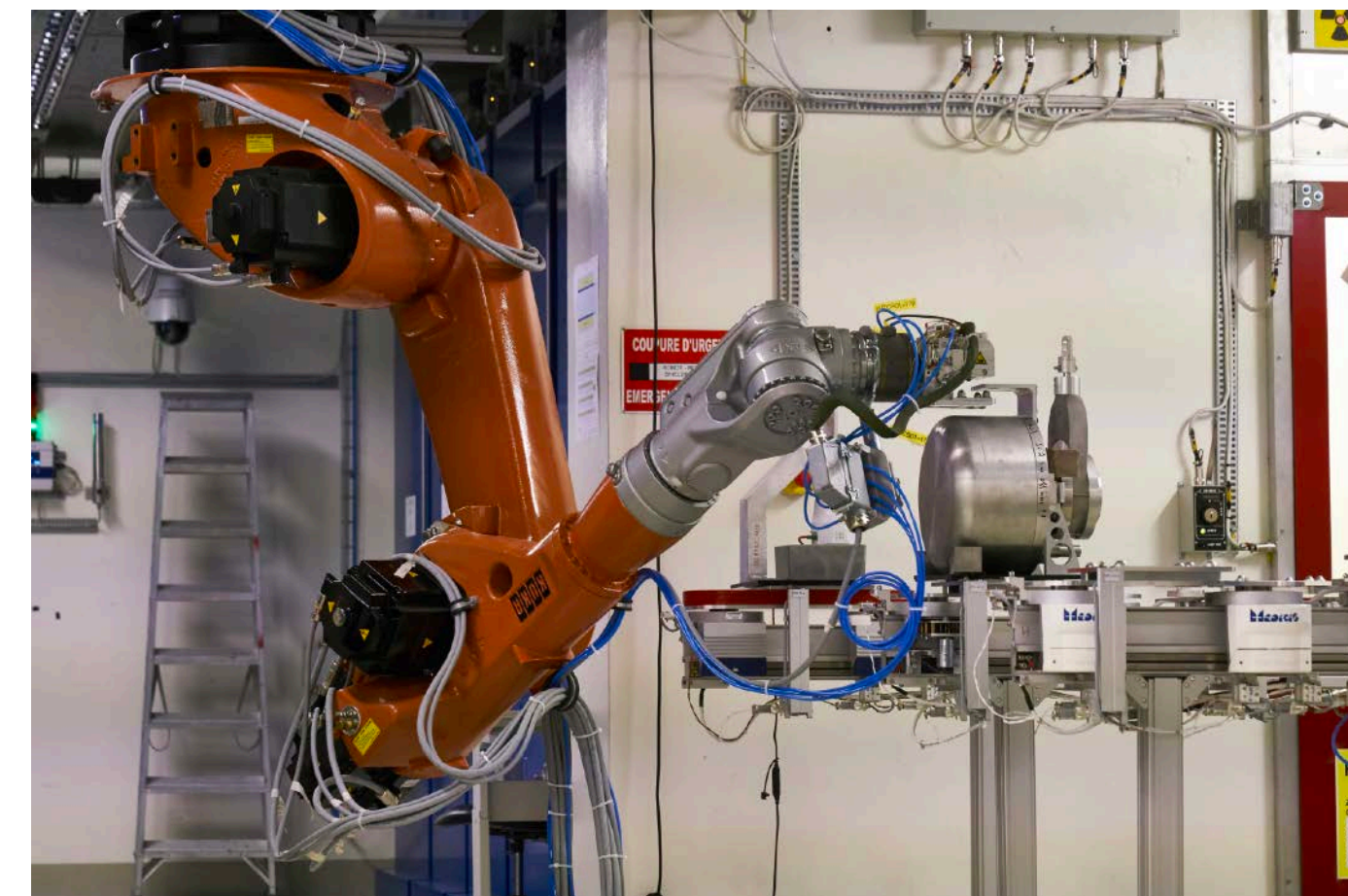
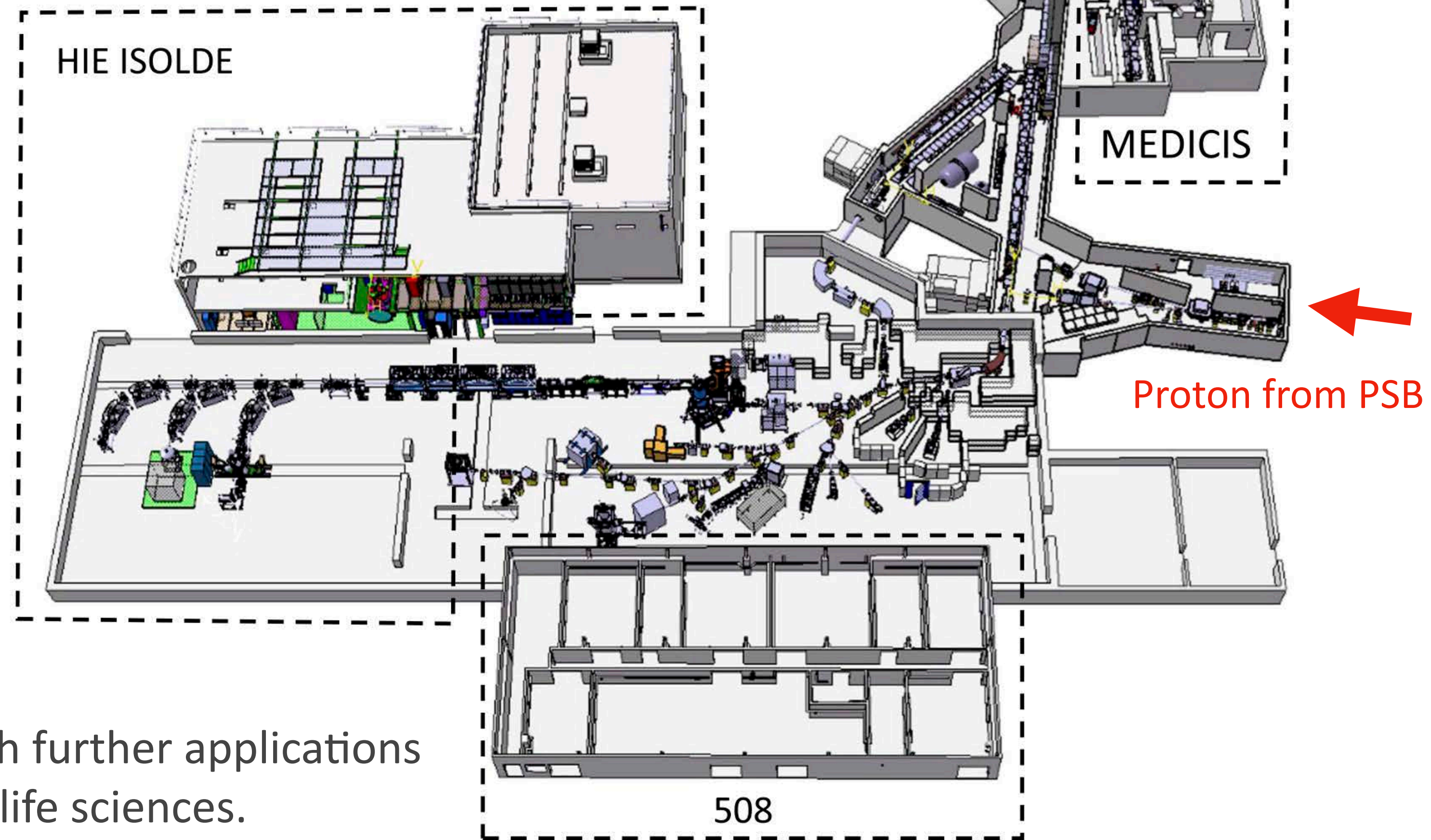
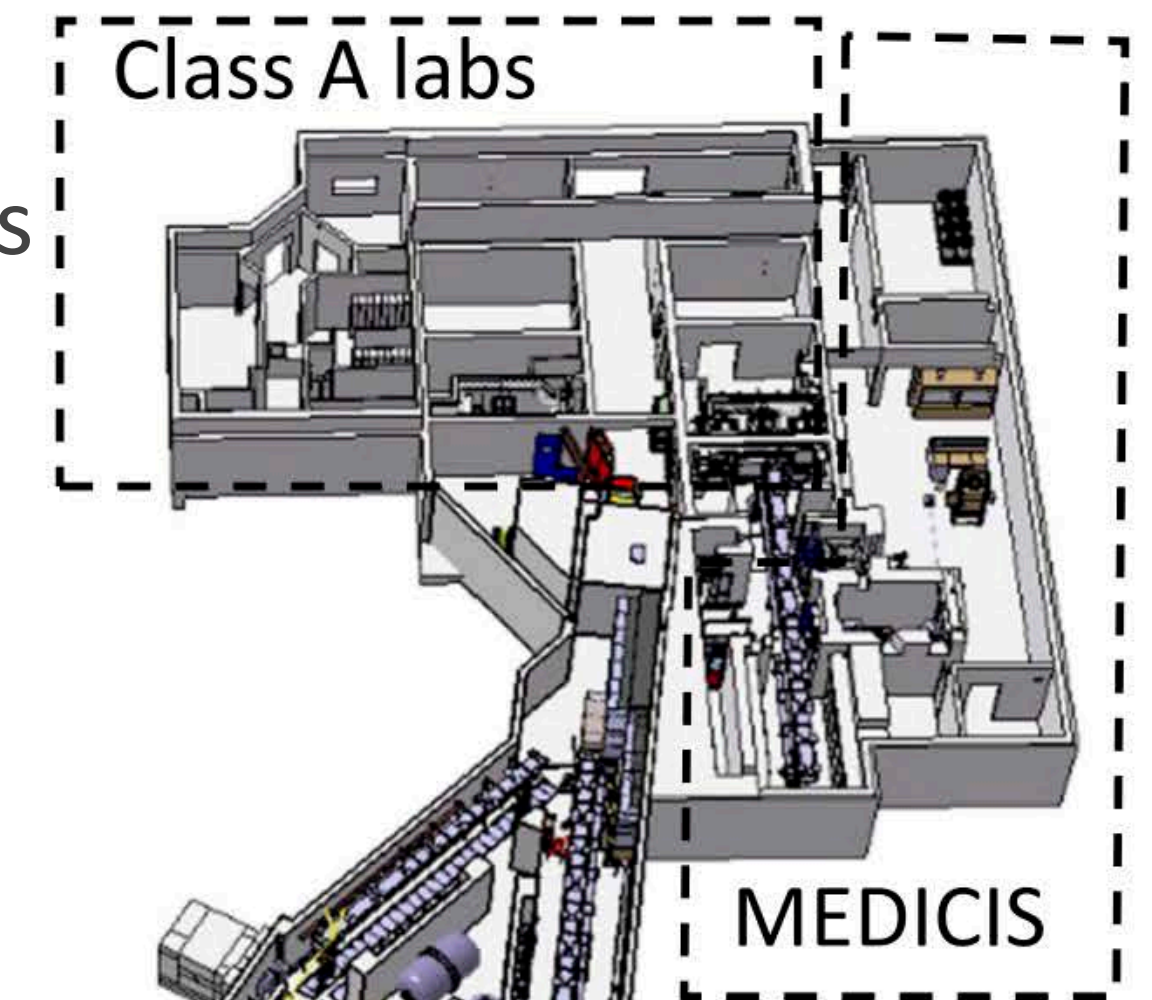
CLOUD

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.

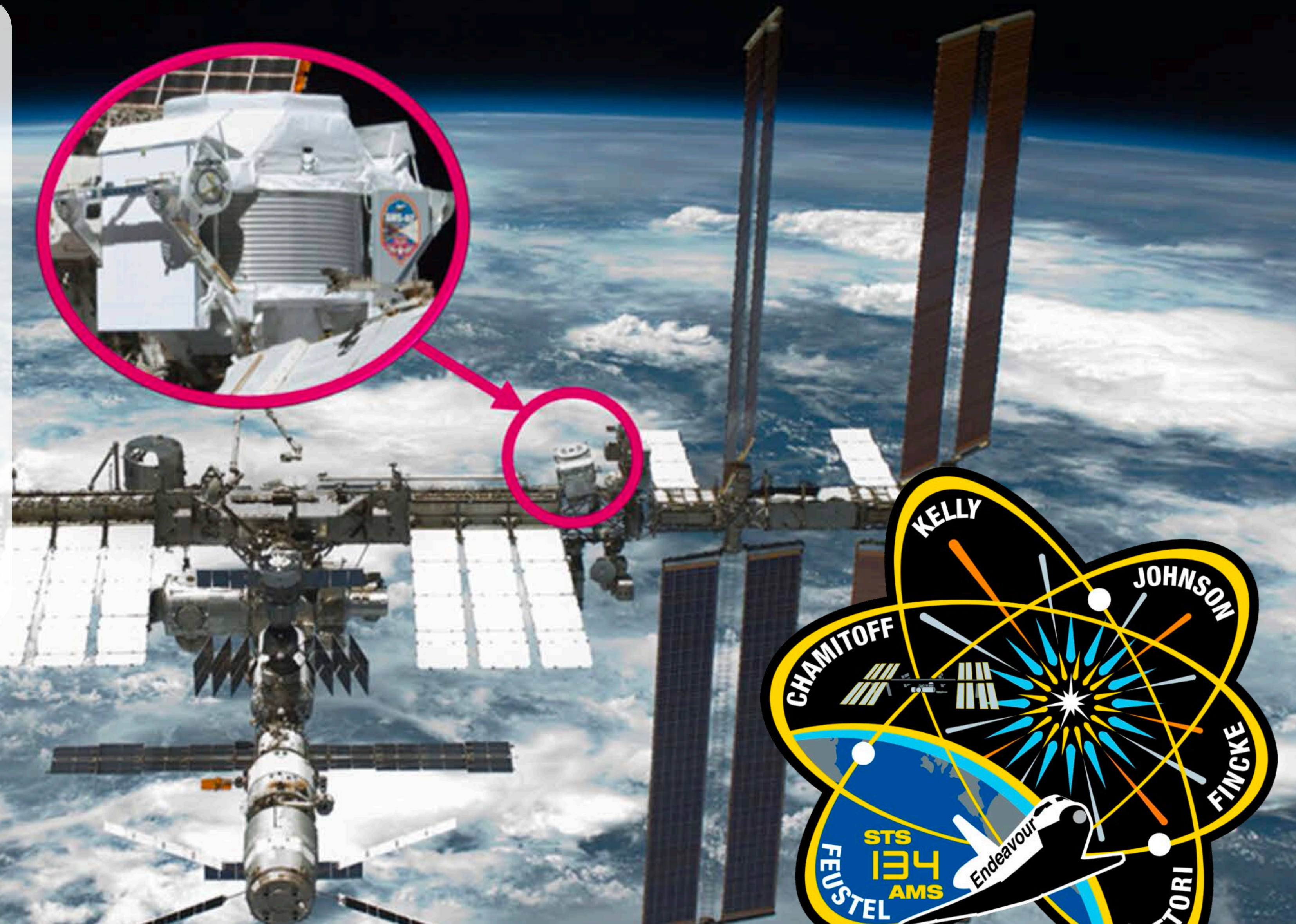
External experiments at CERN: AMS

AMS

The Alpha Magnetic Spectrometer looks for dark matter, antimatter and missing matter from a module on the International Space Station.

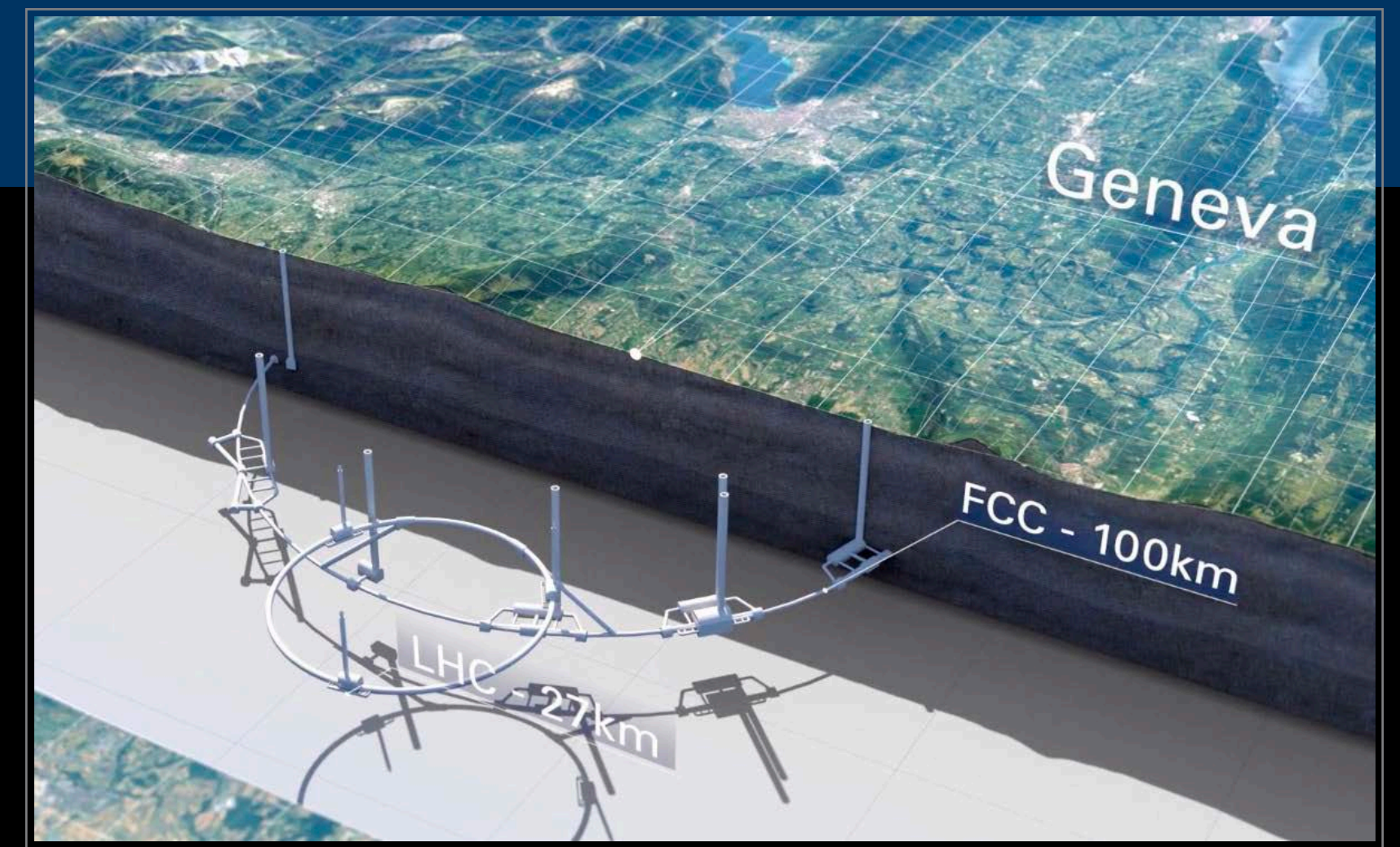
16 May 2011: Space shuttle Endeavour delivered the AMS detector to ISS.

19 May 2011 - Now: Data from AMS is sending back to Earth – to NASA in Houston and then from NASA to CERN for analysis.

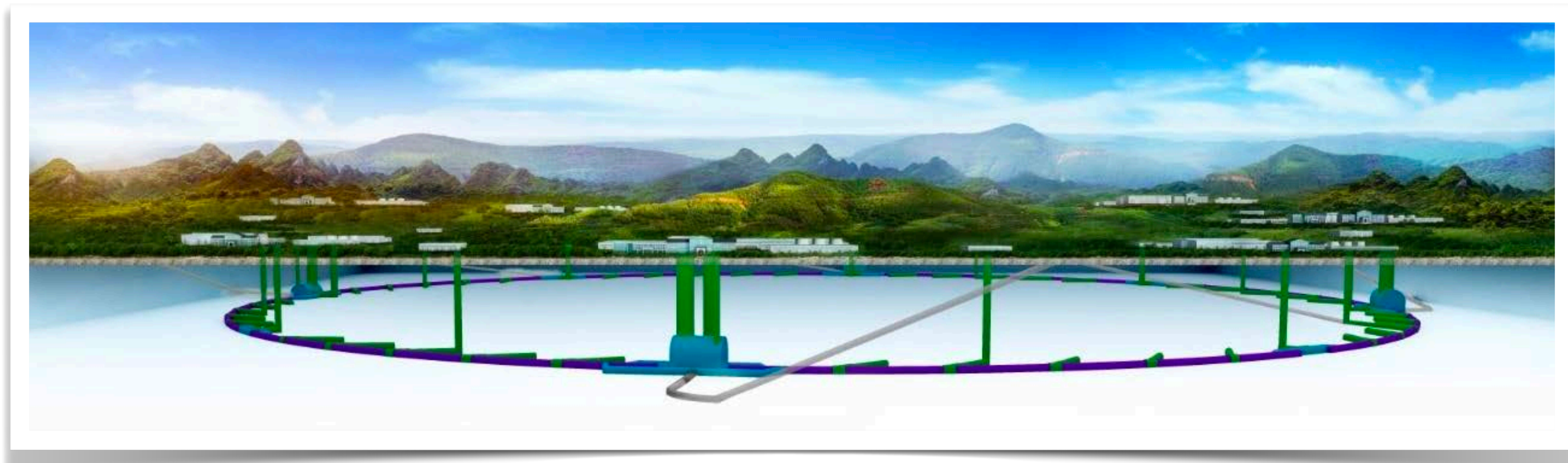


Beyond LHC

- **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 ($p\bar{p}$)

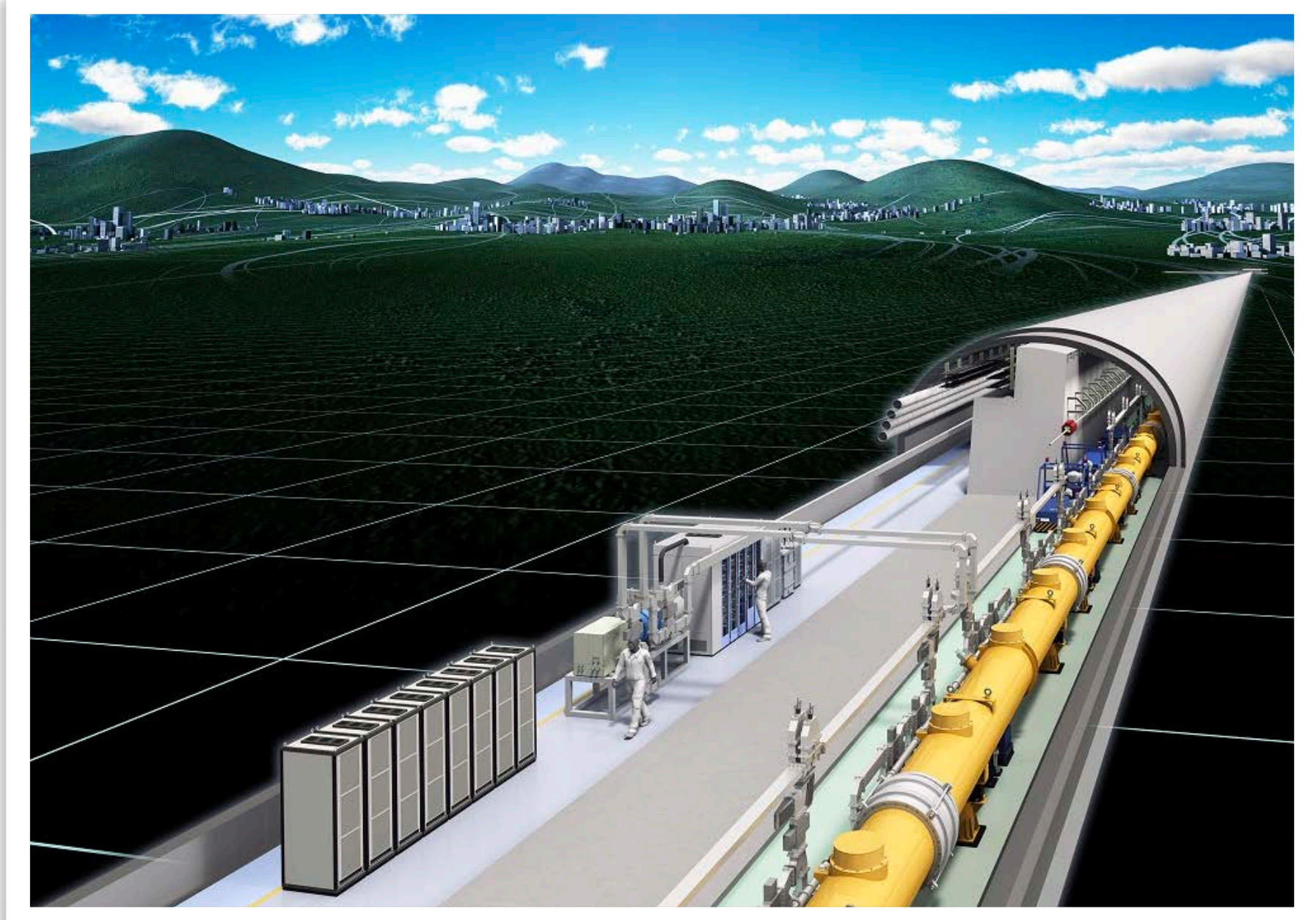


Beyond LHC: Precision Measurement

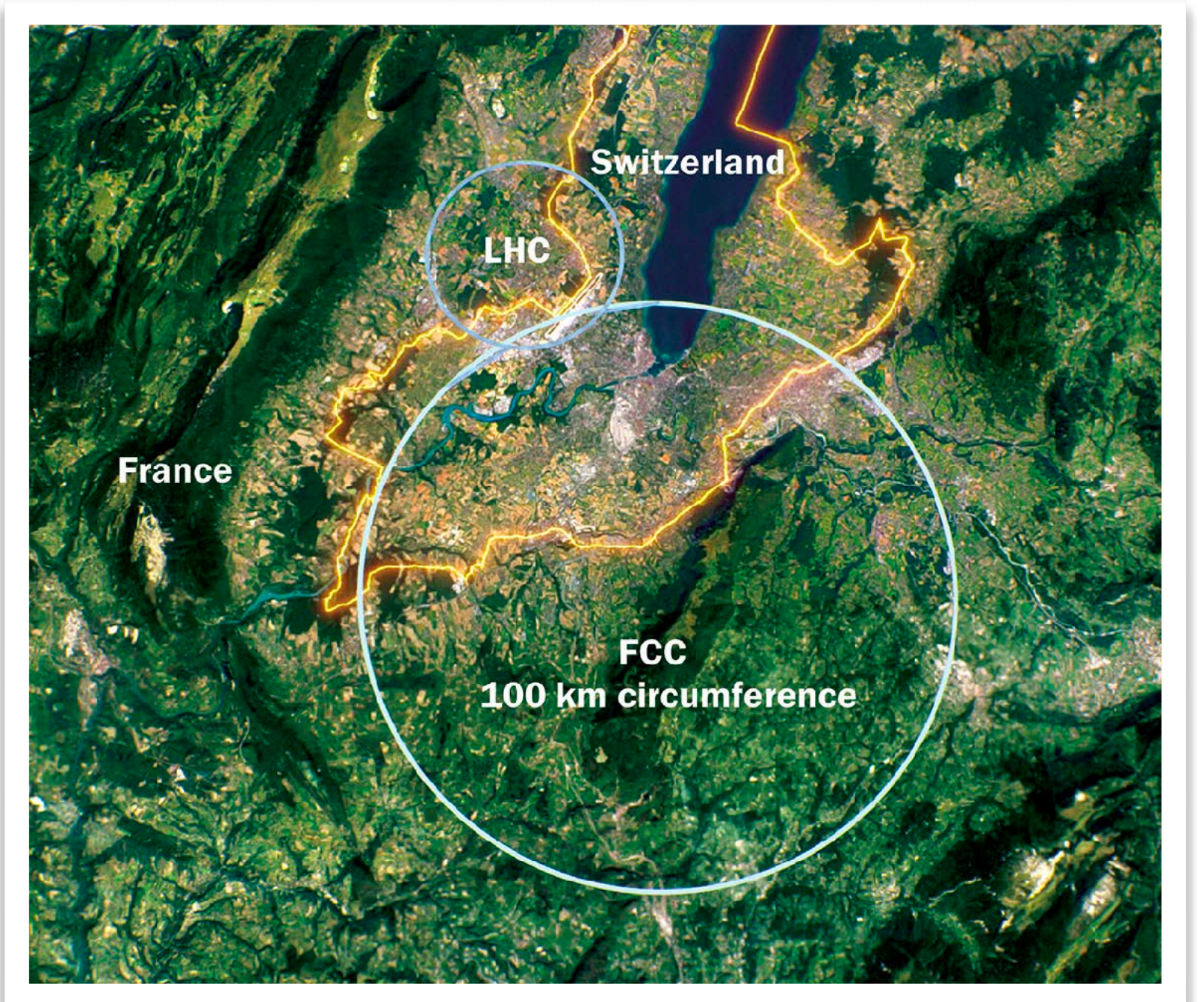
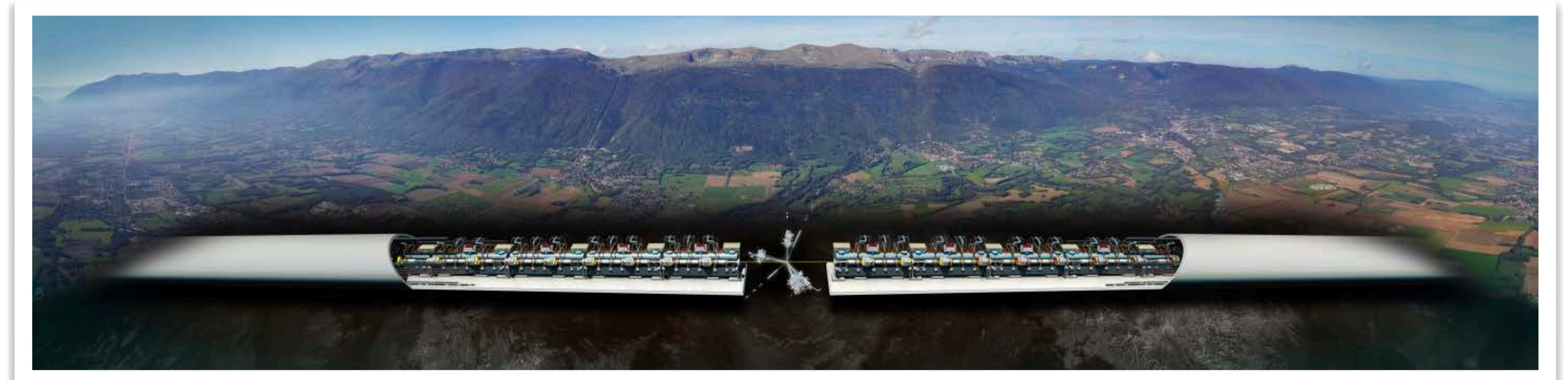


CEPC (Circular Electron Positron Collider), China

International Linear Collider (ILC)



Compact Linear Collider (CLIC)



**Future Circular Collider (FCC) - ee,
Switzerland-France**

Beyond LHC: Muon Collider

Why muon collider?

As electron, muon is elementary particle (AFAWK) with higher mass (x206 electron mass). The mass of muon is the key of high energy collision.

Consider the power emitted from charged particles which are accelerated in a curved path (known as synchrotron radiation), it is proportional to $\frac{1}{m^4}$. The amount of synchrotron radiation from a muon will be reduced by a factor of about 1 billion of an electron.

$$P = \frac{q^2}{6\pi\epsilon_0 m^4 c^5 r^2 \sin^2(\alpha)} (E^2 - m^2 c^4)^2$$

Something to solve?

We need to handle the muon's lifetime. At rest, it will decay in $2 \mu\text{s}$. If we can accelerate a muon close to the speed of light before decaying, its lifetime will stretch longer. This is the result of the special relativity.

Muon Collider Conceptual Layout

Project X

Accelerate hydrogen ions to 8 GeV using SRF technology.

Compressor Ring

Reduce size of beam.

Target

Collisions lead to muons with energy of about 200 MeV.

Muon Capture and Cooling

Capture, bunch and cool muons to create a tight beam.

Initial Acceleration

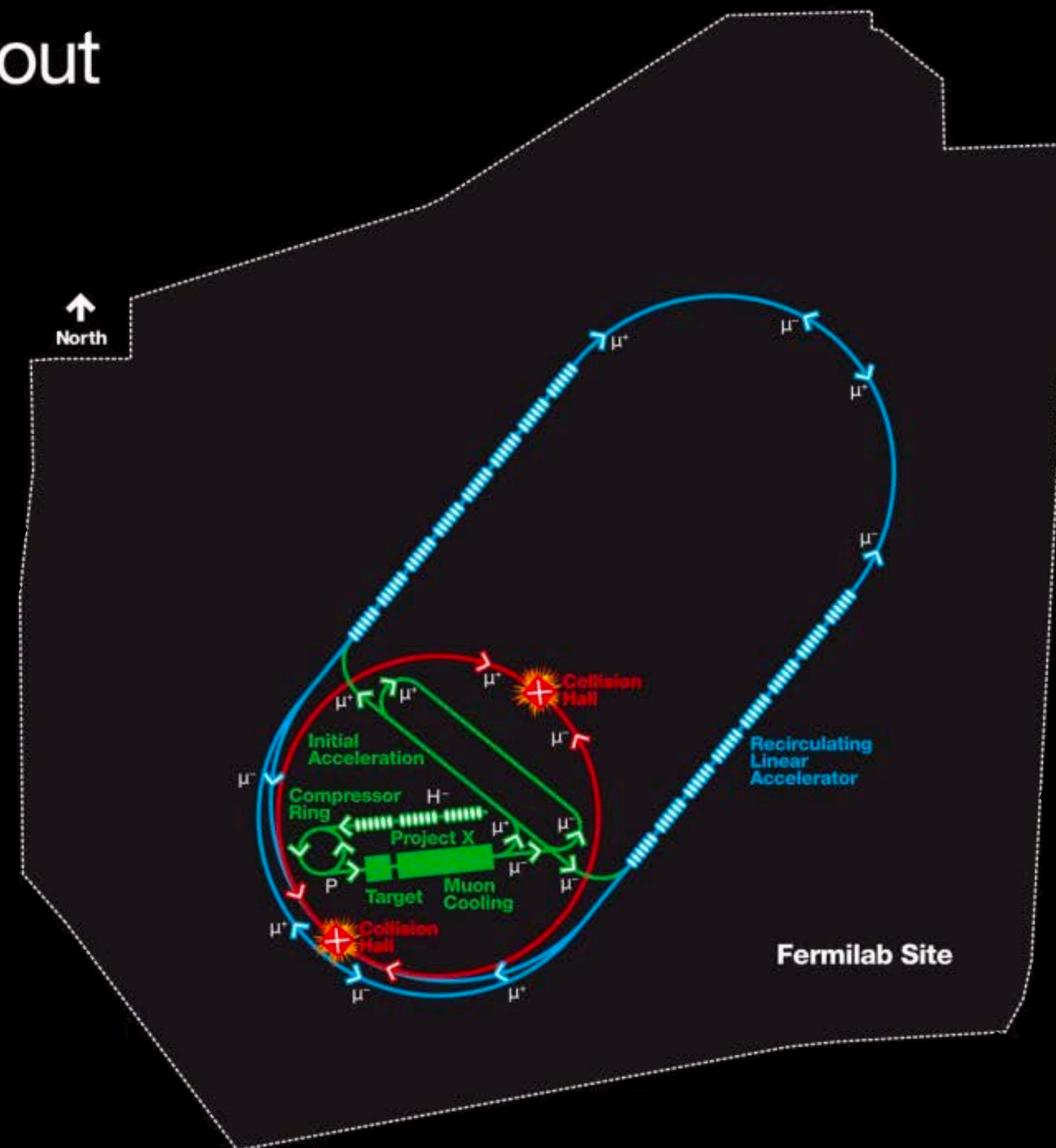
In a dozen turns, accelerate muons to 20 GeV.

Recirculating Linear Accelerator

In a number of turns, accelerate muons up to 2 TeV using SRF technology.

Collider Ring

Bring positive and negative muons into collision at two locations 100 meters underground.



<https://www.symmetrymagazine.org/breaking/2009/11/19/what-a-muon-collider-could-look-like>

Why particle physics matters

<http://www.symmetrymagazine.org/article/october-2013/why-particle-physics-matters>

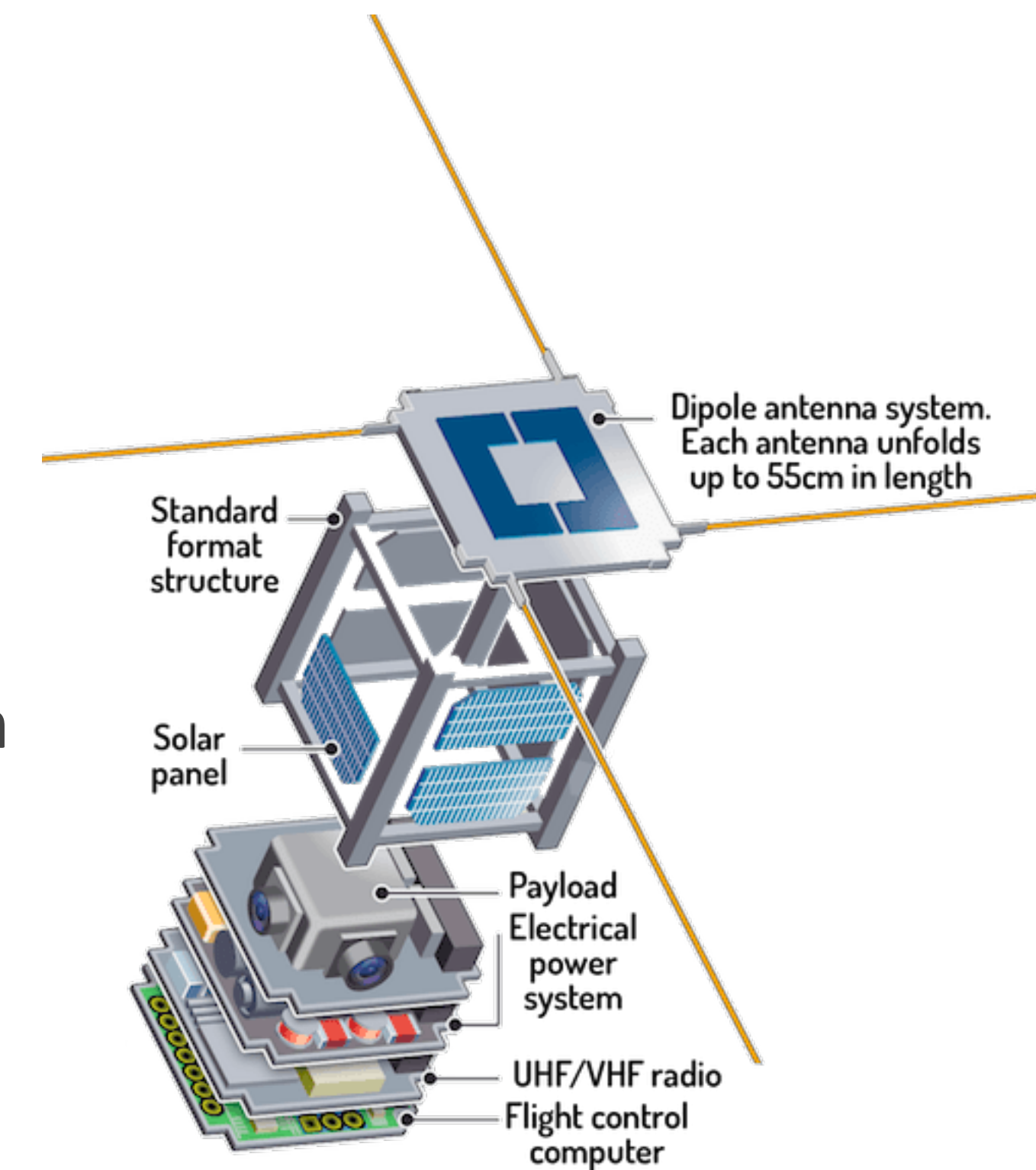


CERN latchup and radmon experiment student satellite

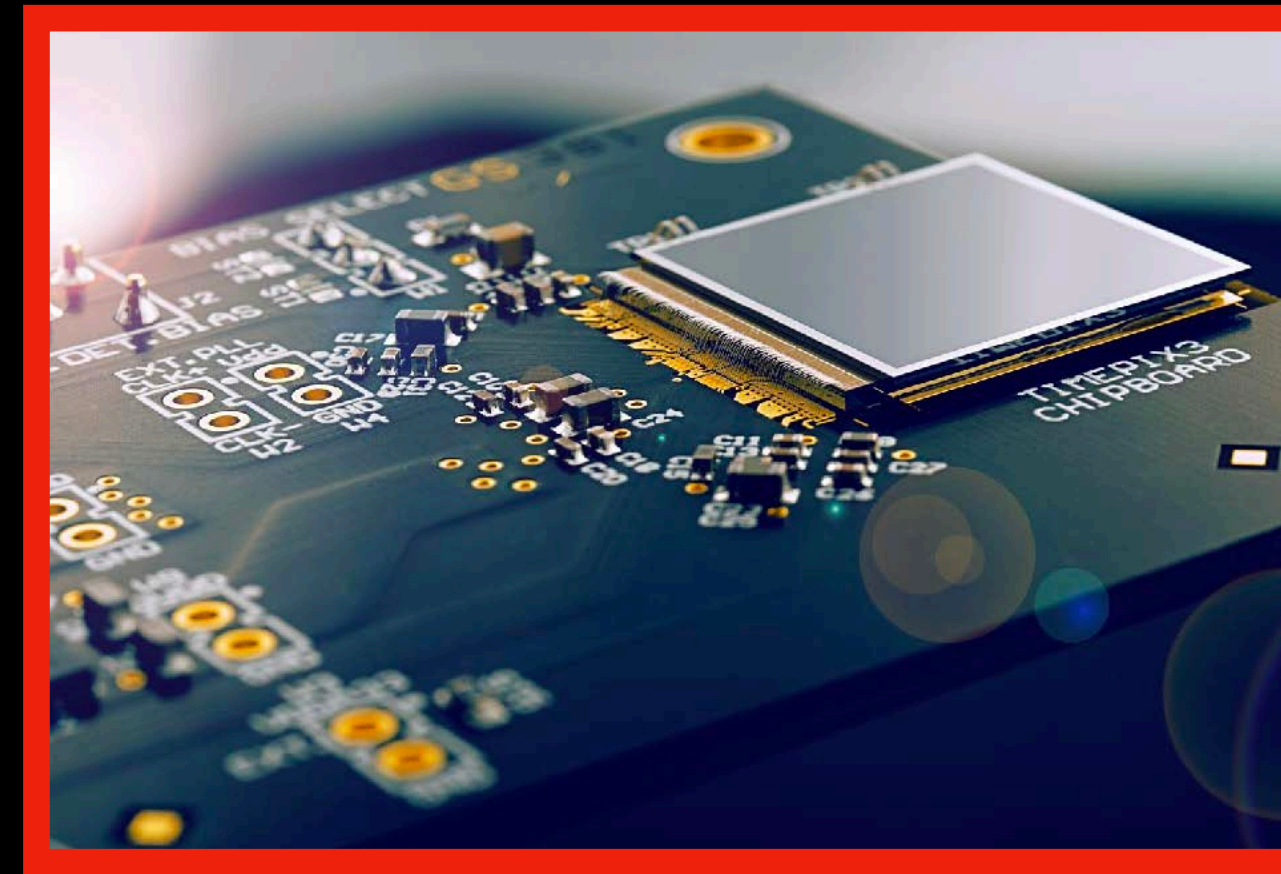
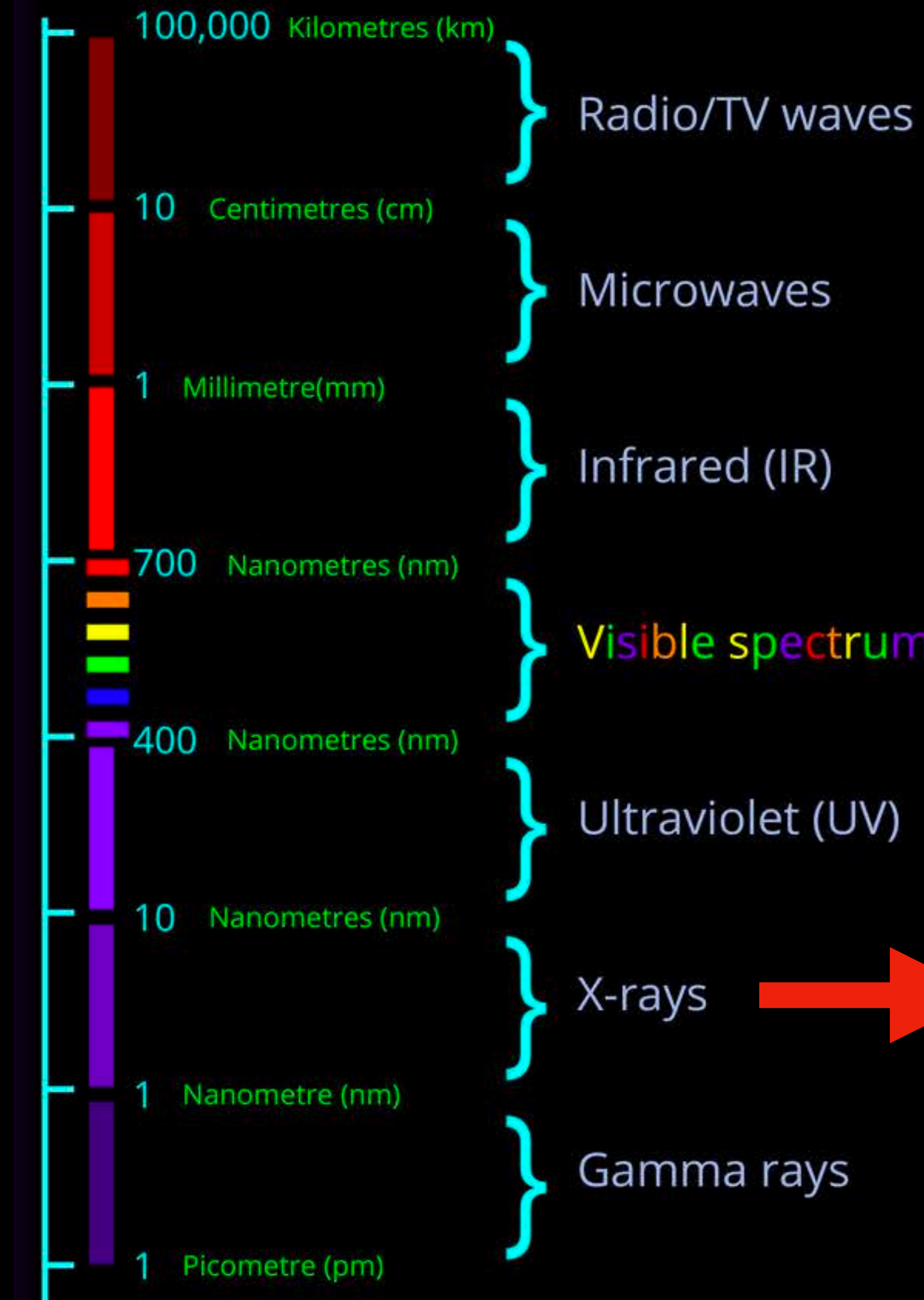


Ref: [here](#)

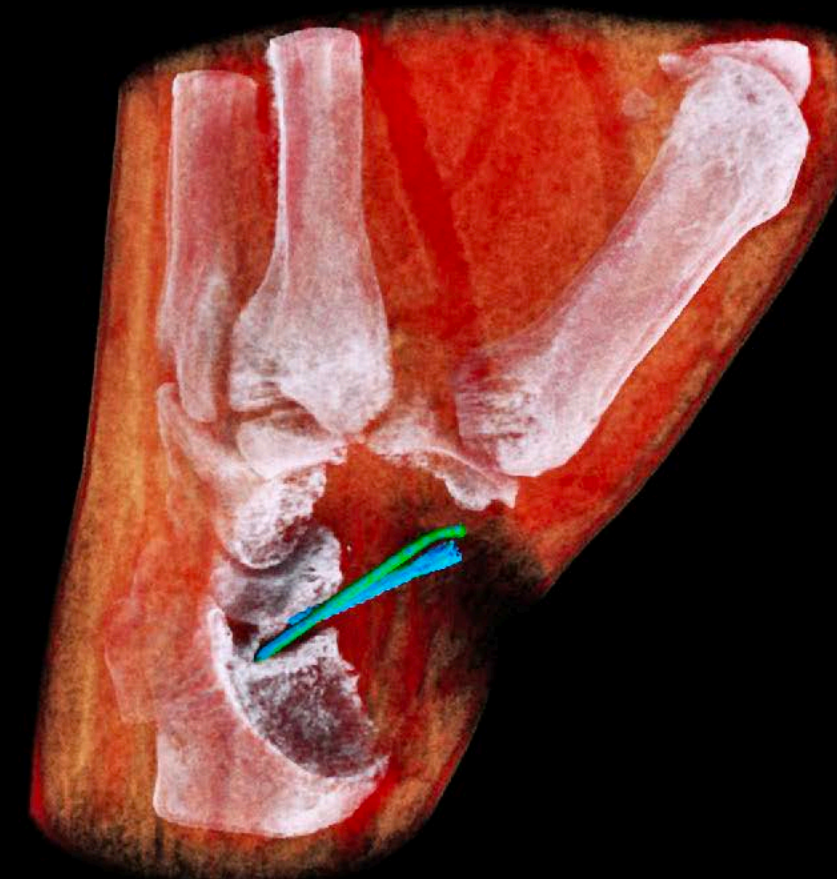
CELESTA (CERN latchup and radmon experiment student satellite) is a 1U CubeSat with weight of one kilogram and measuring 10 cm on each of its sides. It is designed to study the effects of cosmic radiation on electronics. The satellite carries a Space RadMon, a miniature version of a well-proven radiation monitoring device deployed in CERN's Large Hadron Collider (LHC).



Blue skies research ... not with imaginations/ideas

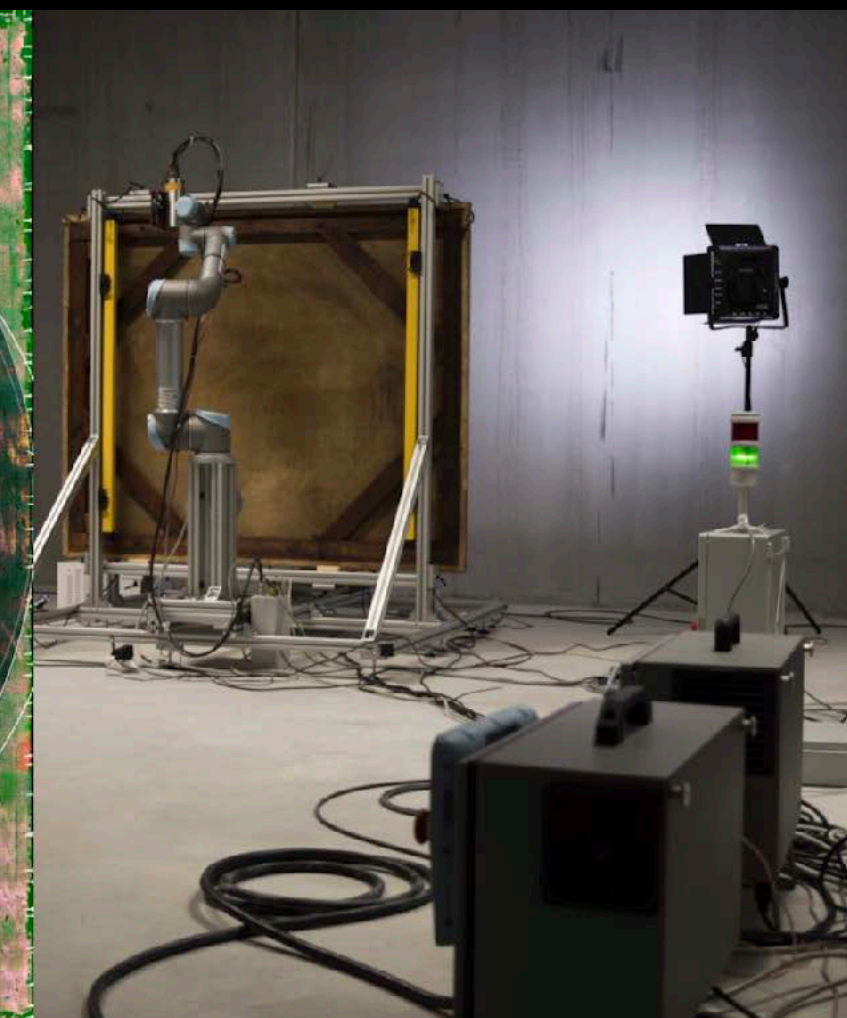


Medipix3; a CMOS pixel detector readout chip designed to be connected to a segmented semiconductor sensor.



3D colour human X-ray, clinical trial

High resolution spectroscopic radiography



Blue skies research ... not with imaginations/ideas

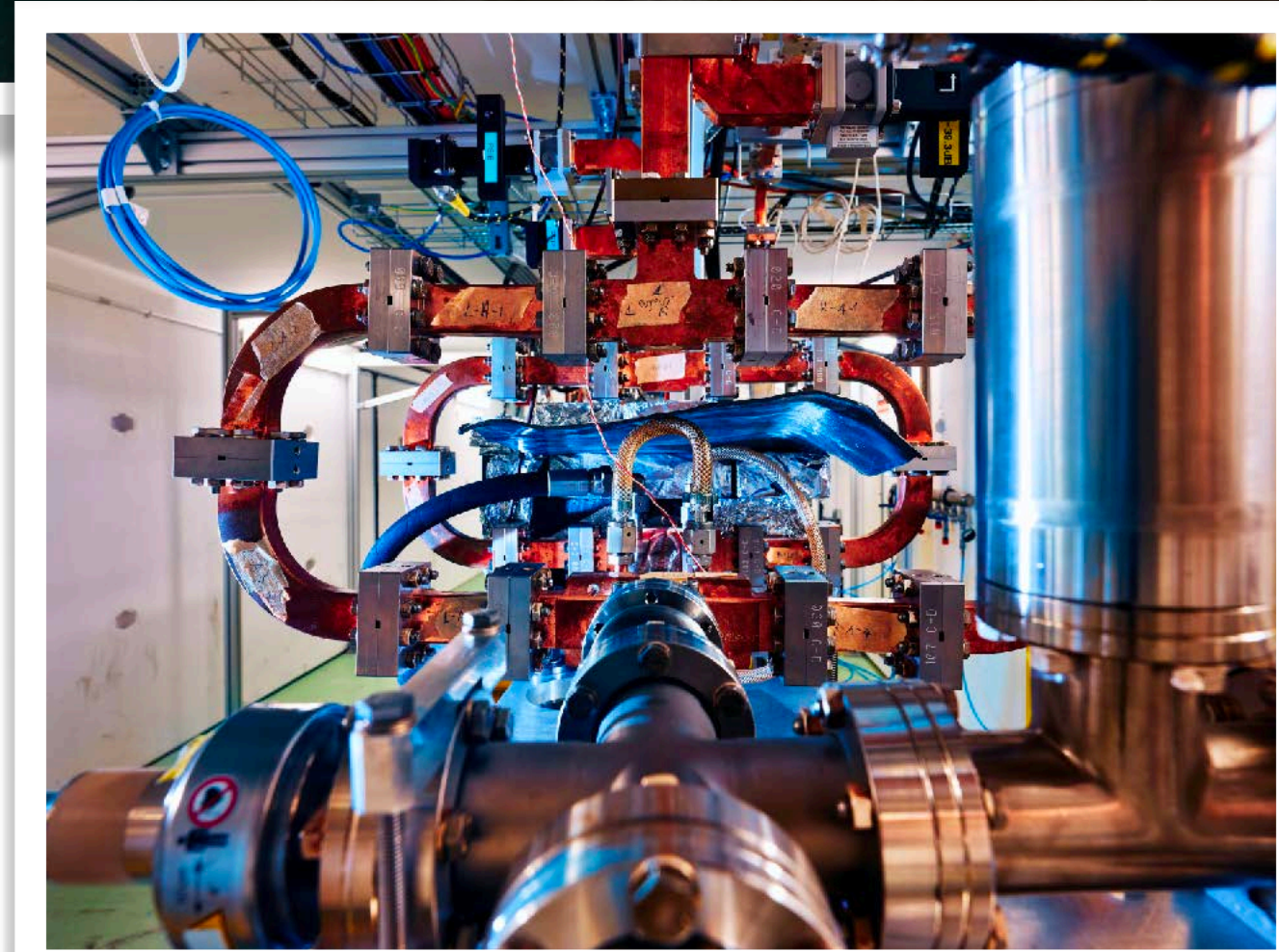
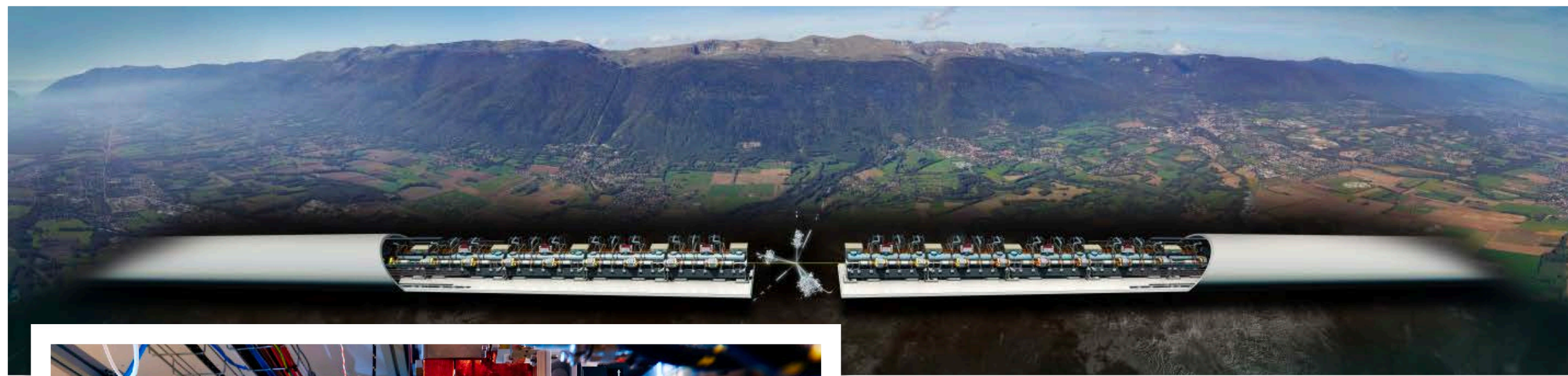


The irrigation system will use fibre optic sensors designed to measure parameters such as temperature, humidity, concentration of pesticides, fertilisers and enzymes in the soil of cultivated fields. This is the same fibre optic sensors developed by CMS experiment in order to monitor the environment in the CMS tracking system.

<https://cms.cern/news/how-can-high-energy-physics-help-water-shortage>

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".

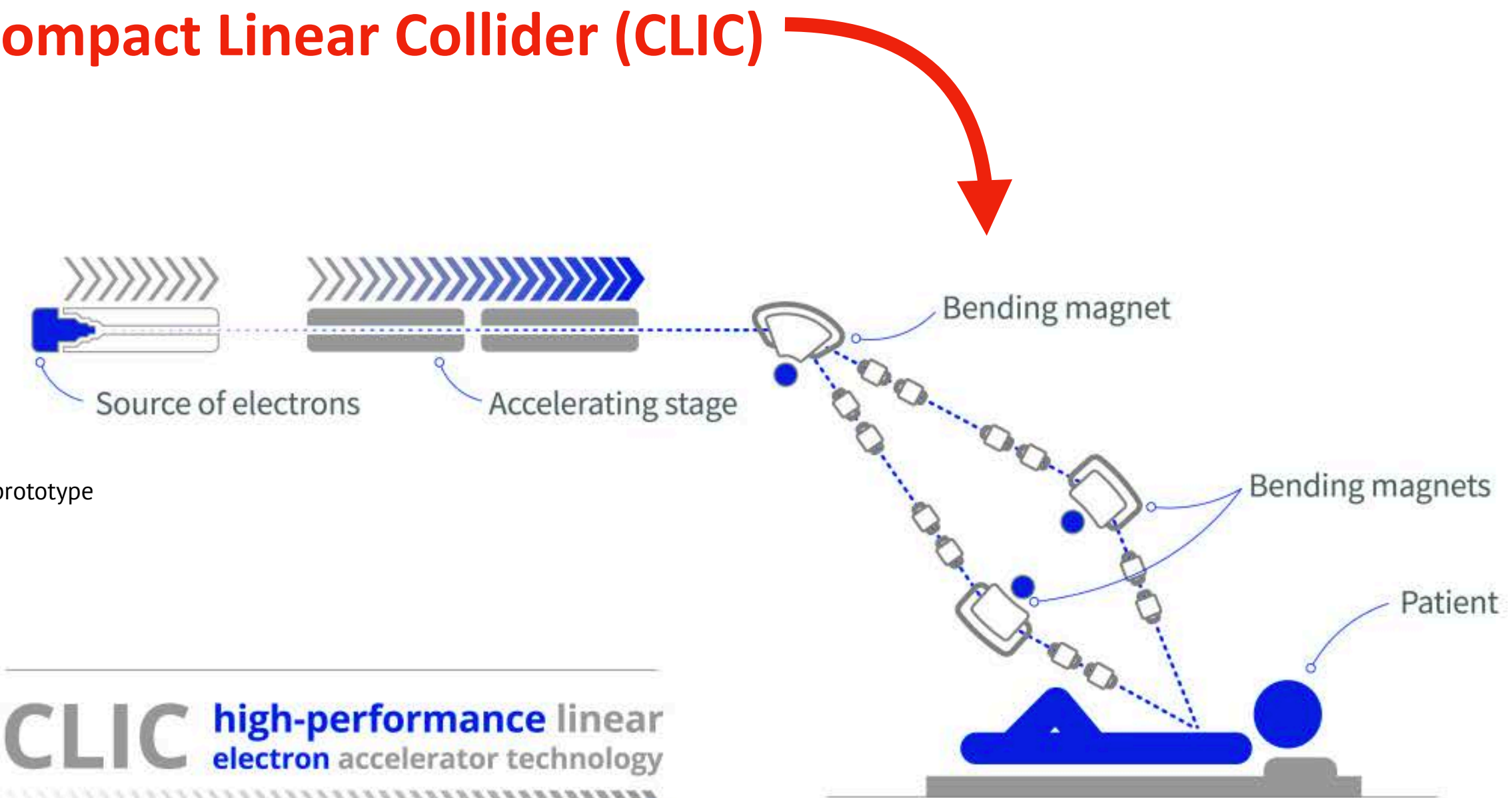


CLIC prototype

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)



CLIC high-performance linear electron accelerator technology

< 1s
Full dose is delivered by a beam of electrons in less than a second

More healthy tissue spared

FLASH treatments of large and deep-seated tumours

Innovative Radiation Therapy with Electrons

CERN Beamline for Schools



- Beamline for Schools (BL4S) is an international physics competition for high school students organised by CERN, and DESY
- Teams of high-school students from all around the world to propose a scientific experiment that they want to perform at a particle accelerator.
- The three teams that prepare the best proposals will win a trip to a particle accelerator facility to perform their experiments at a fully-equipped beamline.
- <https://beamlineforschools.cern/>
(2024 Application, Early next year) BUT you should start thinking now!!!