https://cds.cern.ch/record/1742528

Introduction to CERN and High Energy Particle Physics Programs

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24 Dec 2022, OBEC

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.

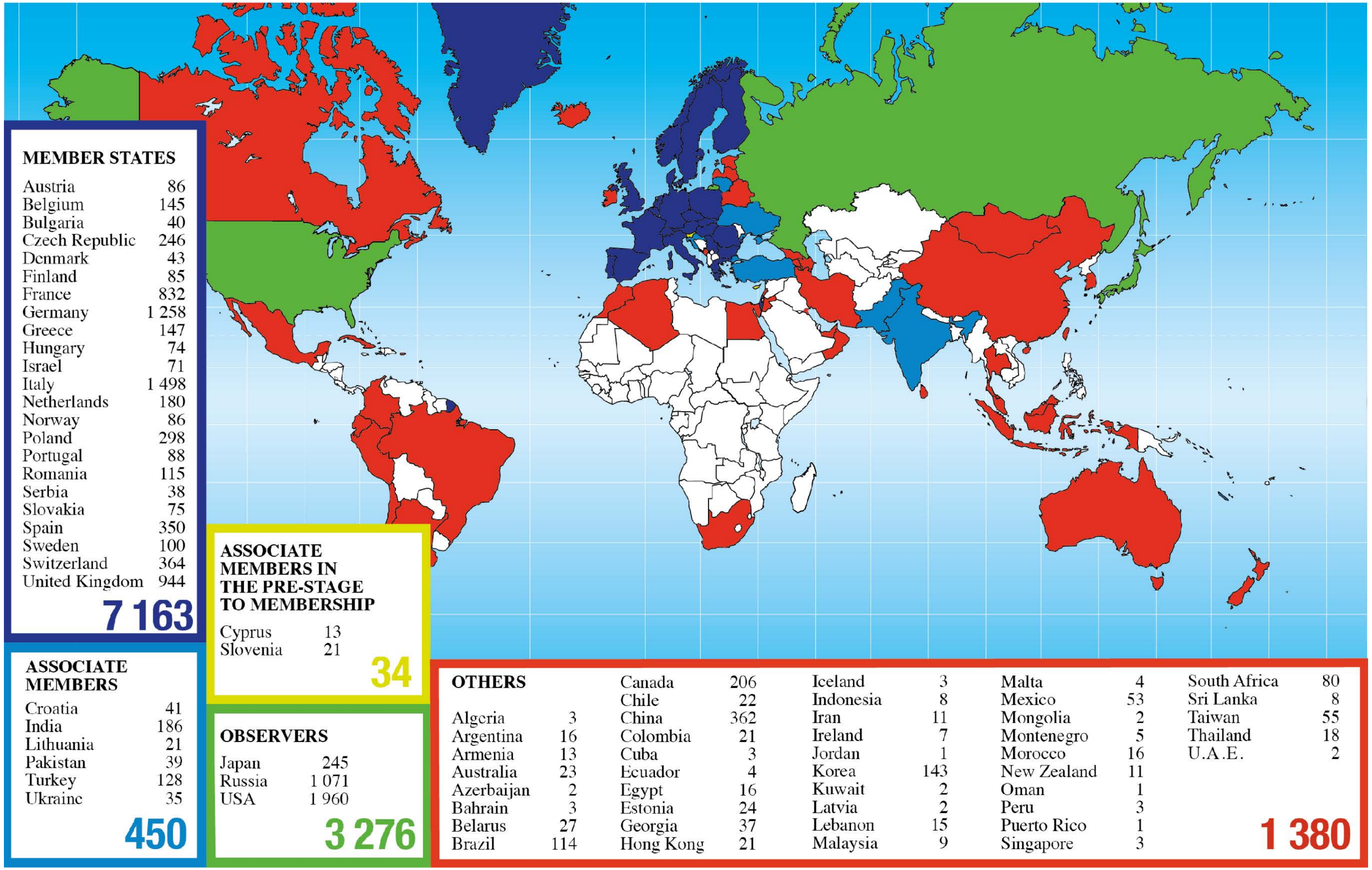
The Sixth Session of the CERN Council took place in Paris on 29 June—1 July 1953. It was here that the Convention establishing the Organization was signed, subject to ratification, by twelve States.

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: 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

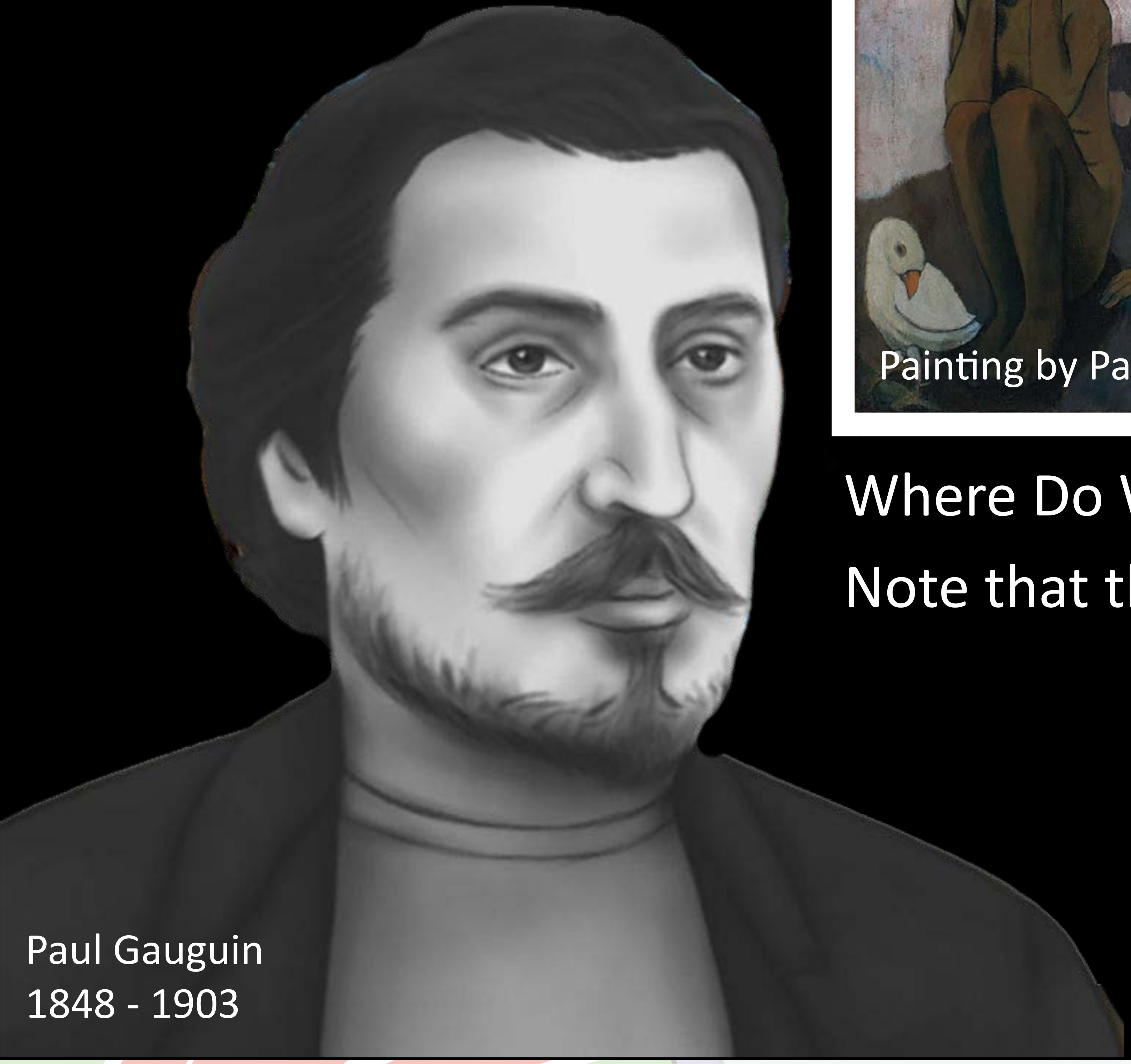
Collaborating
Bringing nations together through science

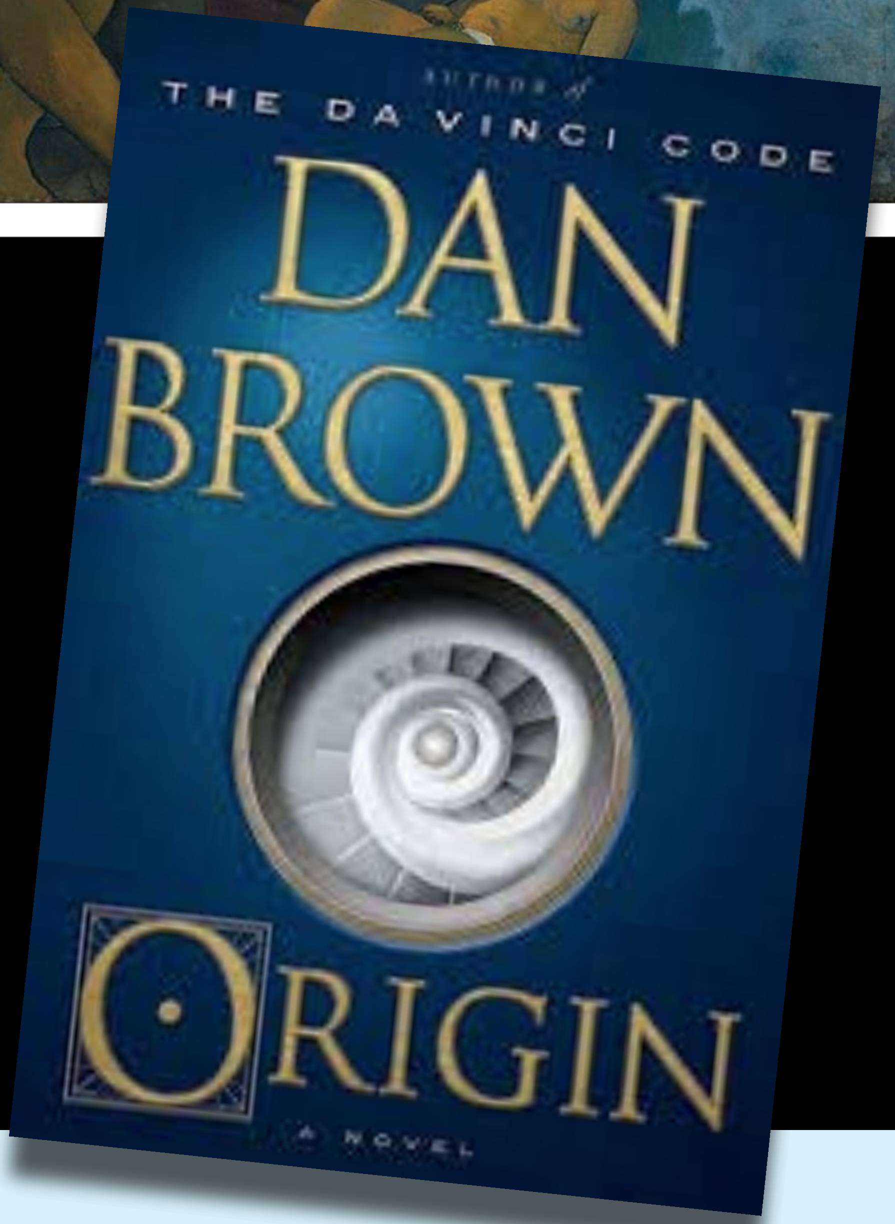
Where do we come from? What are we? Where are we going?

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

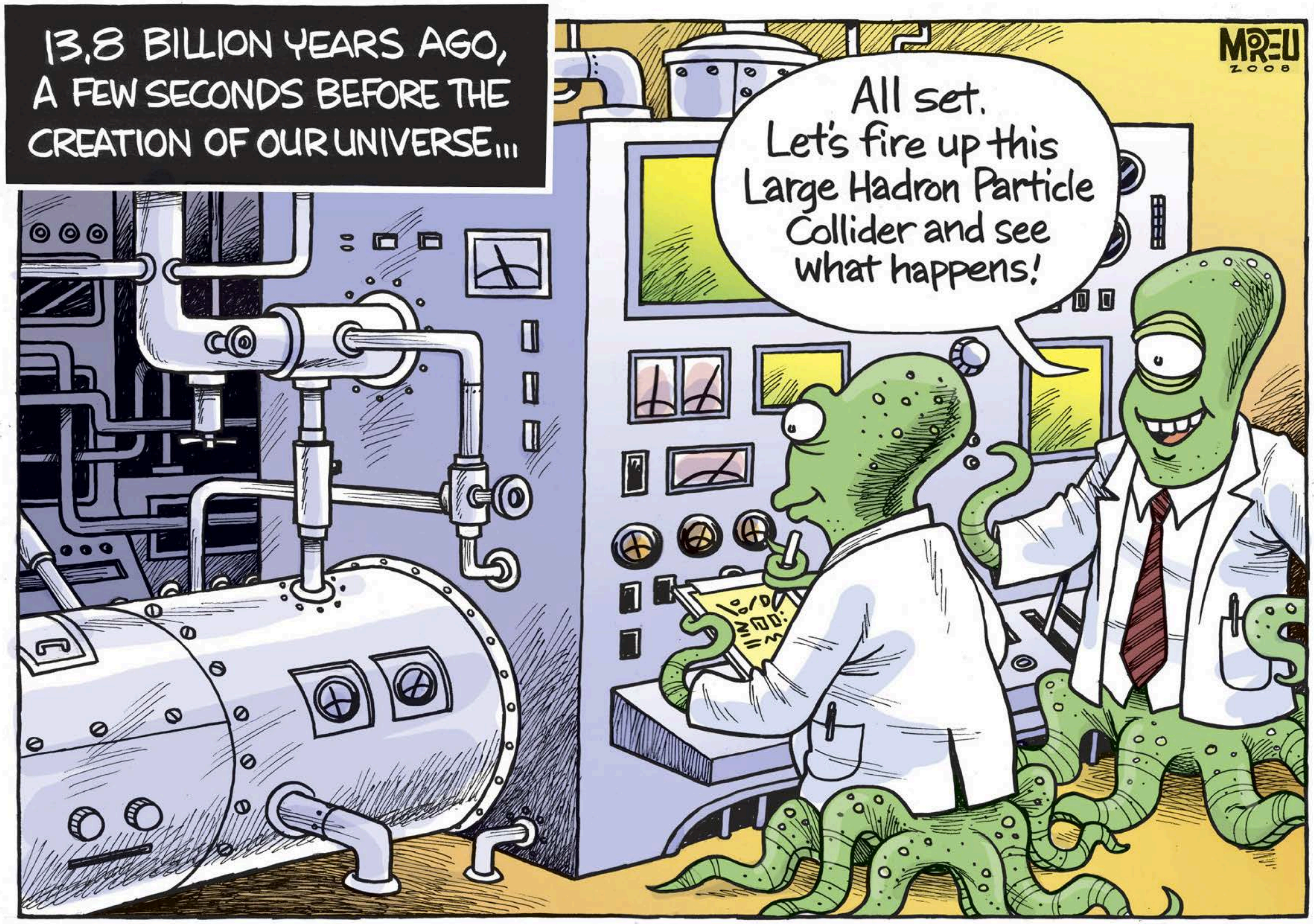
Where Do We Come From? What Are We? Where Are We Going?

Note that this painting should be read from right to left.


Paul Gauguin
1848 - 1903

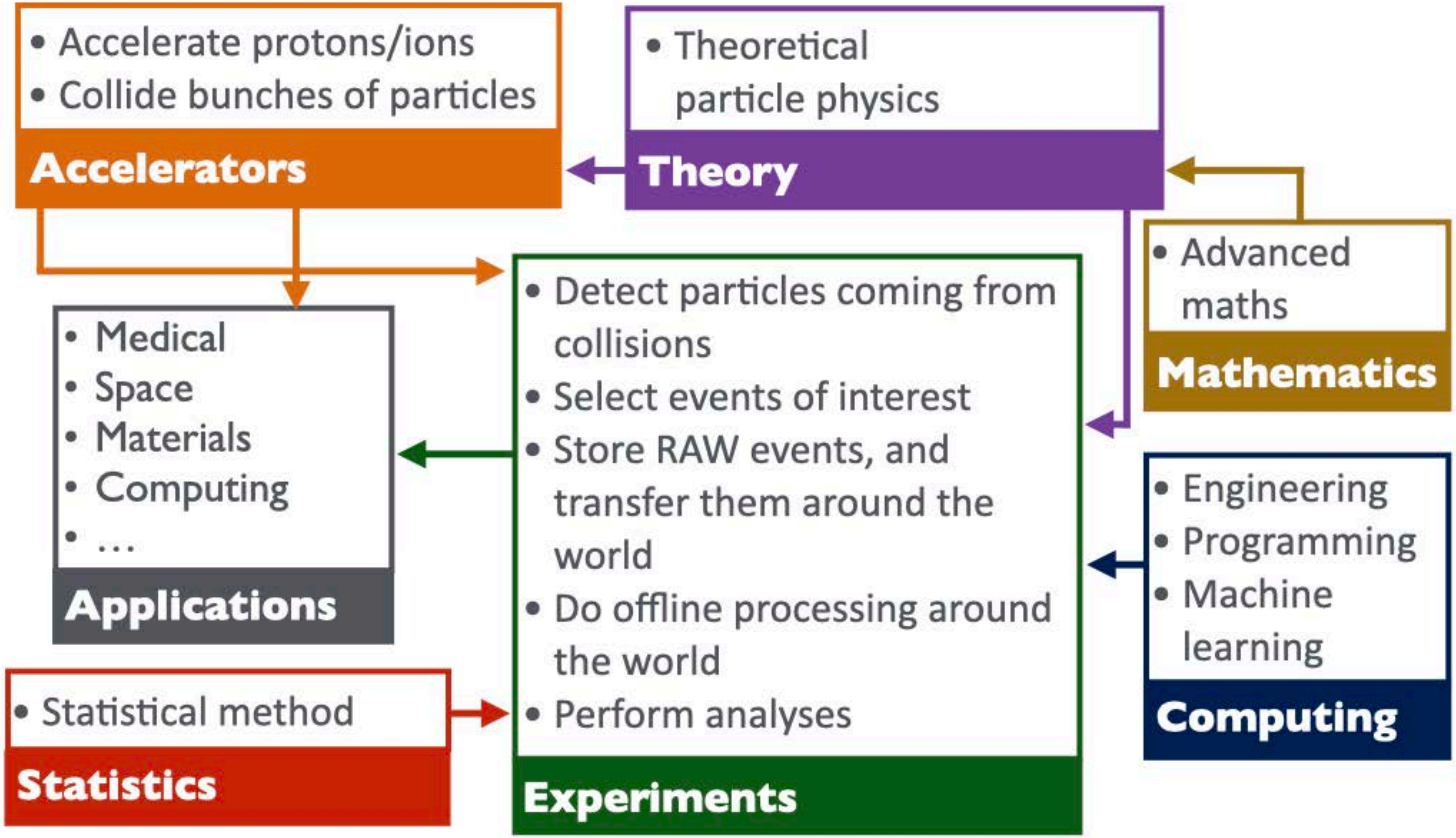


What are we looking for?

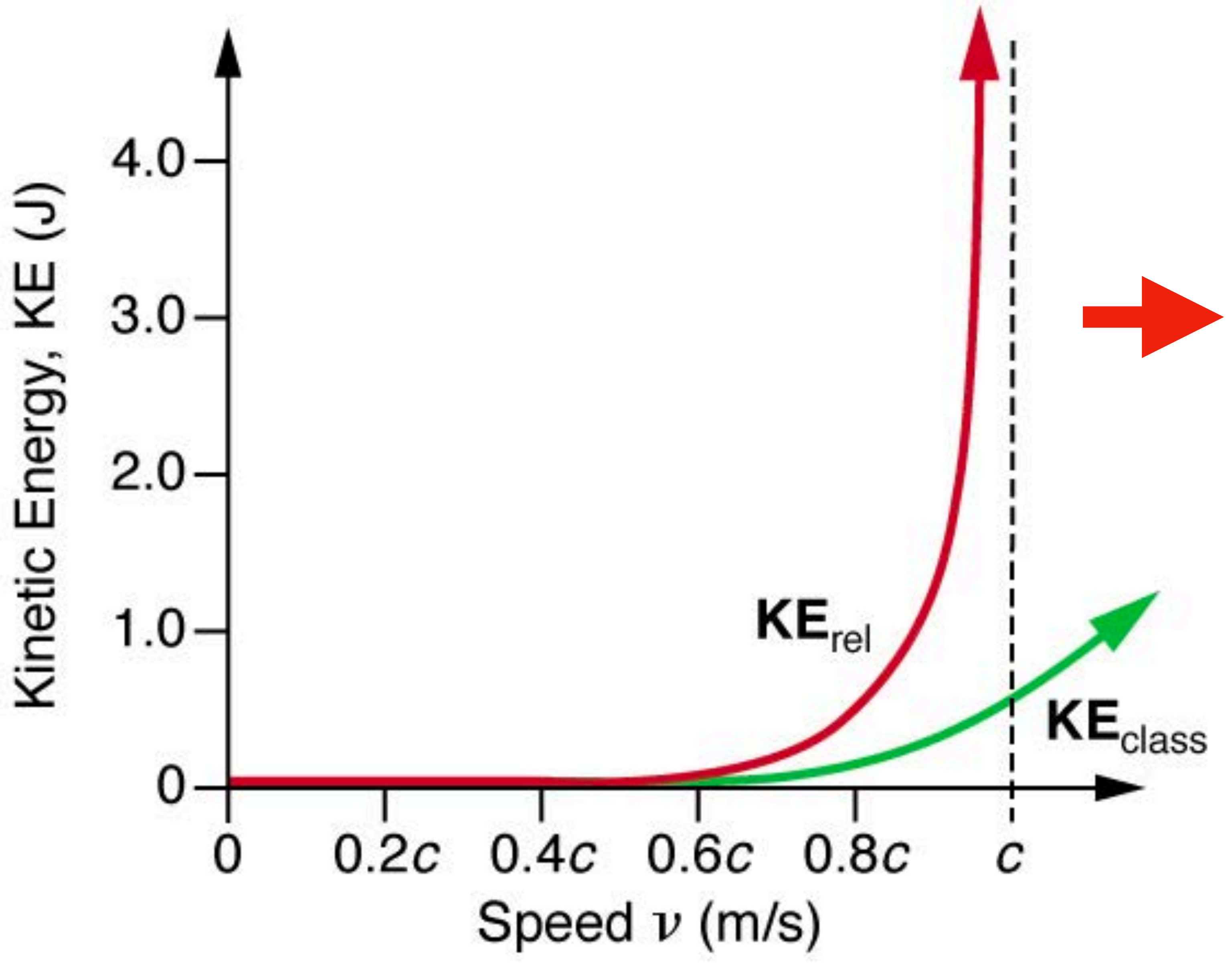


Basic research in the field of experimental and theoretical particle physics, finding out what the Universe is made of and how it works.

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

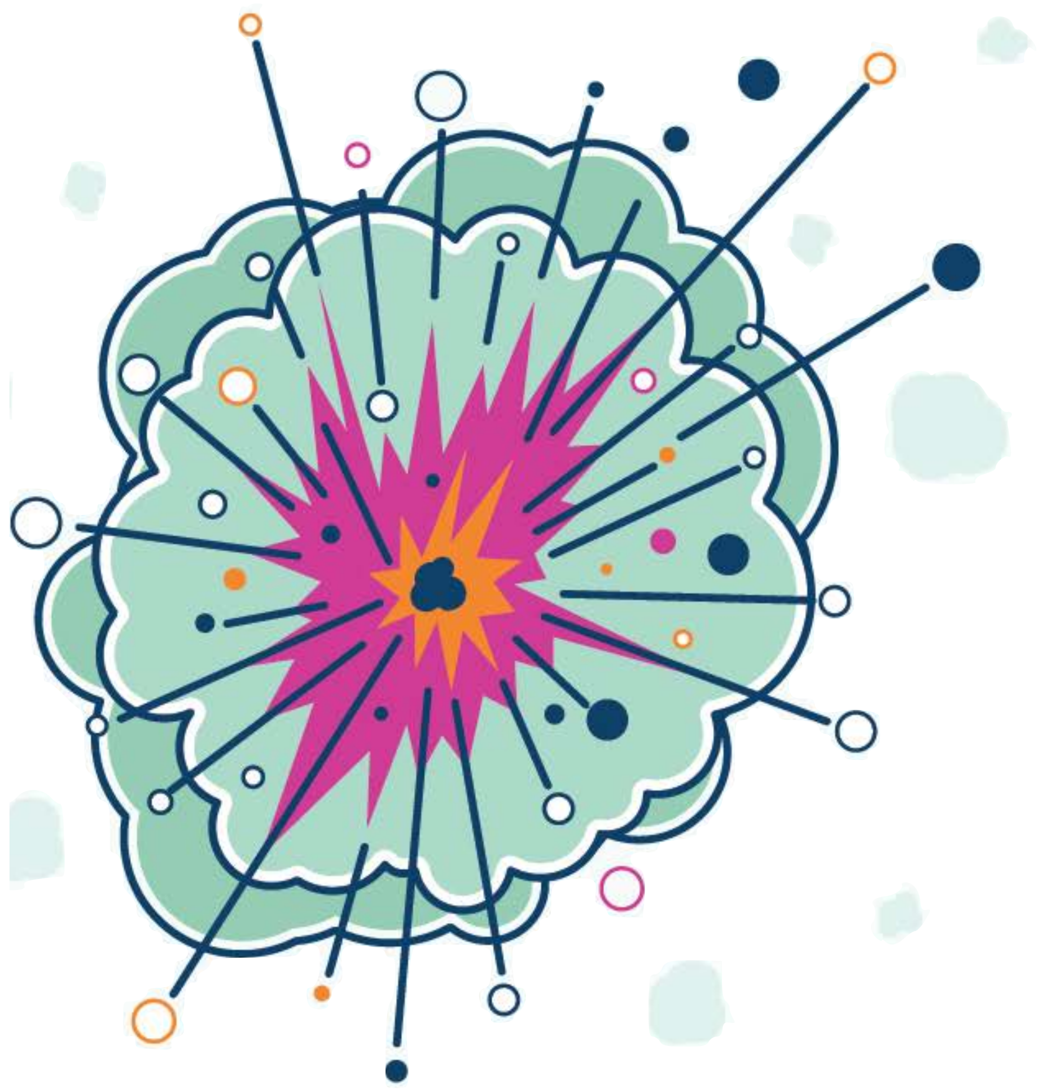
Use high momentum particle to

- create matter by collision

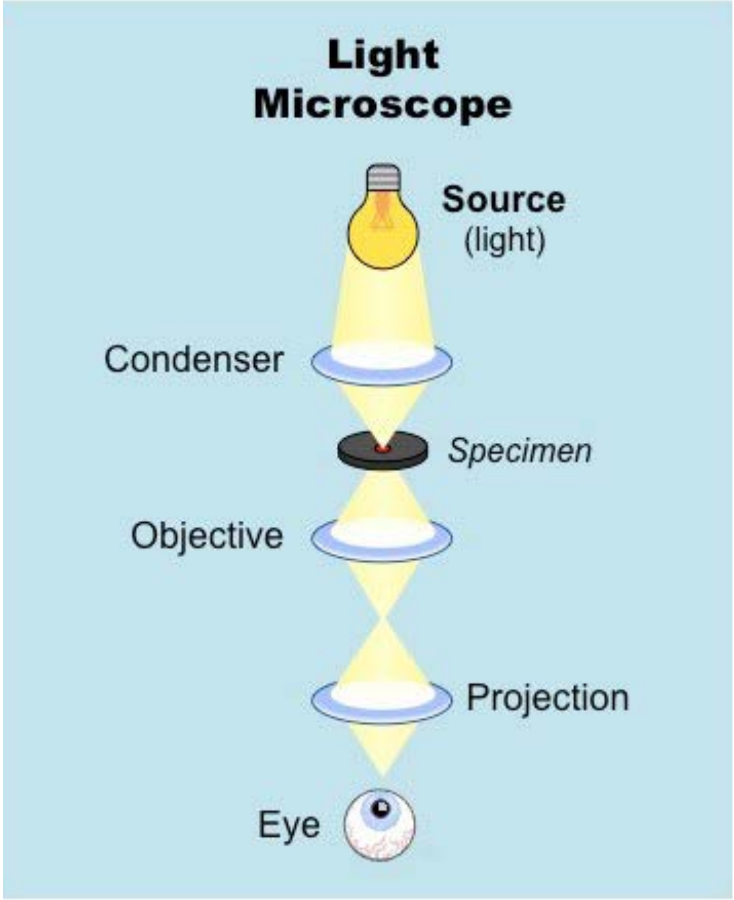
$$E^2 = p^2c^2 + m^2c^4$$

- probe insight in particle structure

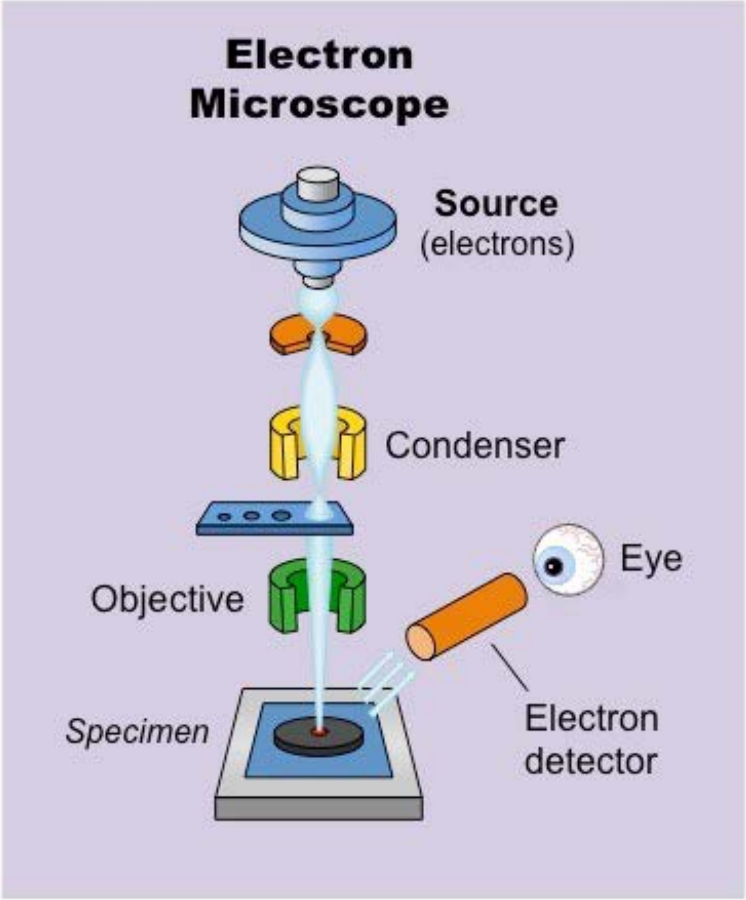
$$\lambda = h/p$$

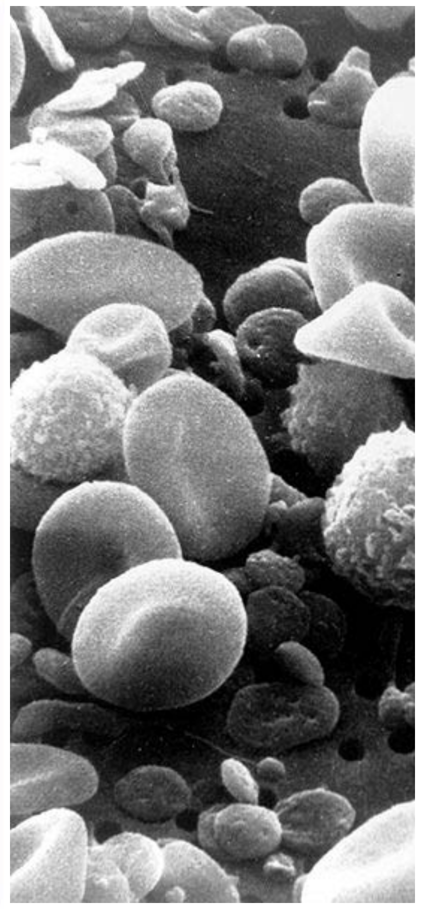


Visible light
400-500 nm

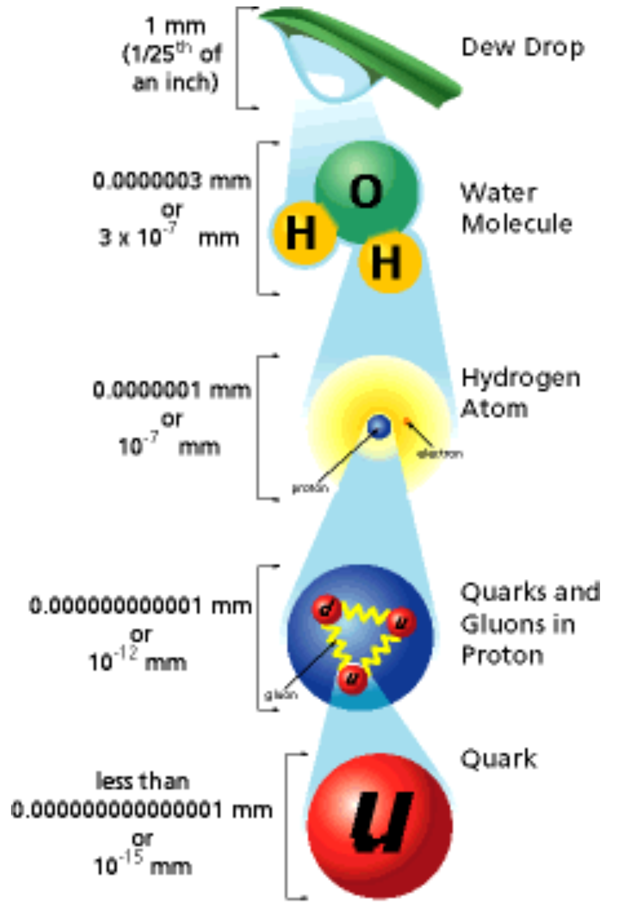


X-Ray
0.01-10 nm





Particle Accelerator
<0.01 nm

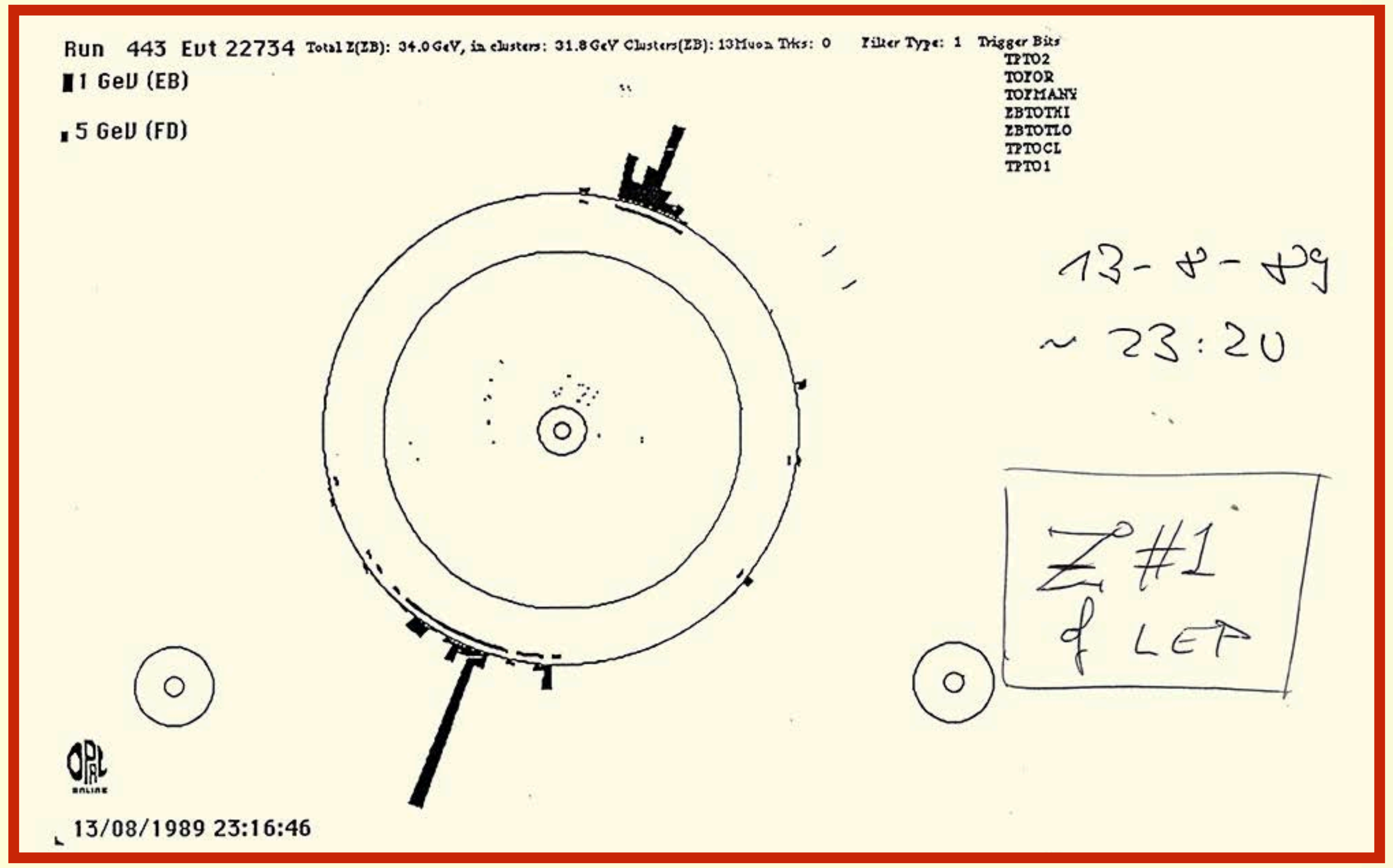


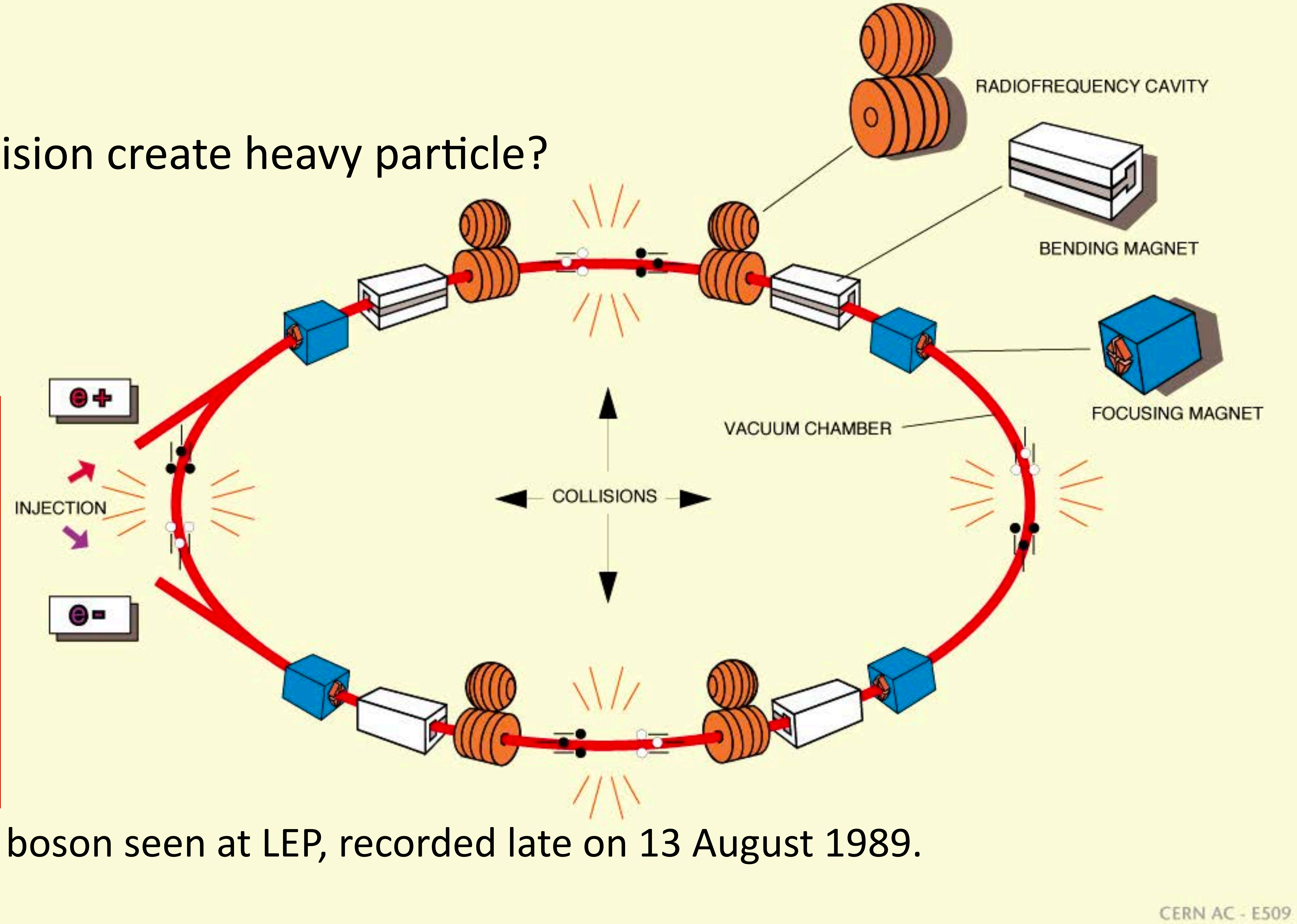
Accelerator is our tool to find answers

Electron mass = 0.511 MeV/c^2

Z-boson mass = 91.18 GeV/c^2

How does very small particle collision create heavy particle?

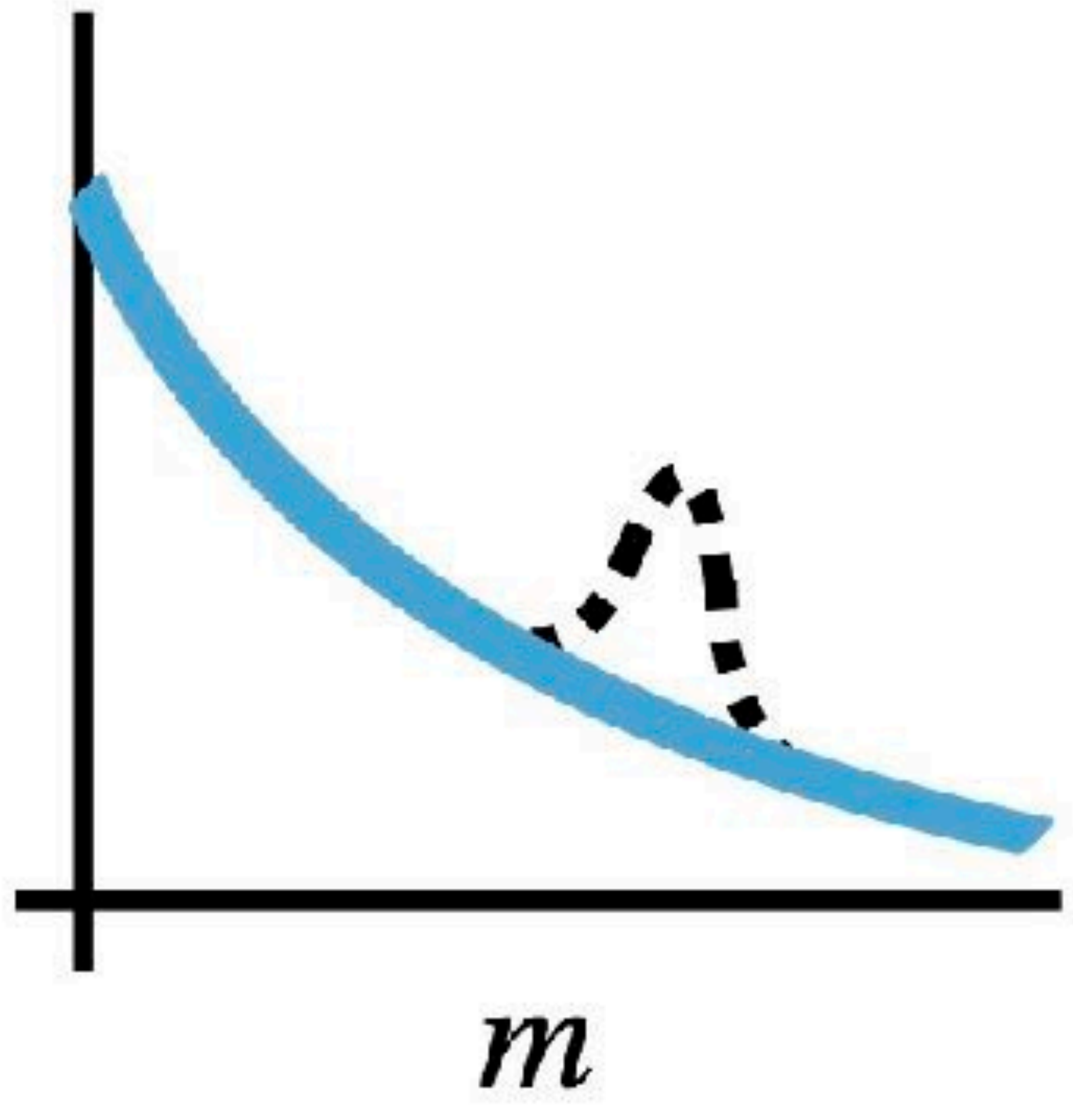




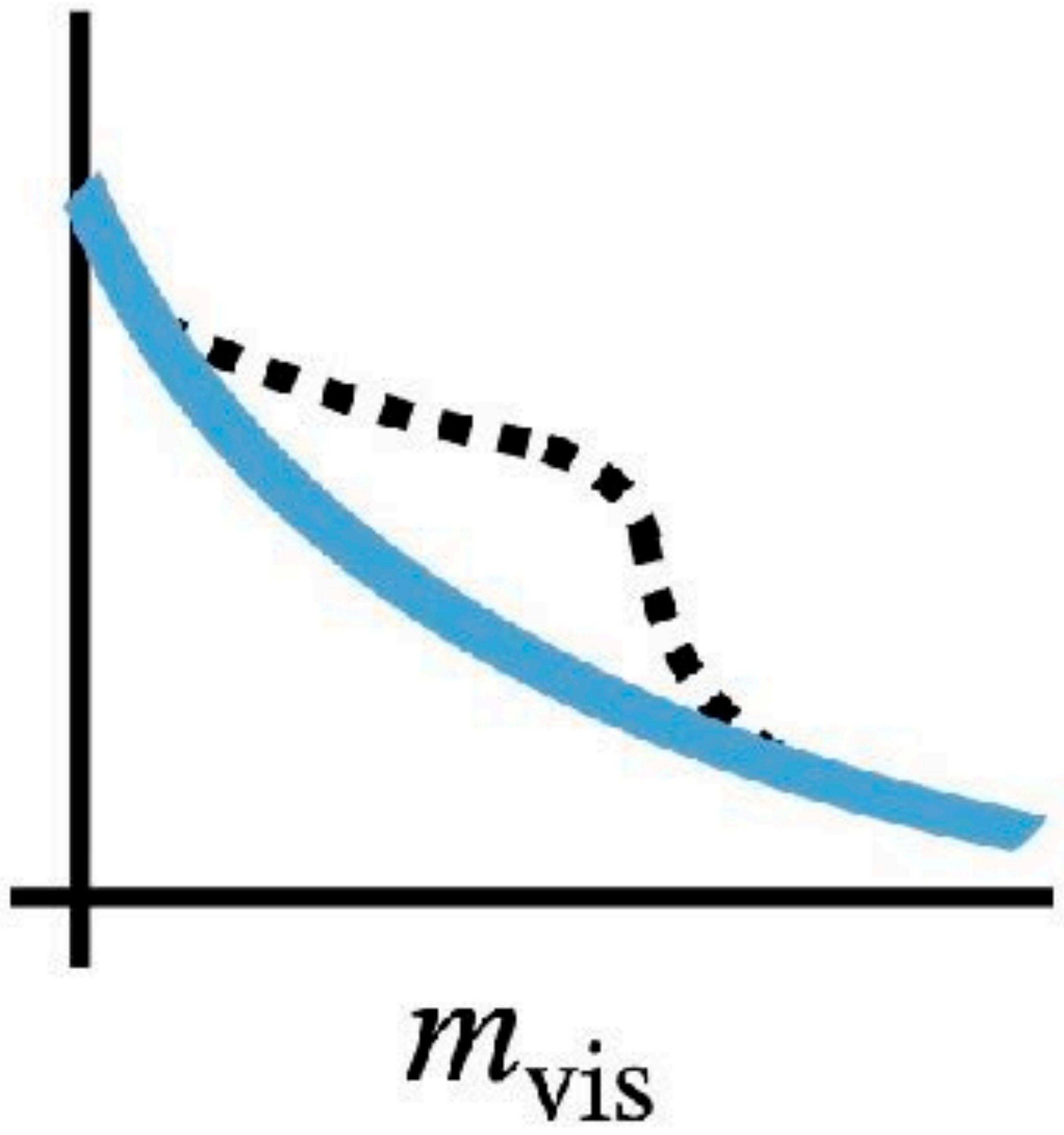
The OPAL logbook entry for the first Z boson seen at LEP, recorded late on 13 August 1989.

Credit: CERN [Link]

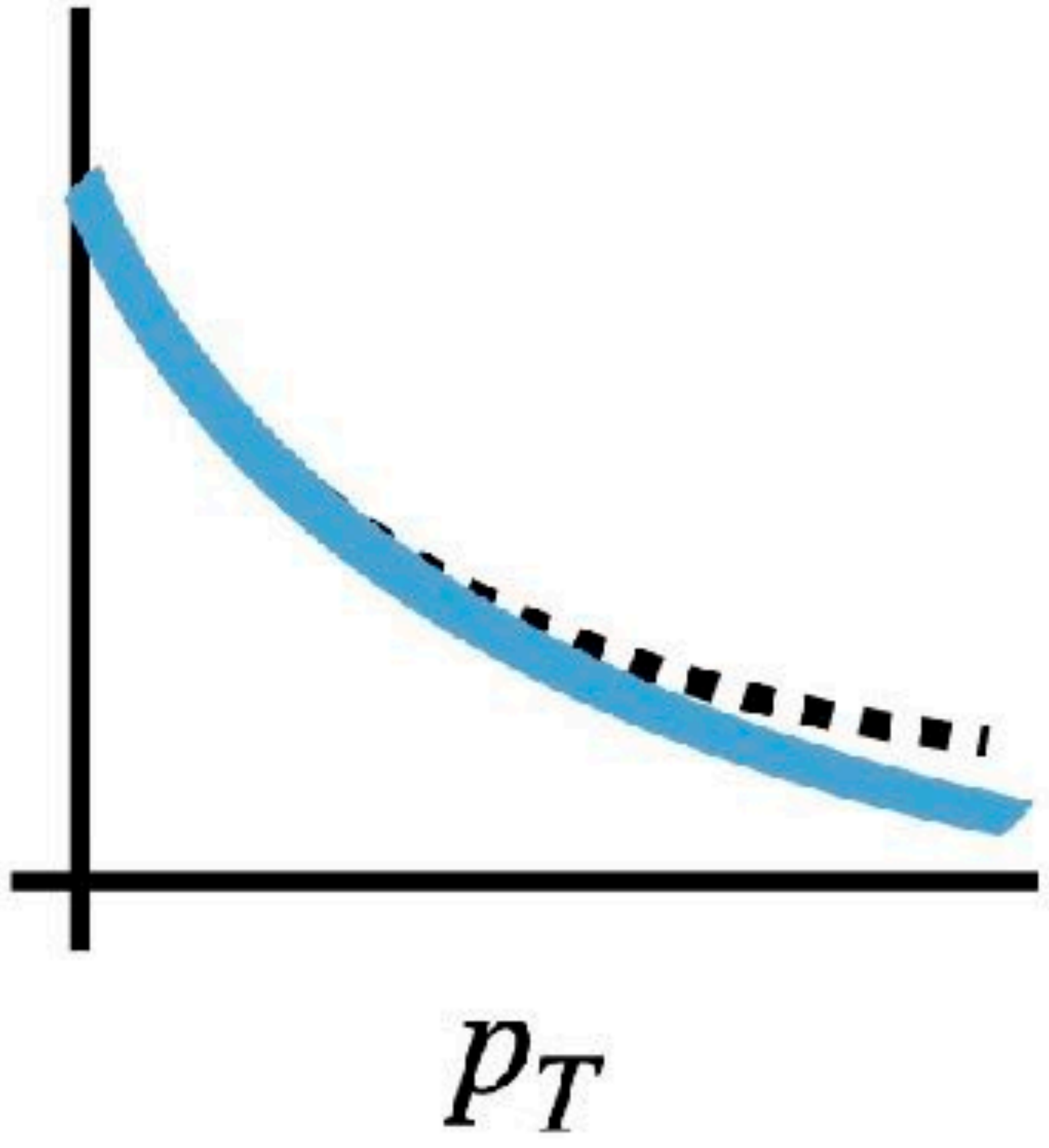
Searching for new physics



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



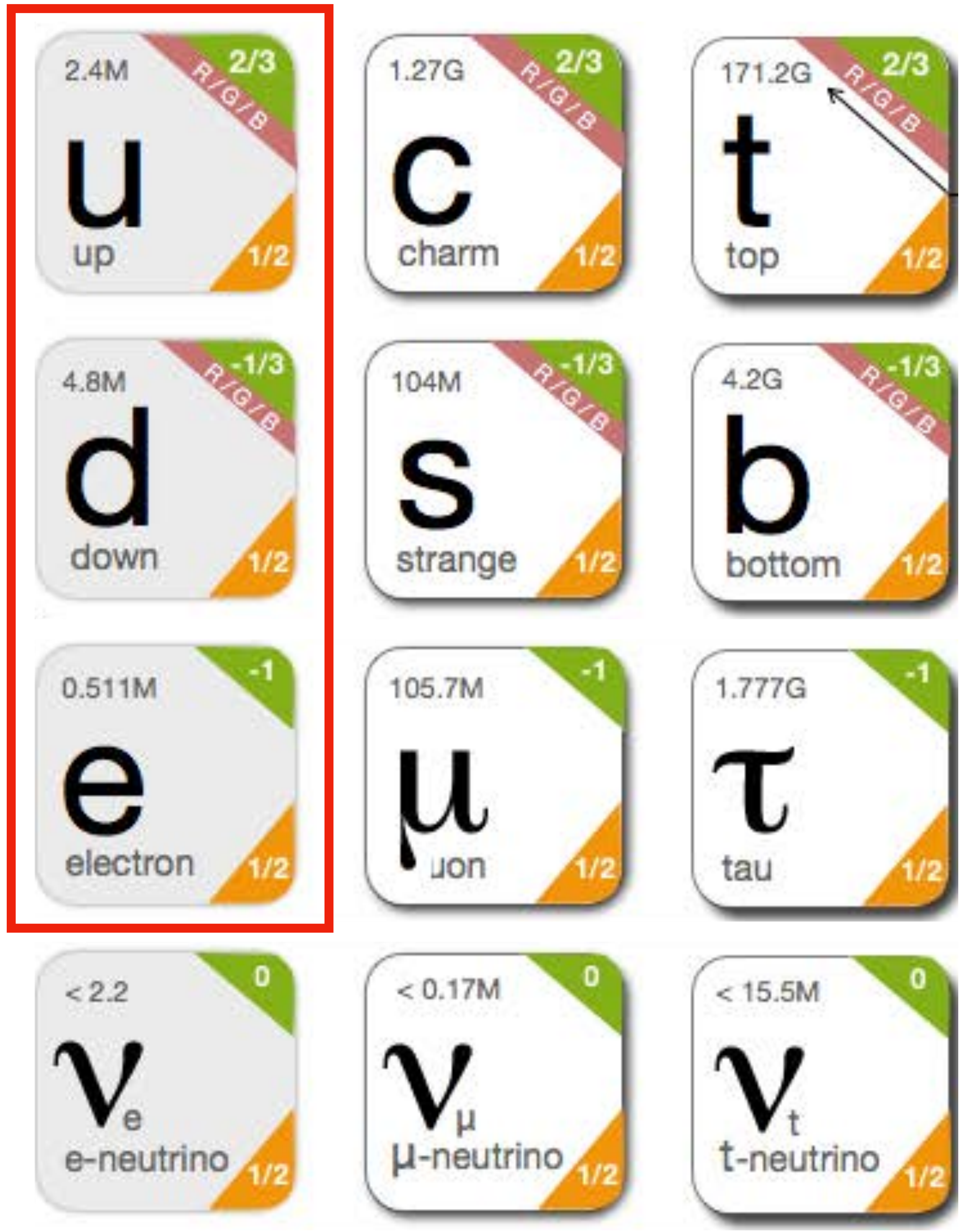
Semi-resonant, end-point
Heavy charged bosons,
...



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

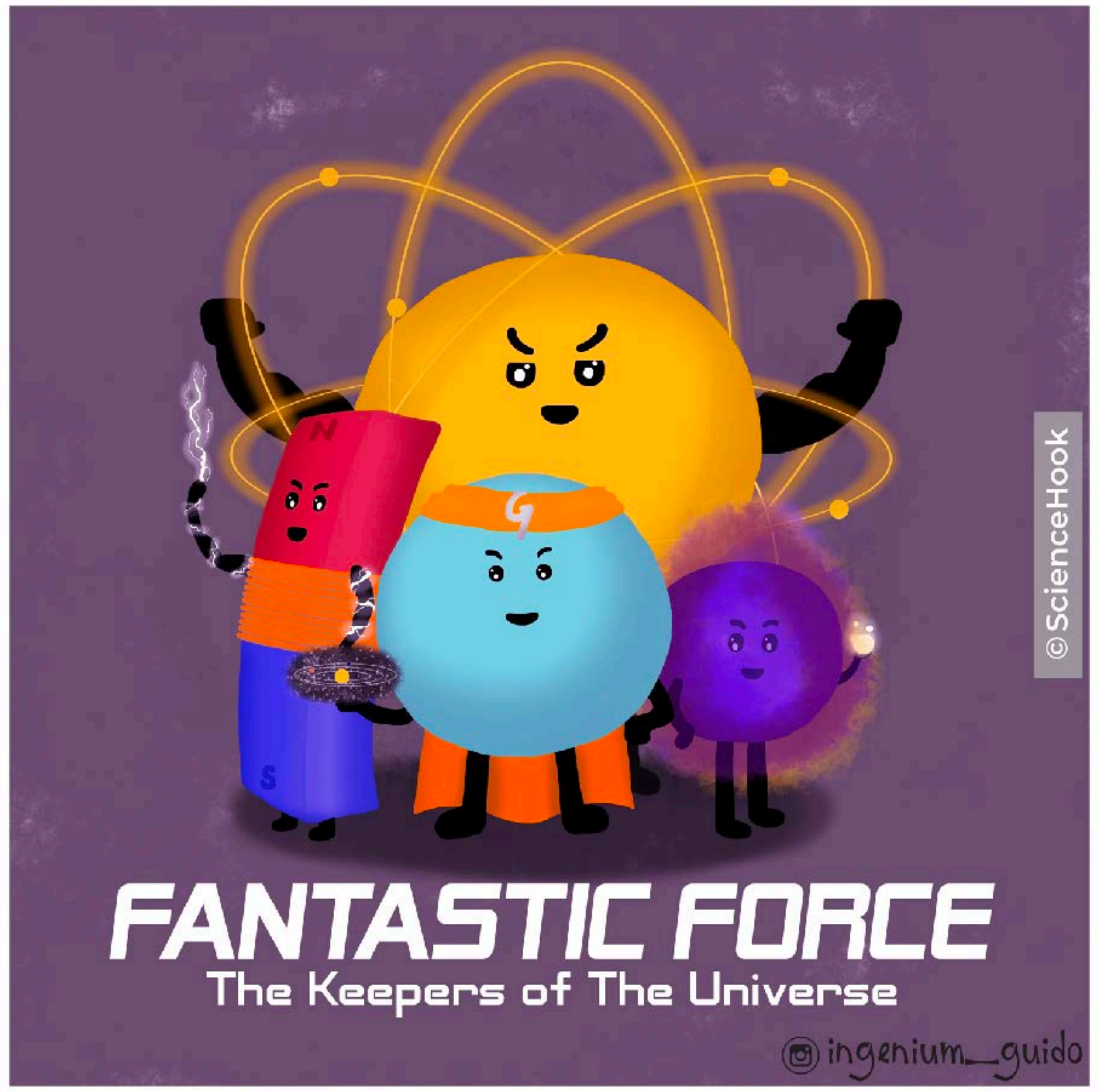
Known universe's ingredients

Known universe's ingredients



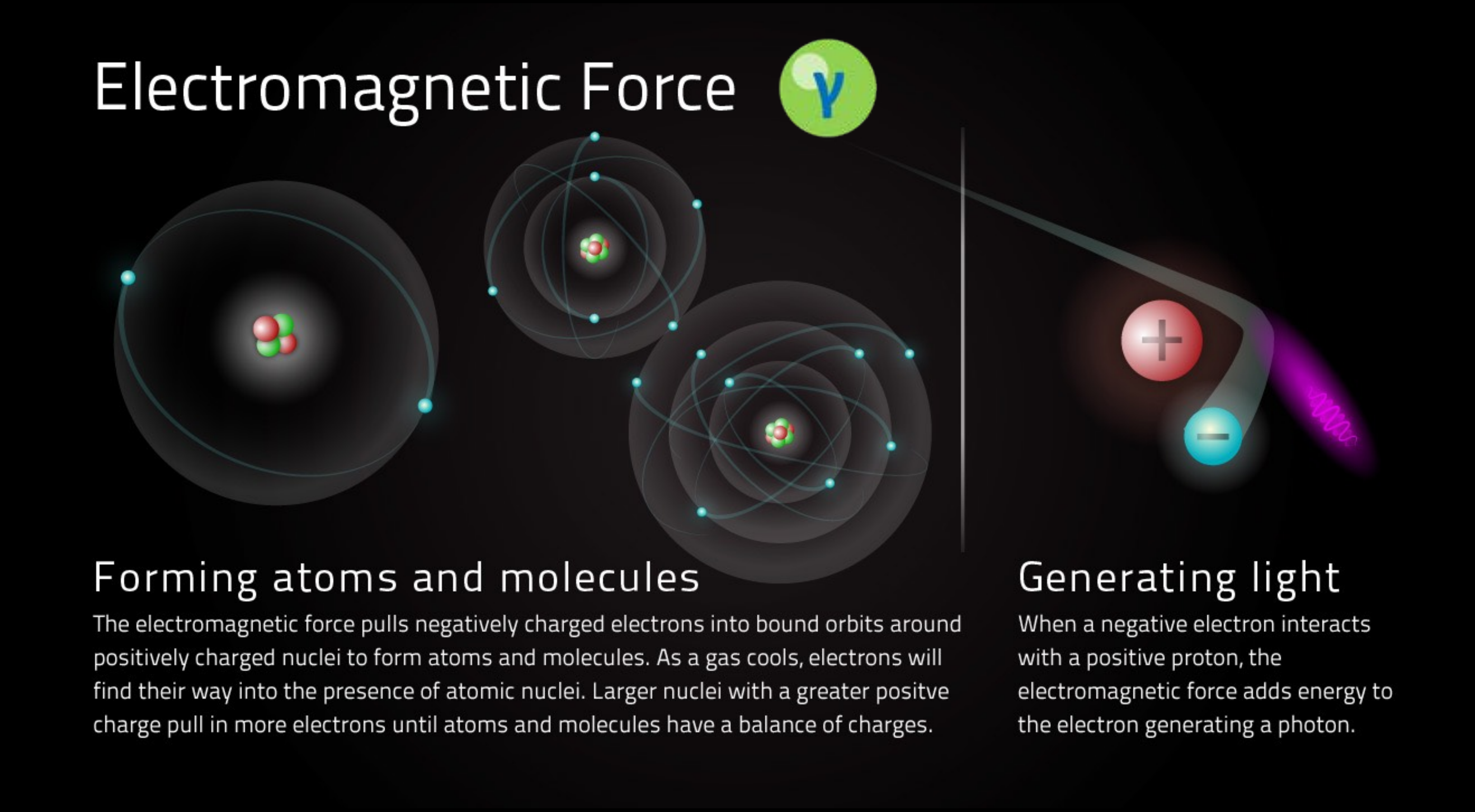
Everything around us (the whole periodic table) is made up of the **first three particles (u-quark, d-quark and electron)**. But somehow nature

- 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**.



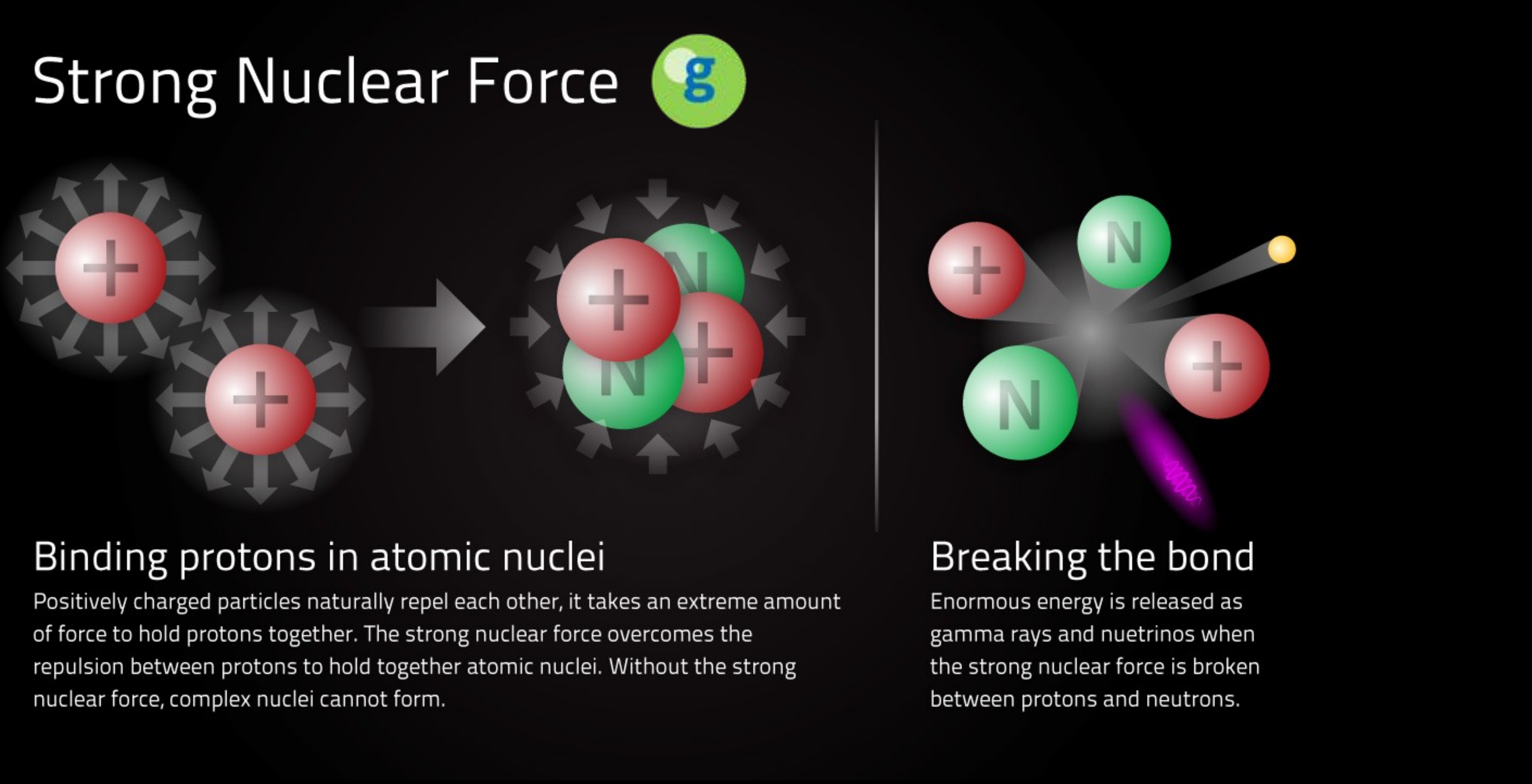
This is so simple, compared to Periodic Table in Chemistry, or Biological taxonomy!

Electromagnetic force



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

Strong nuclear force

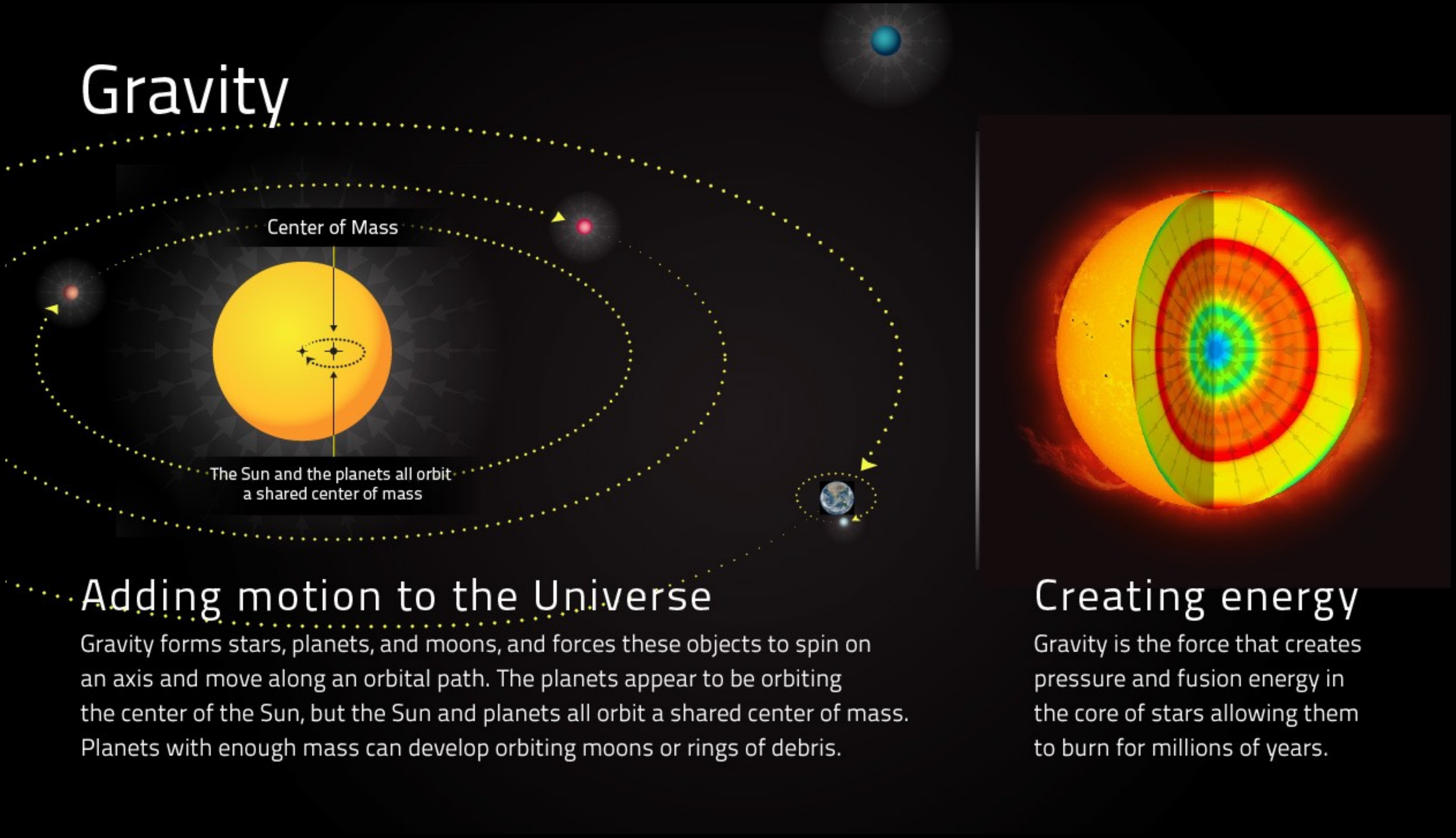


http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/03.html

Weak nuclear force

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

Gravity



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

Goals of today high energy particle physics

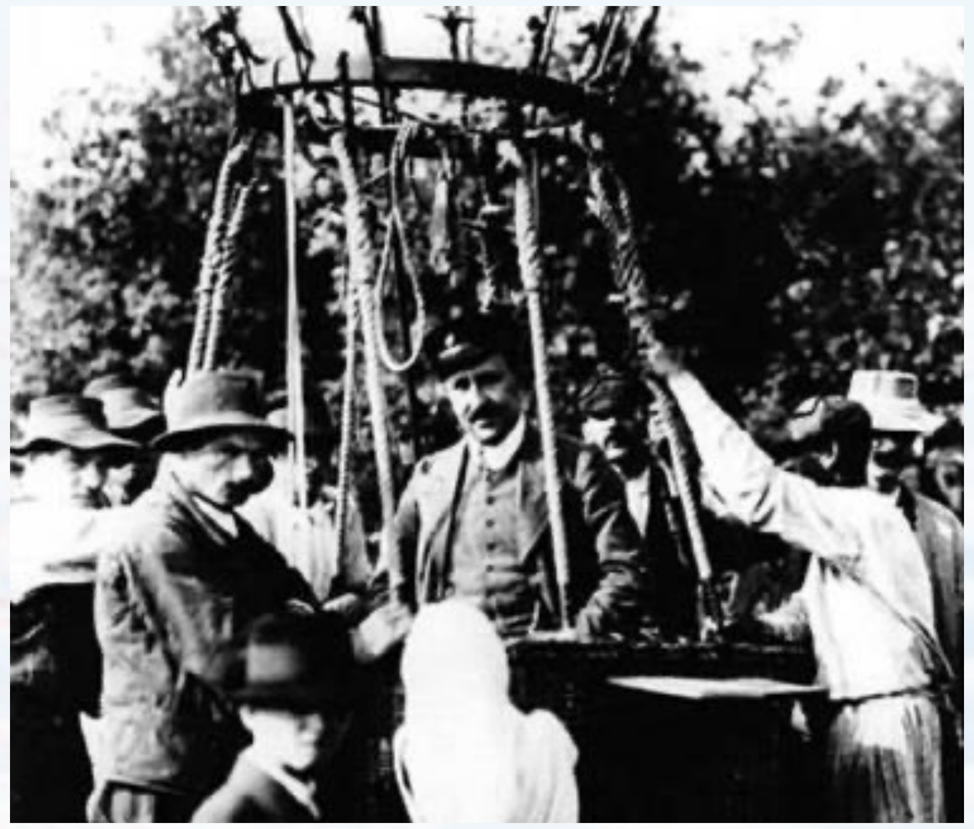
The SM is one of the most successful models in physics, but *is it enough?*

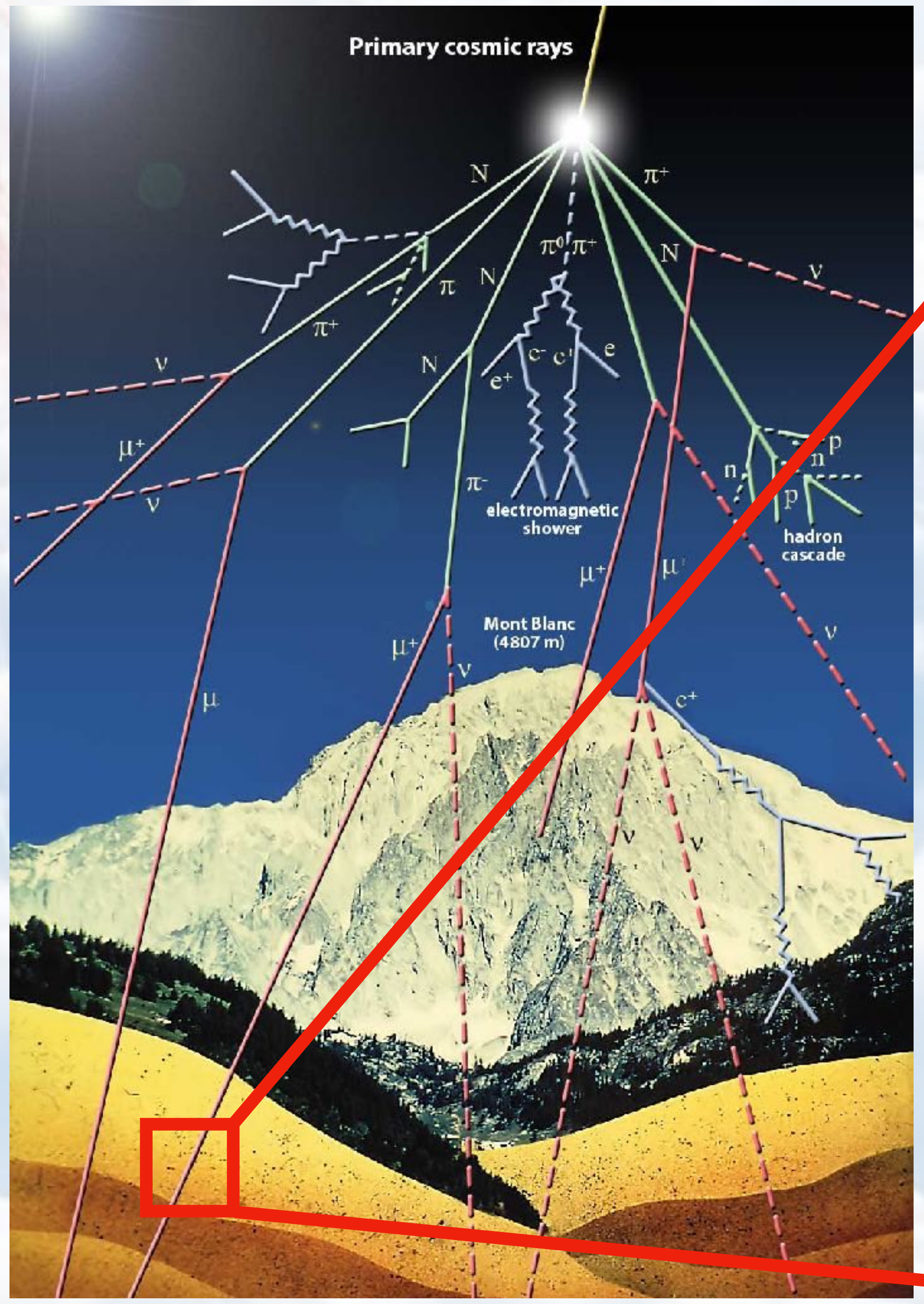
- **SM tells you how, but not why:**
  - Families – 3 families of quark/lepton
  - Number of parameters – 19 free parameters
- **Some phenomenon not explained by the SM:**
  - Gravity – not explained, why so weak?, SM incompatible with general relativity
  - Dark Matter & Dark Energy – accounts for 95%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

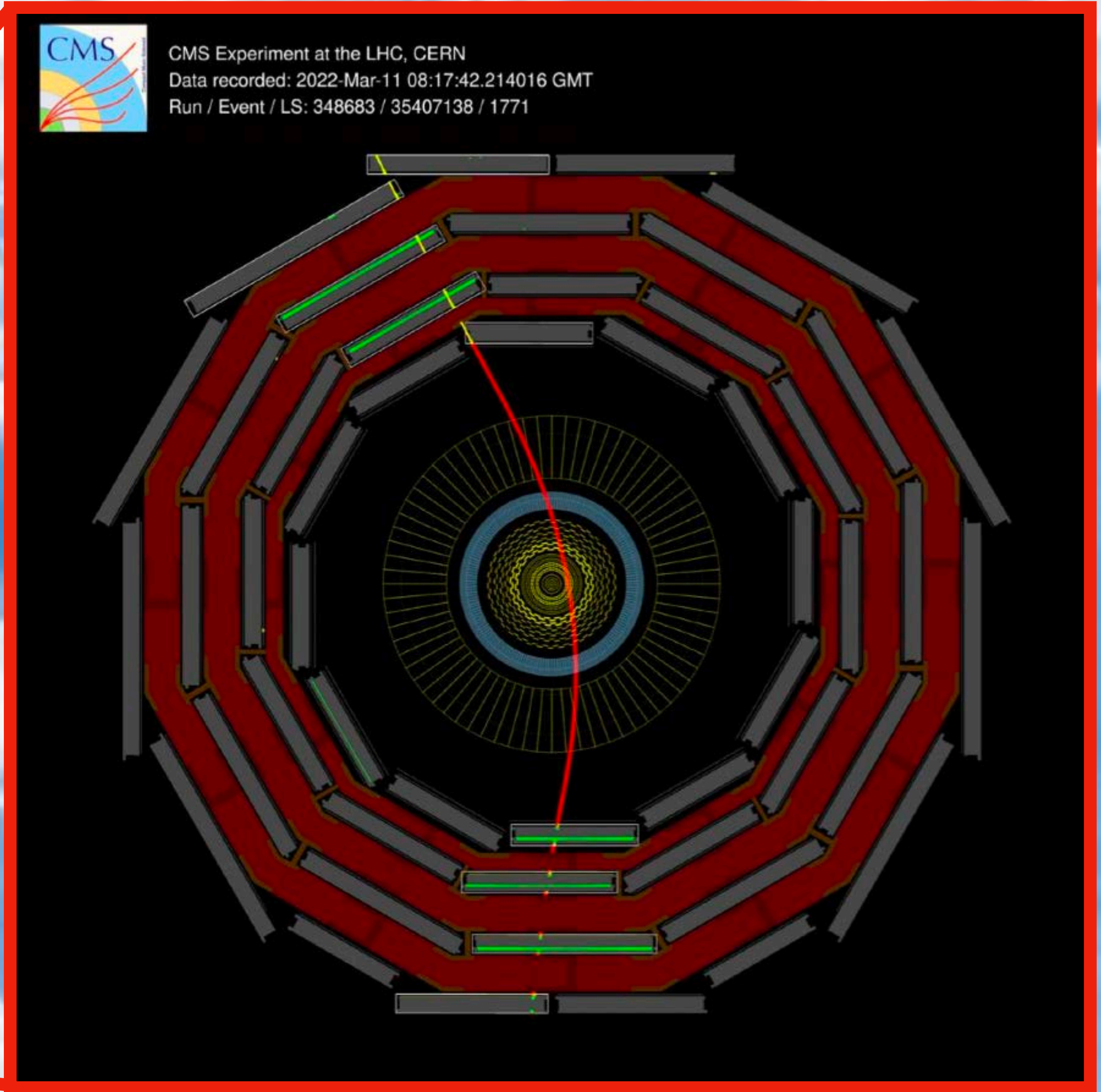
Cosmic rays: Particles from outer space accelerators

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.



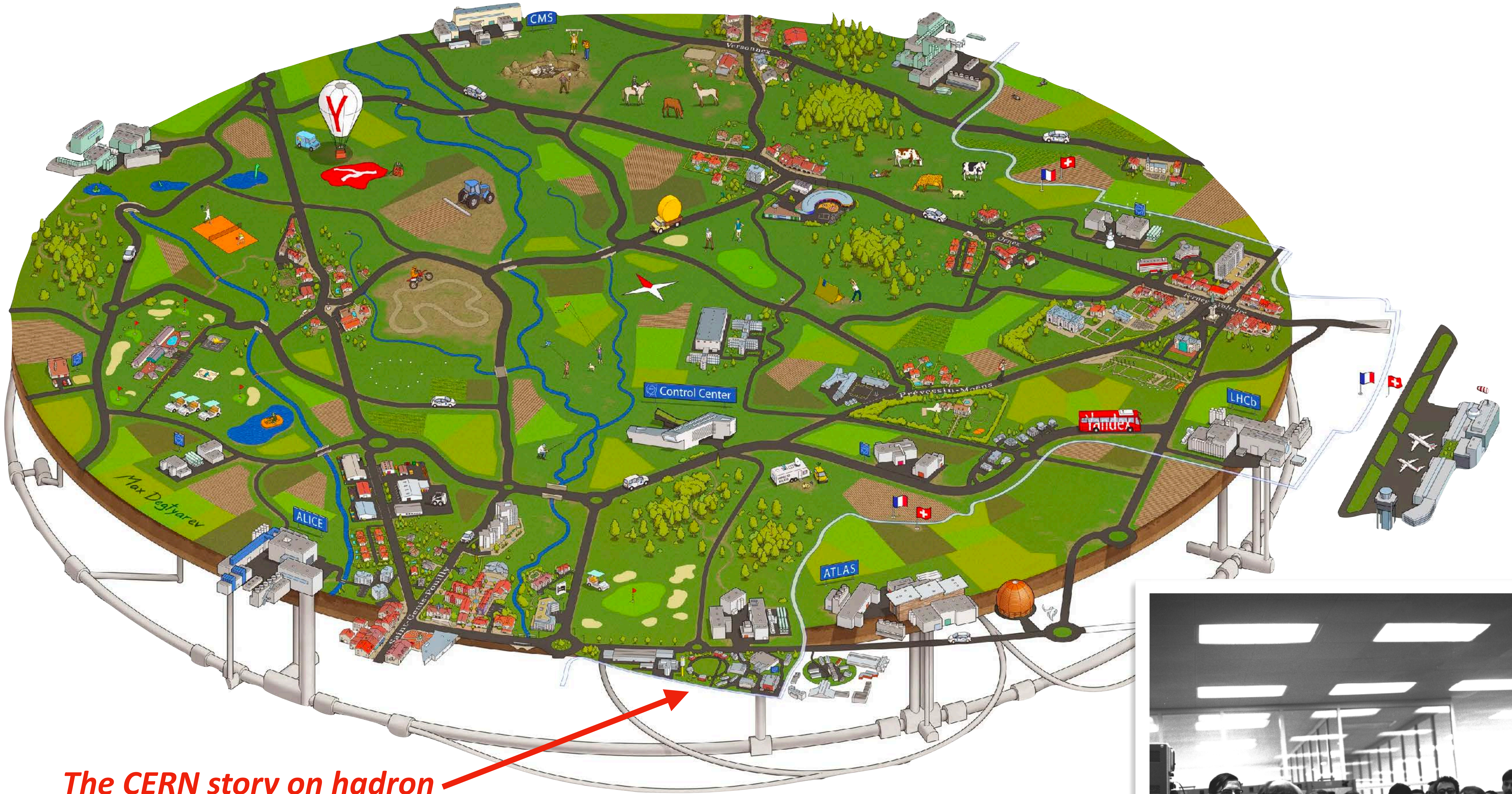




27 Jan 1971 ... the era of hadron collider has begun

A vacuum chamber where the proton beams collide in the ISR
http://cds.cern.ch/record/41966

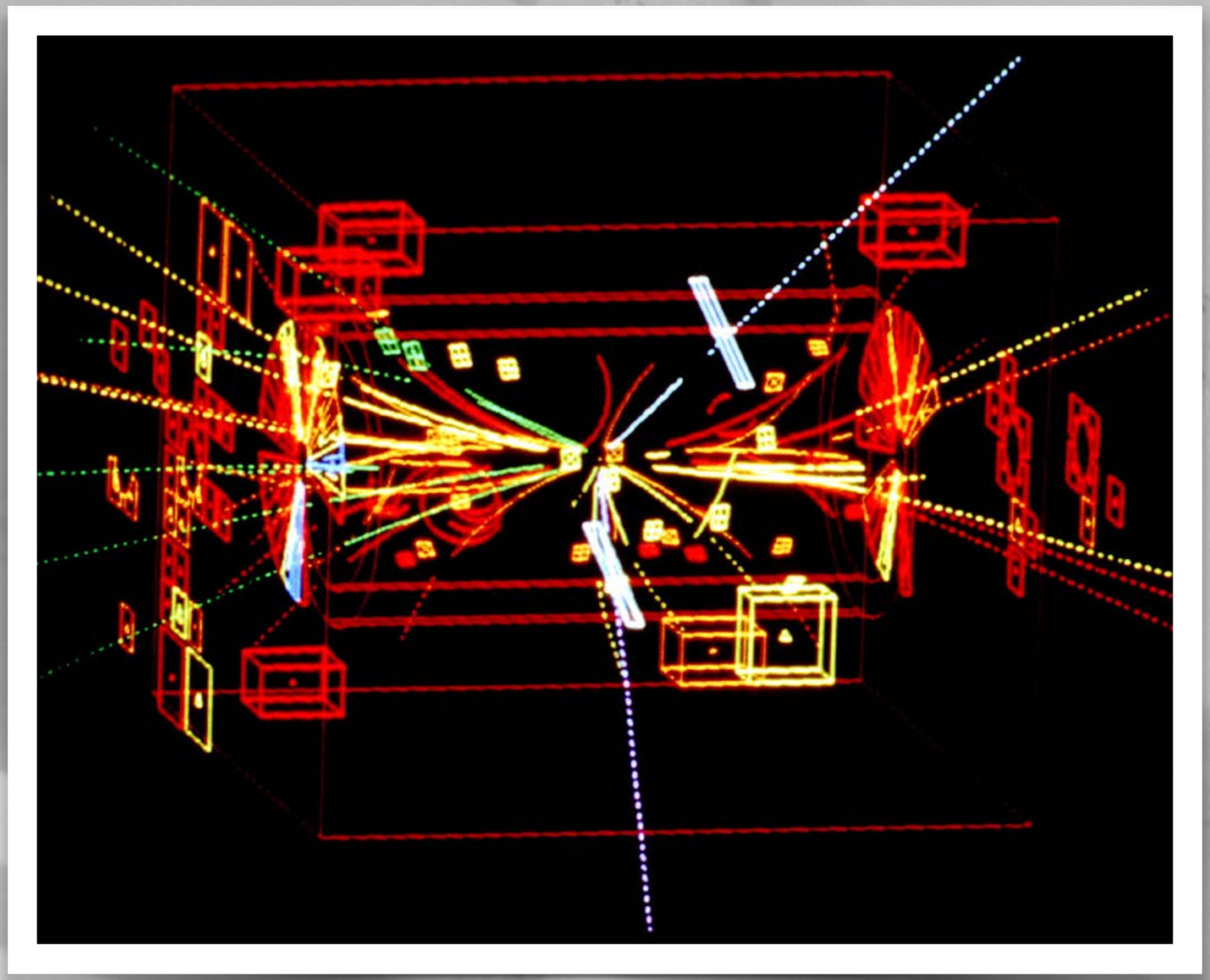
https://www.reddit.com/r/CERN/comments/8xnwz1/the_map_of_cern_and_cutaway_illustration_of_lhcb/



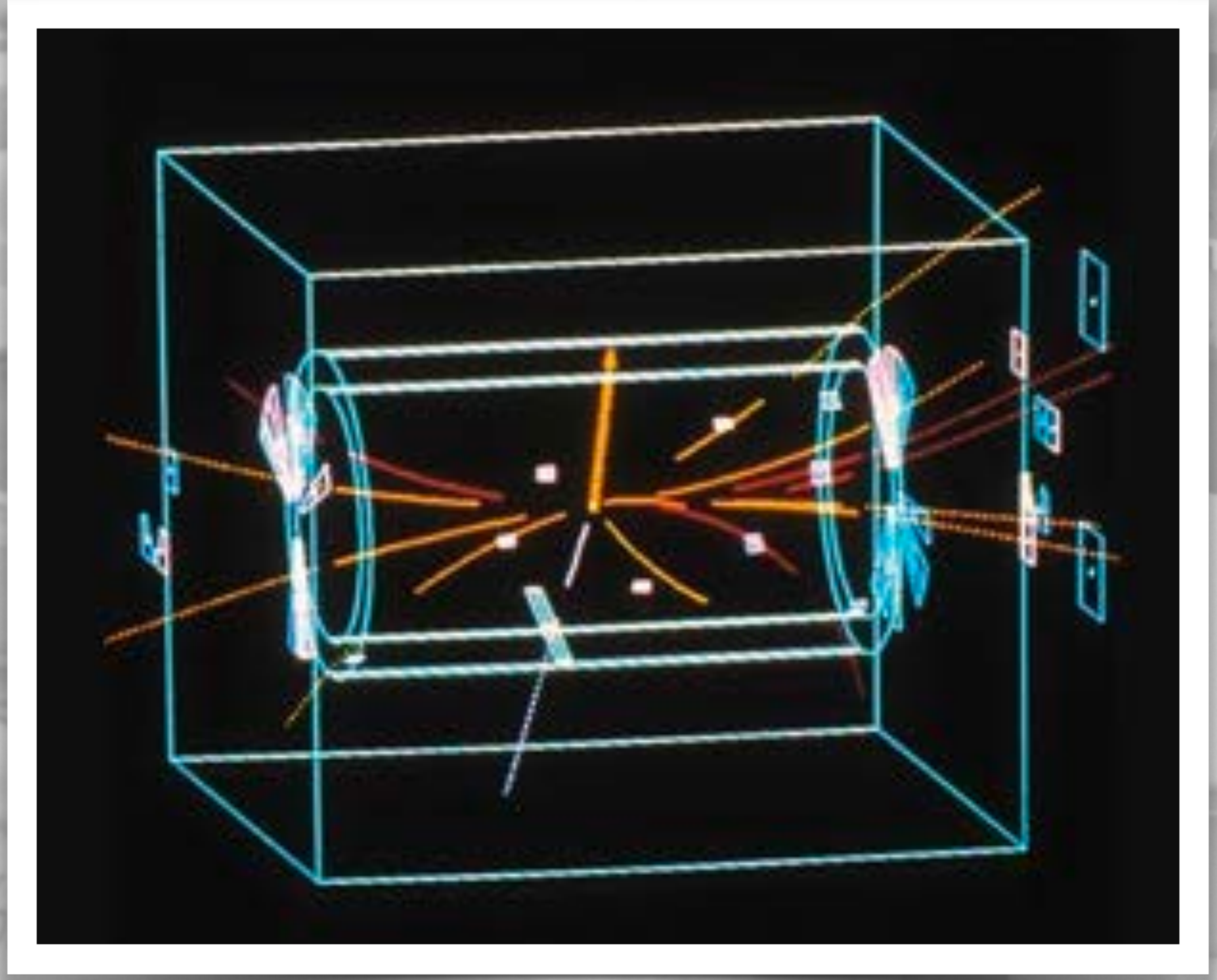
The CERN story on hadron collider started from here

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

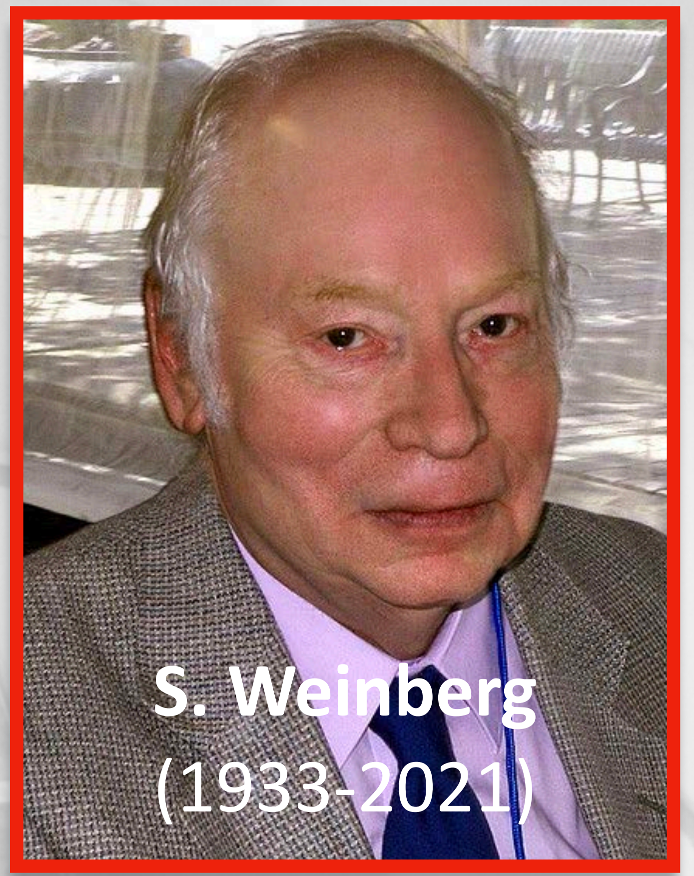


30 April 1983, Image taken by the UA1 which later confirmed to be Z candidate decays to electron-positron pair

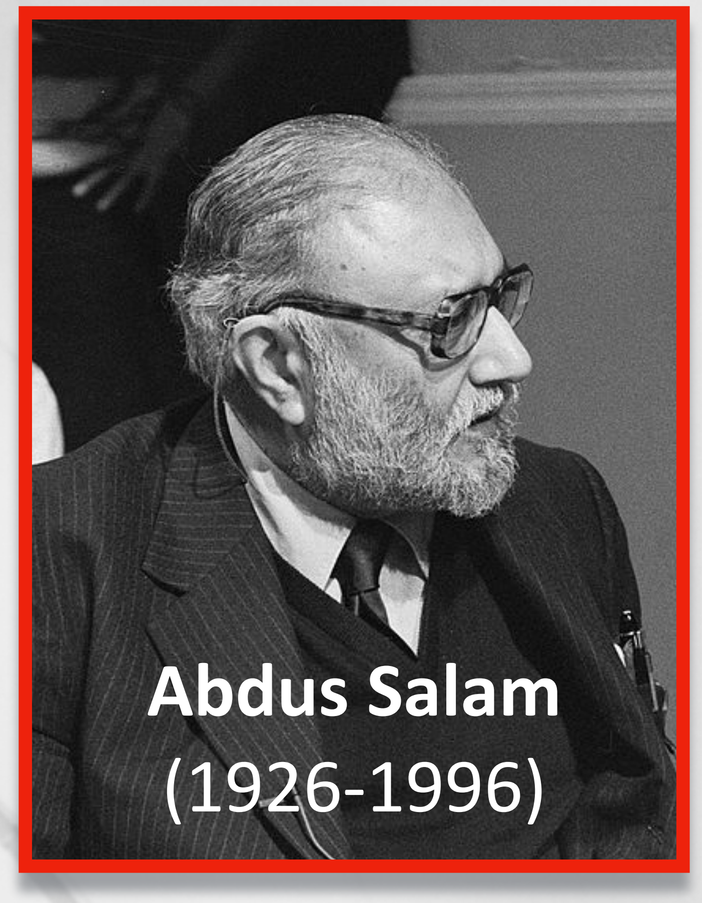


UA1 detected the W candidate event with electron and high missing energy

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.

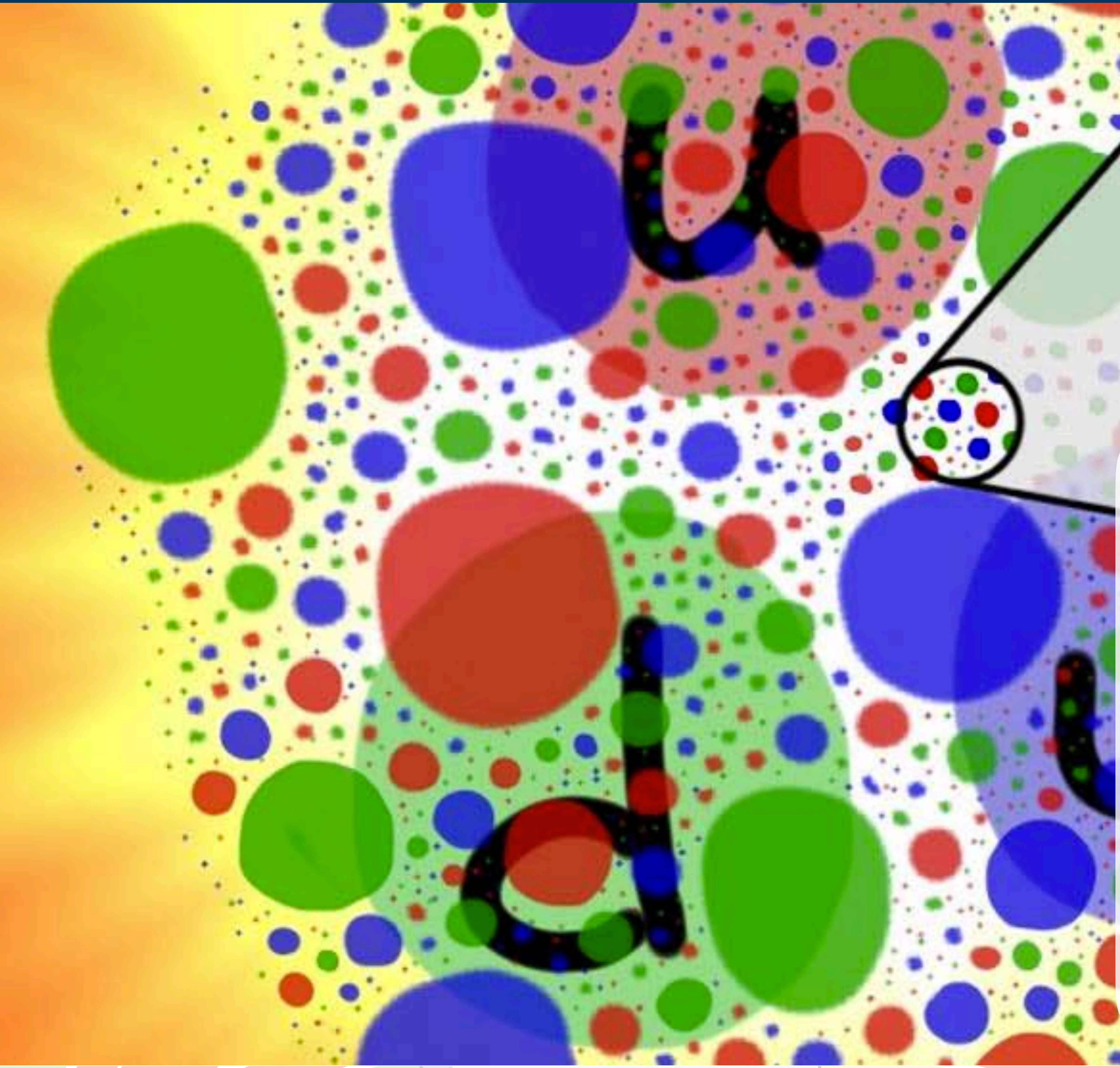
Large Hadron Collider

Large Hadron Collider by numbers

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

Parton - Proton

http://www.fnal.gov/pub/today/archive/archive_2012/today12-05-04_NutshellReadMore.html



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.

Parton - Proton

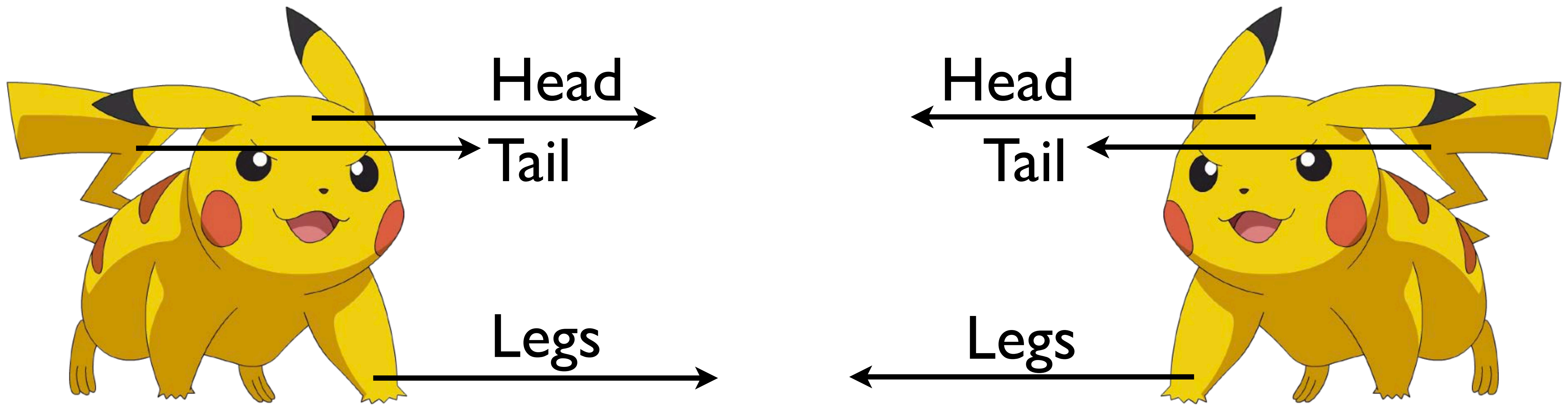
http://www.fnal.gov/pub/today/archive/archive_2012/today12-05-04_NutshellReadMore.html

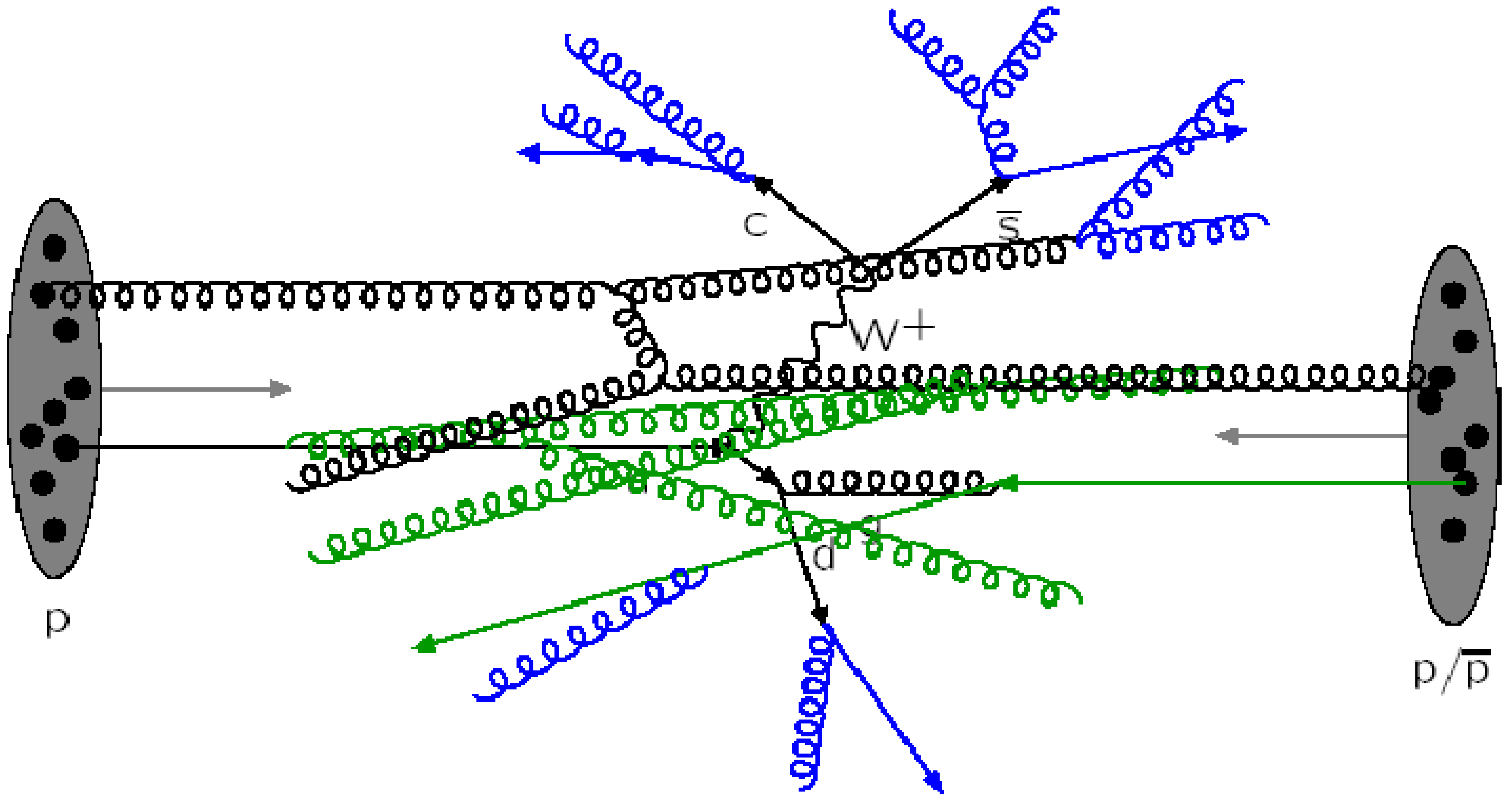
Proton

- 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.





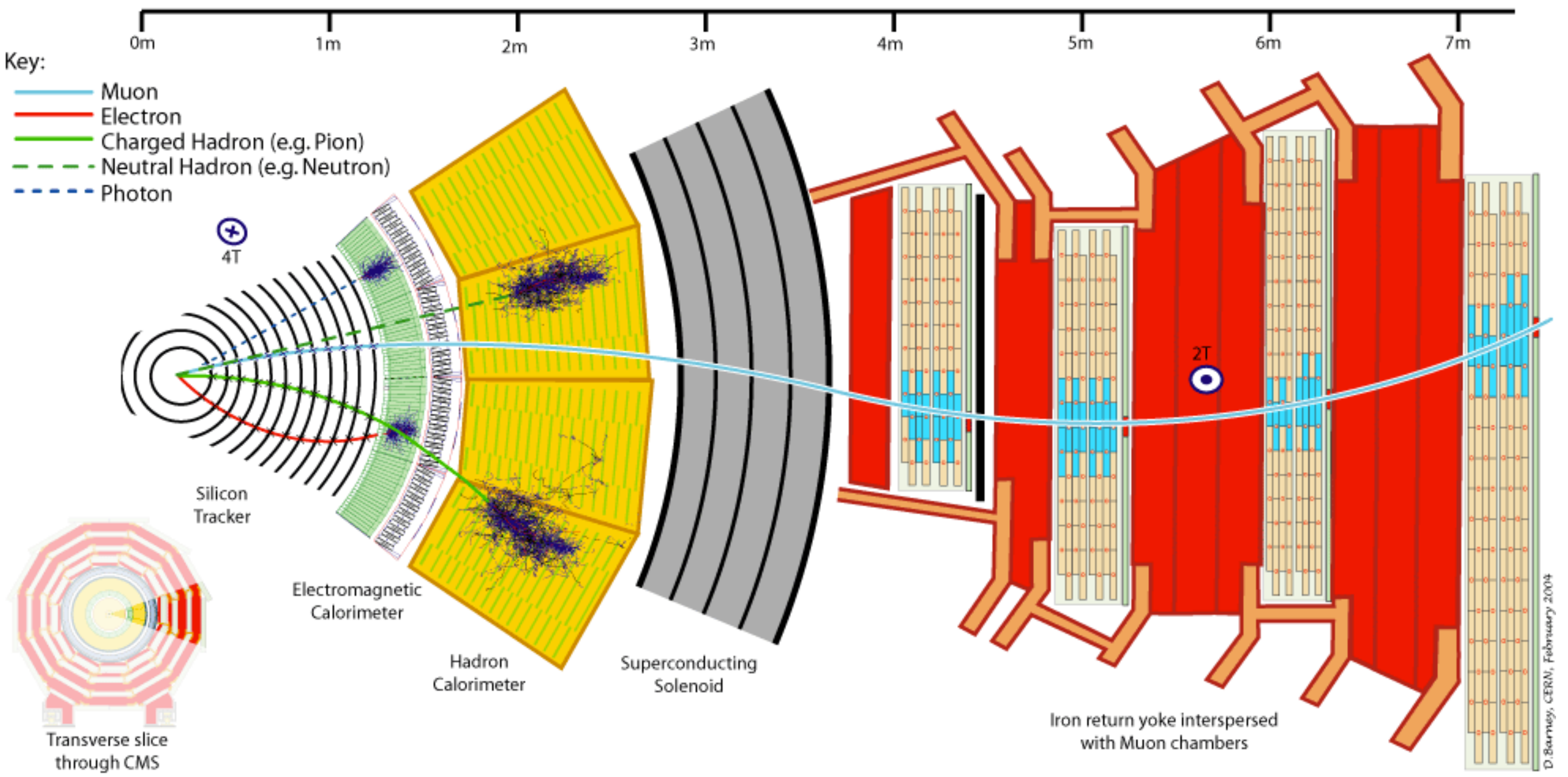
Particle detection

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.

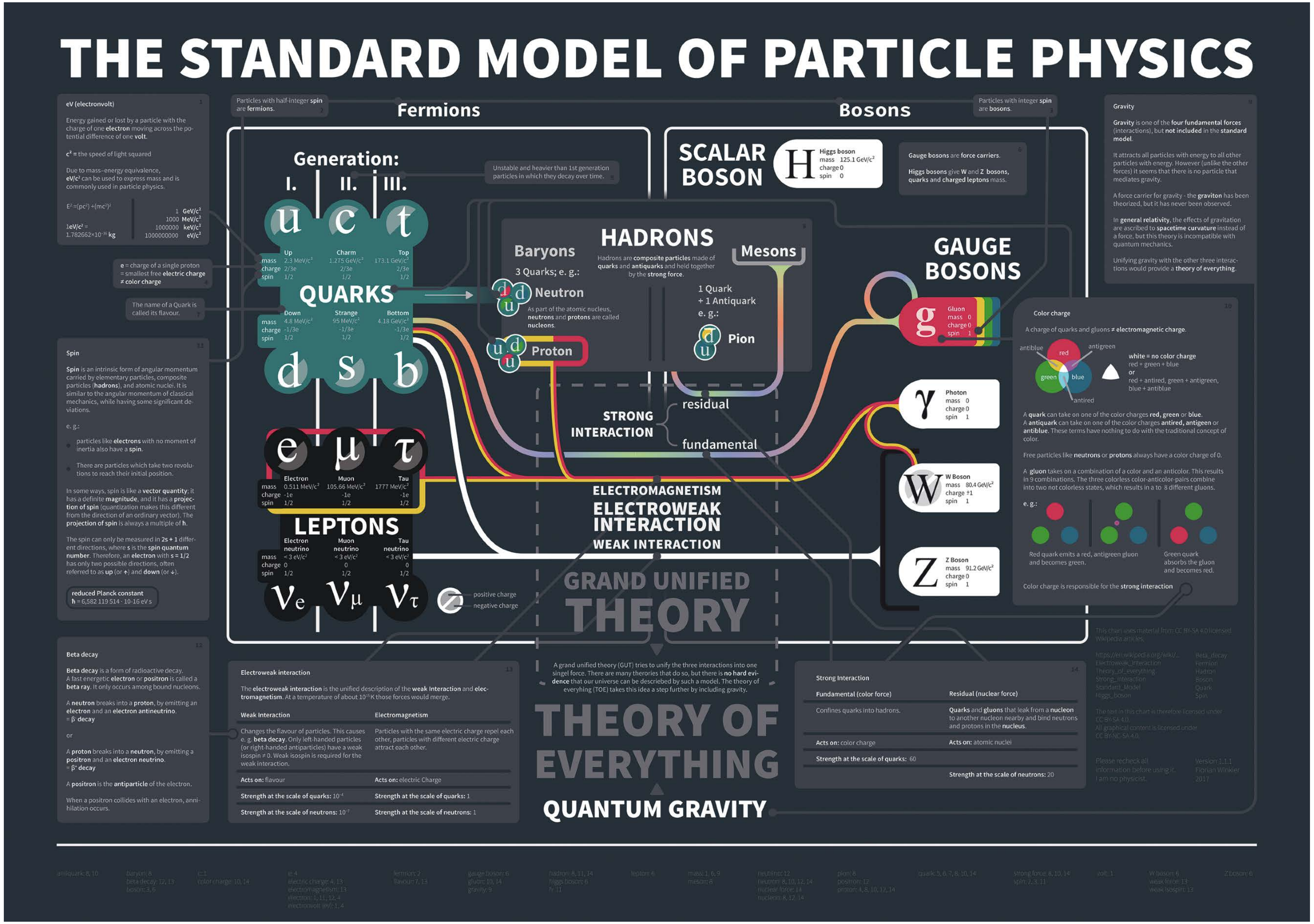


Standard Model

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.



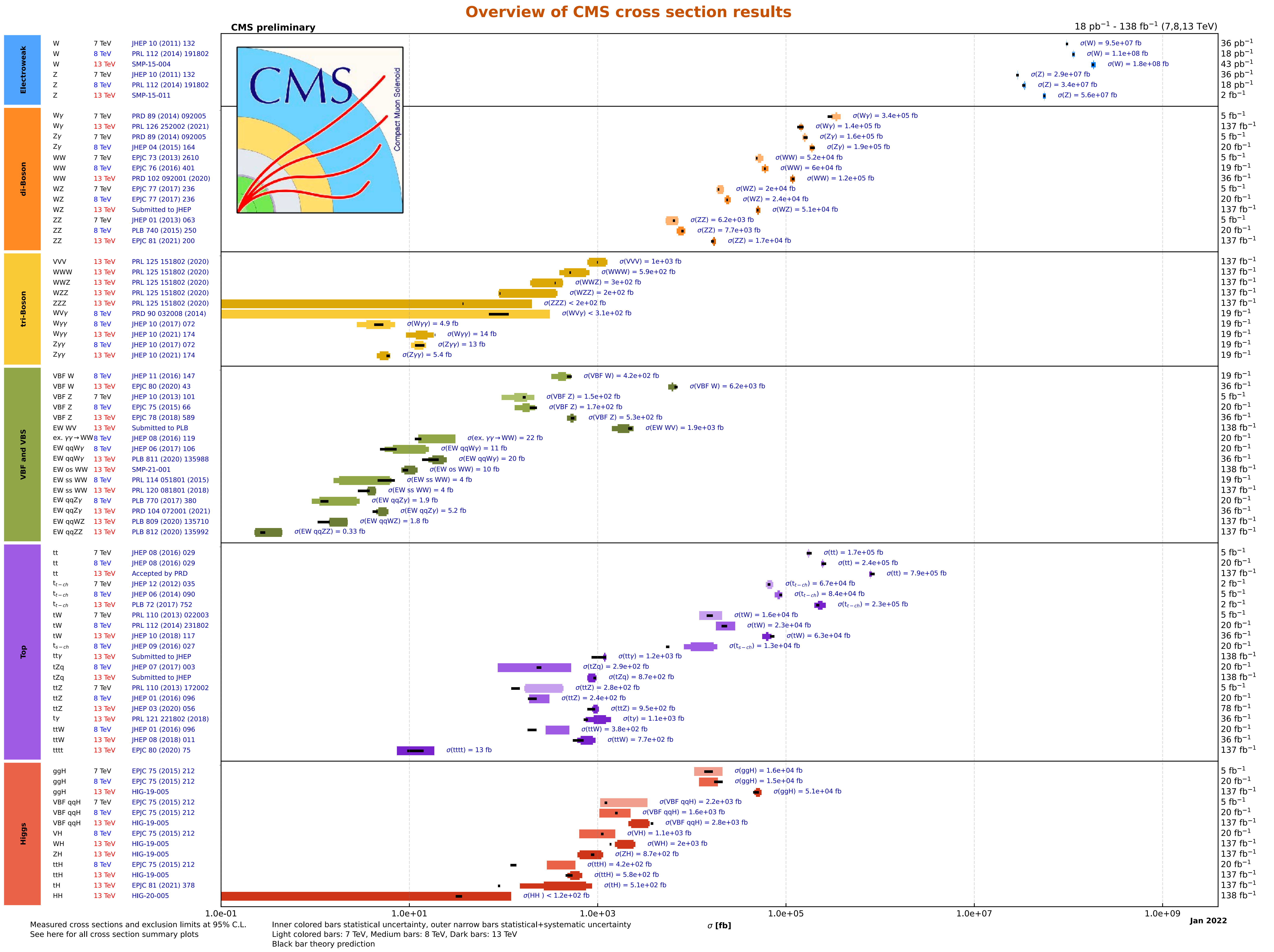
Steven Weinberg | Sheldon Glashow | Abdus Salam



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:

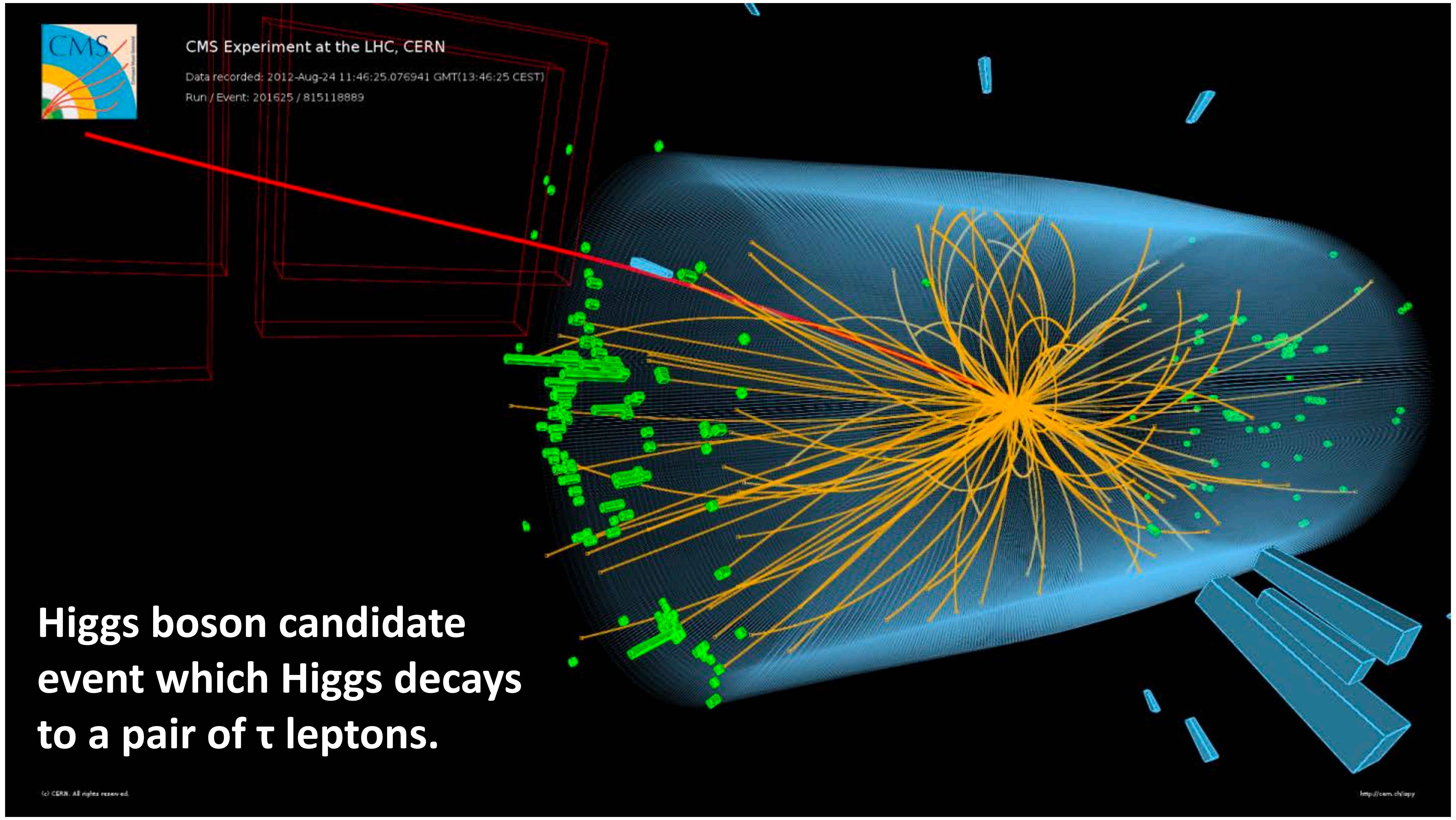
- Excellent performance and calibration
- Probe uncovered parameter space
- Try new techniques to enhance Signal/ Background separation, i.e. new machine learning techniques



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,

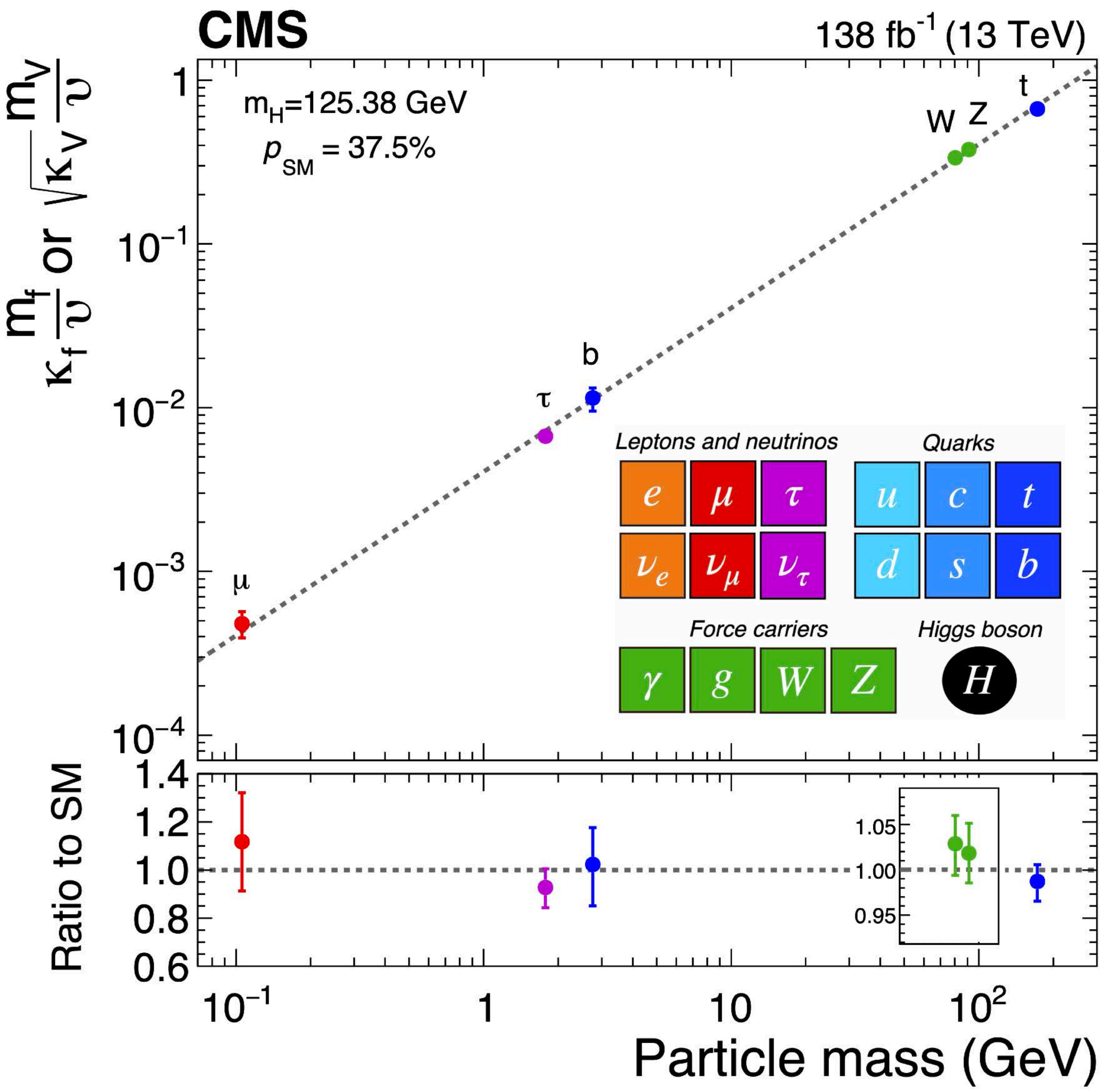
- by **Robert Brout** and **François Englert** [Phys. Rev. Lett. 13, 321];
- by **Peter Higgs** [Phys. Rev. Lett. 13, 508];
- by **Gerald Guralnik**, **C. R. Hagen**, and **Tom Kibble** [Phys. Rev. Lett. 13, 585].



Higgs boson candidate event which Higgs decays to a pair of τ leptons.

July 2012, Announcement for the discovery of what could be the long-sought Higgs boson!!

Mass of elementary particles?

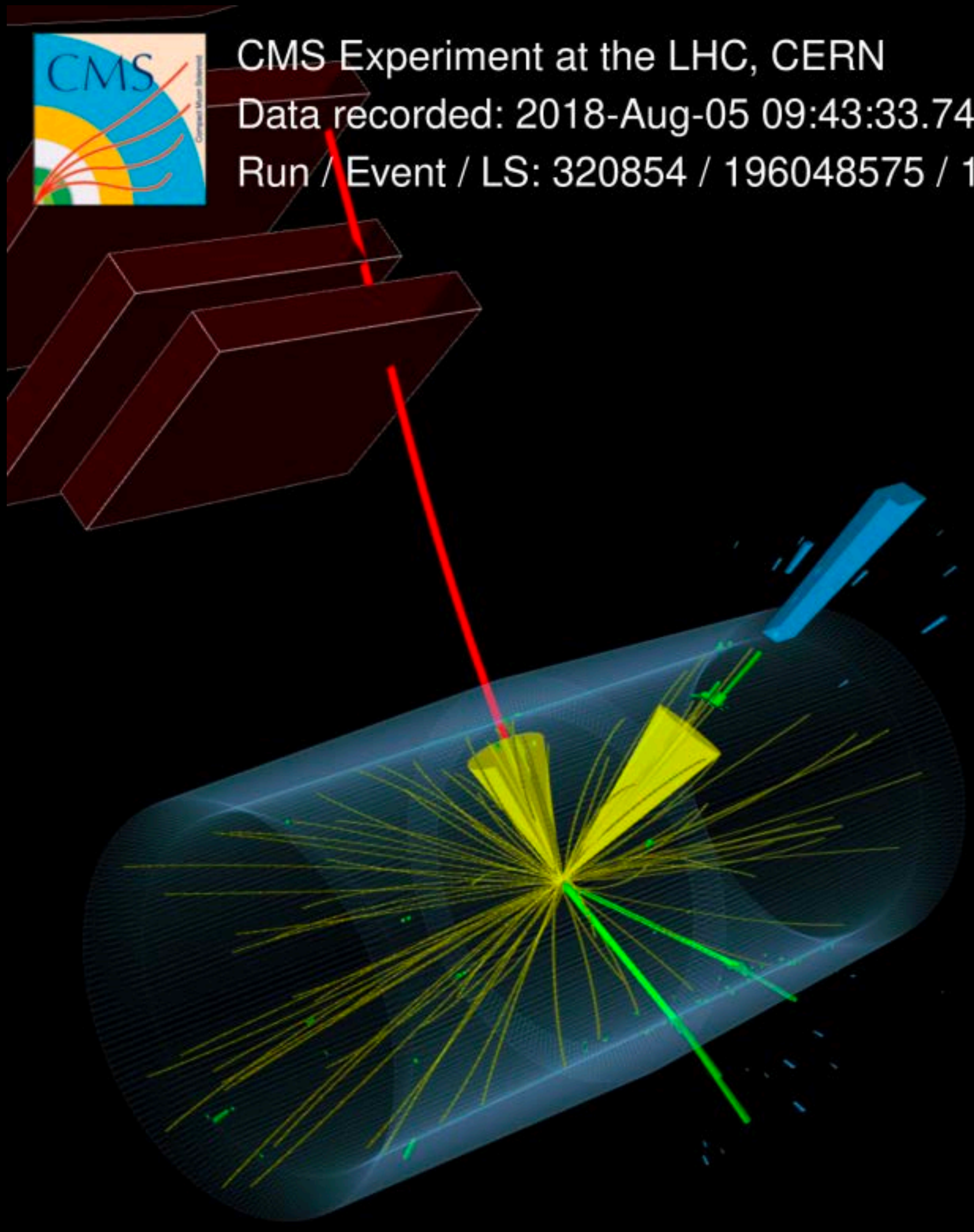


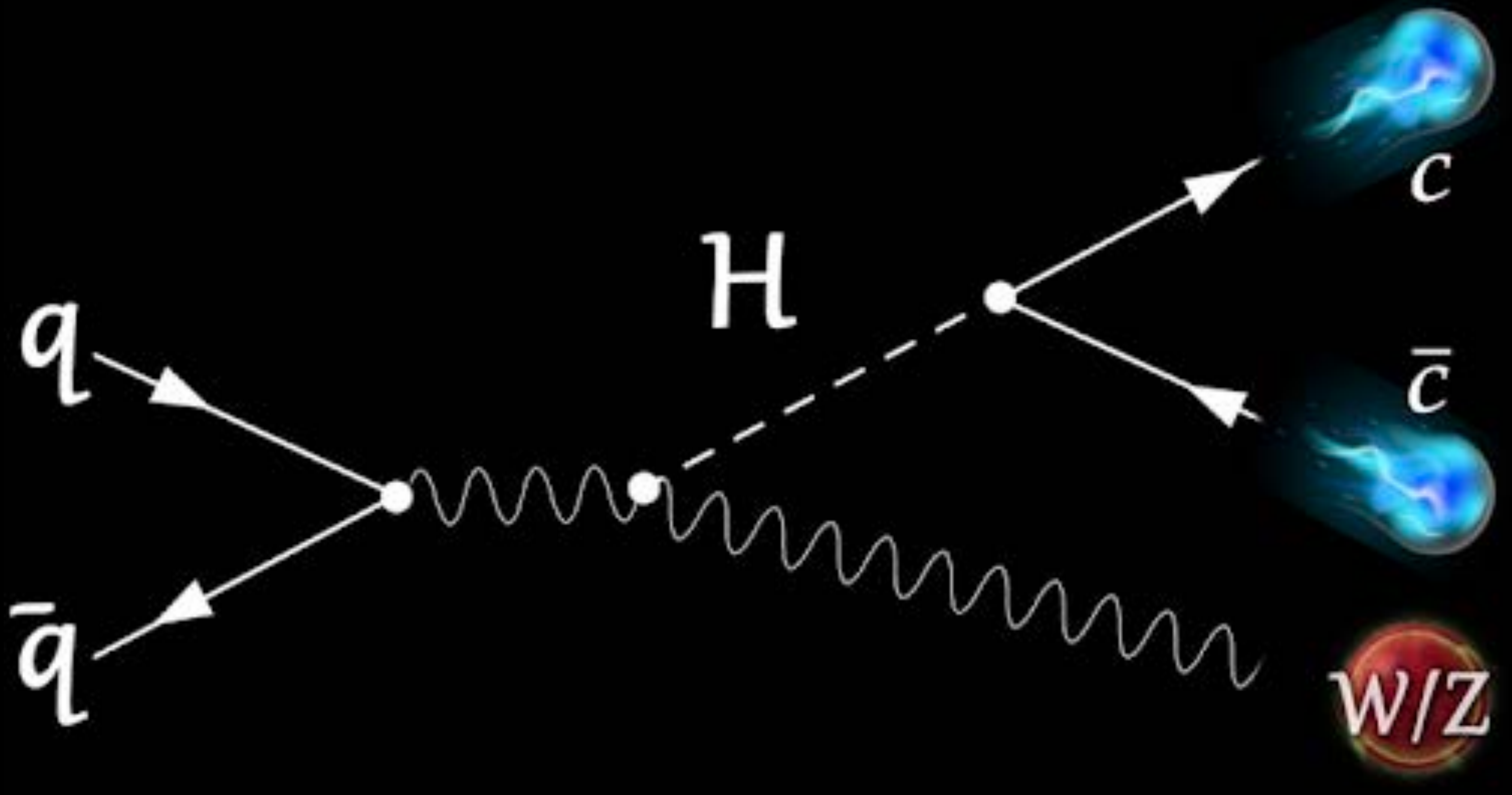
The Higgs boson is predicted to couple to particles (or decay into them) with a strength depending on their masses in a well-defined way: the higher the mass, the stronger the coupling. The measurement of the many ways this Higgs boson decays and the measurement of its couplings to different particles,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

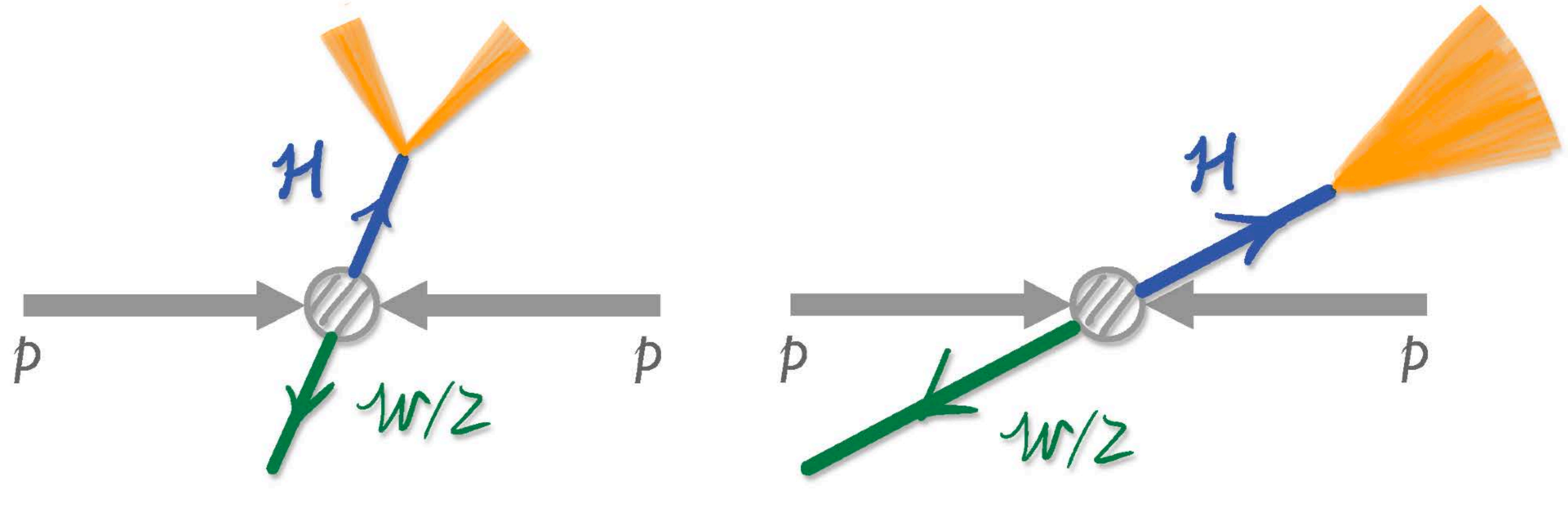




We know that Higgs is there, why do we need precise measurements?

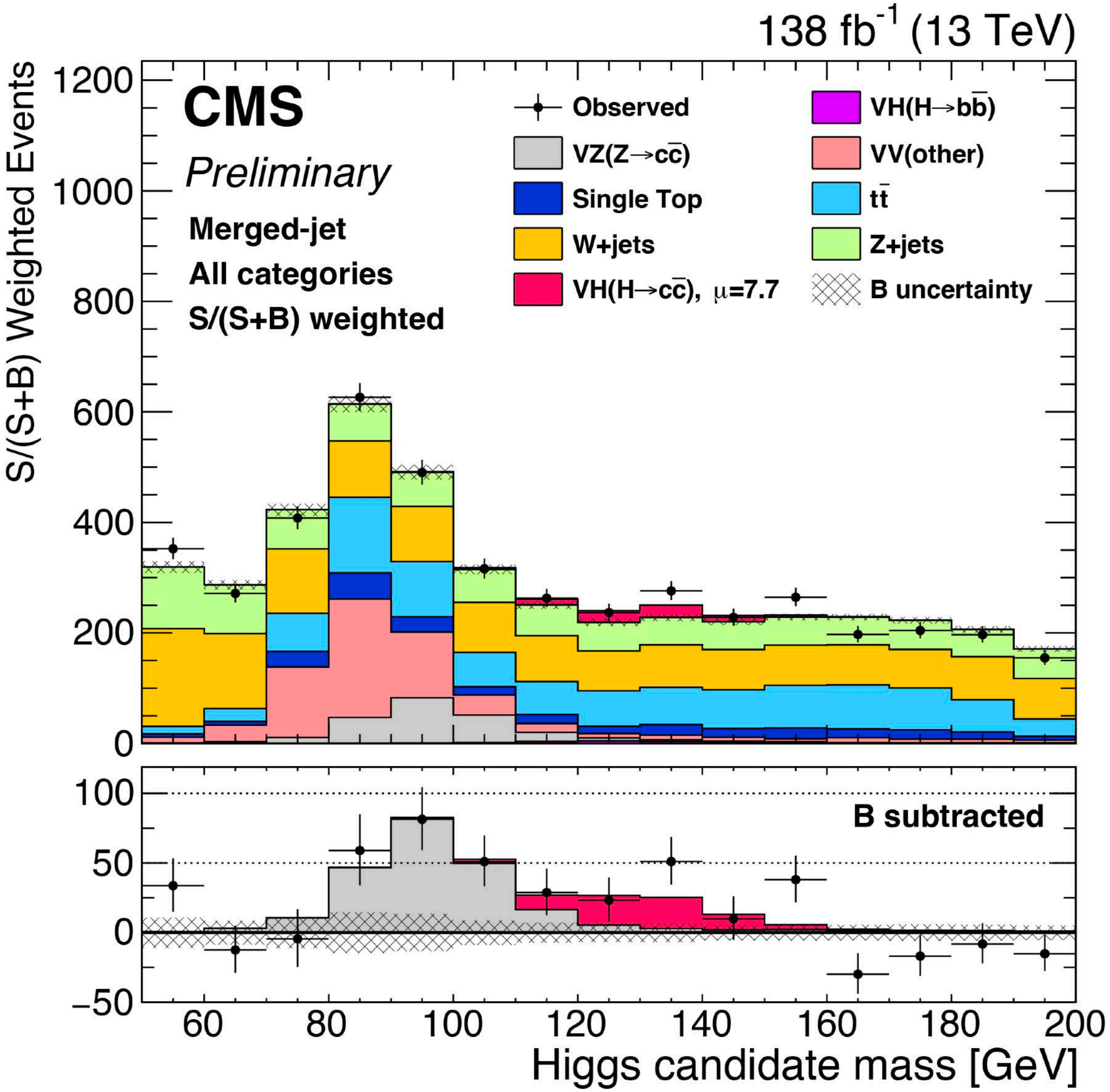
Because the lack of direct observations of new particles at the LHC!, we need an alternative approach which we consider that BSM physics interfere with standard model particles and subsequently leave an imprint on their properties. With precise measurement, we may see hint(s) of new physics.

Higgs … from *search* to *precision measurement*



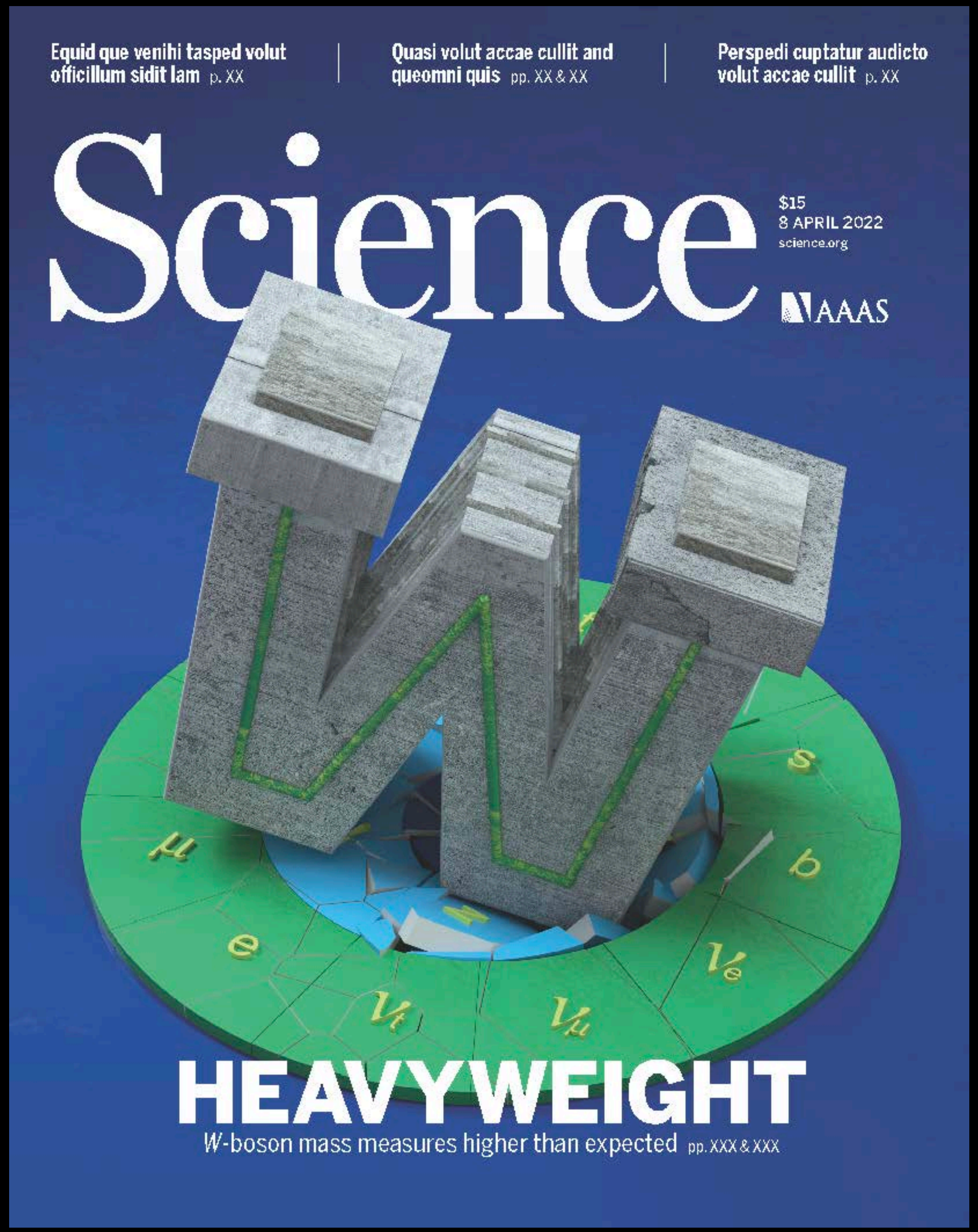
(a) (b)

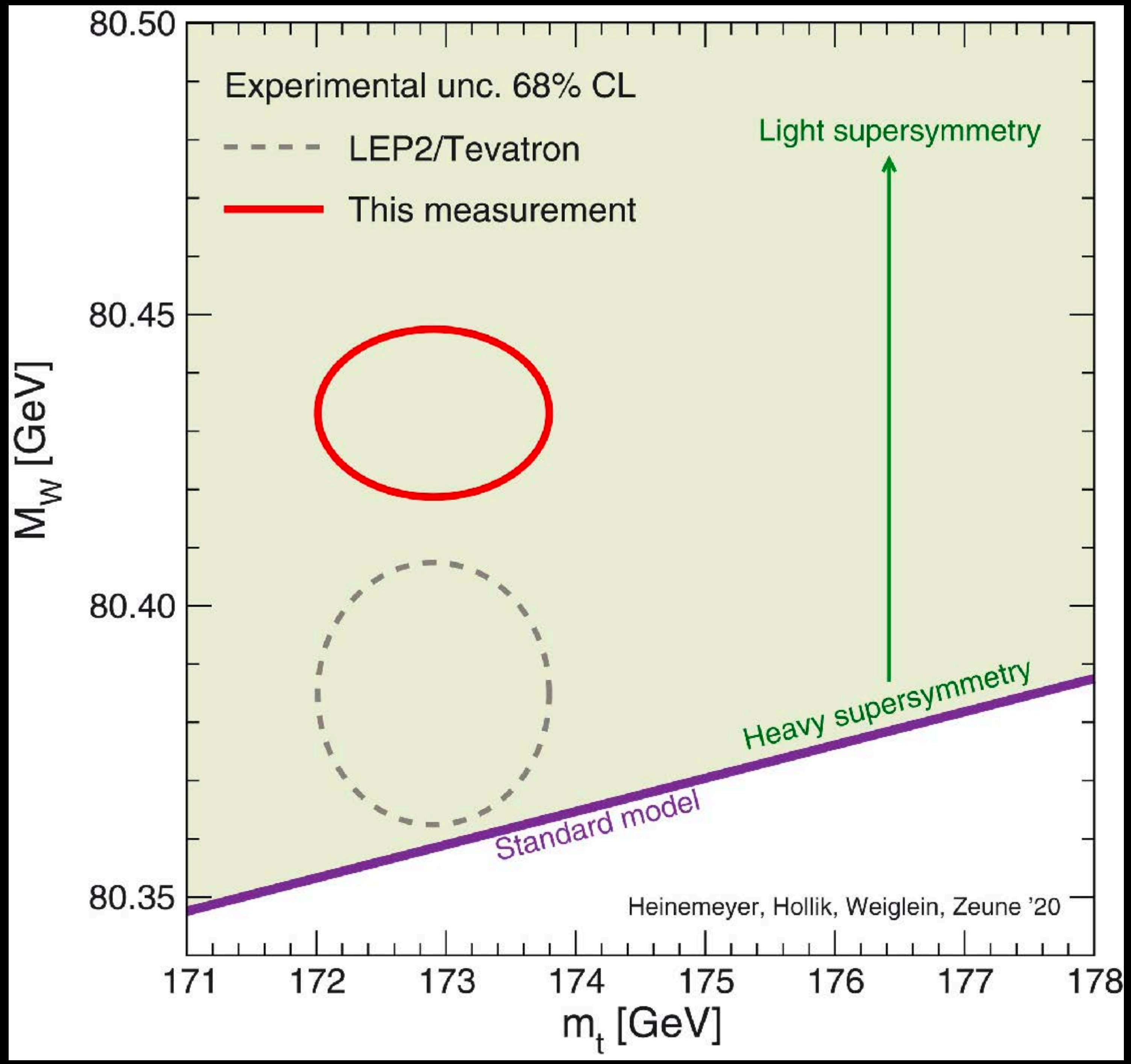
Higgs-charm coupling challenge: Improve identification algorithms by innovative usages of deep learning techniques. [See detail about the analysis here]

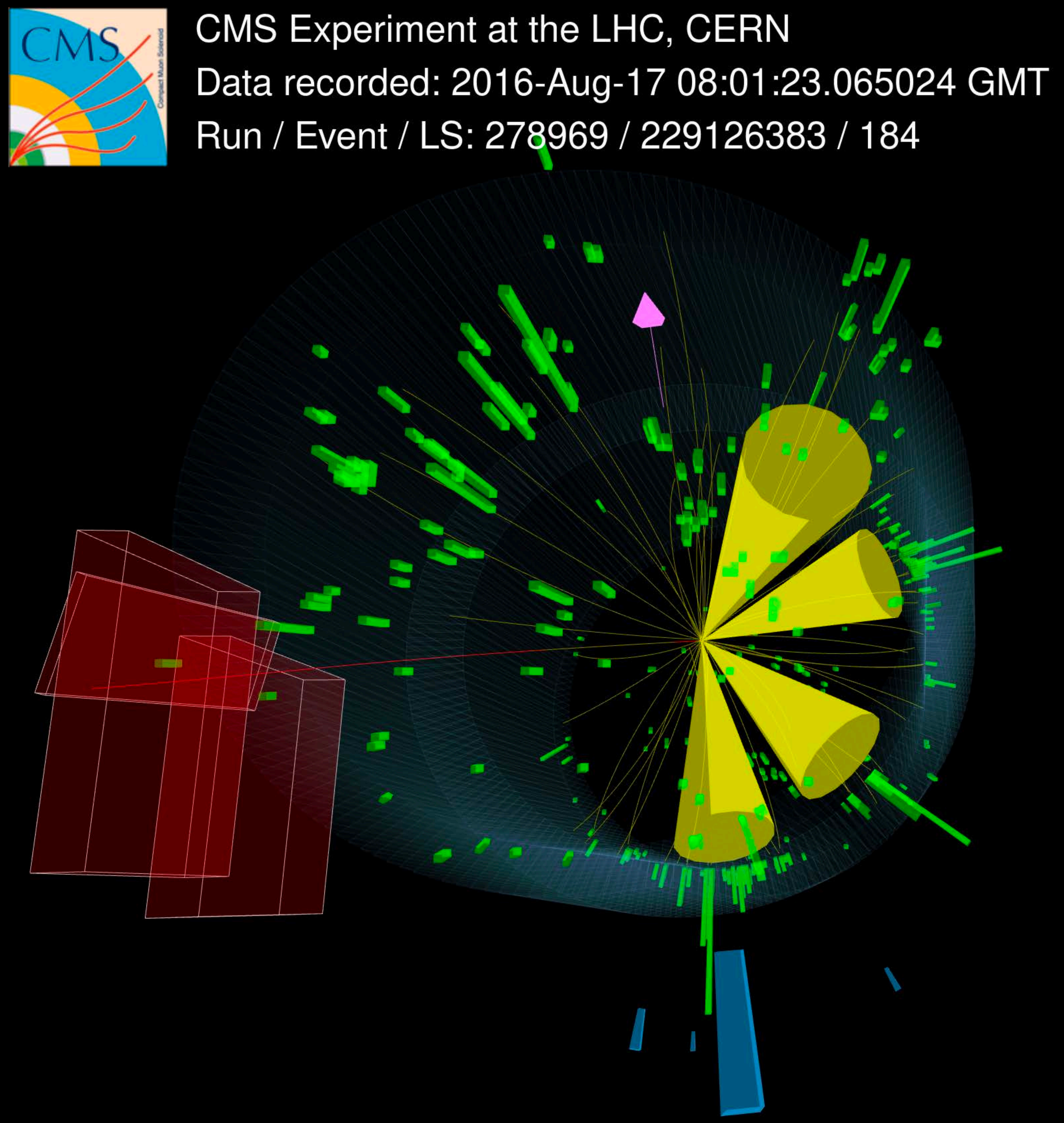


Top quark ... a tool for discoveries

- 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)***





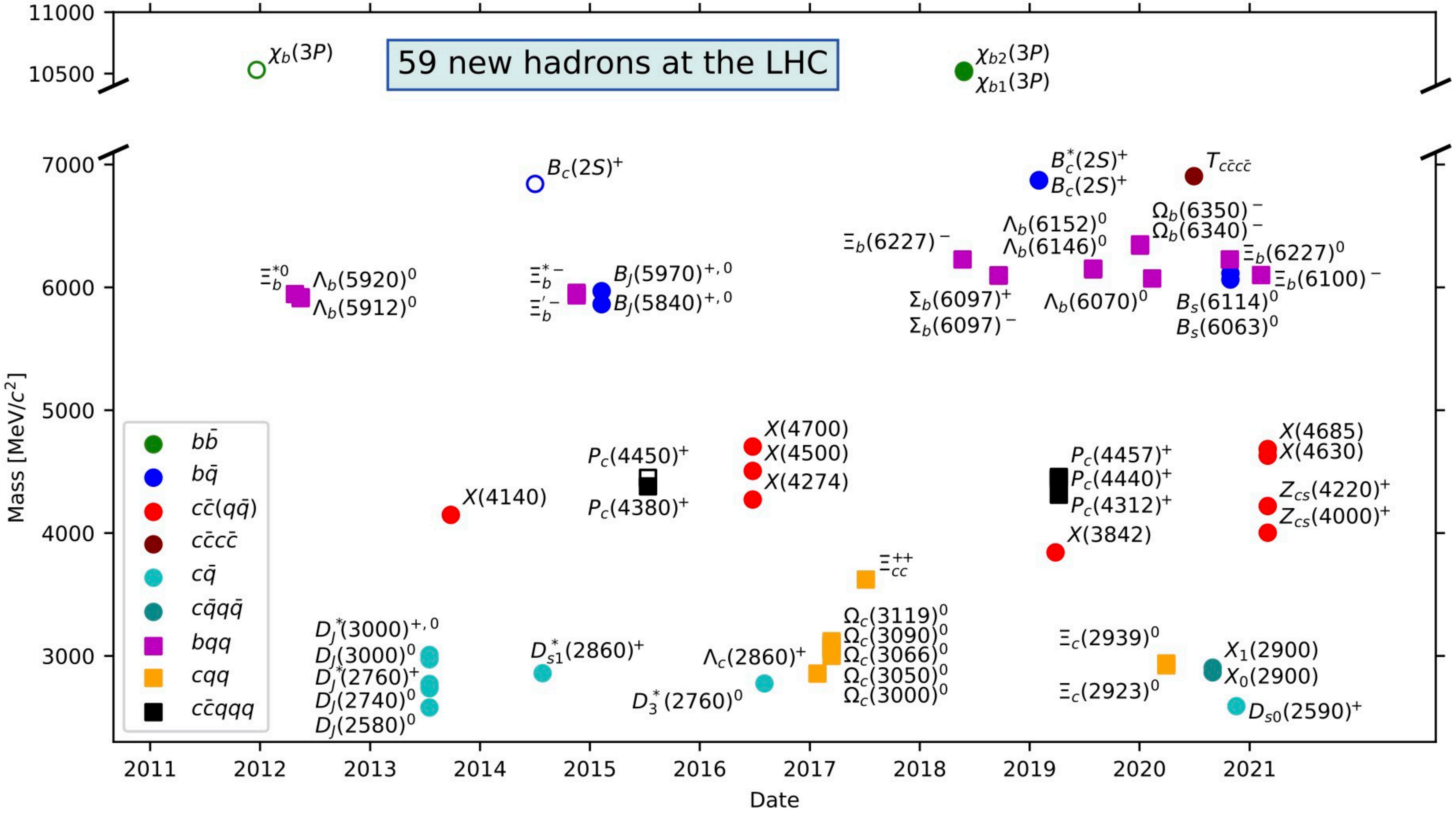


10 years (2011-2021) of LHC, 59 new hadrons

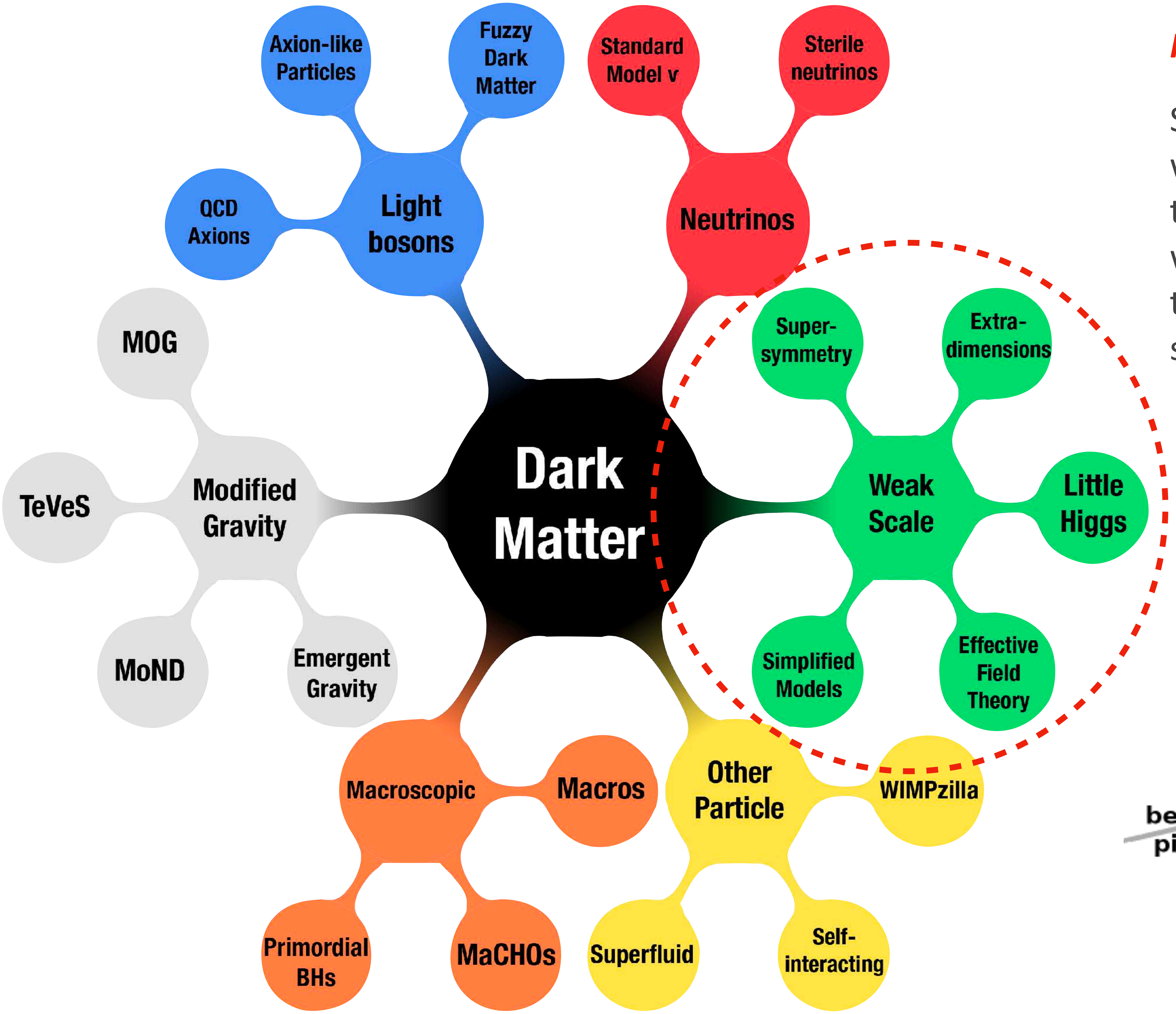
Quantum chromodynamics (or QCD) is still on very solid footing

- QCD is the theory to describe the strong interaction that holds quarks together inside hadrons.
- Experiments continue to discover hadrons including combination of
  - **mesons**: quarks and antiquarks,
  - **baryons**: three quarks,
  - **antibaryons**: three antiquarks,
  - **tetraquarks**: two quarks and two antiquarks,
  - **pentaquarks**: four quarks and one antiquark.
- Reminder: we cannot (yet) prove theoretically that quarks can't stay alone. In addition, we can't also calculate of which combinations of quarks would be/ would not be viable in nature.

LHCB-FIGURE-2021-001



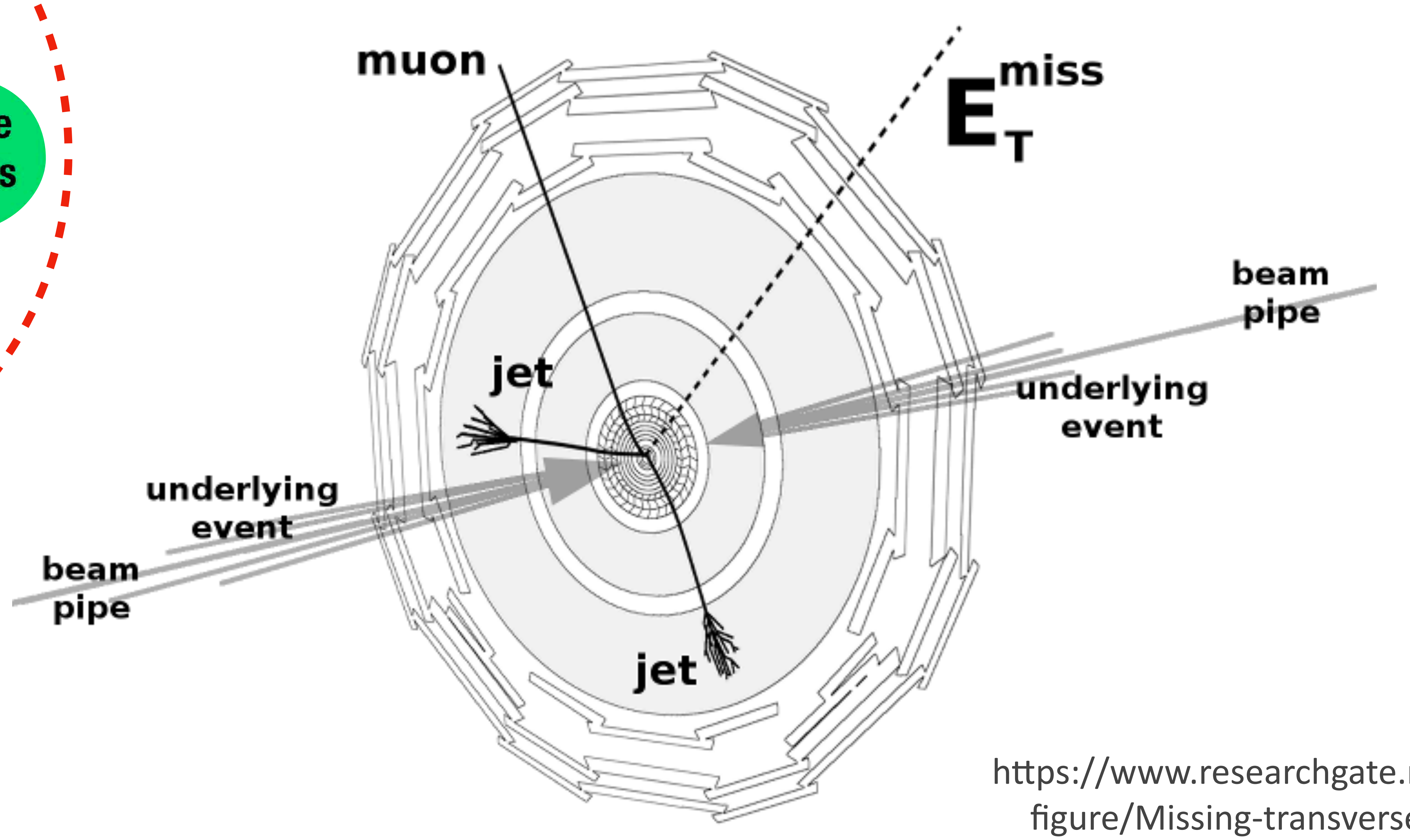
Exotic searches: Dark Matter searches at collider



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

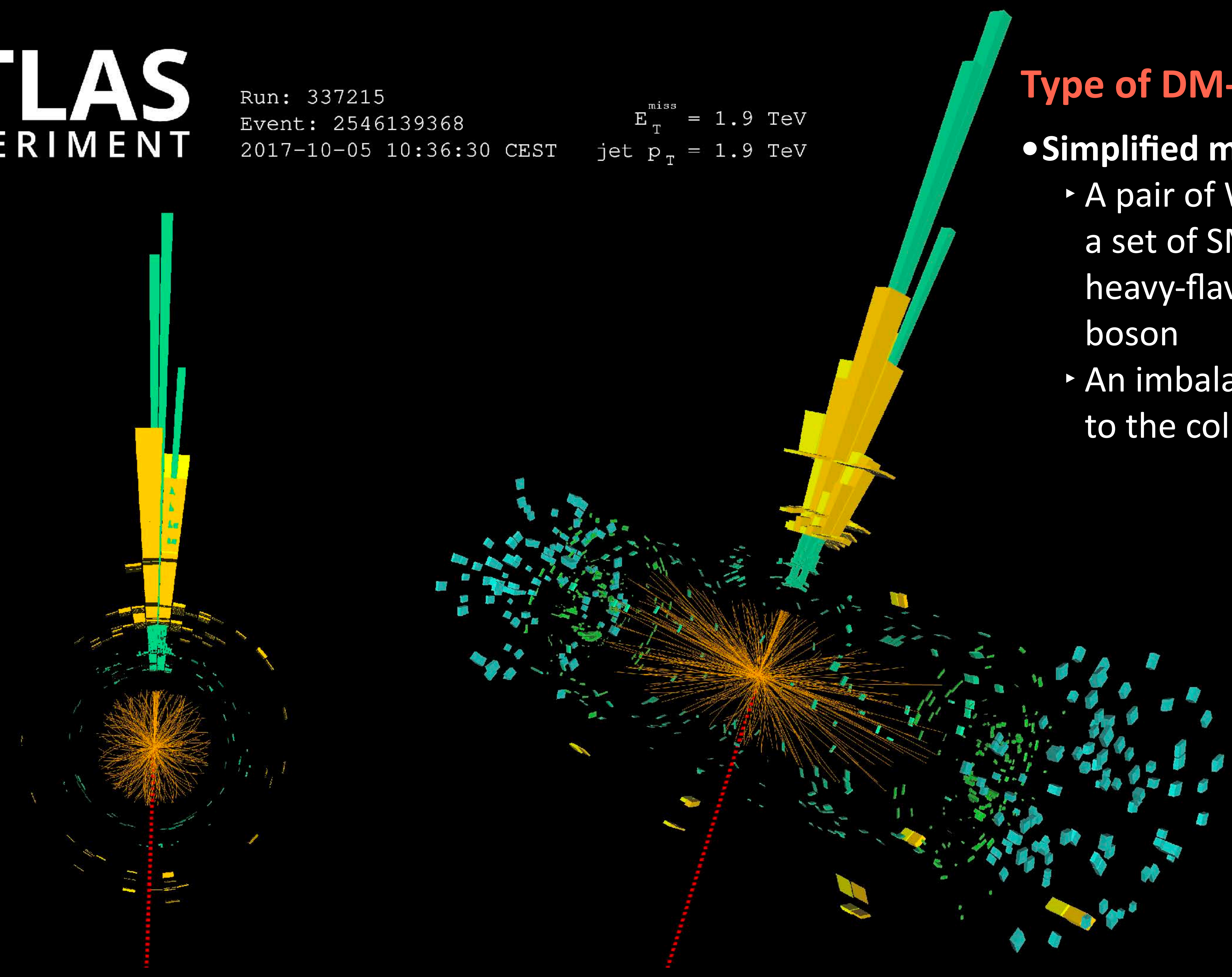
How do we search for dark matter at the collider?

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.



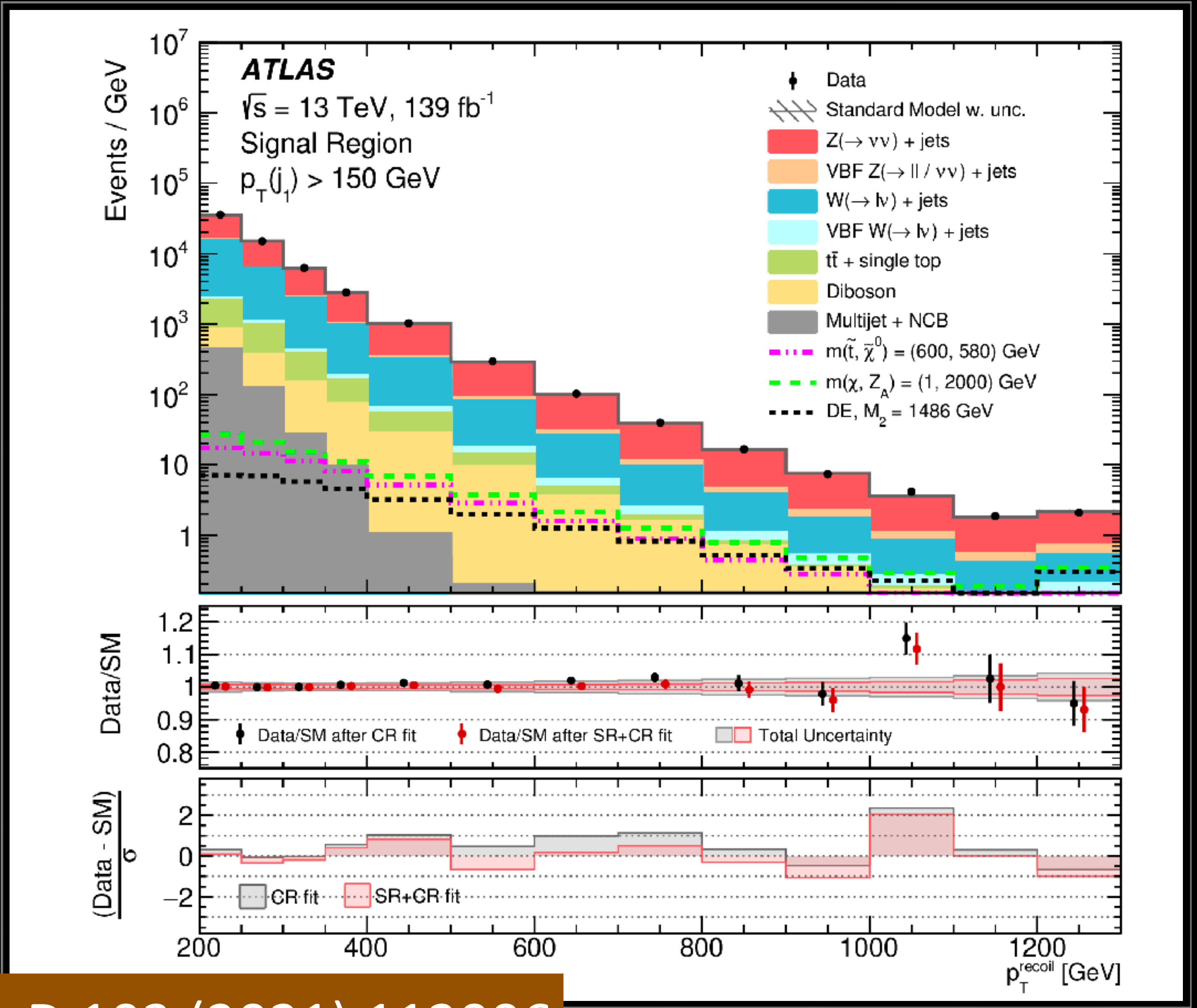
https://www.researchgate.net/figure/Missing-transverse-momentum_fig2_331397740

Exotic searches: ~~Darth Vader~~ Dark Matter



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

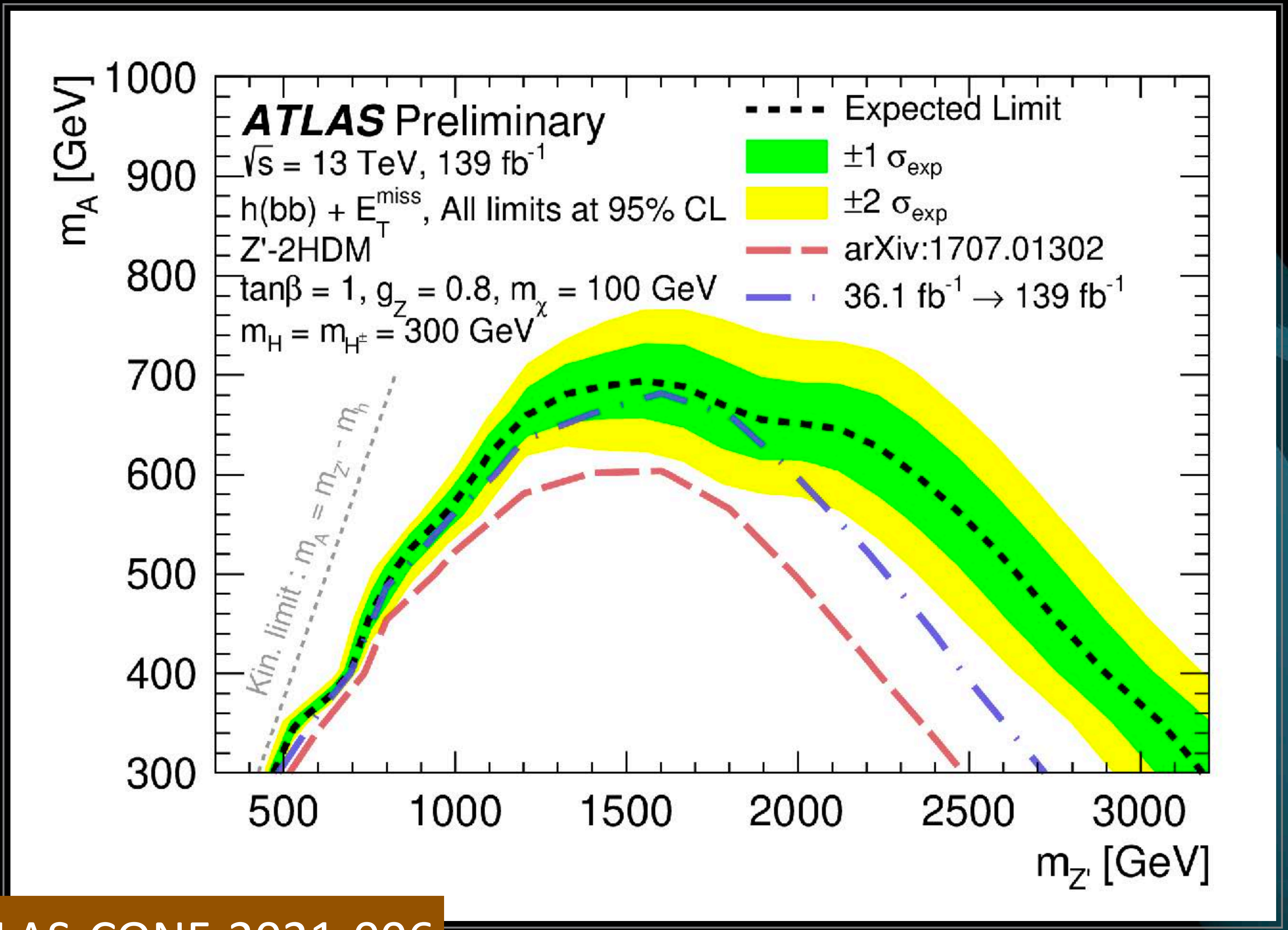
Exotic searches: ~~Darth Vader~~ Dark Matter

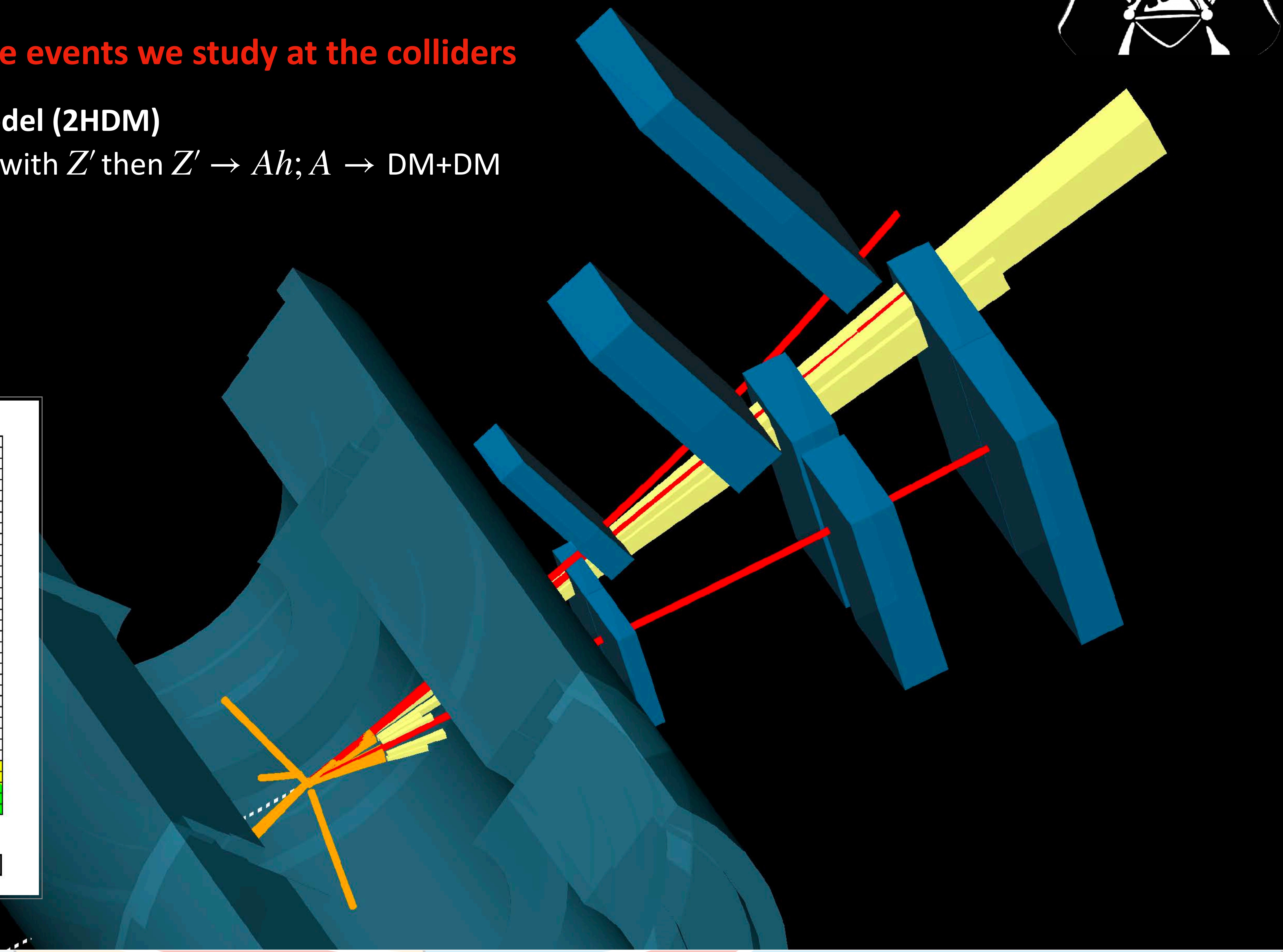
ATLAS EXPERIMENT

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 $Z' \to Ah; A \to$ DM+DM



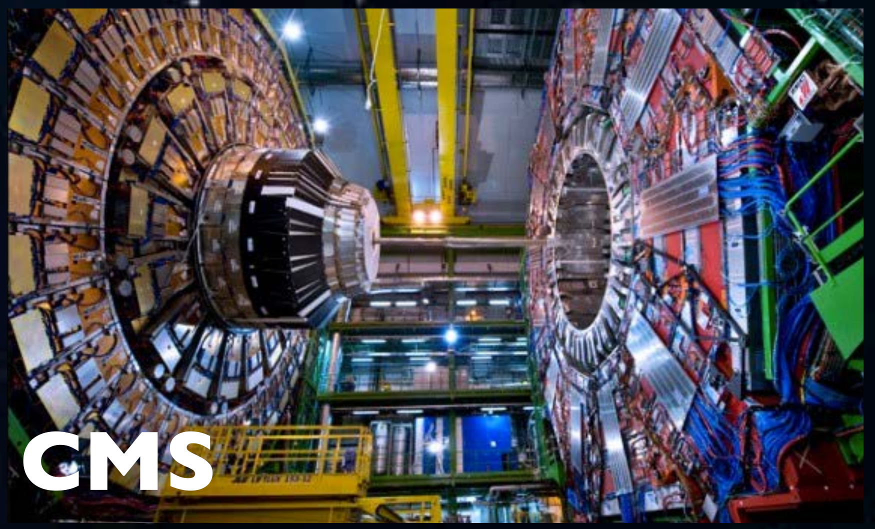


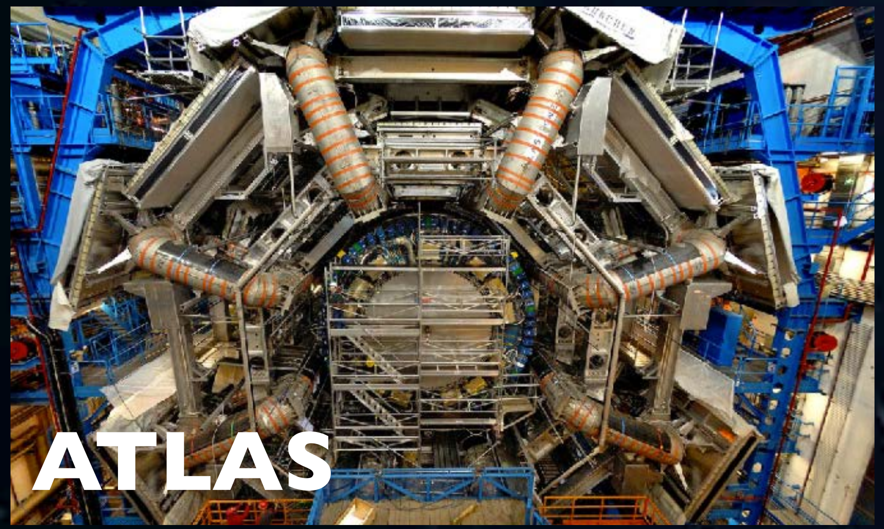
ATLAS-CONF-2021-006

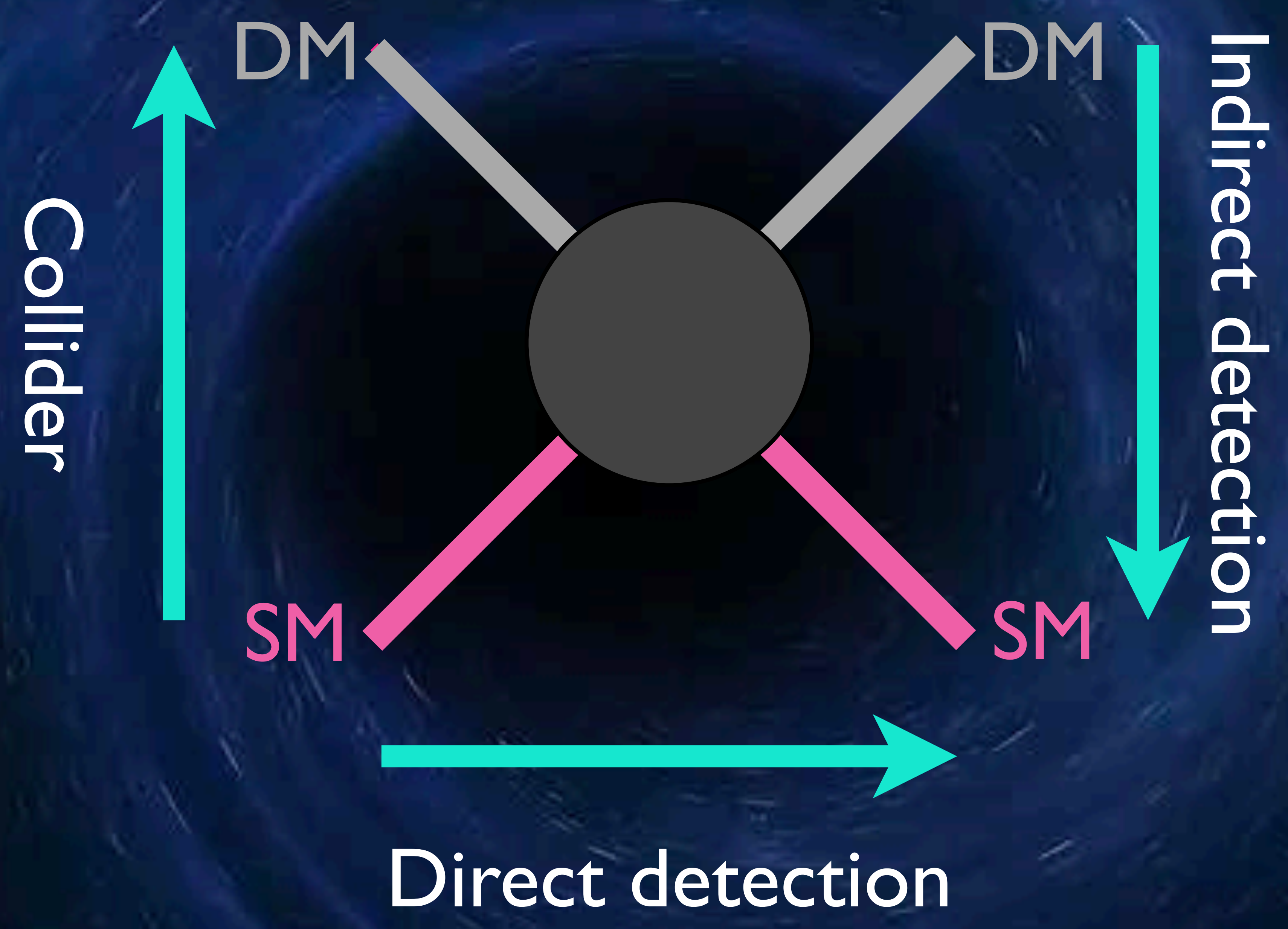
Dark matter searches

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

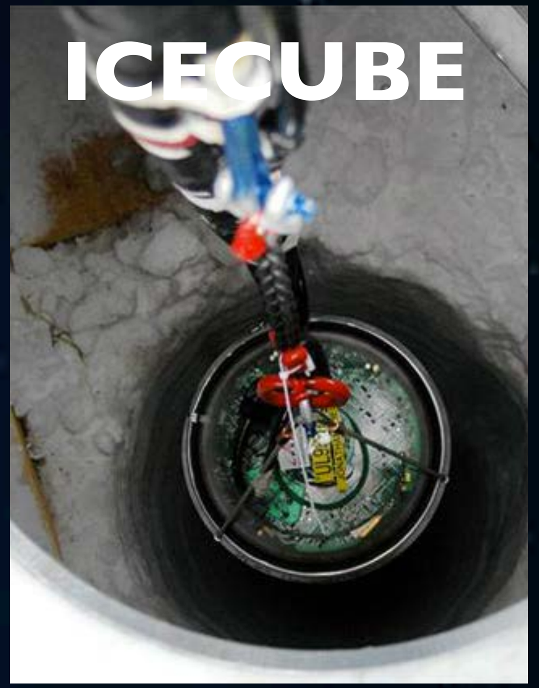
Laboratory production of DM particles

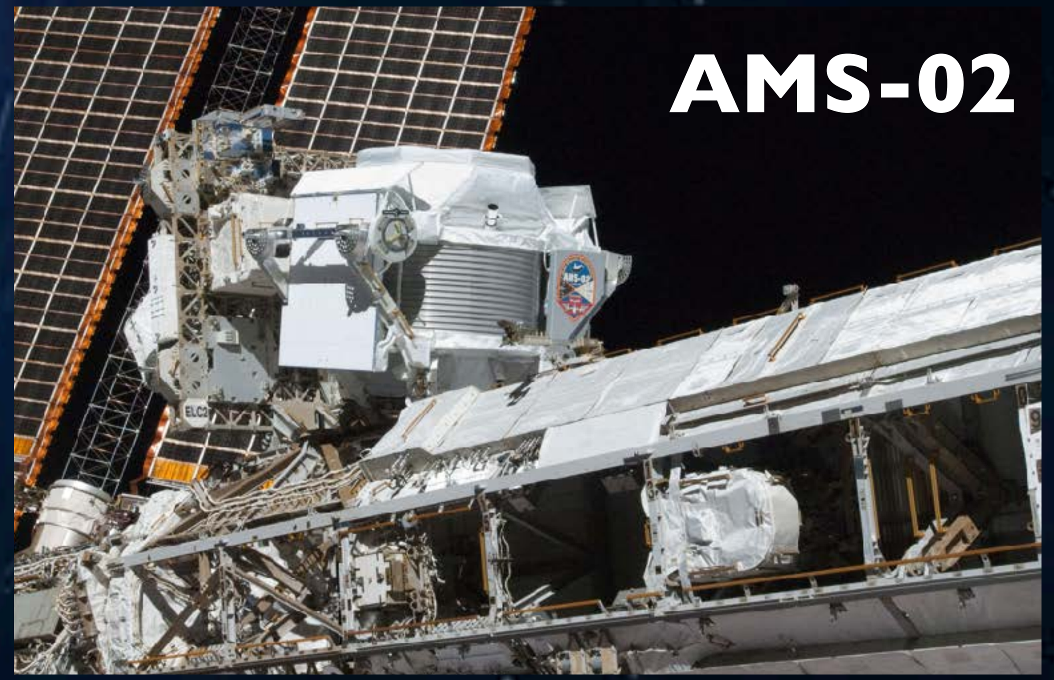




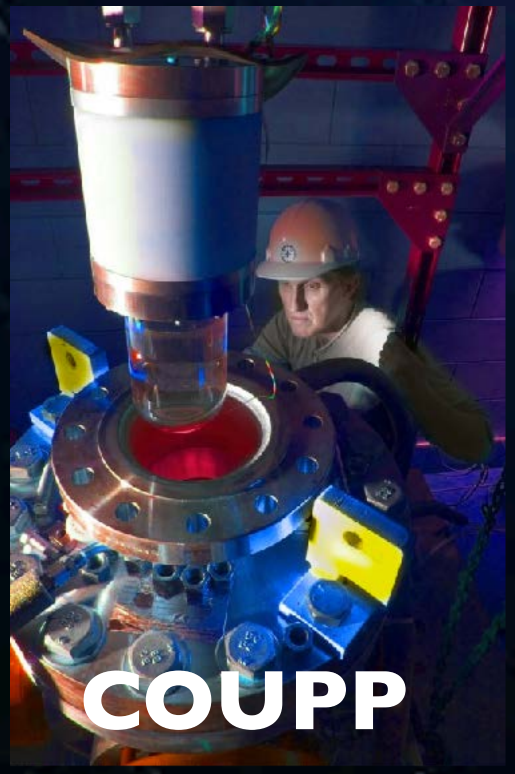


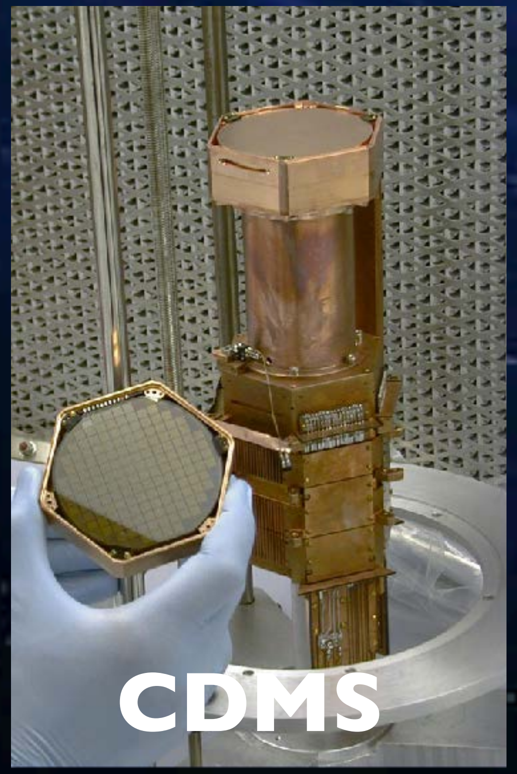
Observe DM annihilation products

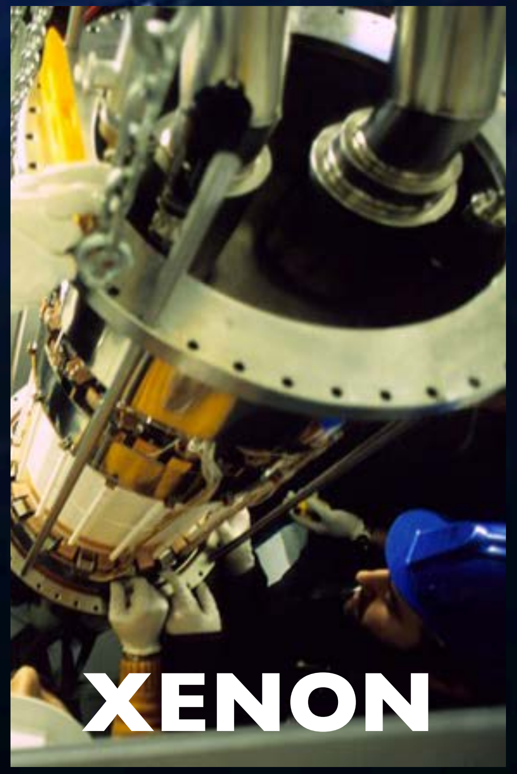




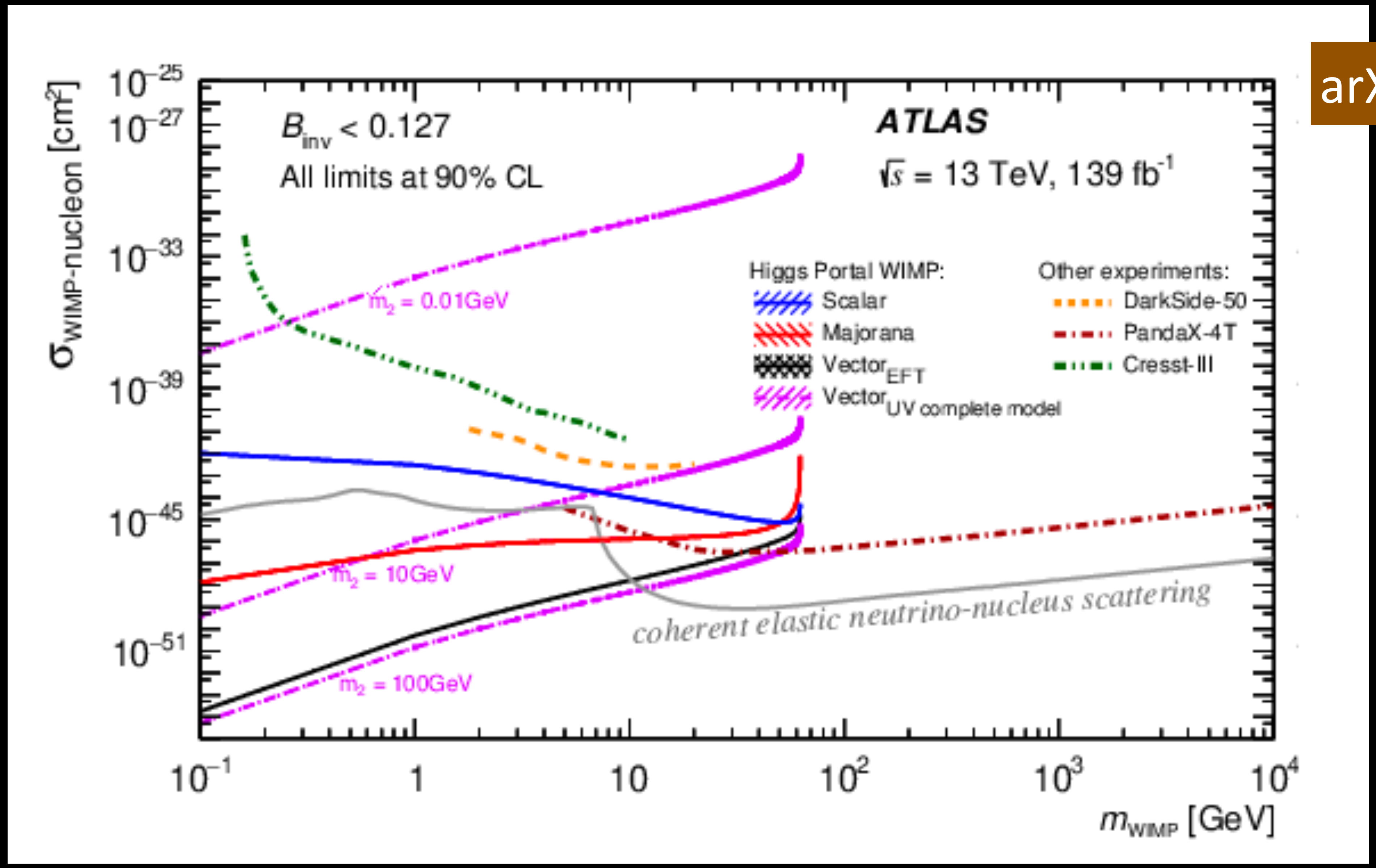
Dark Matter-nucleus scattering



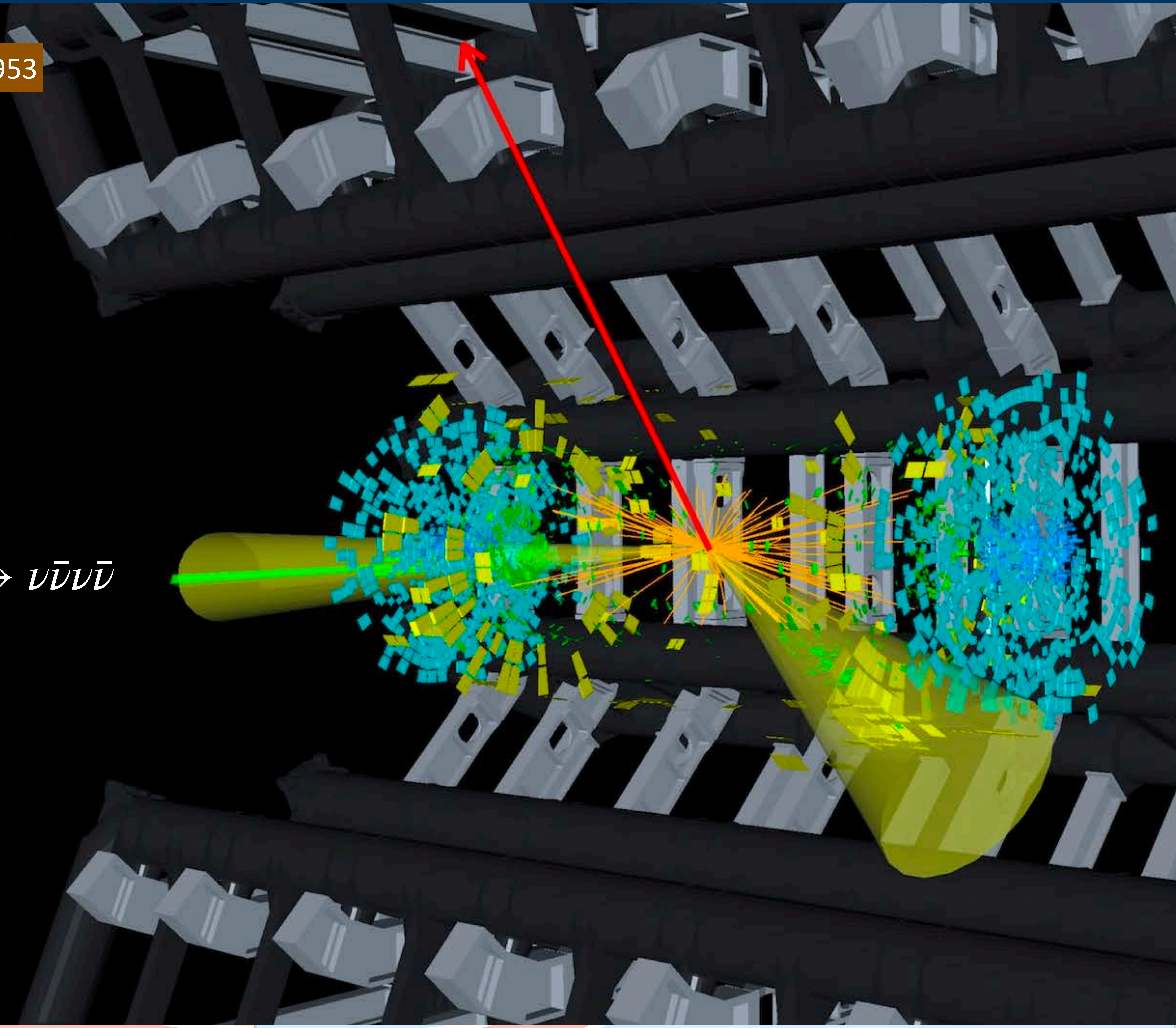




Invisible Higgs



arXiv:2202.07953

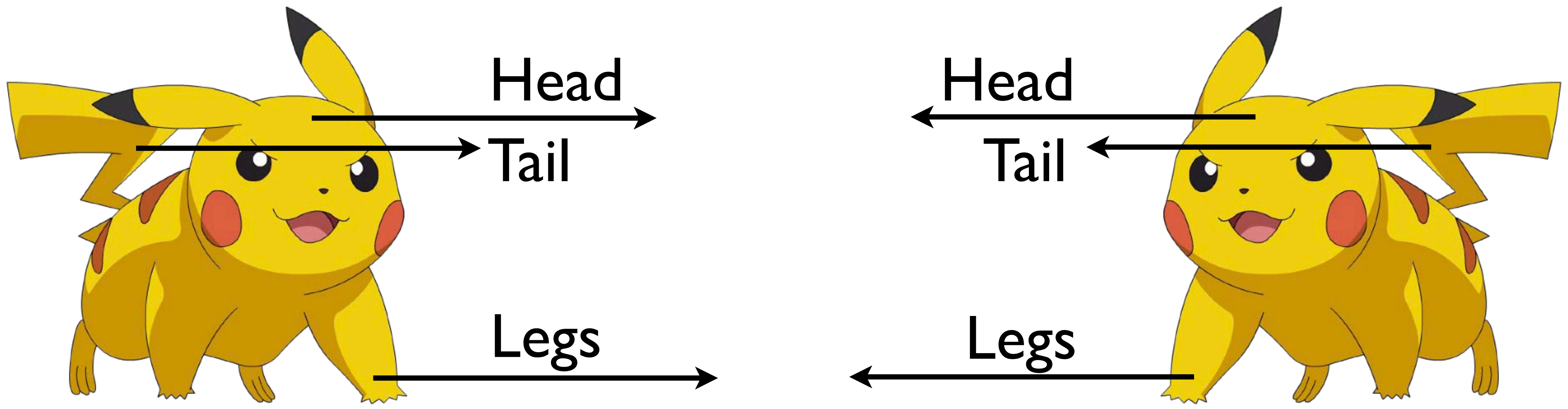


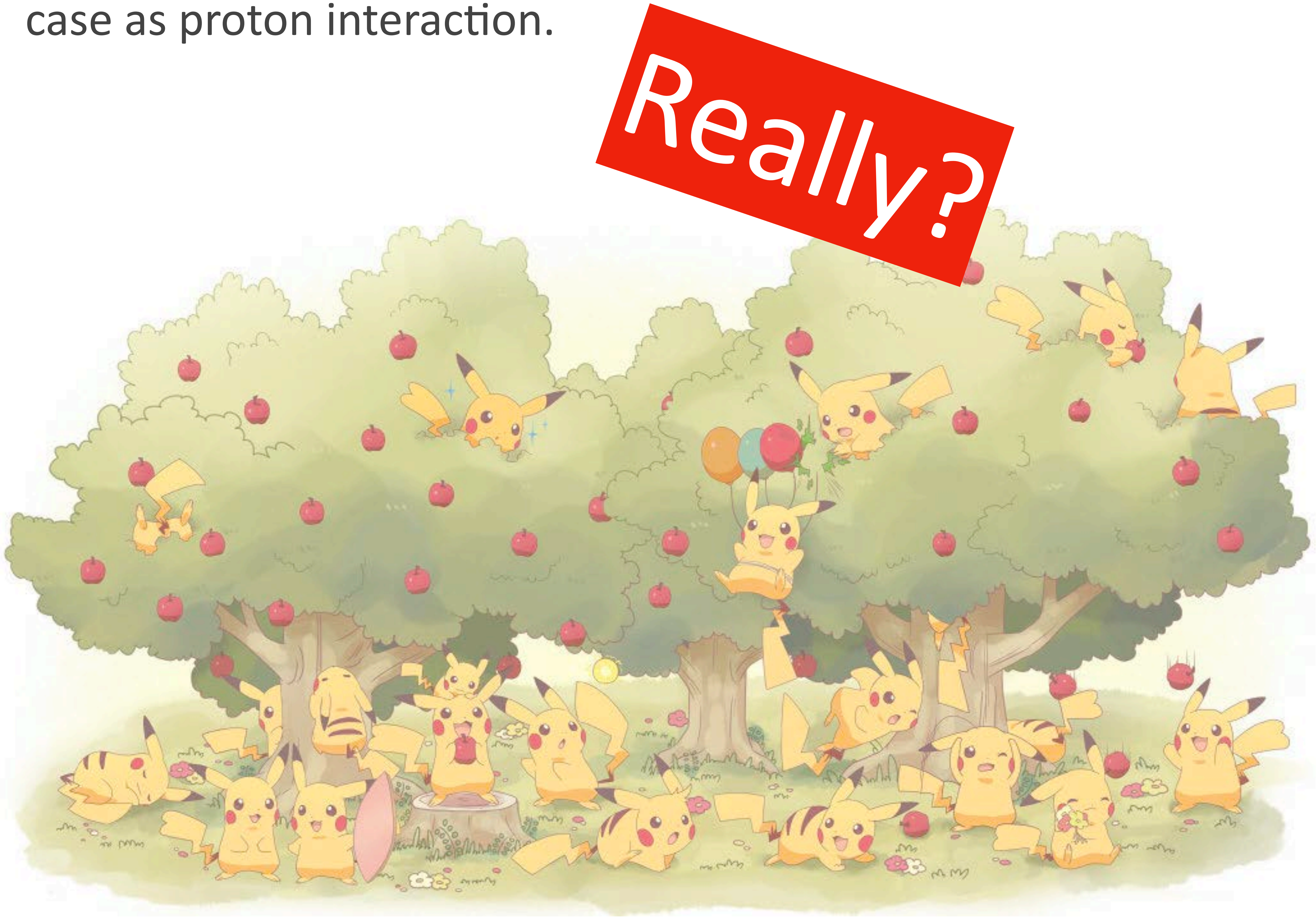
- SM Higgs decay invisible, $H \rightarrow ZZ \rightarrow \nu\bar{\nu}\nu\bar{\nu}$
- DM model $H \rightarrow \chi\chi$

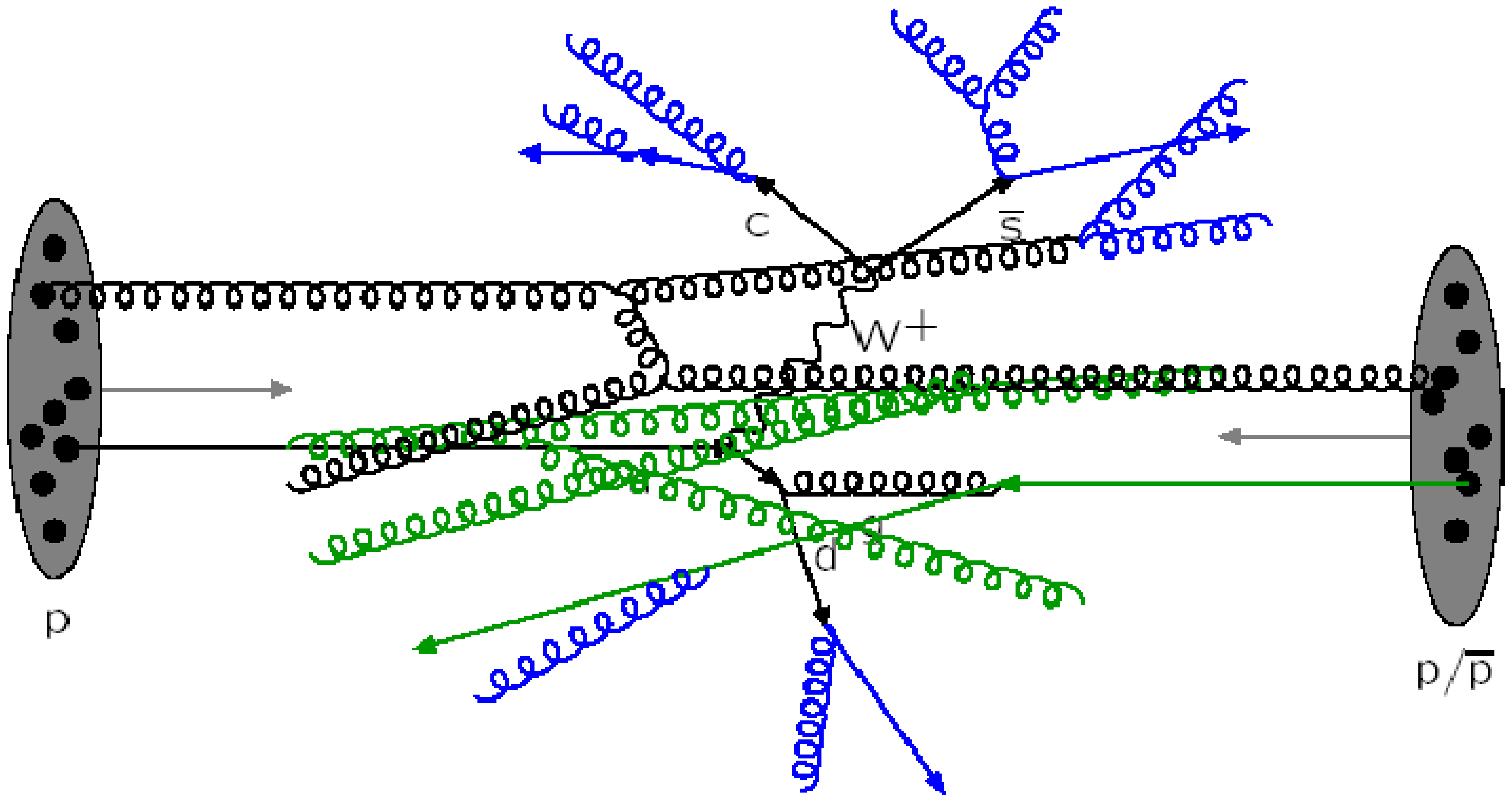
ATLAS EXPERIMENT

Proton collision

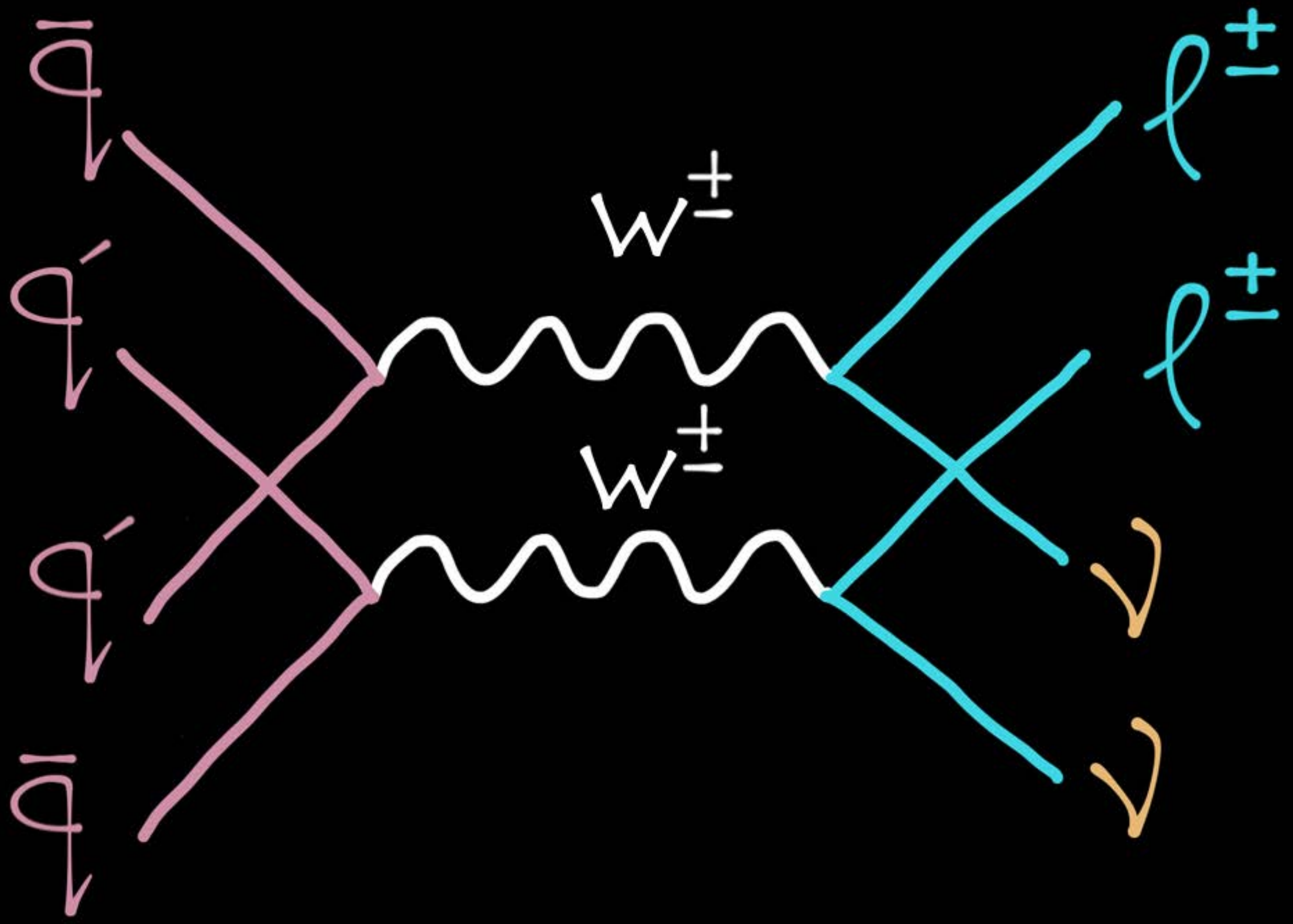
When "You" watch Pikachu fighting, you watch one-by-one interaction, i.e. Head-vs-Head, Tail-vs-Head, Head-vs-Leg, and then you are looking for the final result. This is the same case as proton interaction.

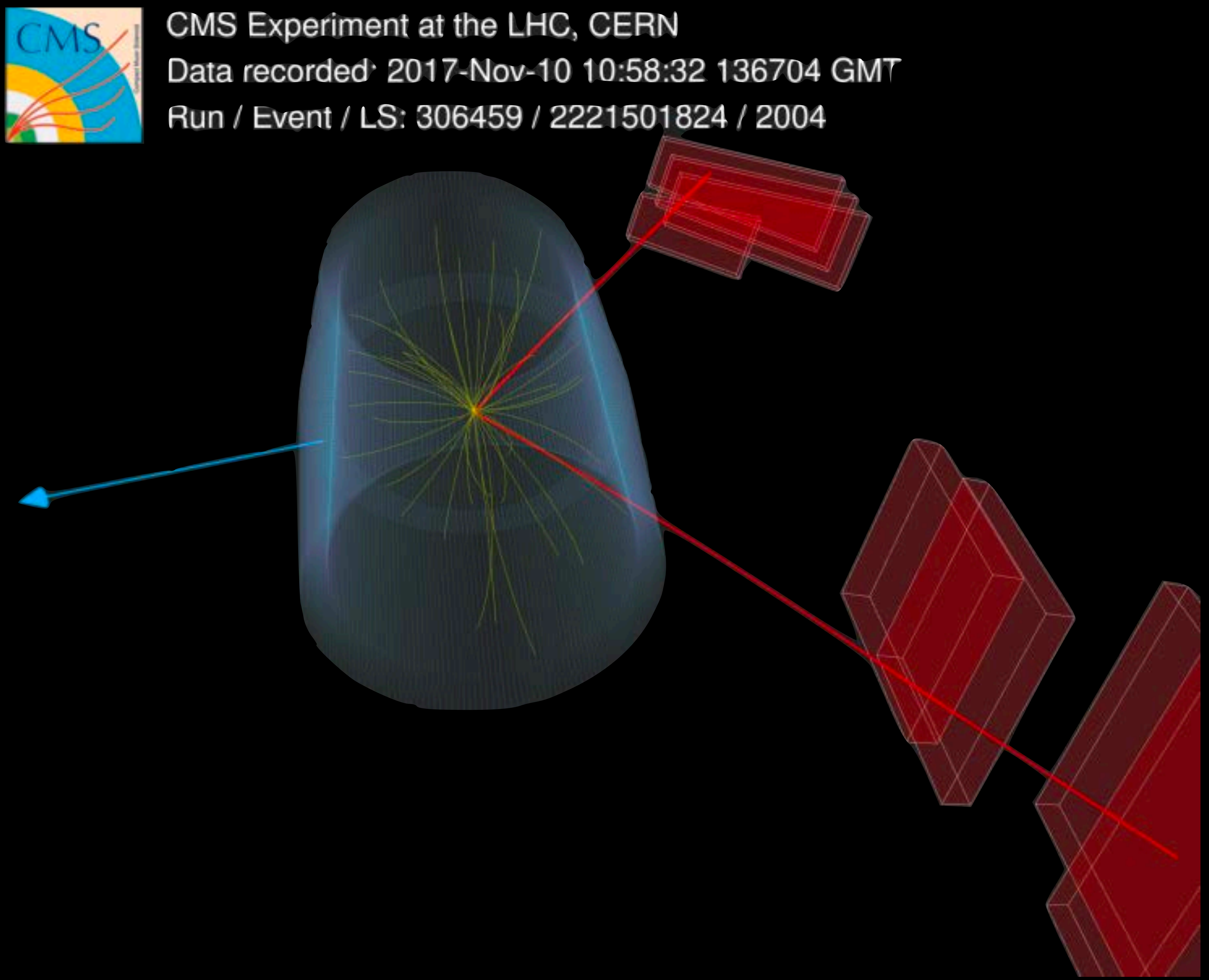




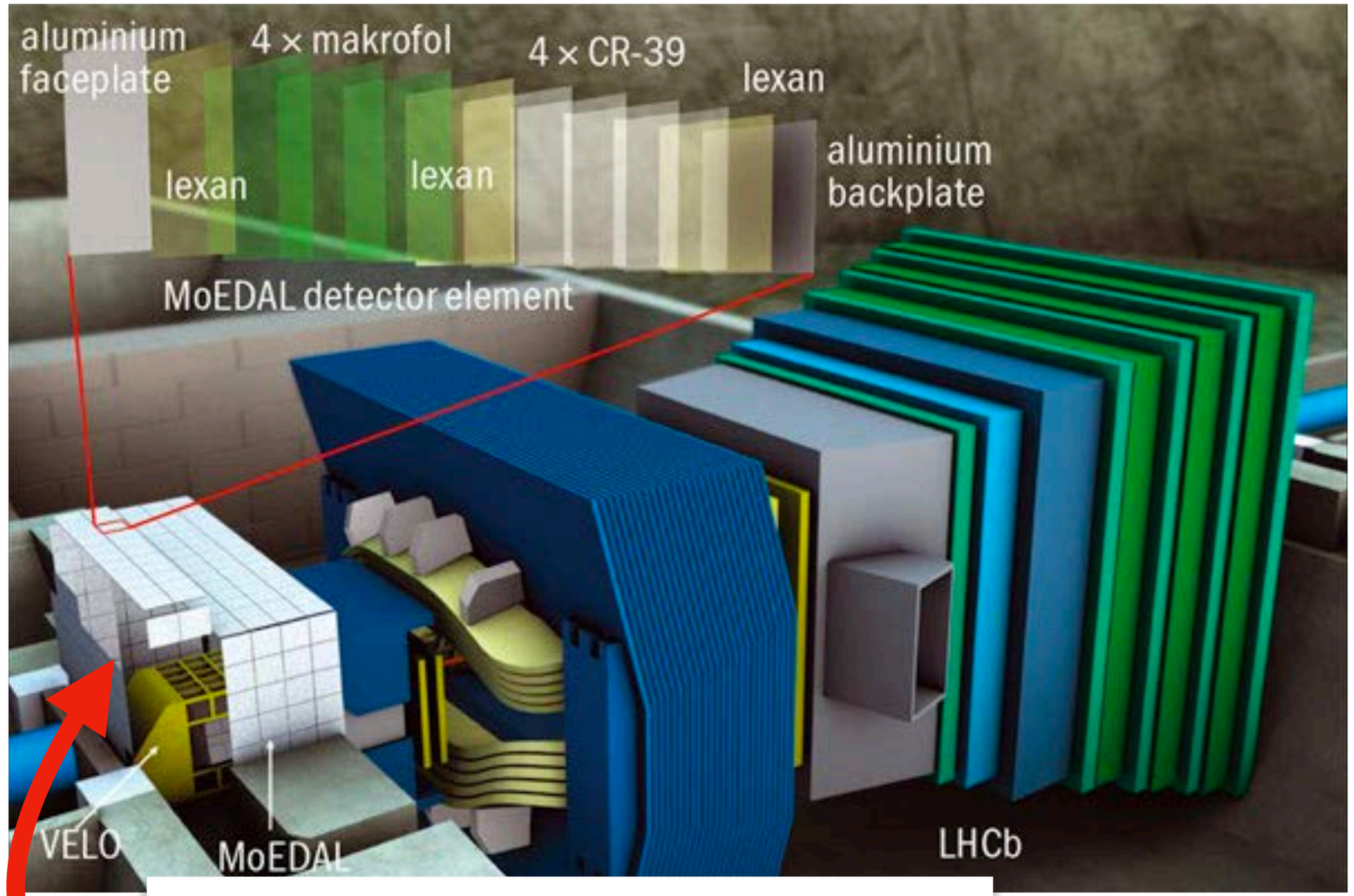


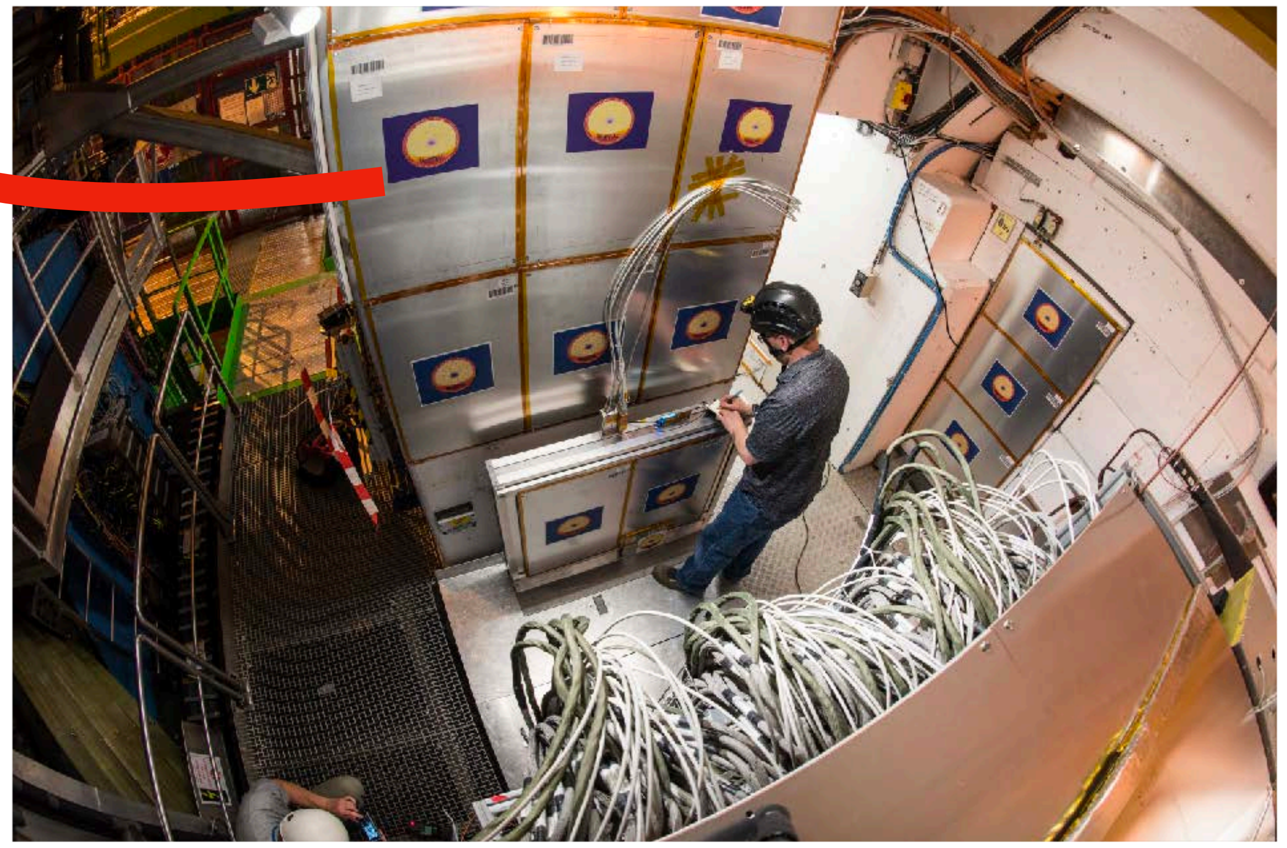
Double parton scattering





Small experiments but big Physics potentials at the LHC

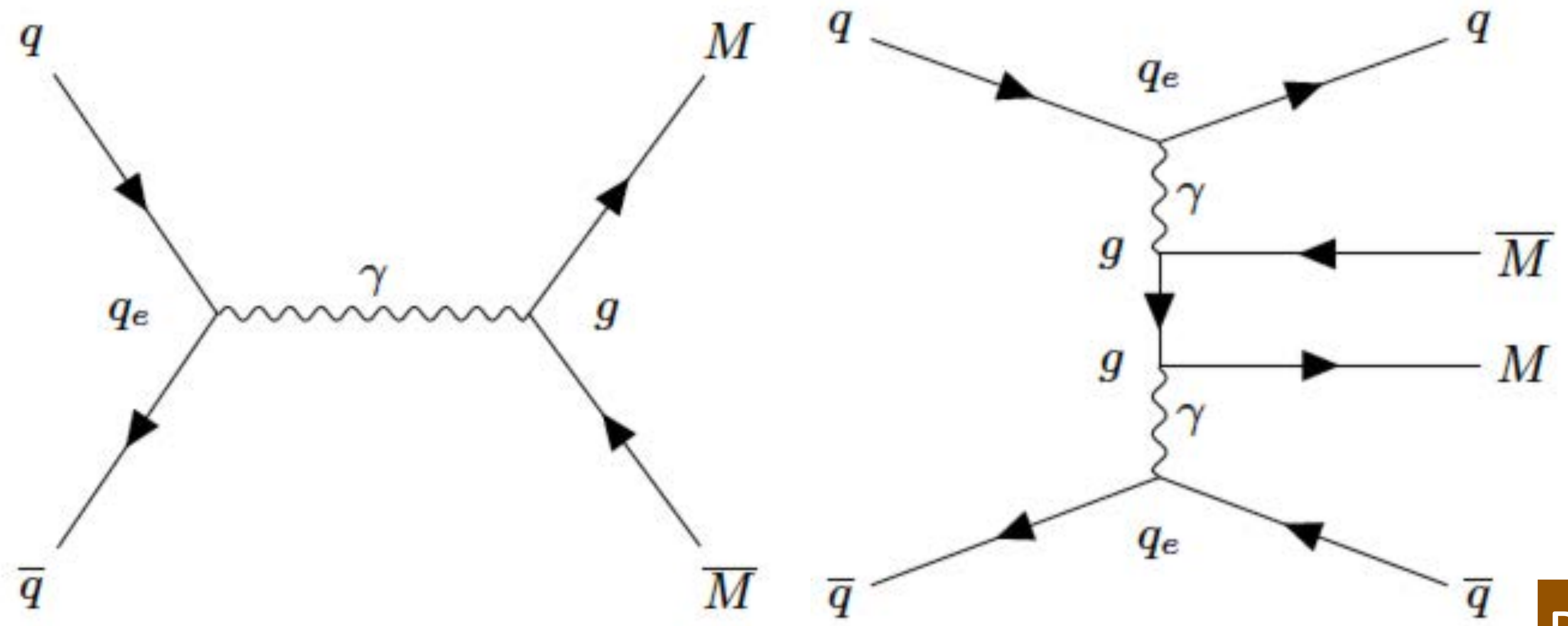


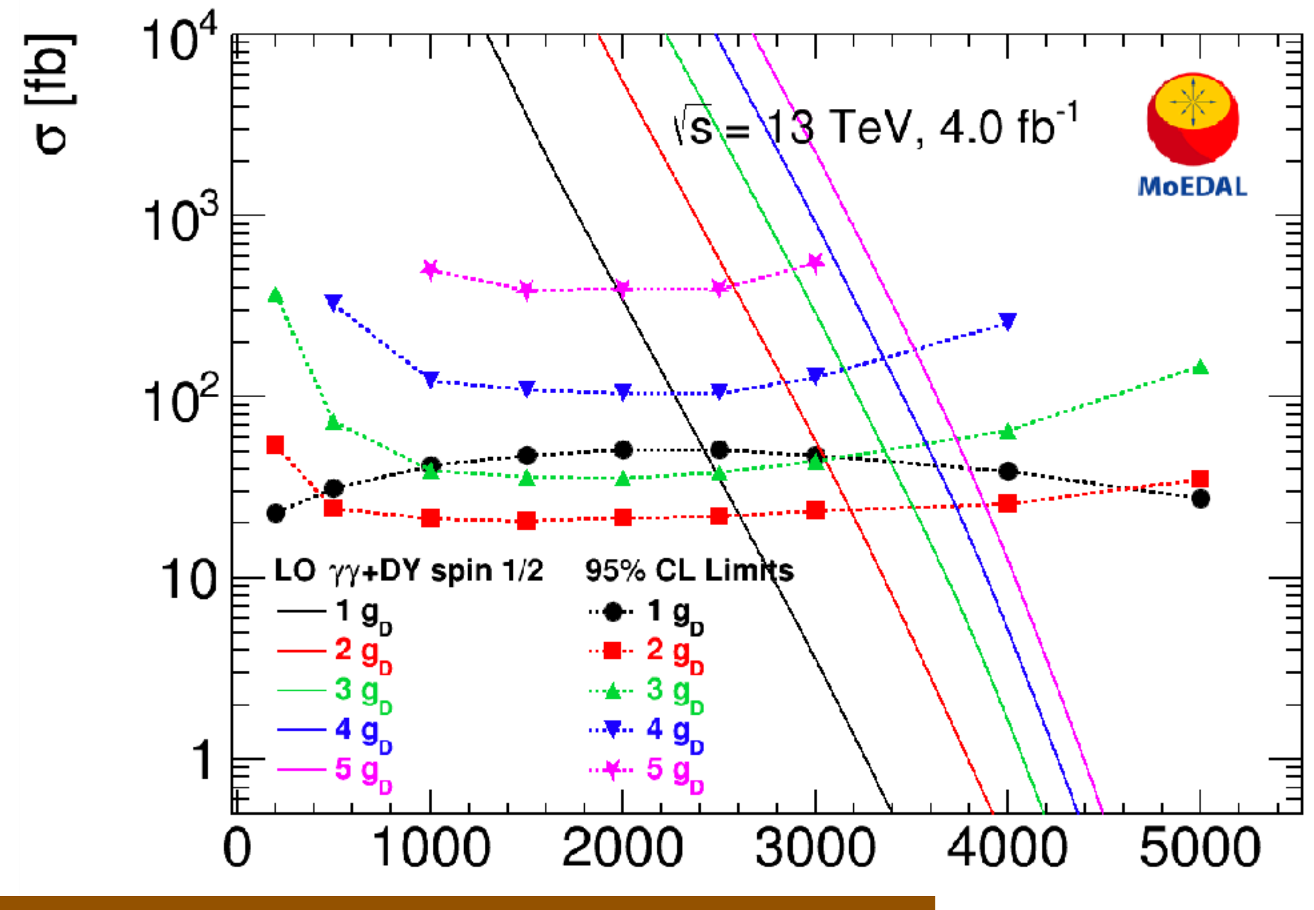


MoEDAL (the Monopole and Exotics Detector At the LHC)

Physicists uses 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.



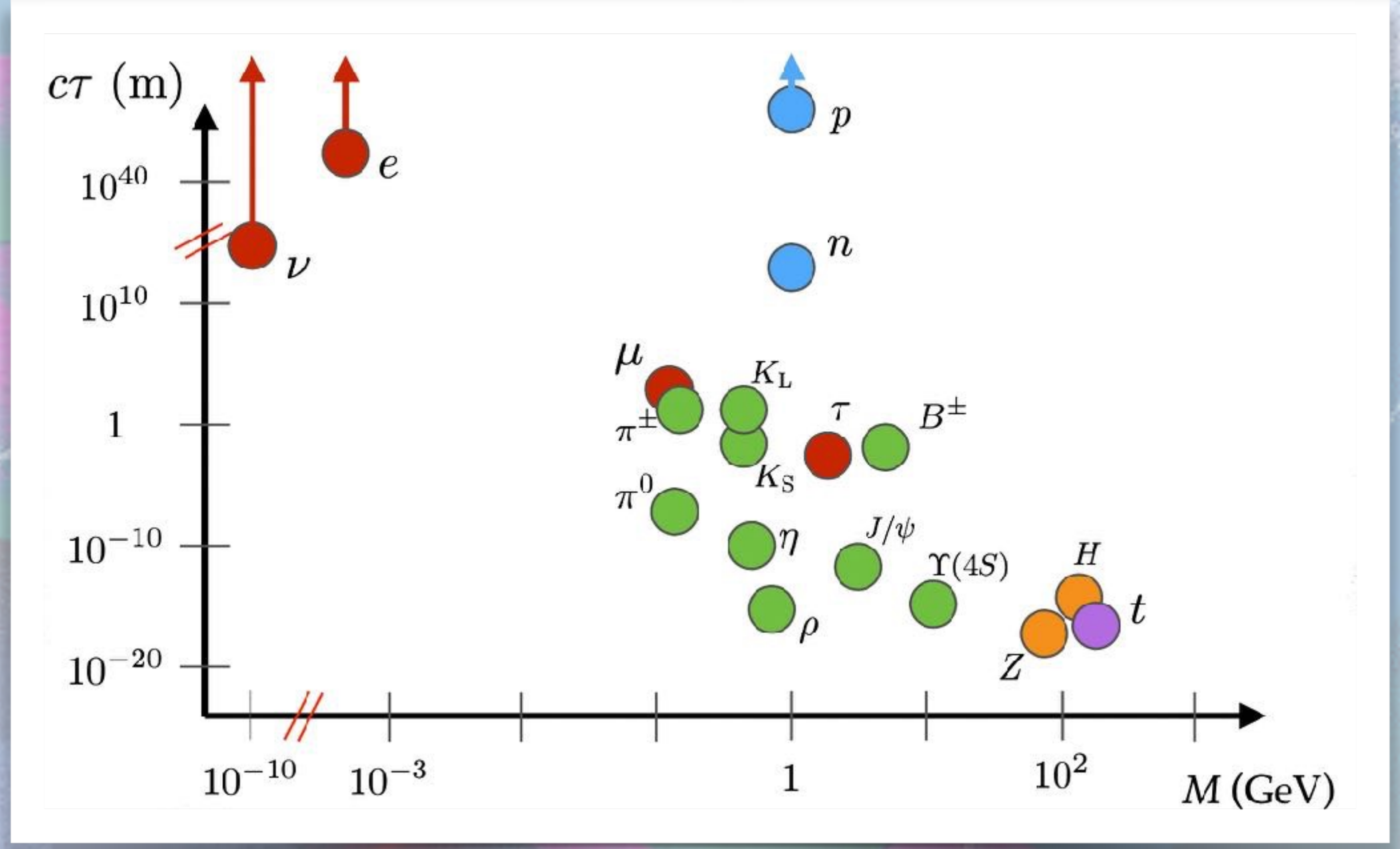


Phys. Rev. Lett. 123, 021802 (2019)

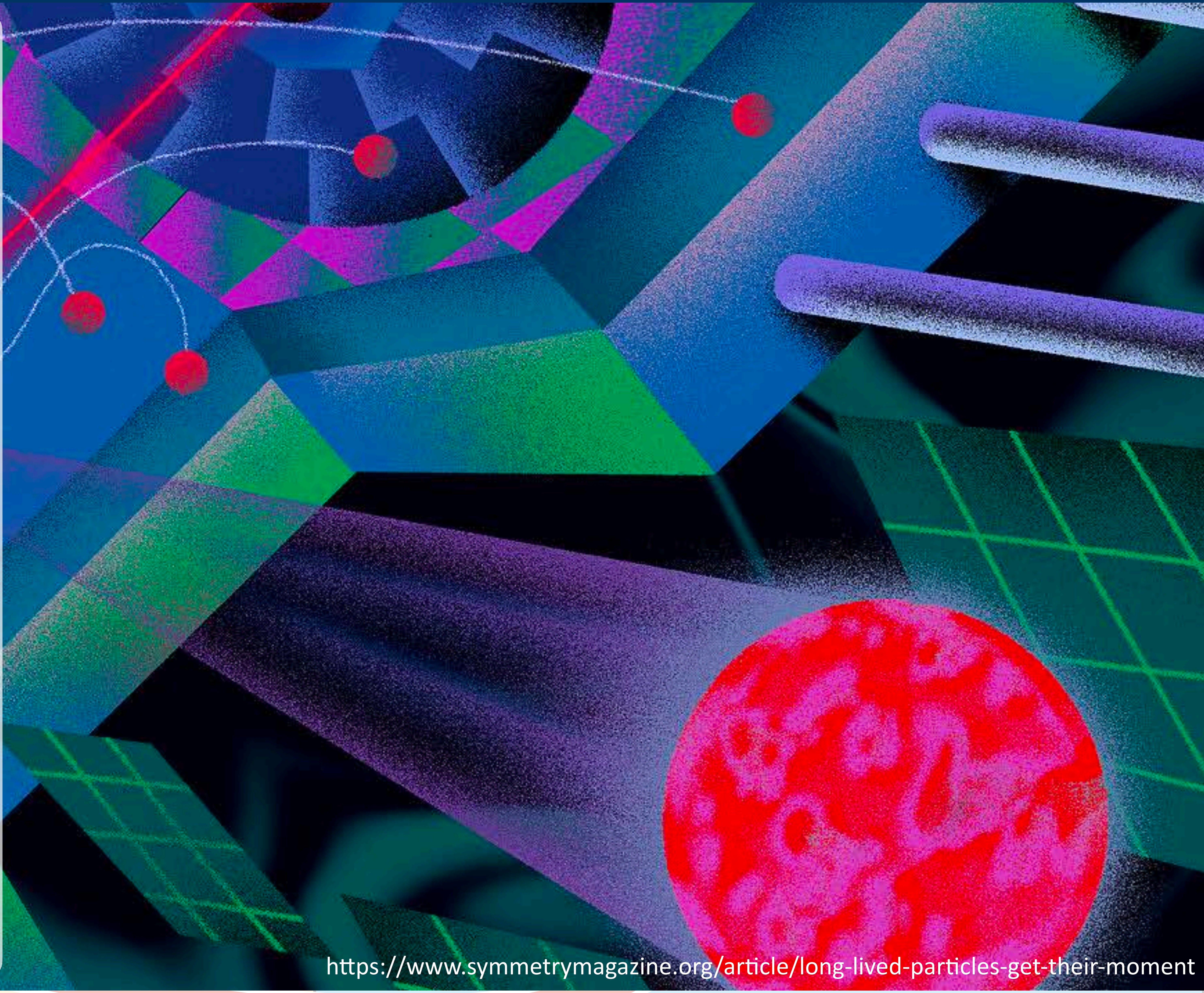
Exotic searches: Long-lived particles

When produced particles will not decay immediately …

In high energy particle physics experiments, physicists often assumes that new *massive* particles produced in particle collisions would decay immediately, closed 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?



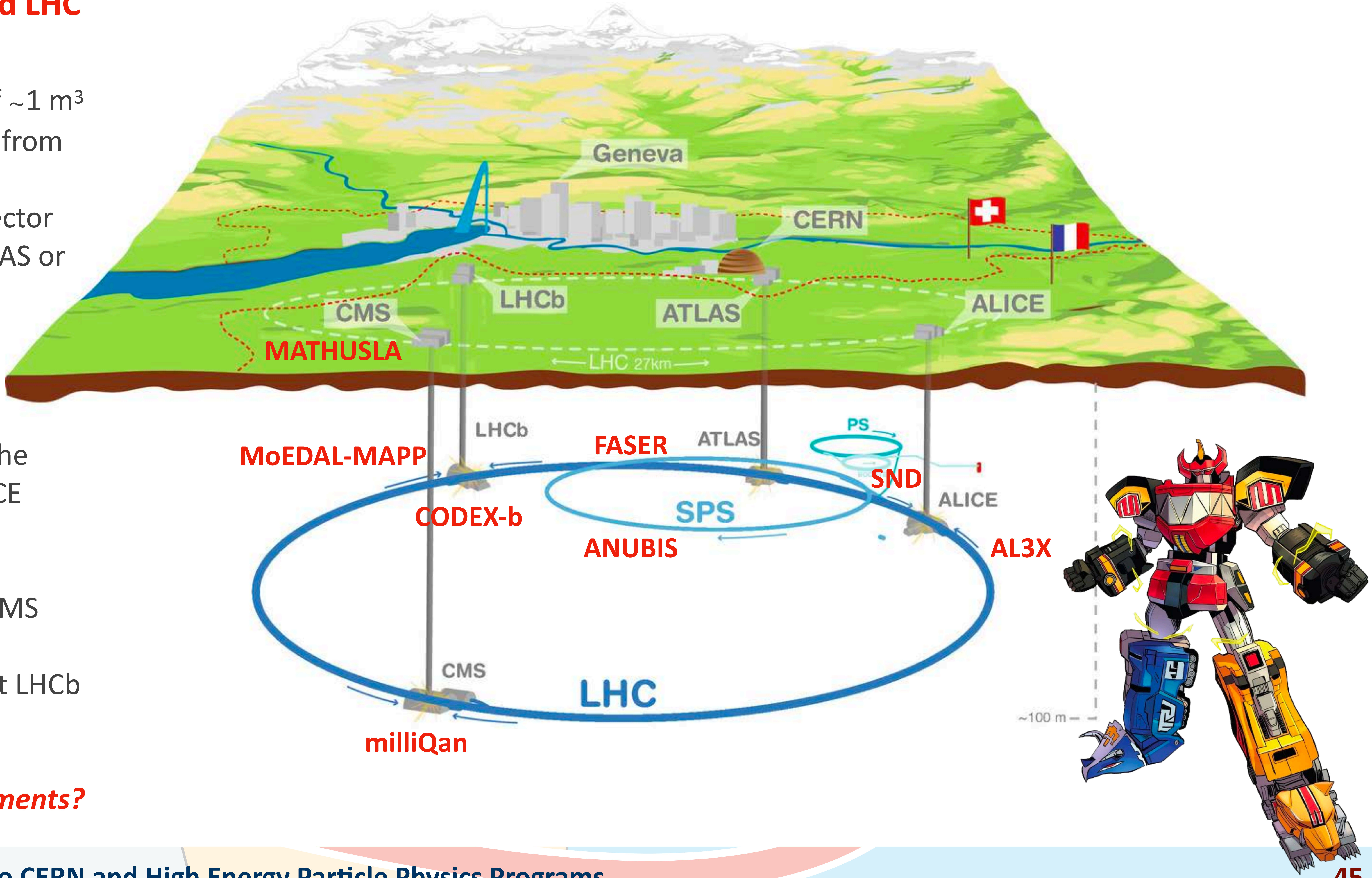
https://www.symmetrymagazine.org/article/long-lived-particles-get-their-moment

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

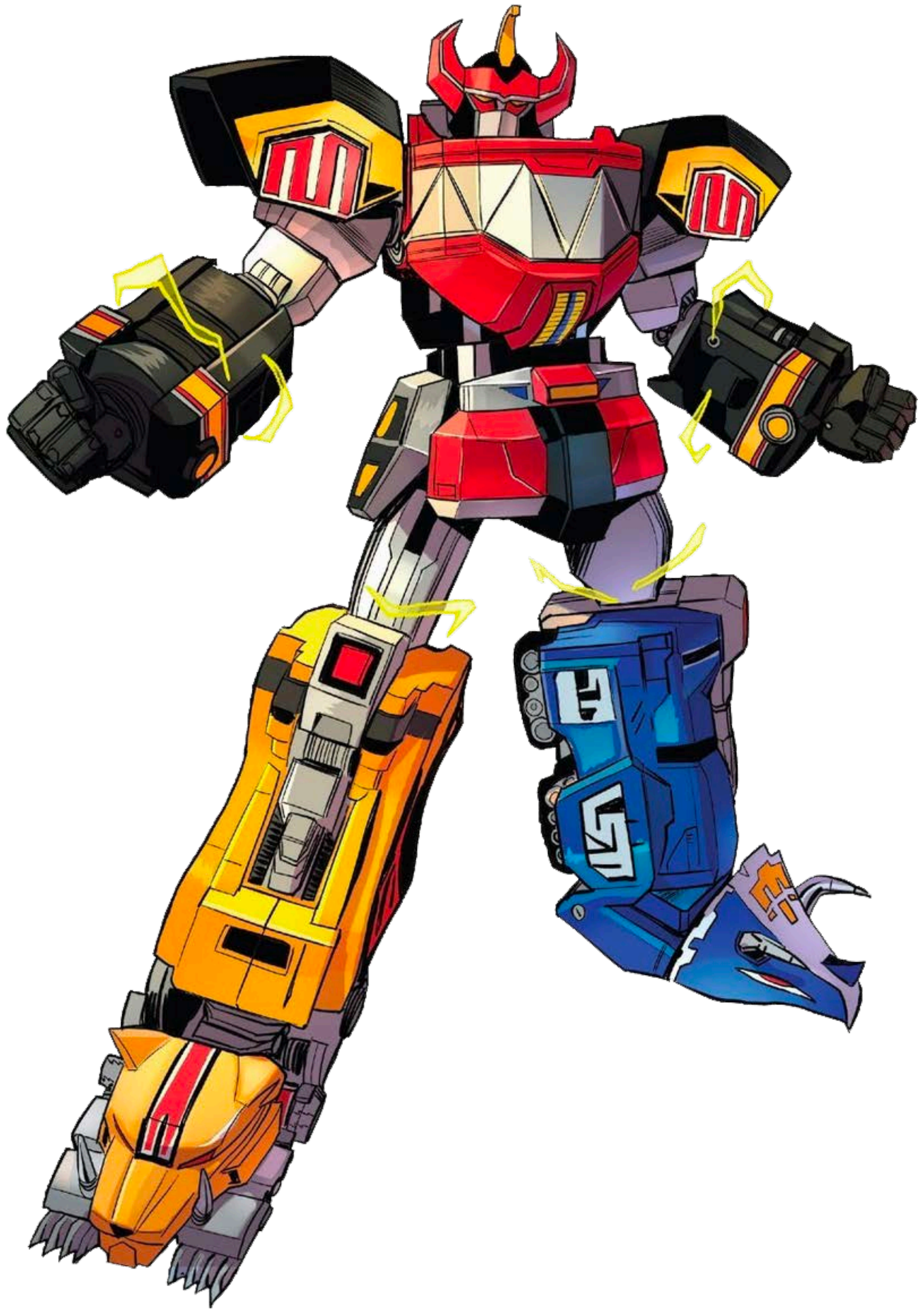
Several small experiments around LHC to search for LLPs

- **FASER** (Approved): with a volume of ~1 m^3 will be installed 480 m downstream from the ATLAS interaction point
- **MATHUSLA**: large scale surface detector instrumenting ~8×10^5 m^3 above ATLAS or CMS
- **CODEX-b**: ~10^3 m^3 detector to be installed in the LHCb cavern
- **AL3X** to use a cylindrical ~900 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

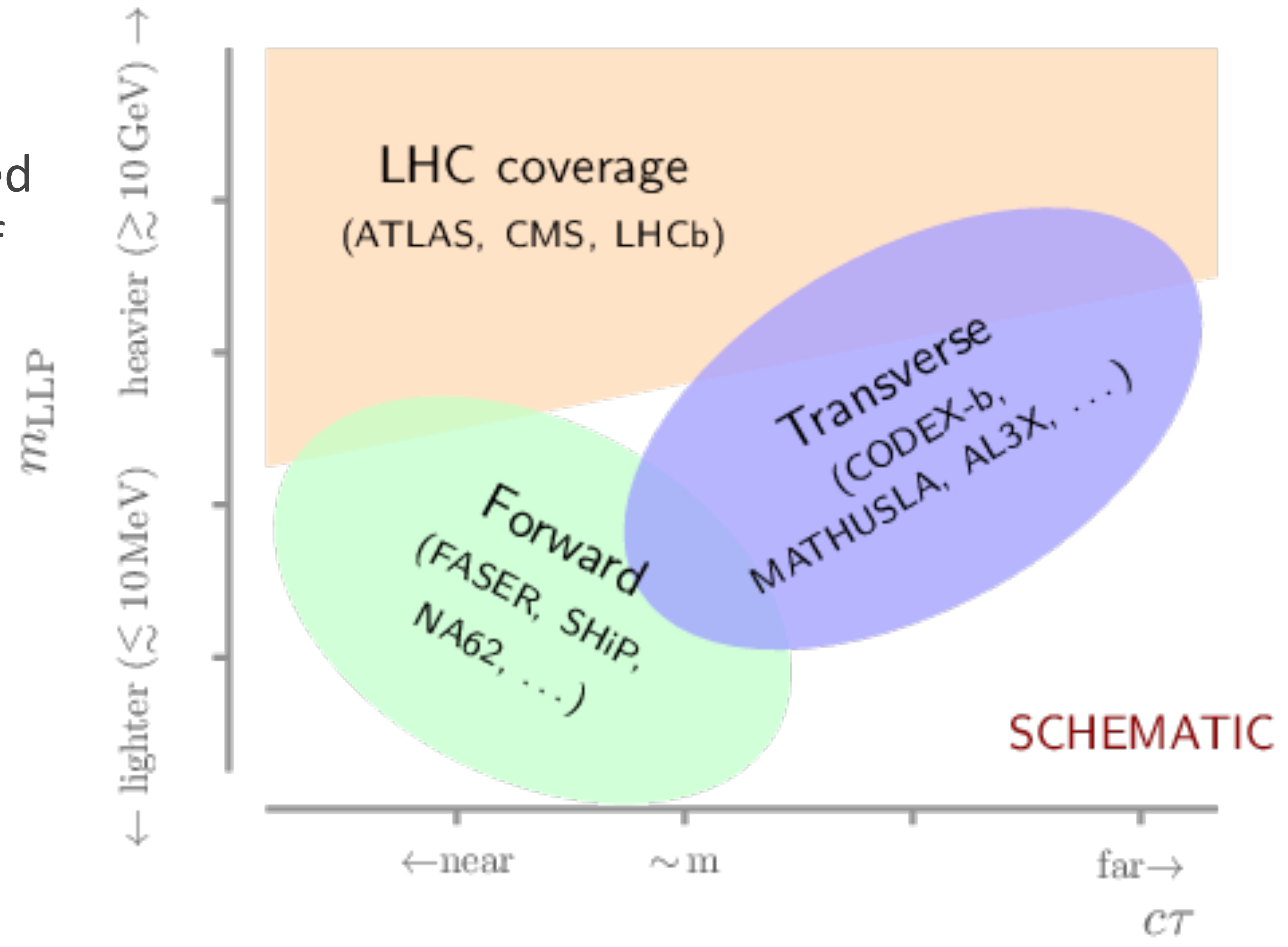


Why do we need detector rangers to search for LLP?

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?***

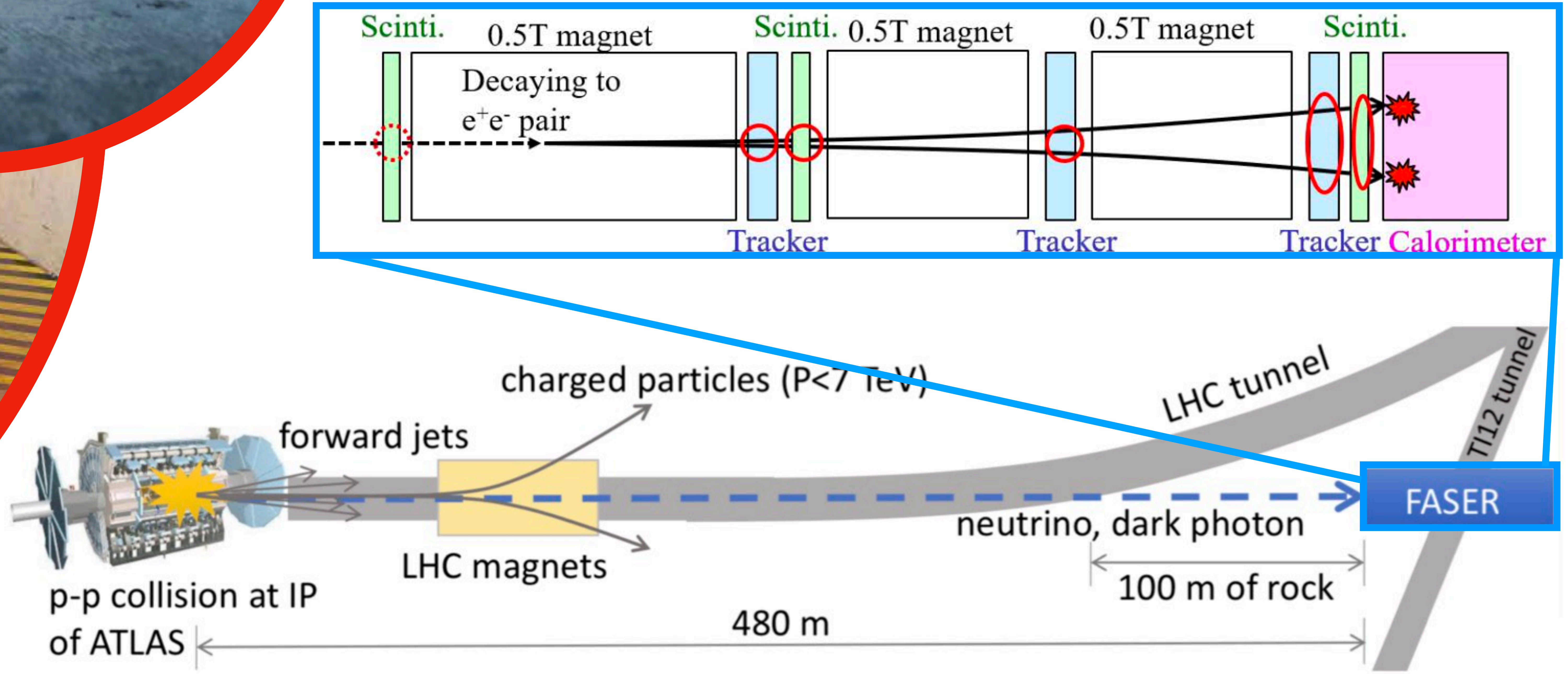
Because we assume that LLPs are produced at the four collision points of LHC. Information including timing can be obtained from big four experiment, to track events of interest.



ForwArd Search ExpeRiment (FASER)

Searches for new weakly-interacting light long-lived particles

- New particles produced in decays of light mesons
- Travel at ~zero angle
- Escaping detection in ATLAS (for FASER)/CMS
- $pp \rightarrow X + LLP$, then LLP travels for ~480m, $LLP \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma,...$
  - 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)

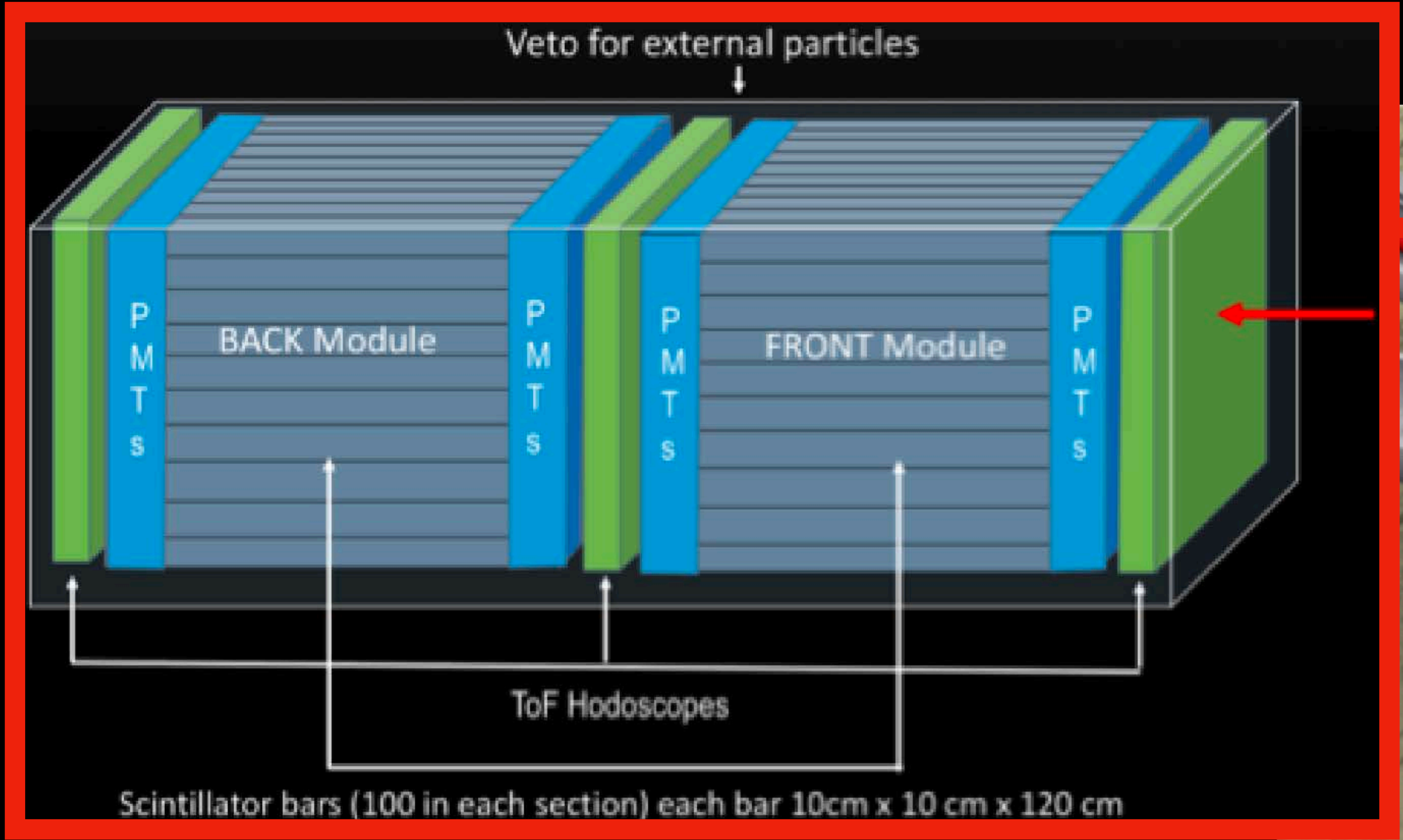
The SND@LHC is located underground close to the ATLAS experiment, in an unused tunnel that links the LHC to the Super Proton Synchrotron. Positioned slightly off the LHC's beamline, it will be able to detect neutrinos produced in the LHC collisions at small angles with respect to the beamline.

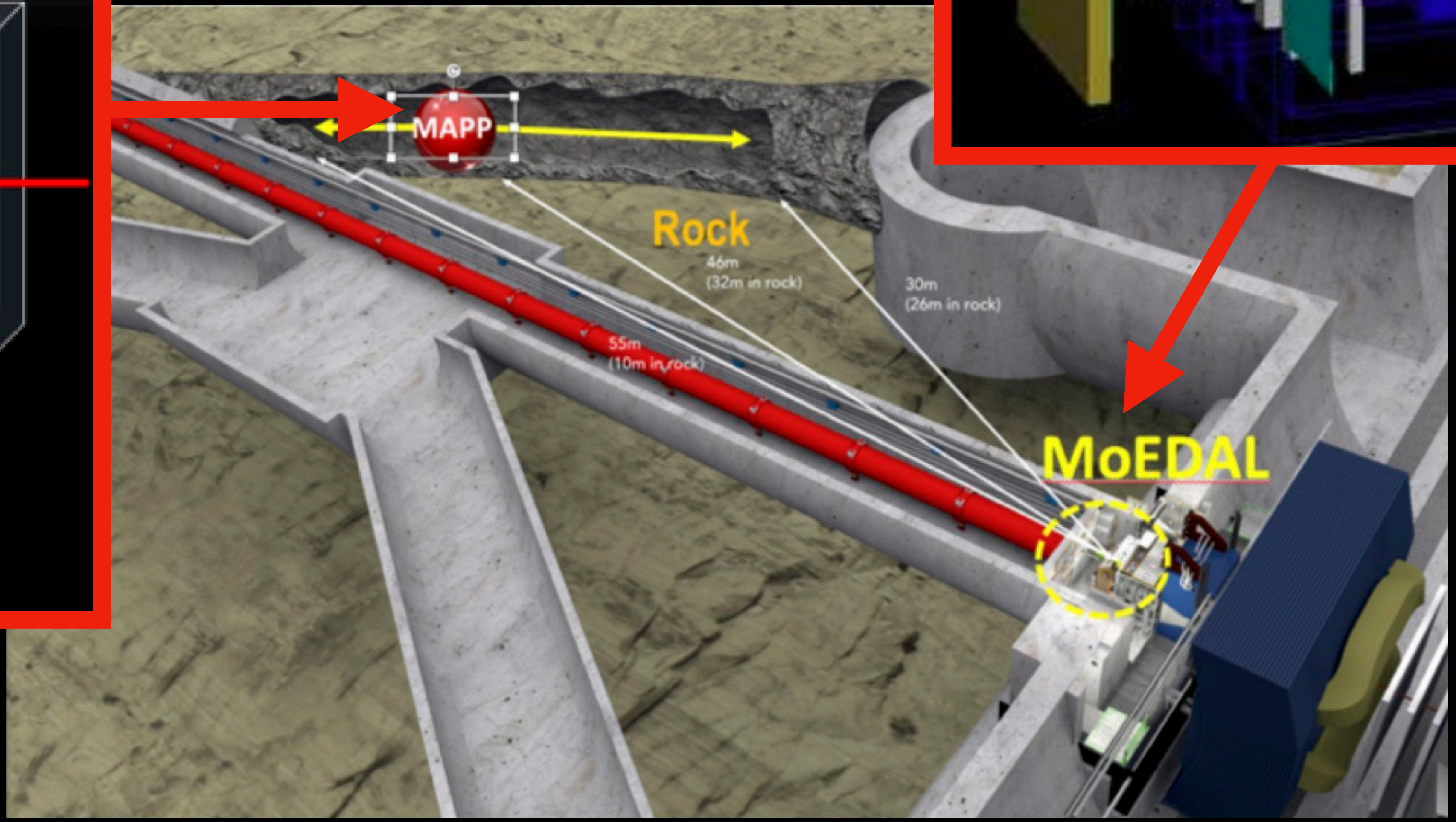
SND@LHC consists of a neutrino target followed downstream by a device to measure the neutrino energy and to detect muons (the heavier cousins of electrons) that are produced when neutrinos interact with the target.

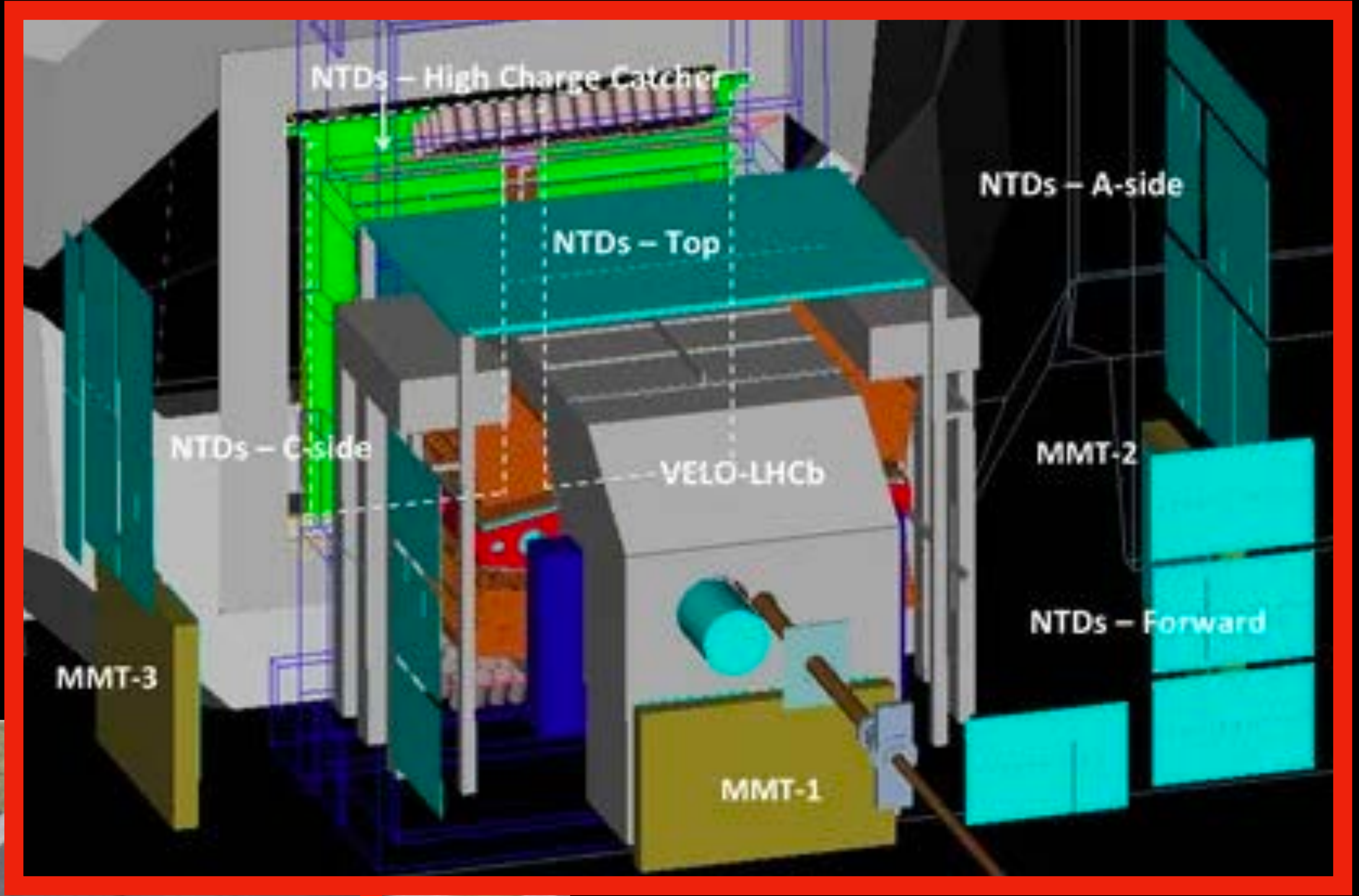
MoEDAL Apparatus for Penetrating Particles (MAPP)

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





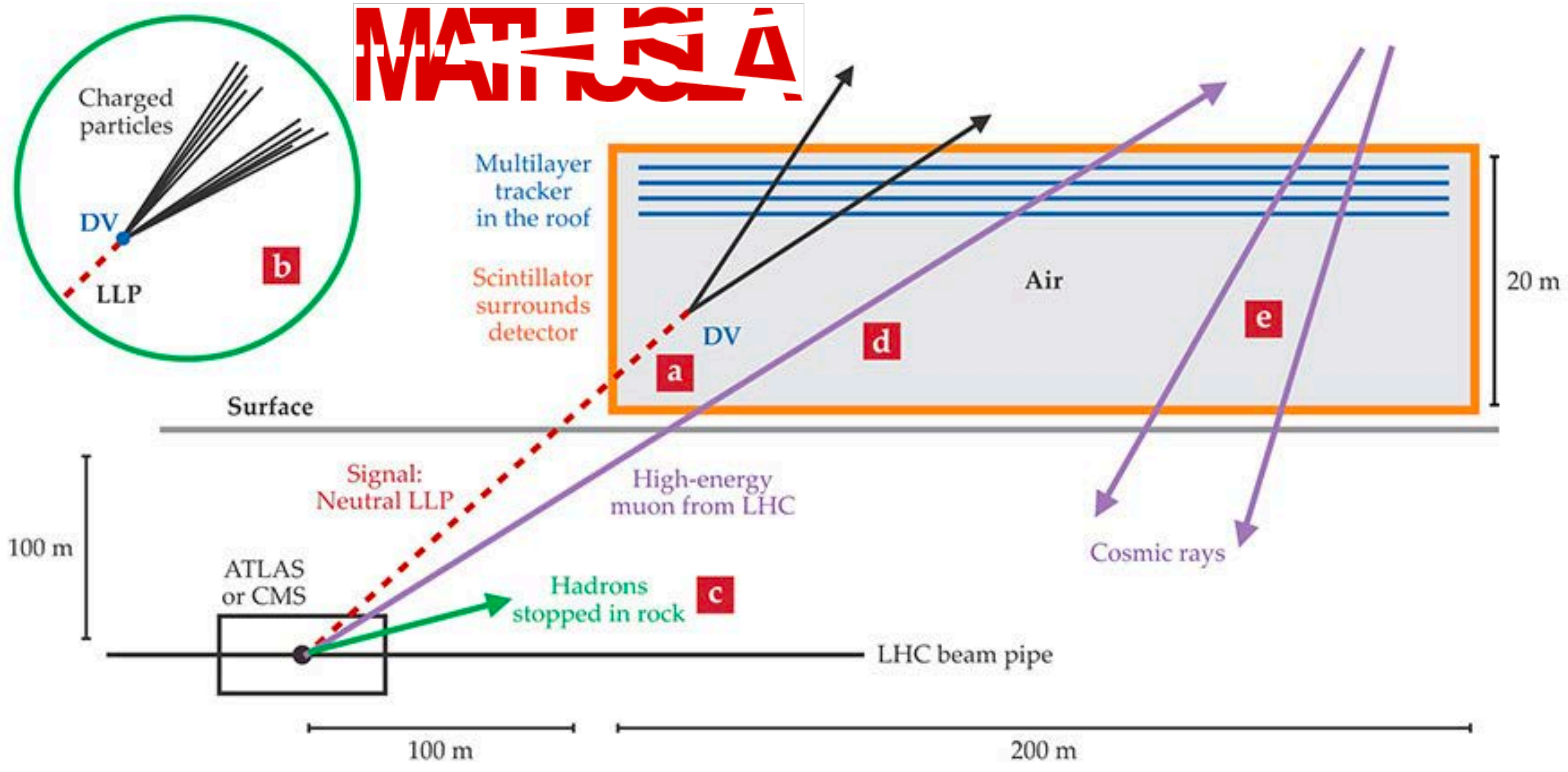


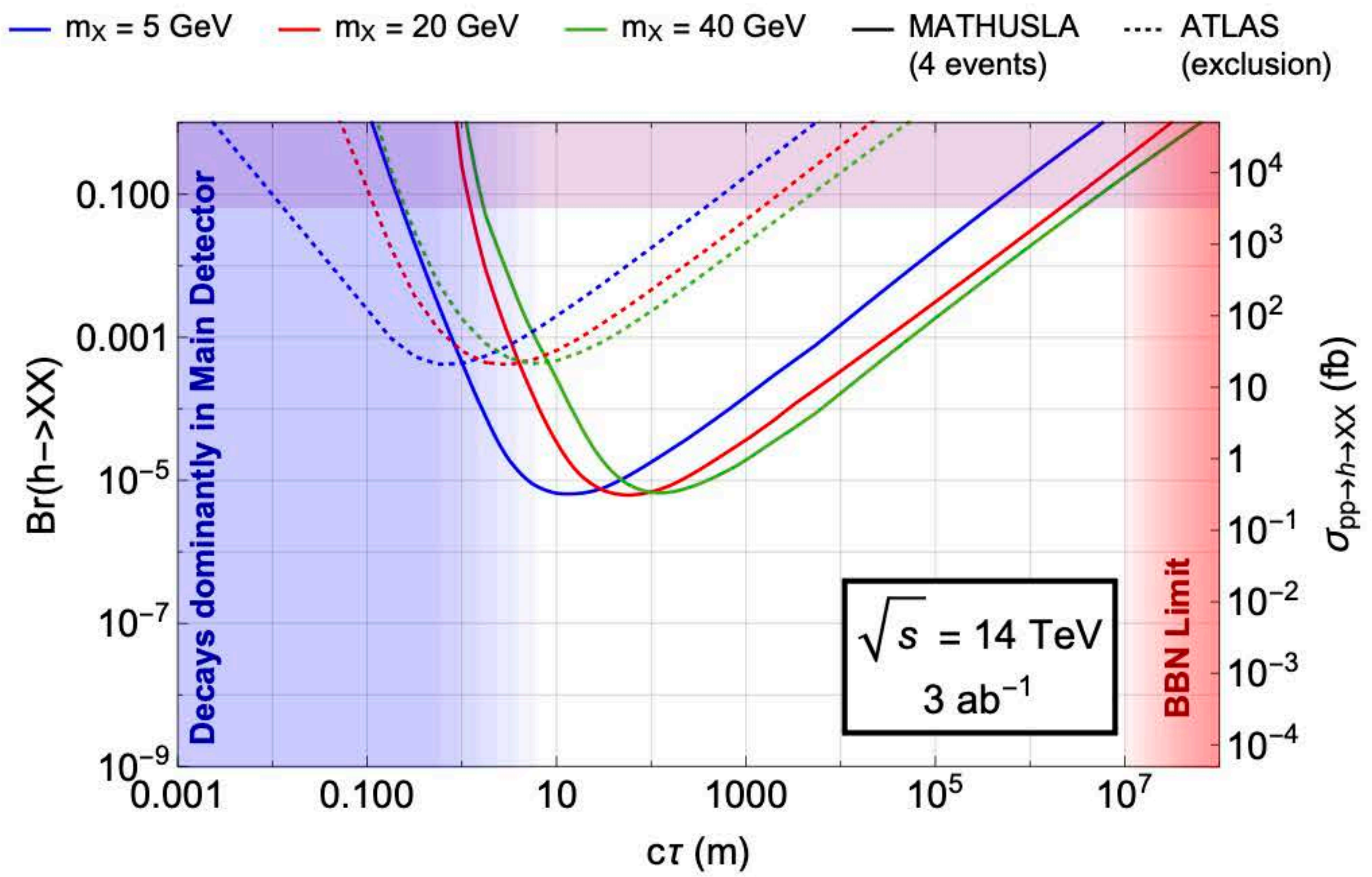
MAssive Timing Hodoscope for Ultra-Stable neutraL pArticles (MATHUSLA)

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:

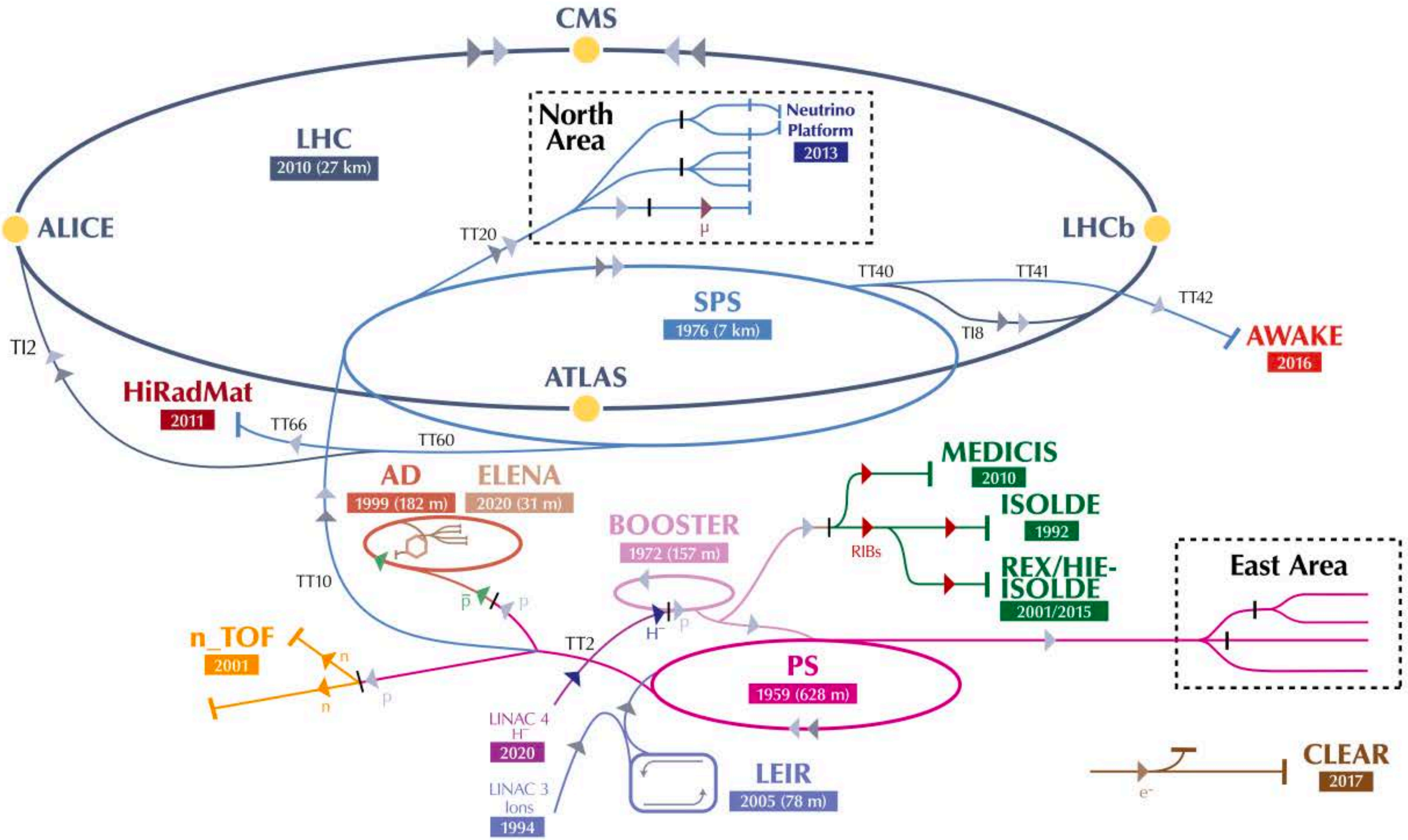
- No additional tunnel
- 100m of rock to protect radiation for LHC
- Background from cosmic muons which are rarely pointed towards IP. Mostly coming from the opposite direction (above instead of below)
- Decay volume filled with air with several detector layers for tracking





Physics Letter B 767 (2017) 29-36

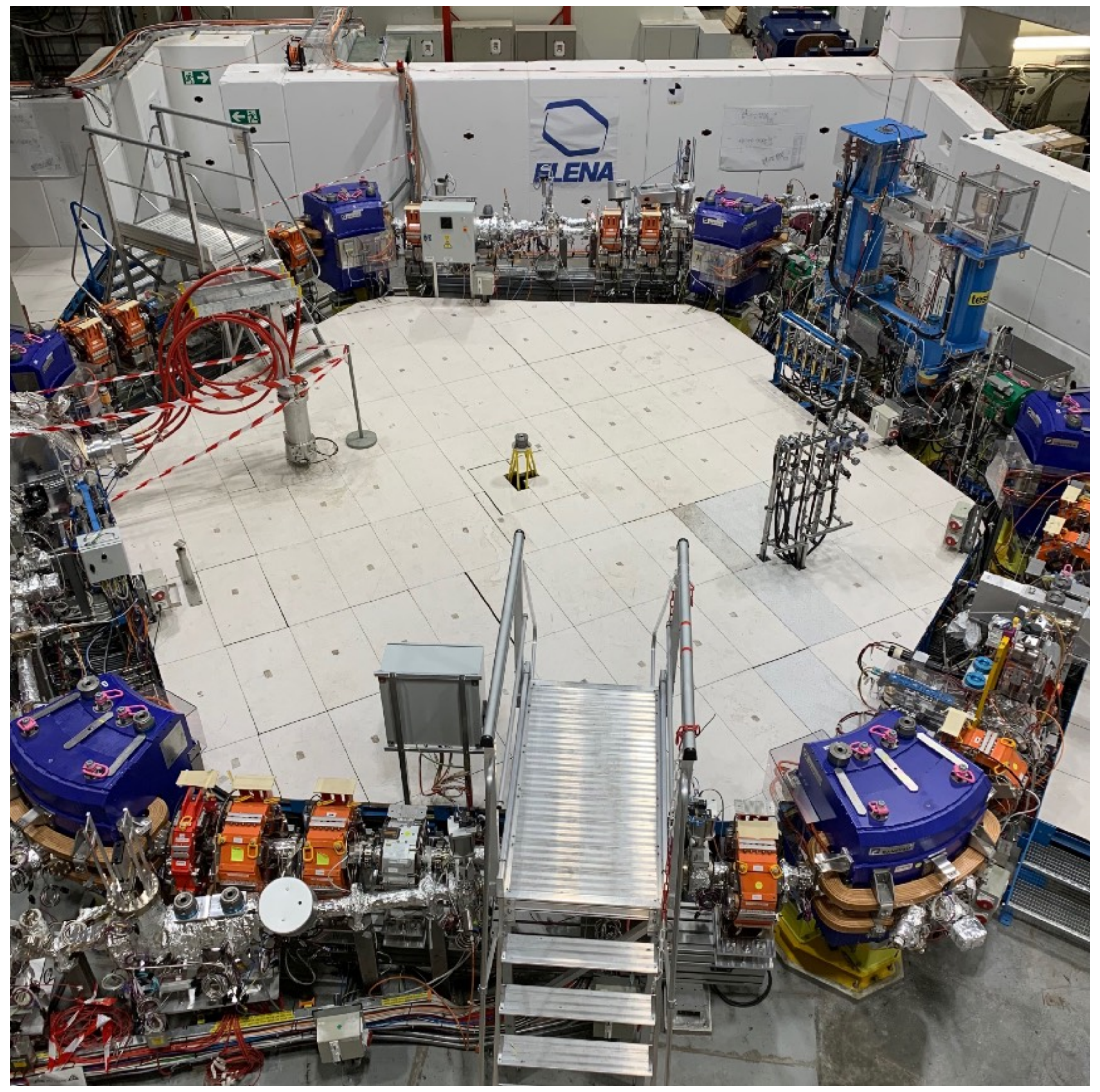
CERN accelerator complex: Not only LHC



Not only accelerate, but also decelerate

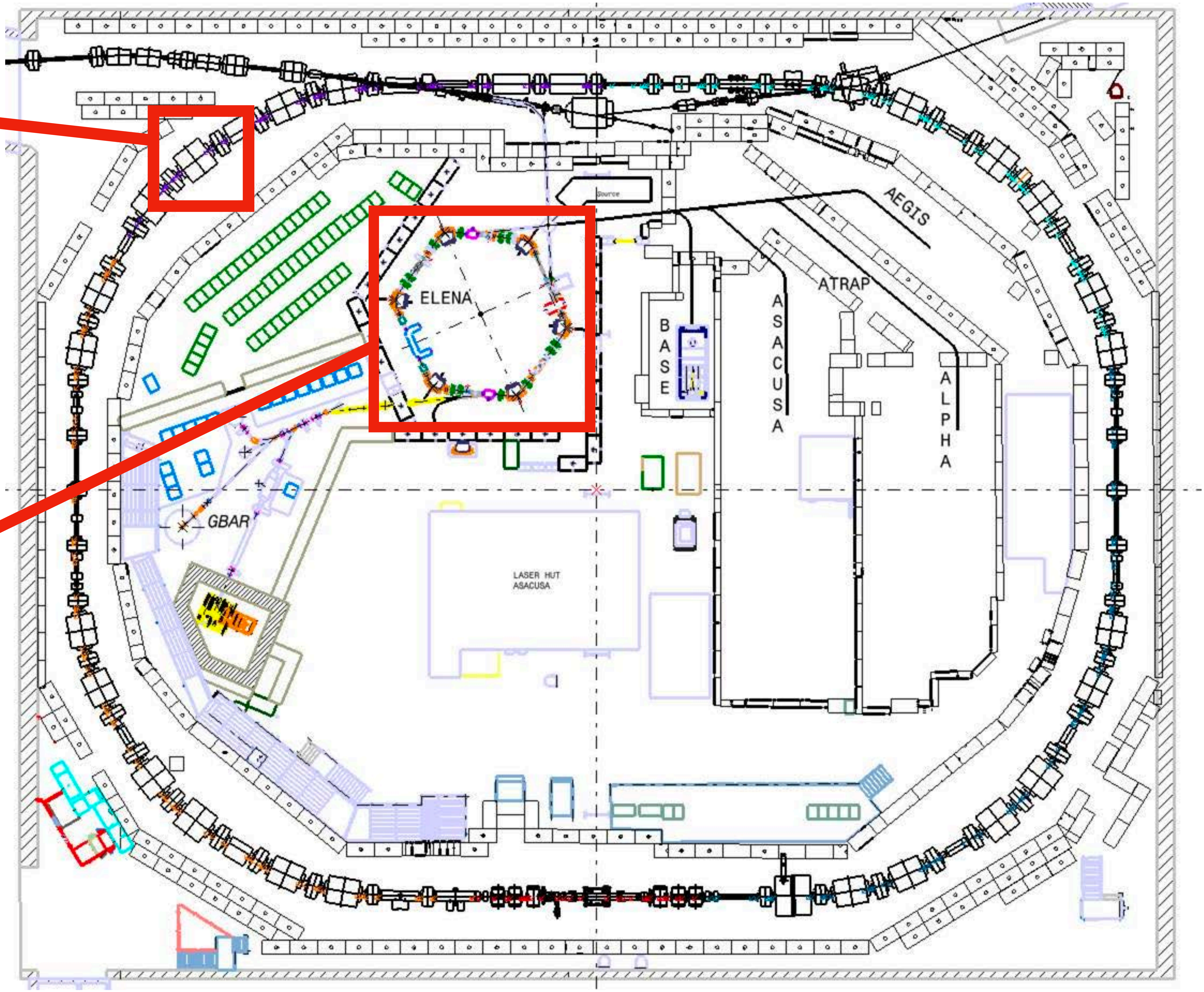
Antiproton Decelerator (AD)

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



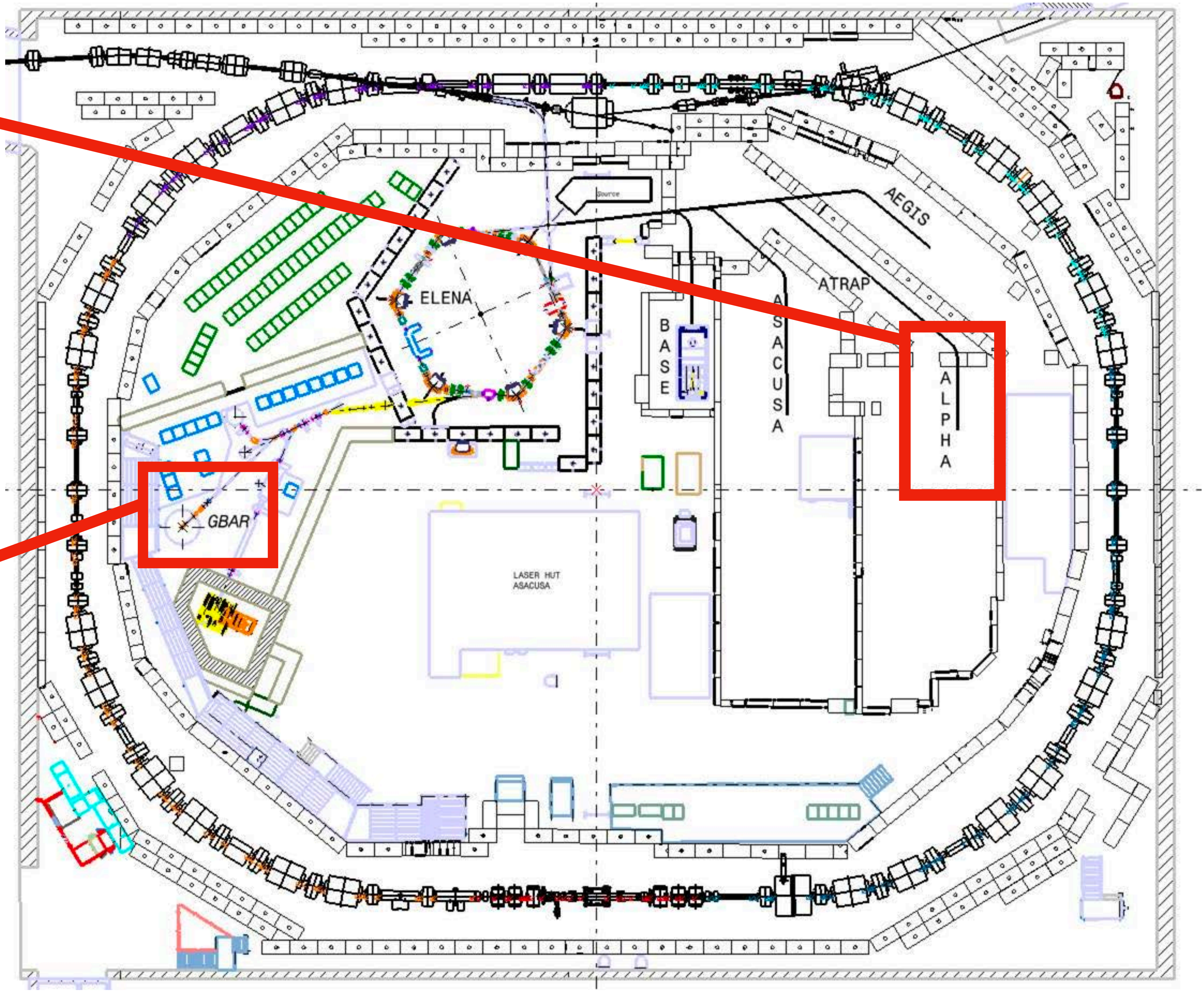
To study anti-matter

Antihydrogen Laser Physics Apparatus (ALPHA)

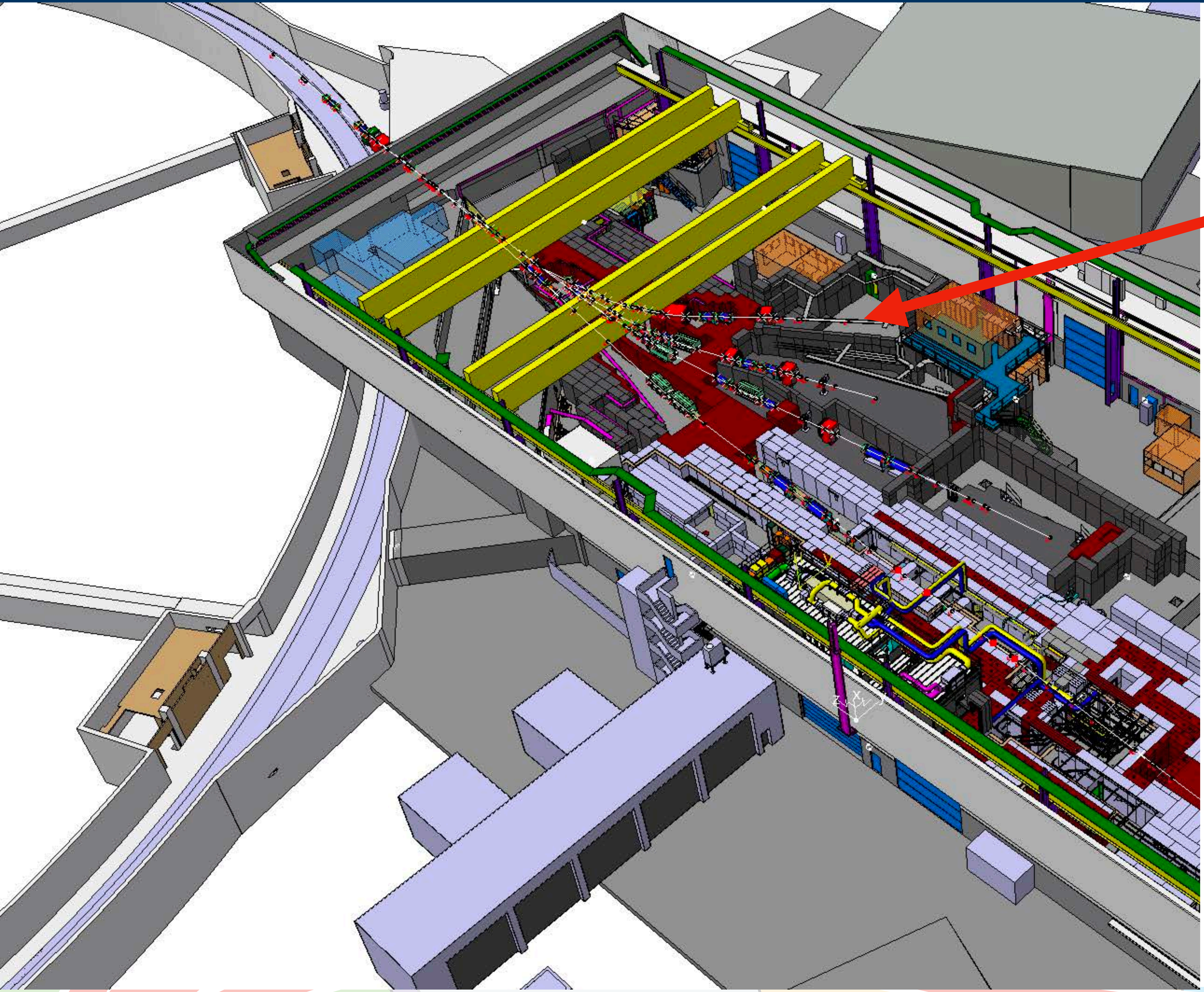
create, capture and then cool antihydrogen to use for experiment

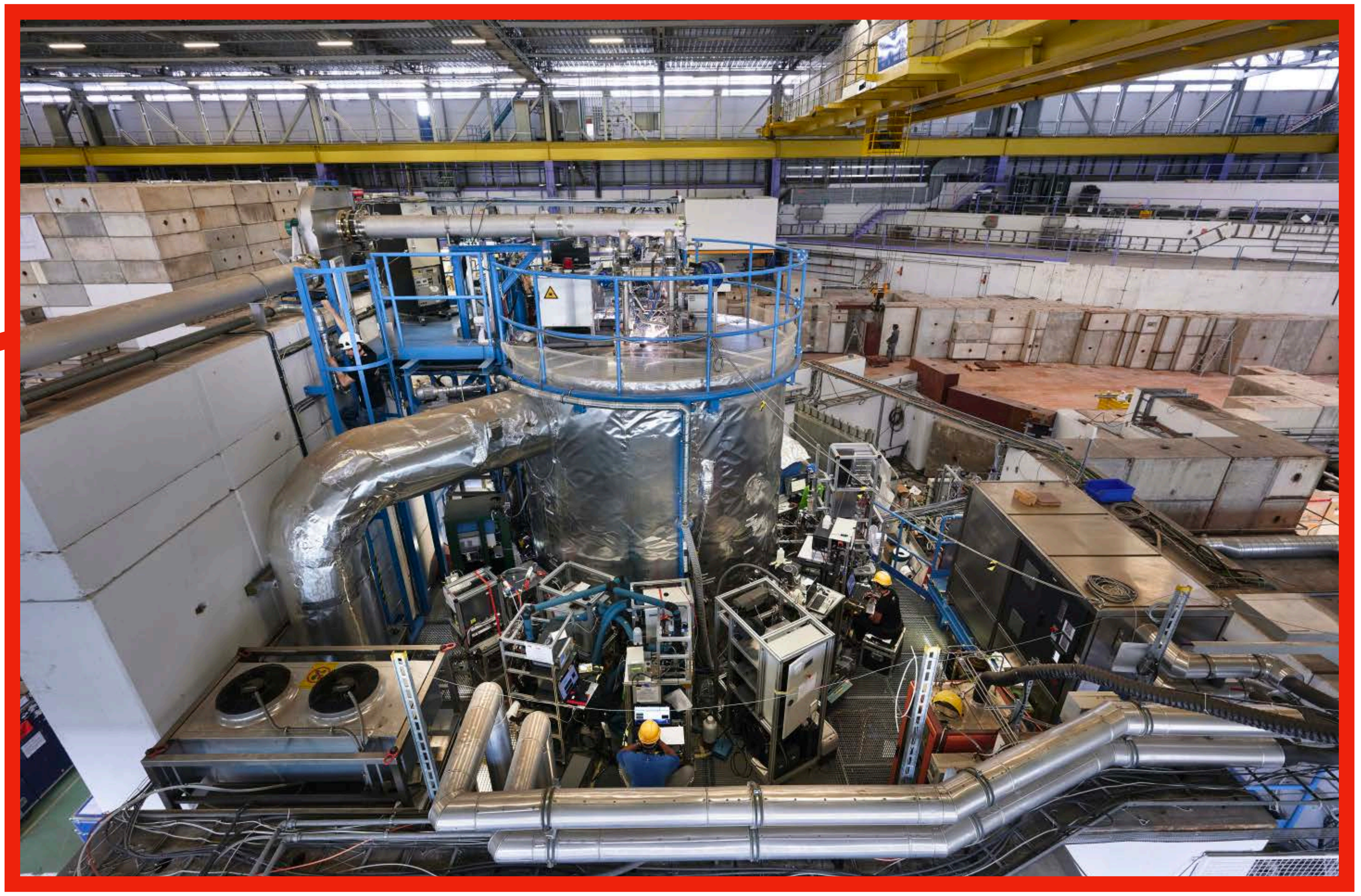
Gravitational Behaviour of Antimatter at Rest (GBAR)

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



To study links between cosmic rays and cloud formation

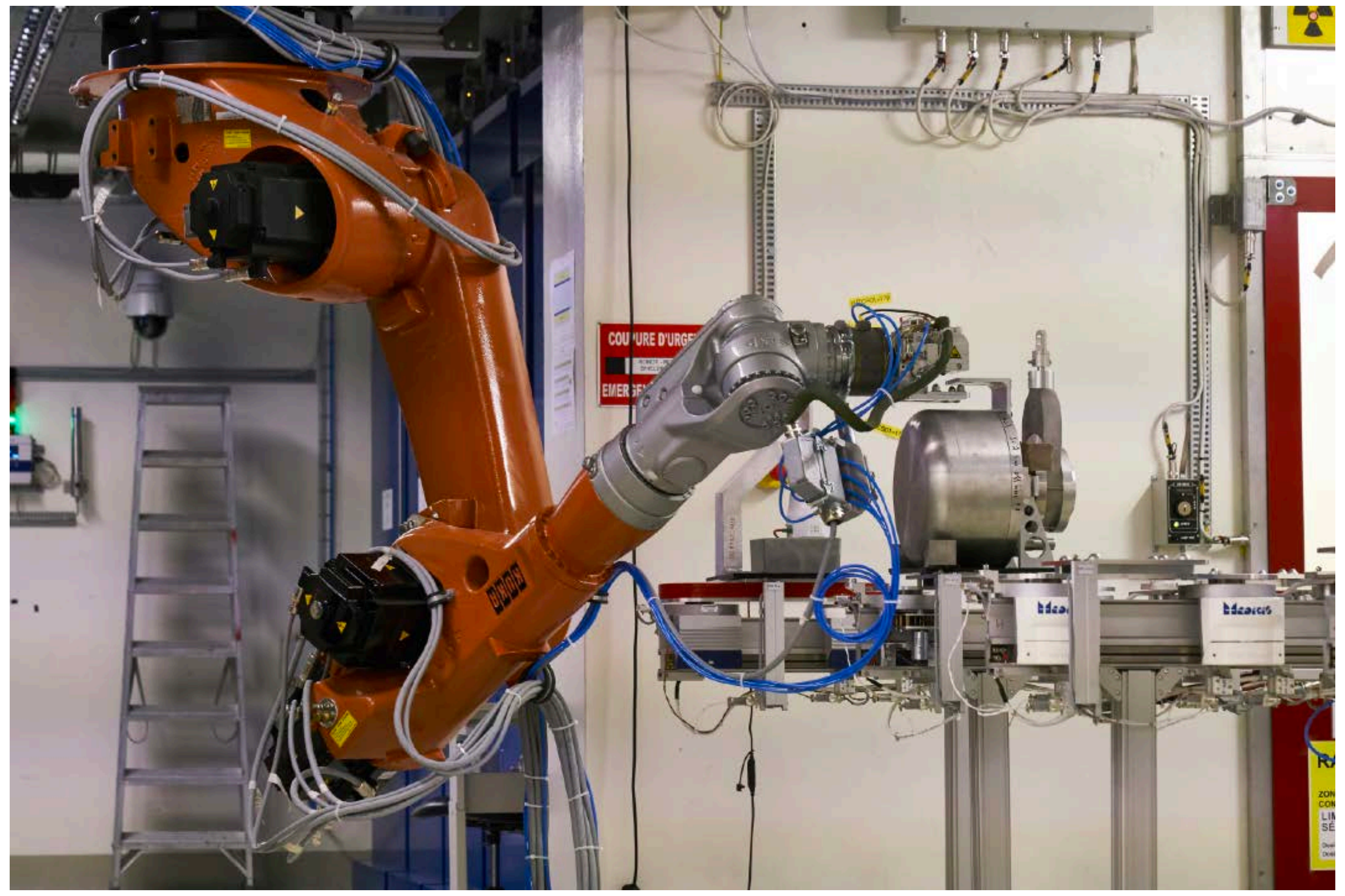




CLOUD

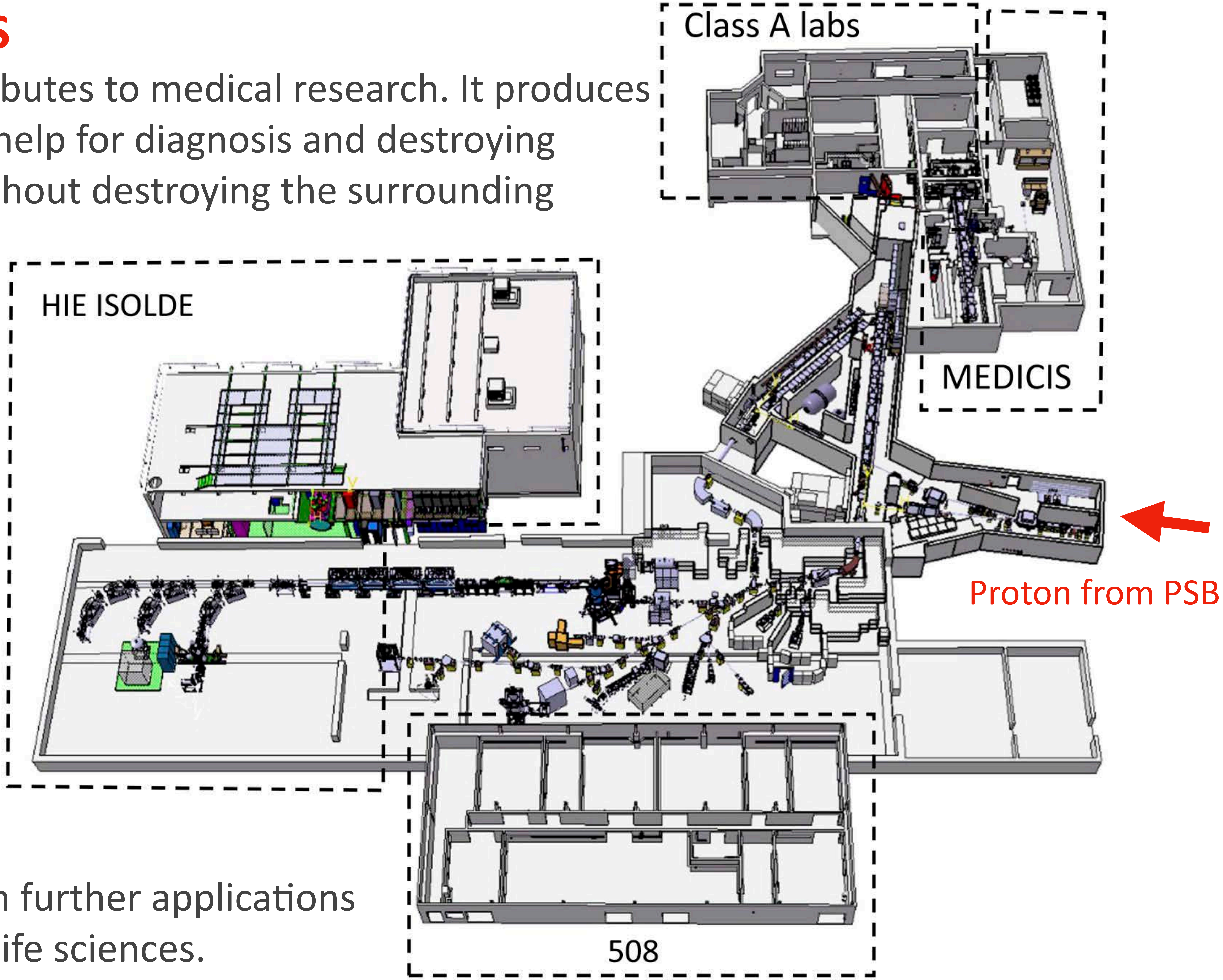
Could there be a link between galactic cosmic rays and cloud formation? An experiment at CERN is using the cleanest box in the world to find out.

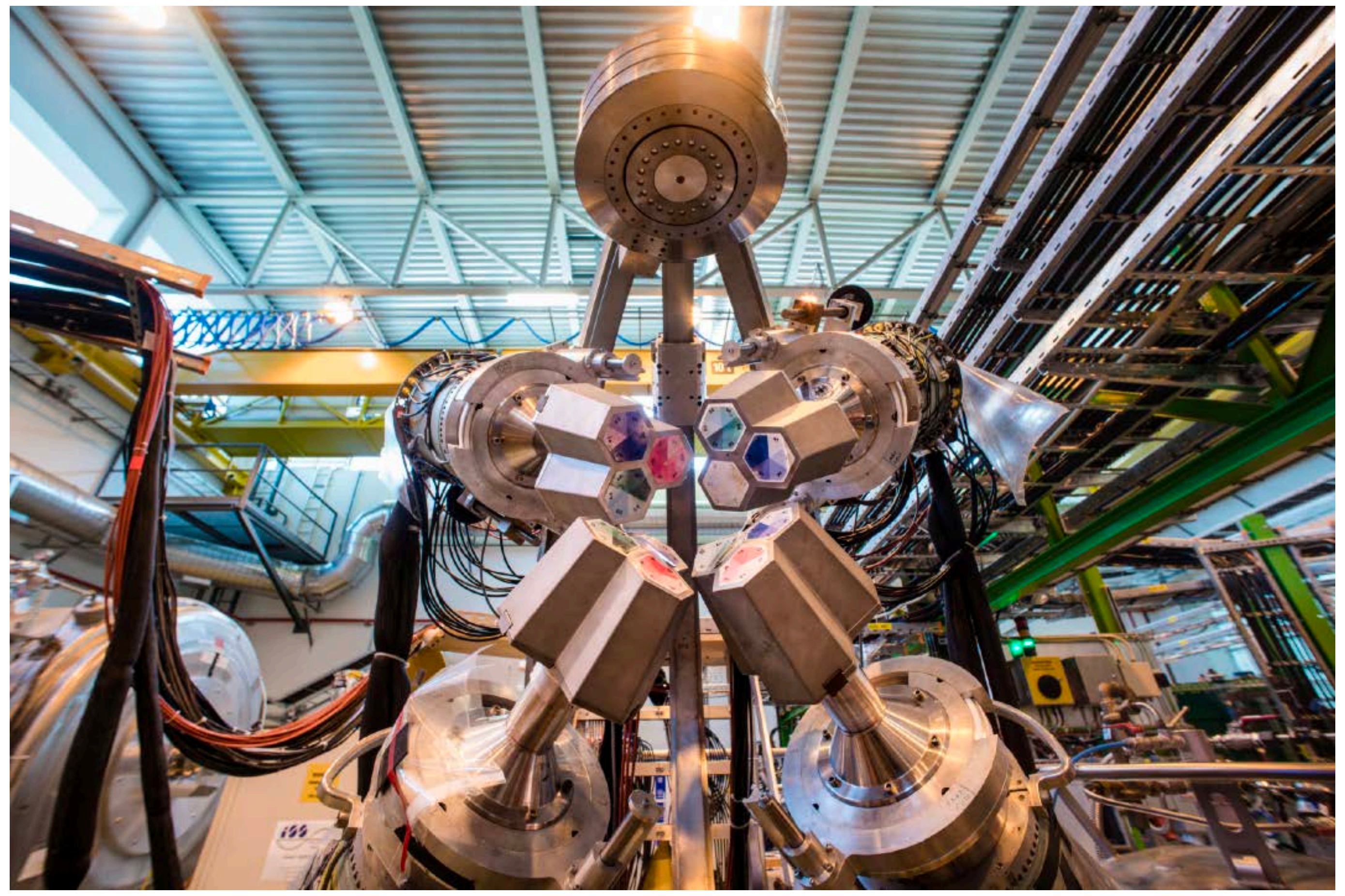
To study on radioisotopes and applications, e.g. medical applications



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

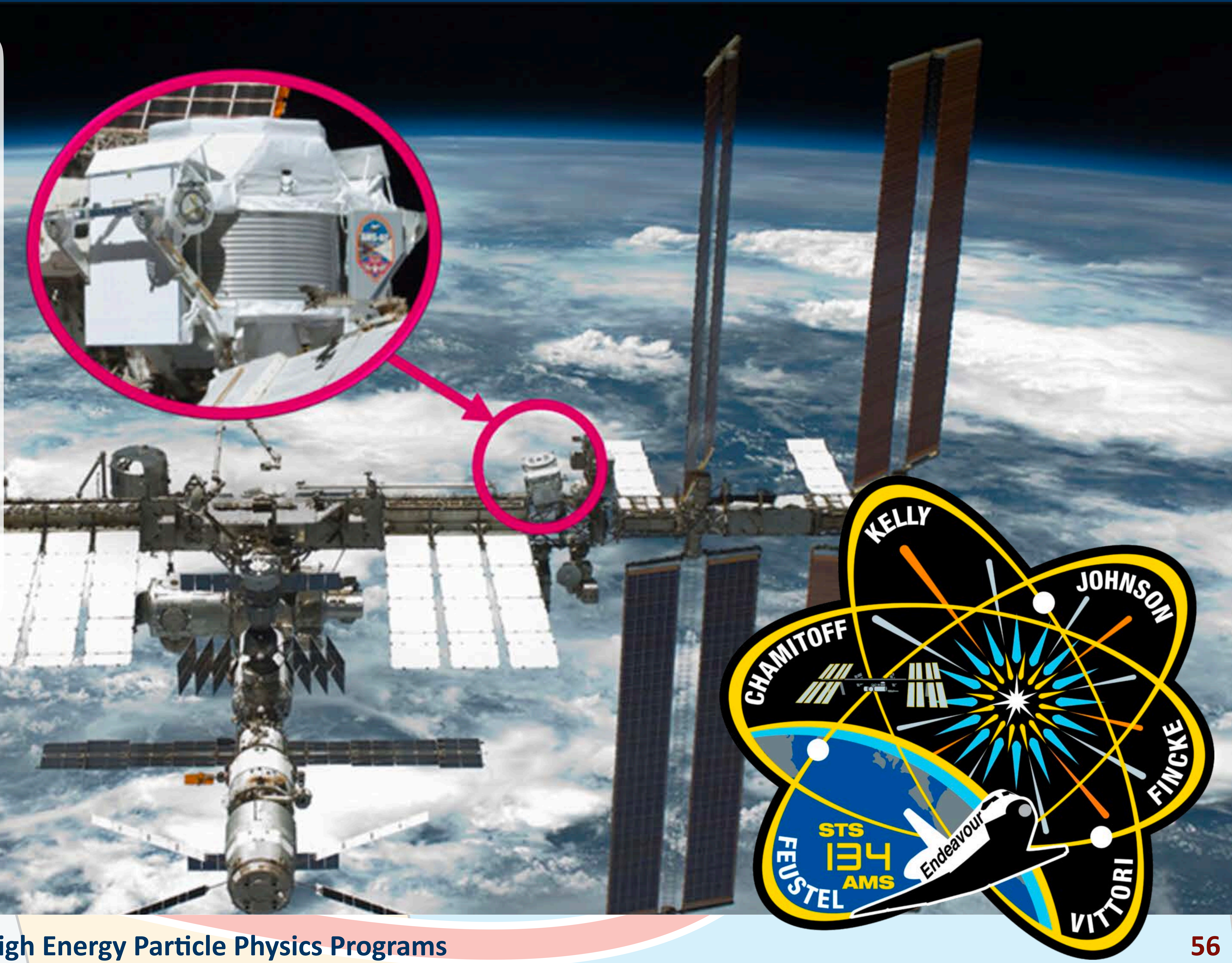
ISOLDE studies the properties of atomic nuclei, with further applications in fundamental studies, astrophysics, material and life sciences.

External experiments at CERN: AMS

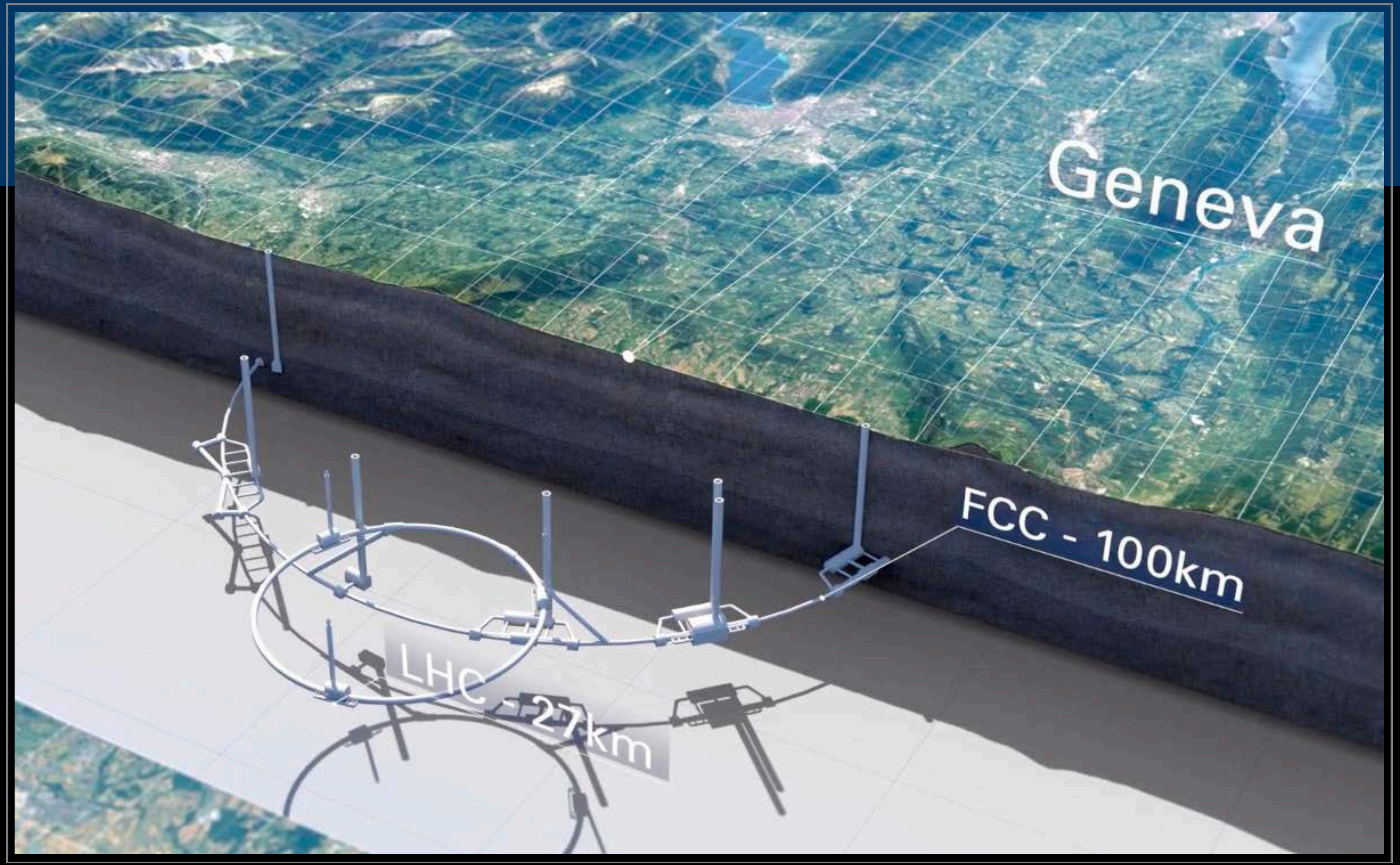
AMS

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

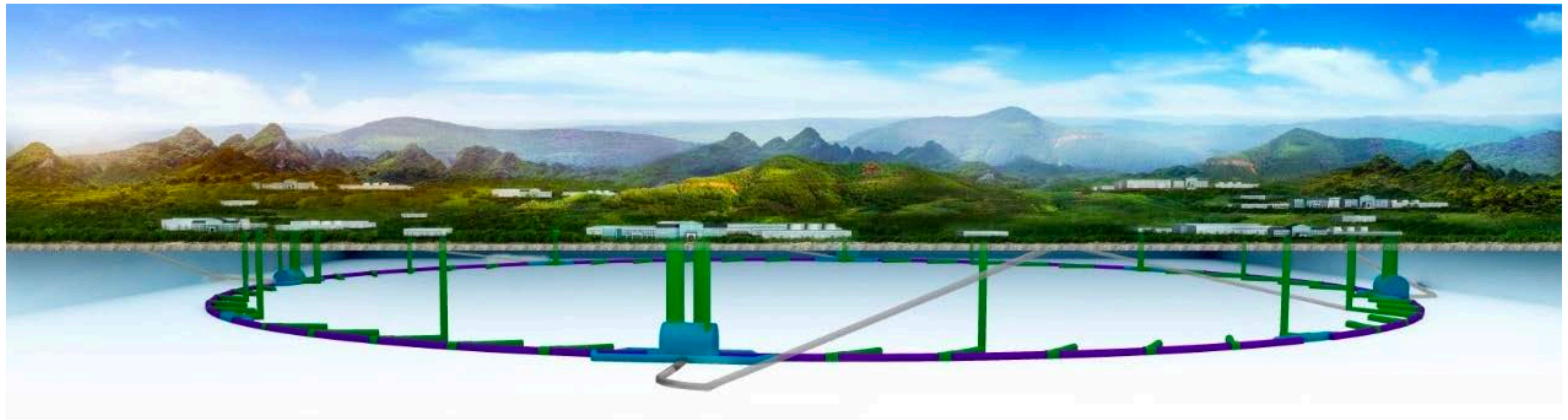


- **Future Circular Collider (FCC)**
  Circumference: 90 -100 km
  Energy: 100 TeV (pp) 90-350 GeV (e^+e^-)

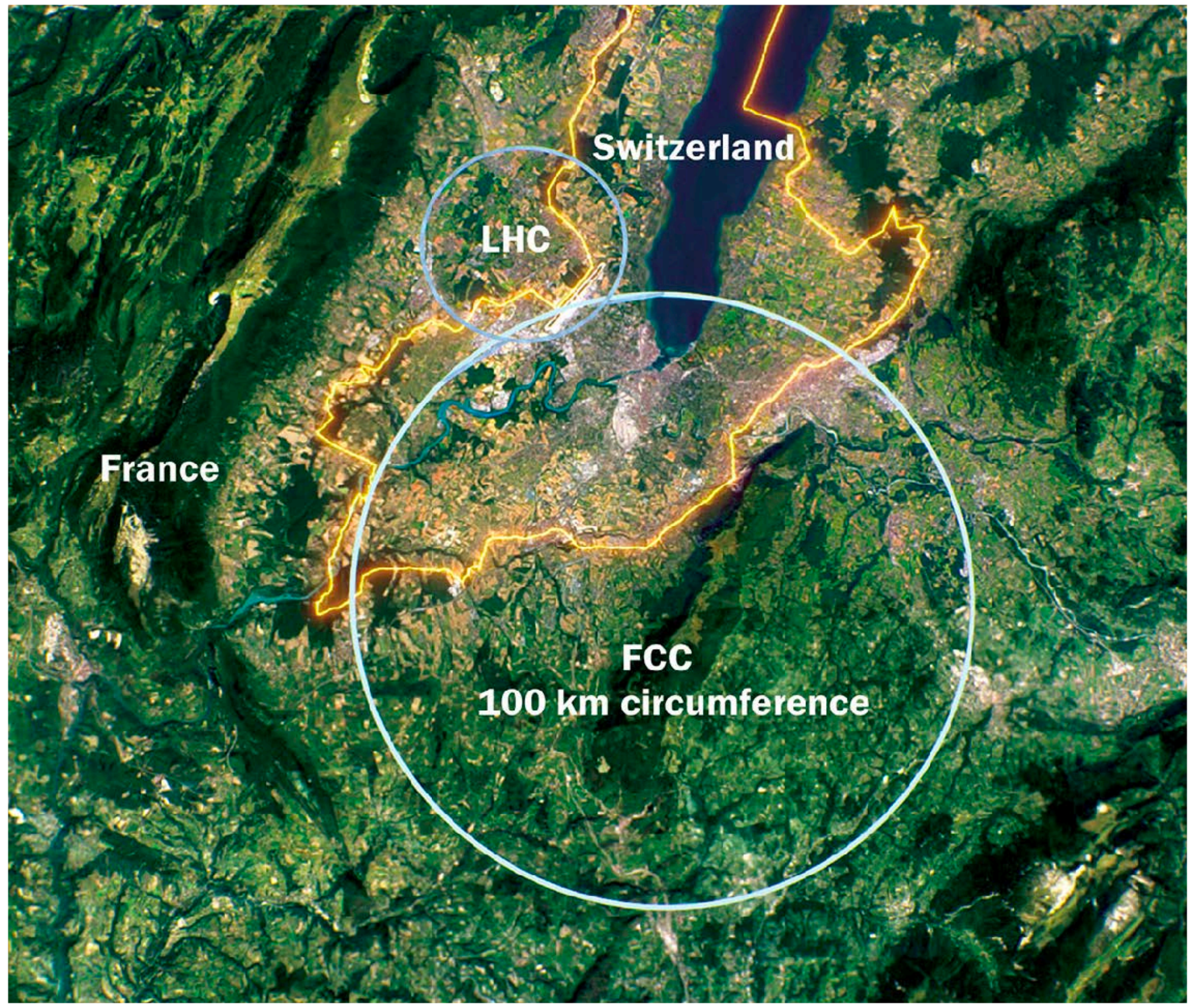
- **Large Hadron Collider (LHC)**
  Large Electron-Positron Collider (LEP)
  Circumference: 27 km
  Energy: 14 TeV (pp) 209 GeV (e^+e^-)

- **Tevatron**
  Circumference: 6.2 km
  Energy: 2 TeV ($p\bar{p}$)

Beyond LHC: Precision Measurement

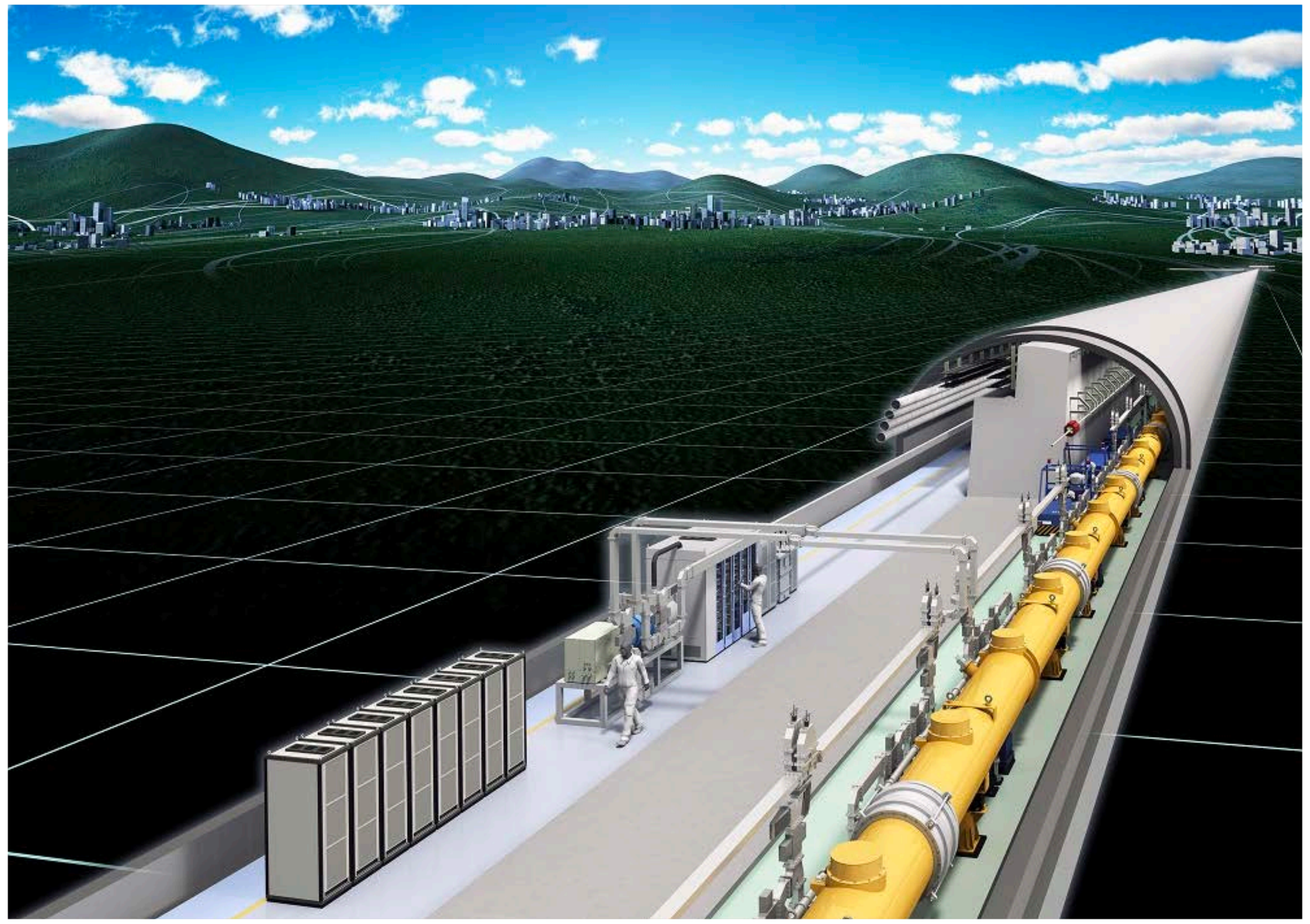


CEPC (Circular Electron Positron Collider), China

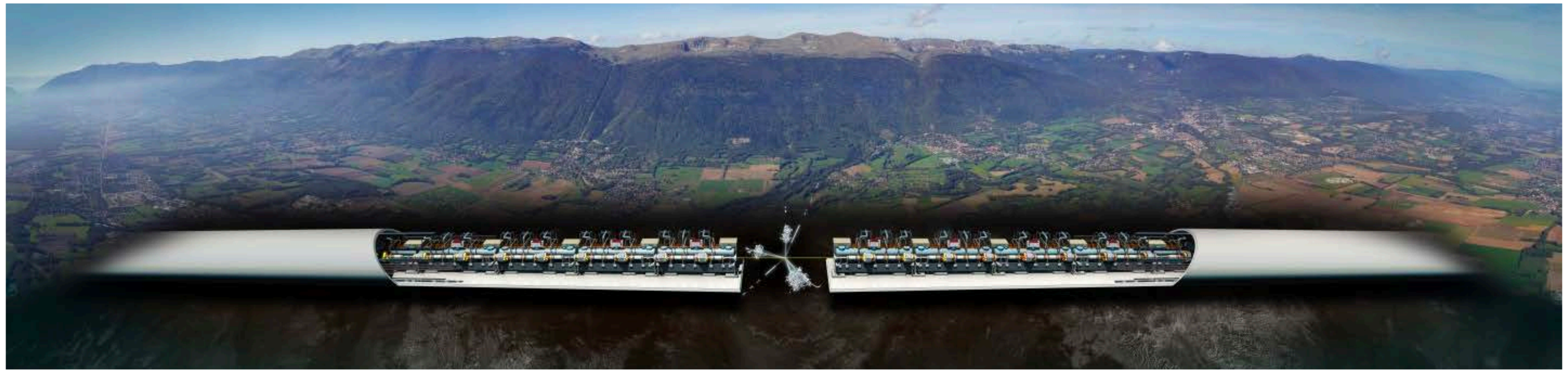


Future Circular Collider (FCC) - ee, Switzerland-France

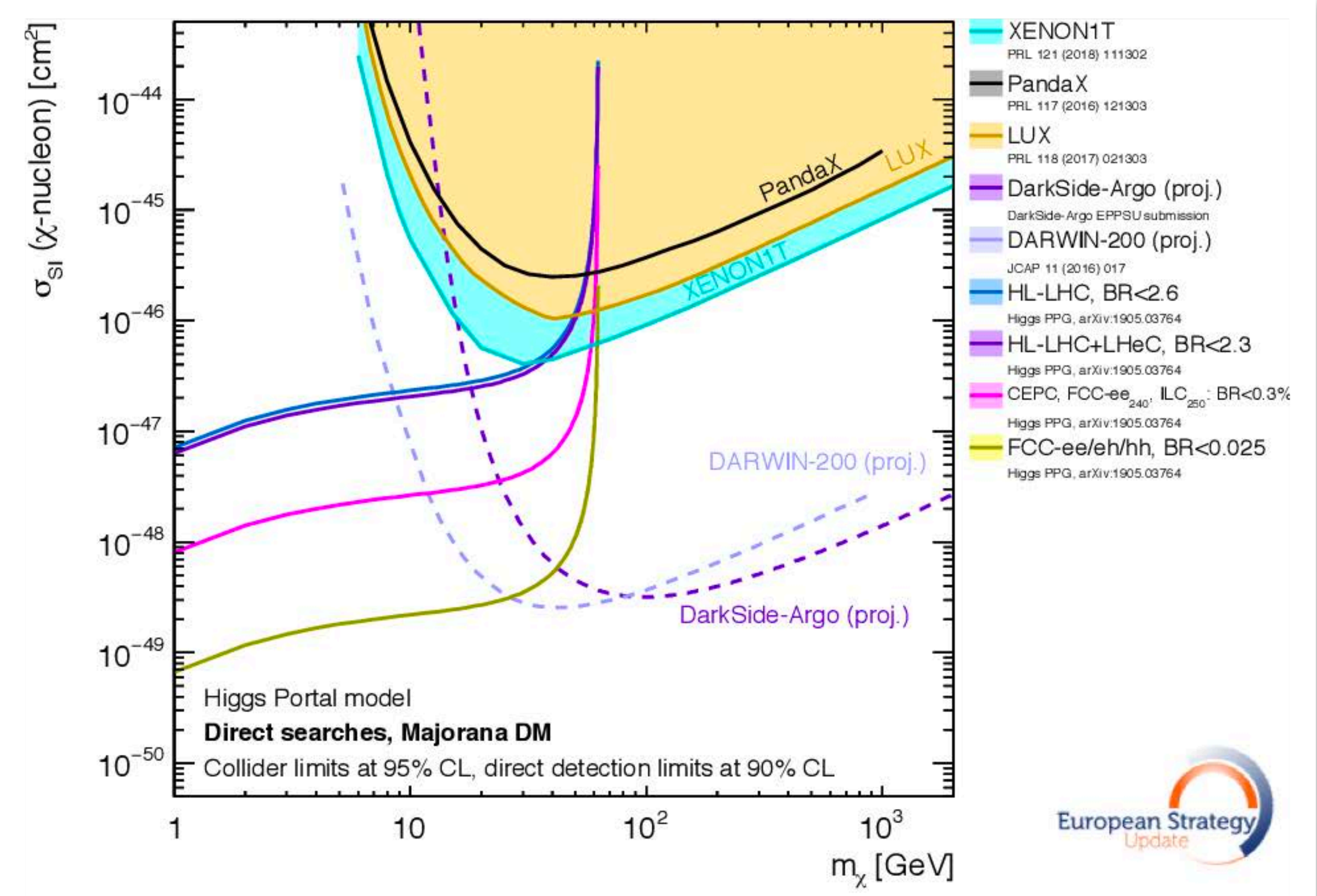
International Linear Collider (ILC)

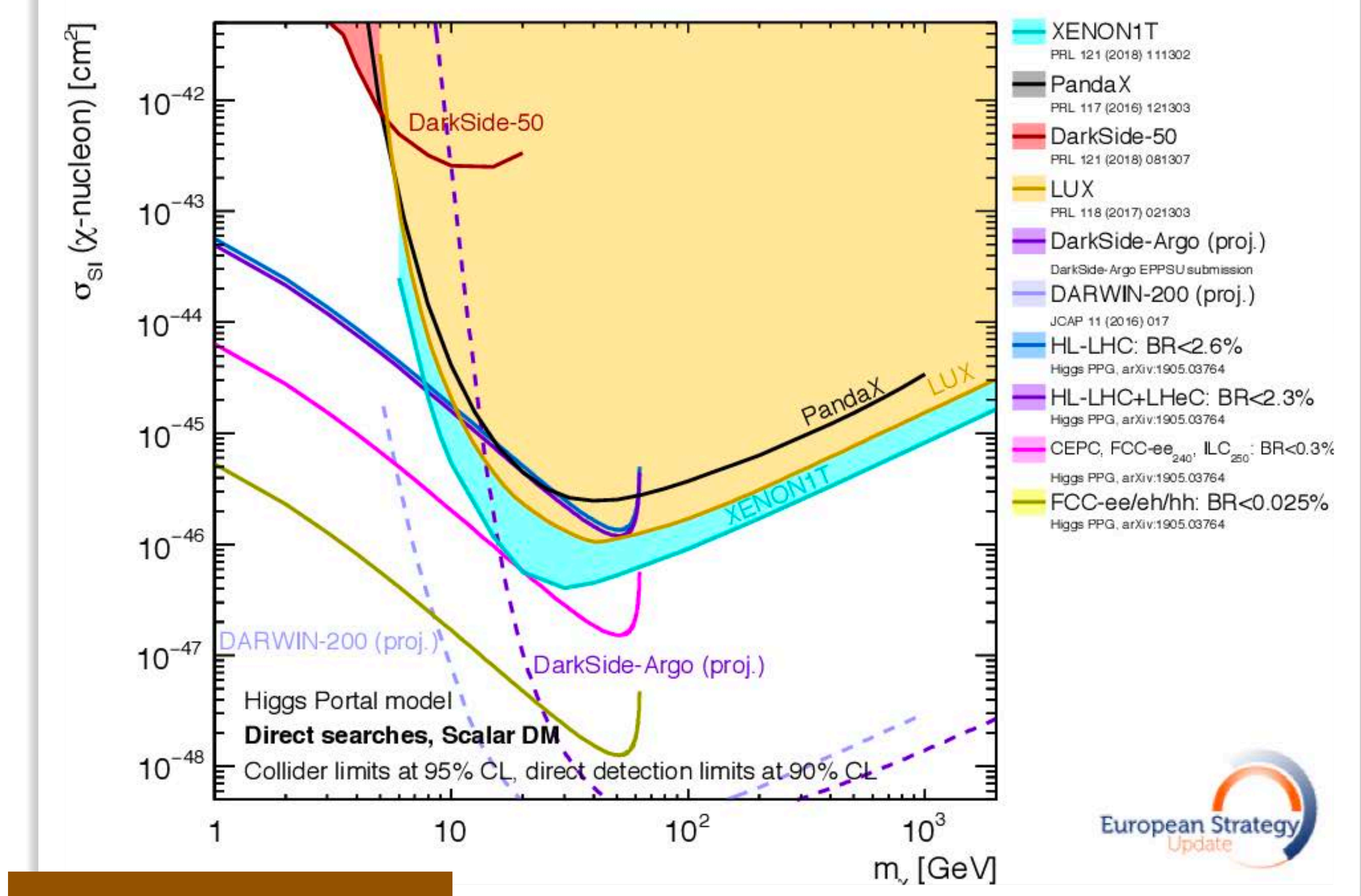


Compact Linear Collider (CLIC)

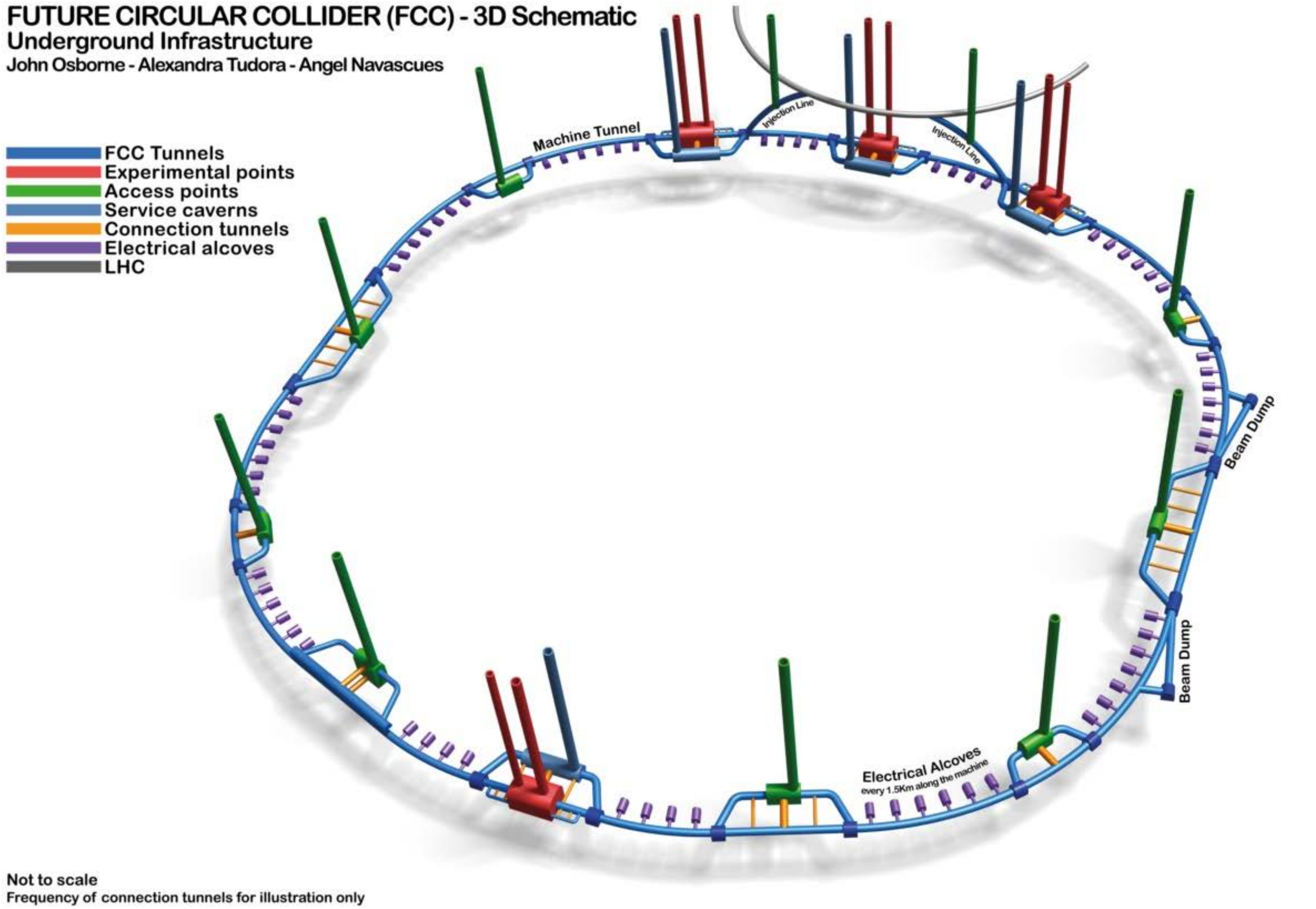


Beyond LHC: 100 TeV pp Collider





arXiv:1910.11775



https://cds.cern.ch/record/2653532

Beyond LHC: Muon Collider

Why muon collider?

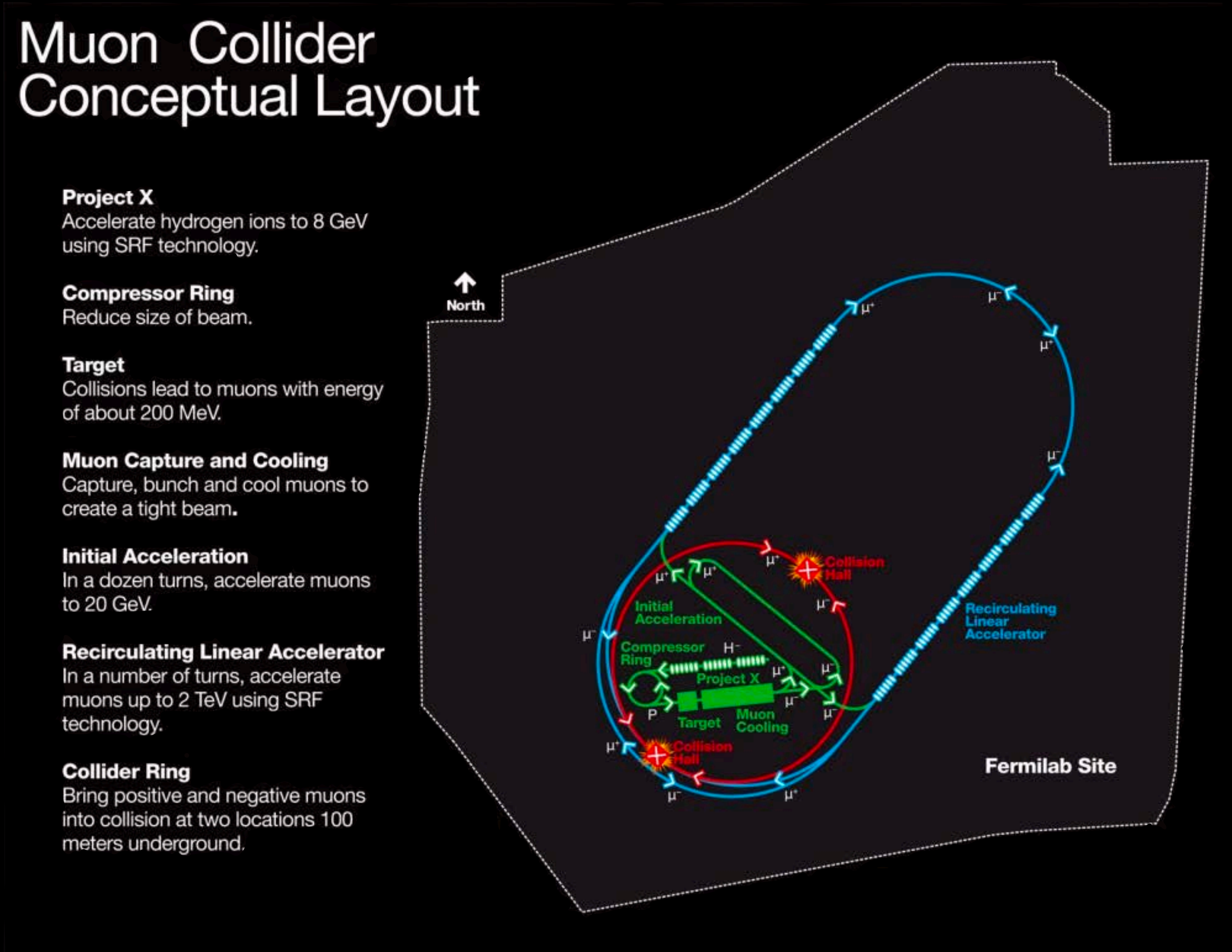
As electron, muon is elementary particle (AFAWK) with higher mass (x206 electron mass). The mass of muon is the key of high energy collision.

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.

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

Something to solve?

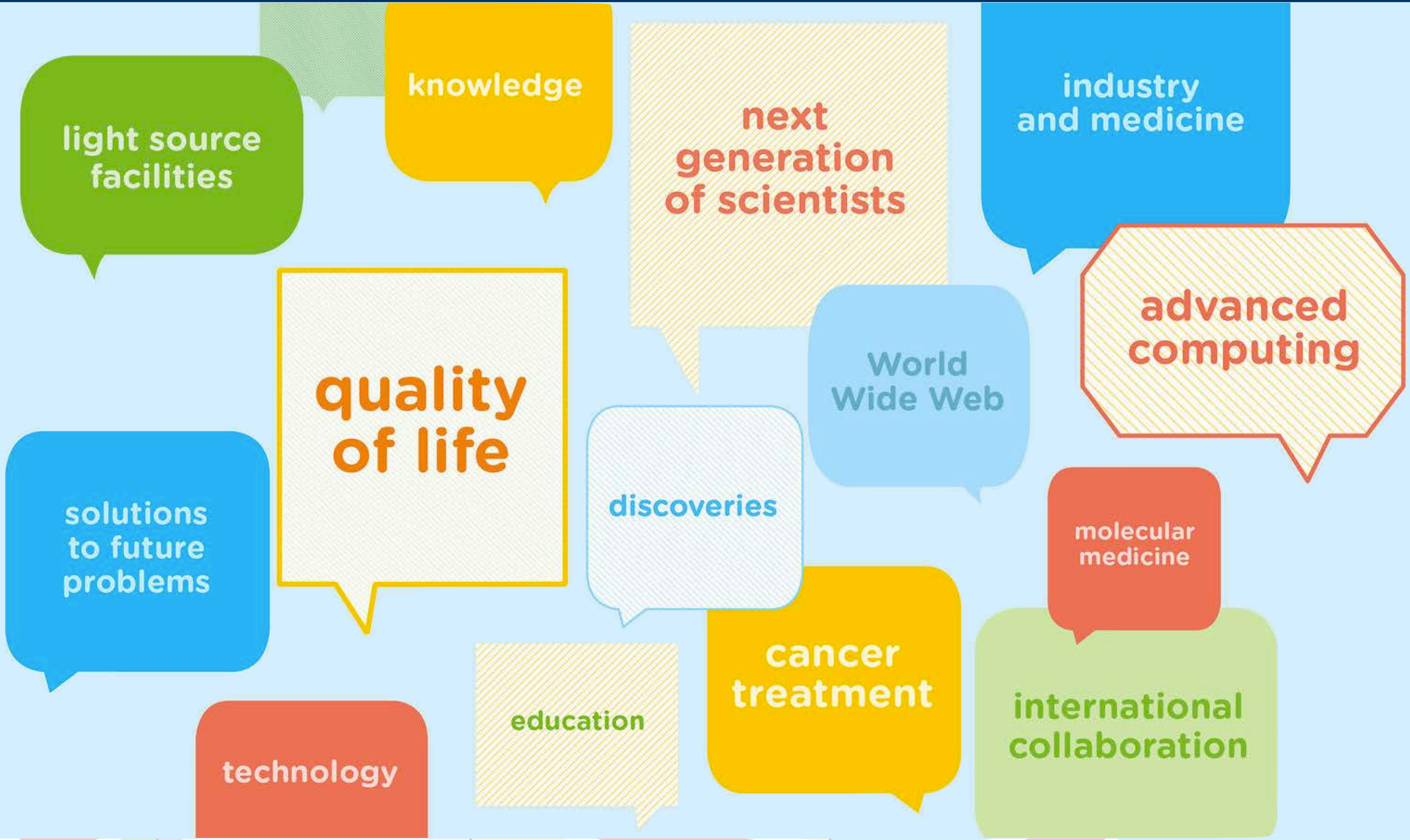
We need to handle the muon's lifetime. At rest, it will decay in 2 μs. If we can accelerate a muon close to the speed of light before decaying, its lifetime will stretch longer. This is the result of the special relativity.



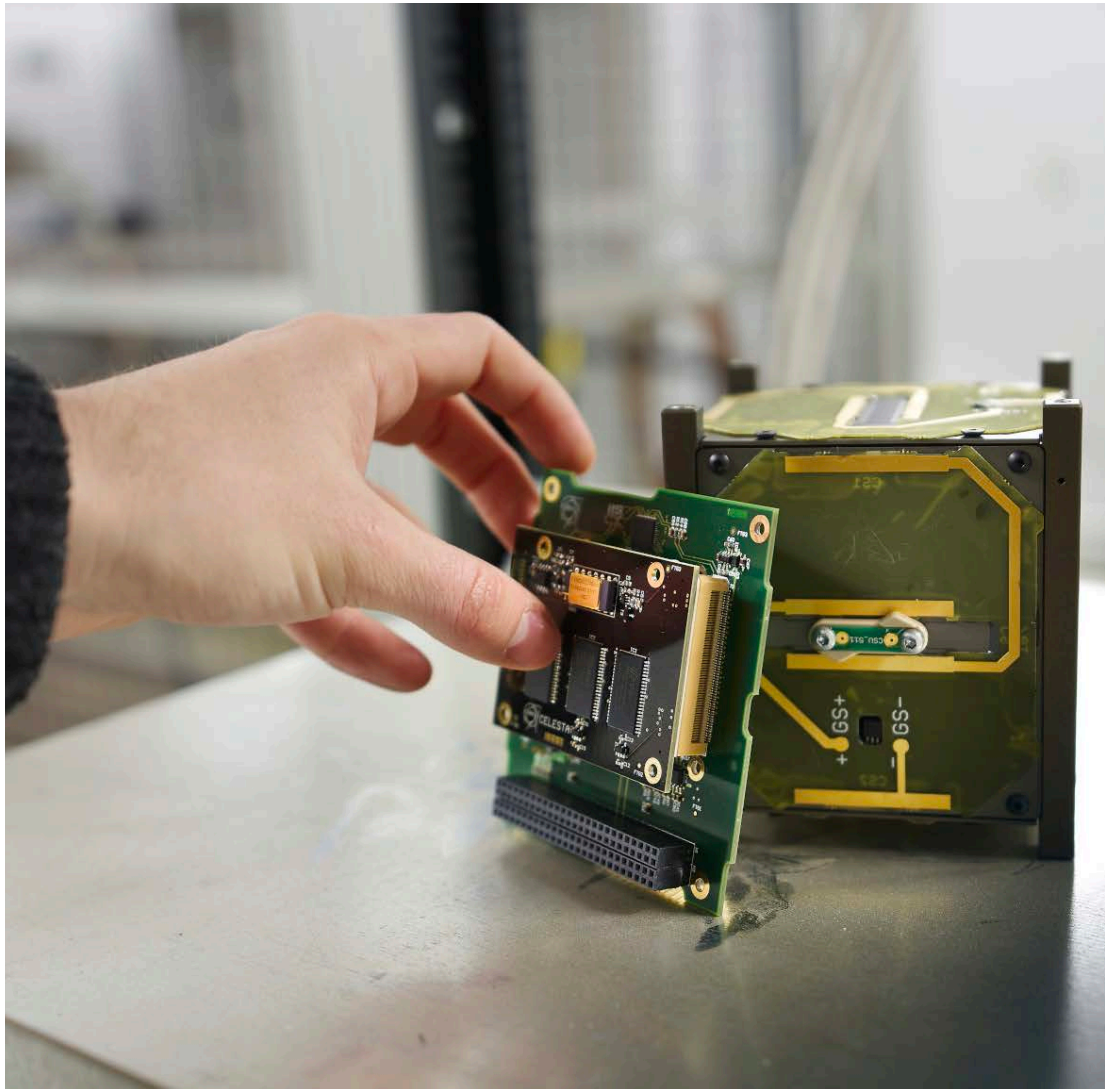
https://www.symmetrymagazine.org/breaking/2009/11/19/what-a-muon-collider-could-look-like

Why particle physics matters

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

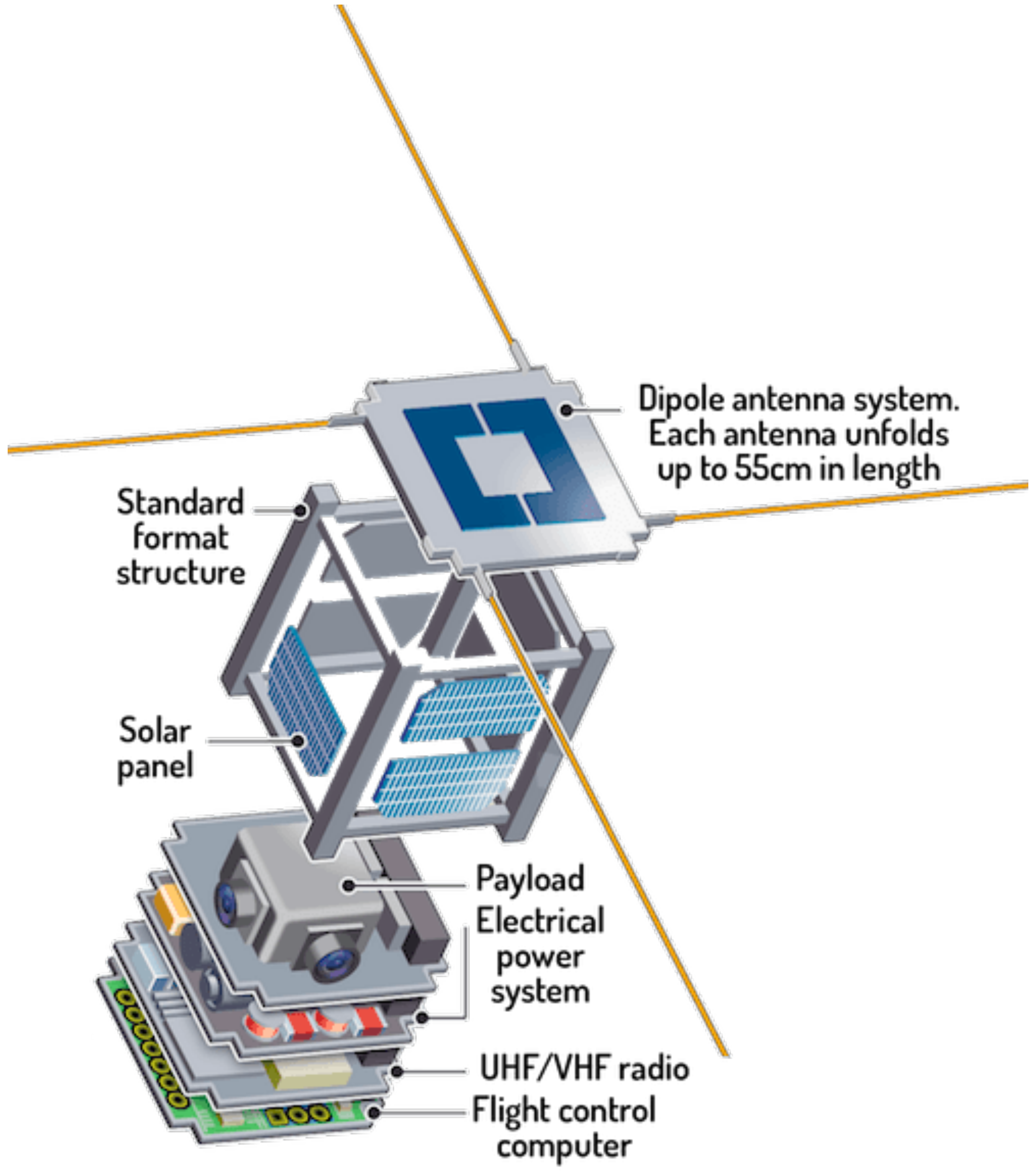


CERN latchup and radmon experiment student satellite

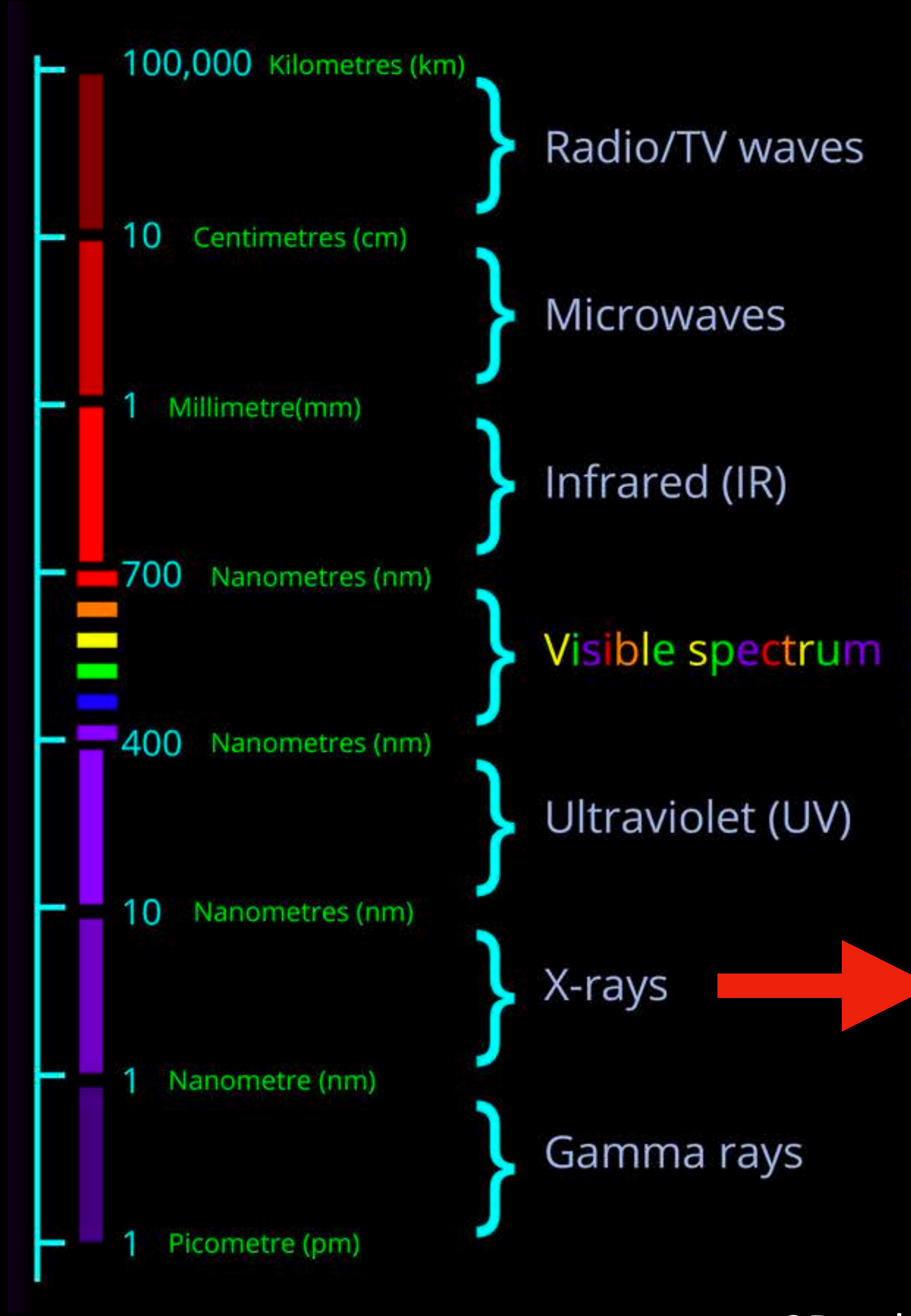


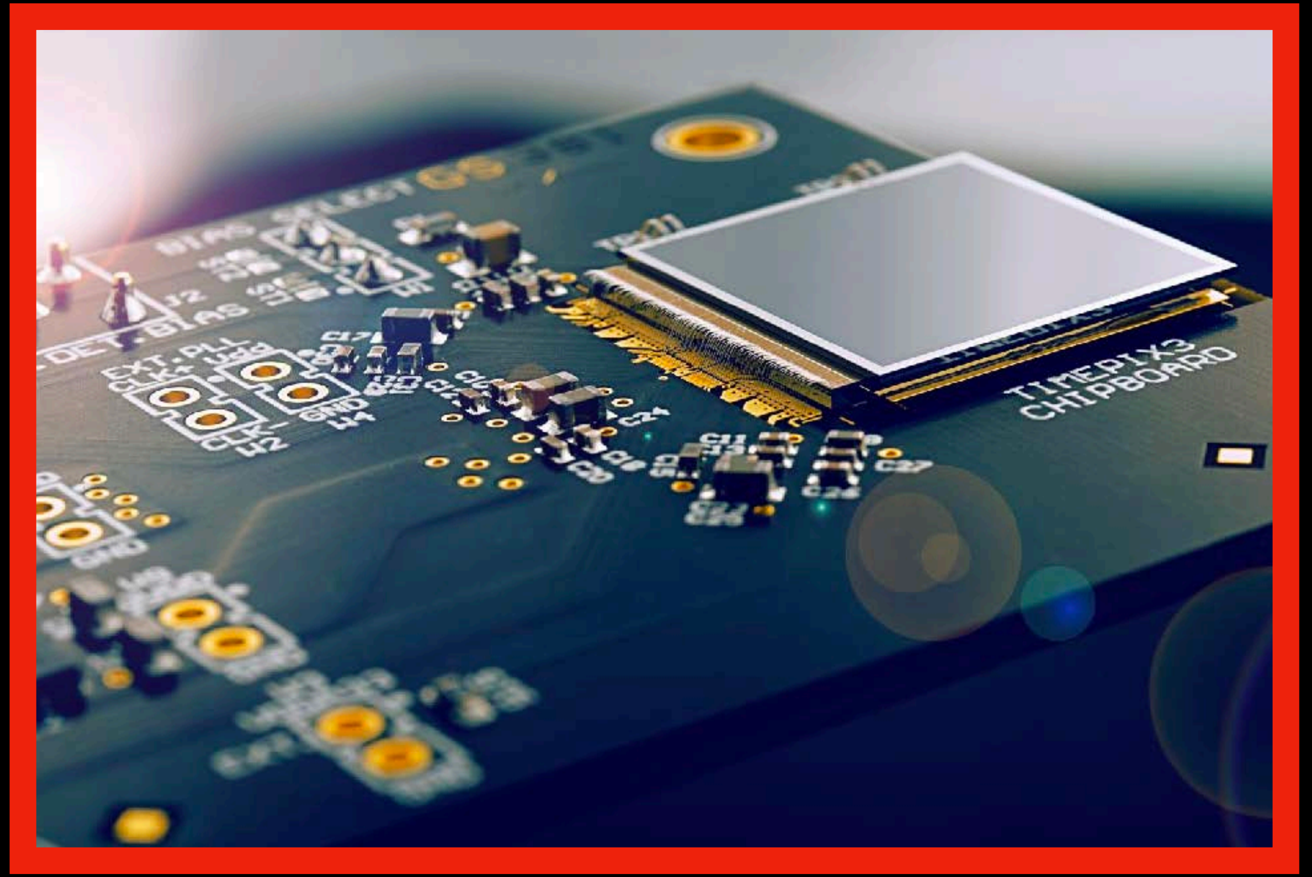
Ref: here

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).

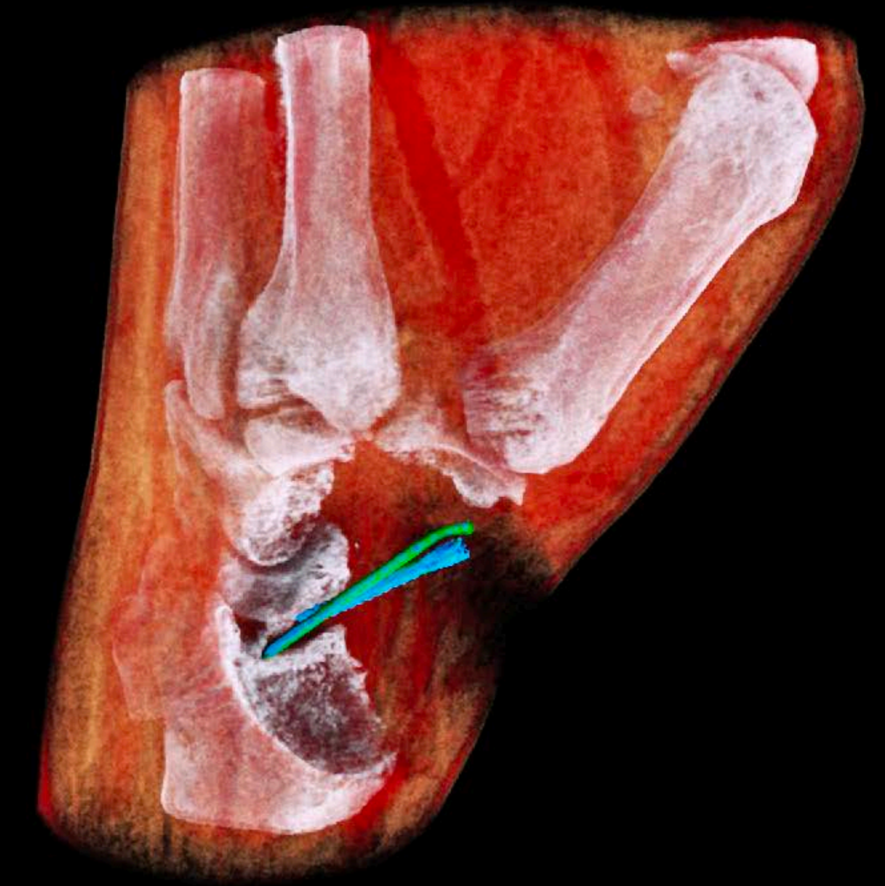


Blue skies research ... not with imaginations/ideas



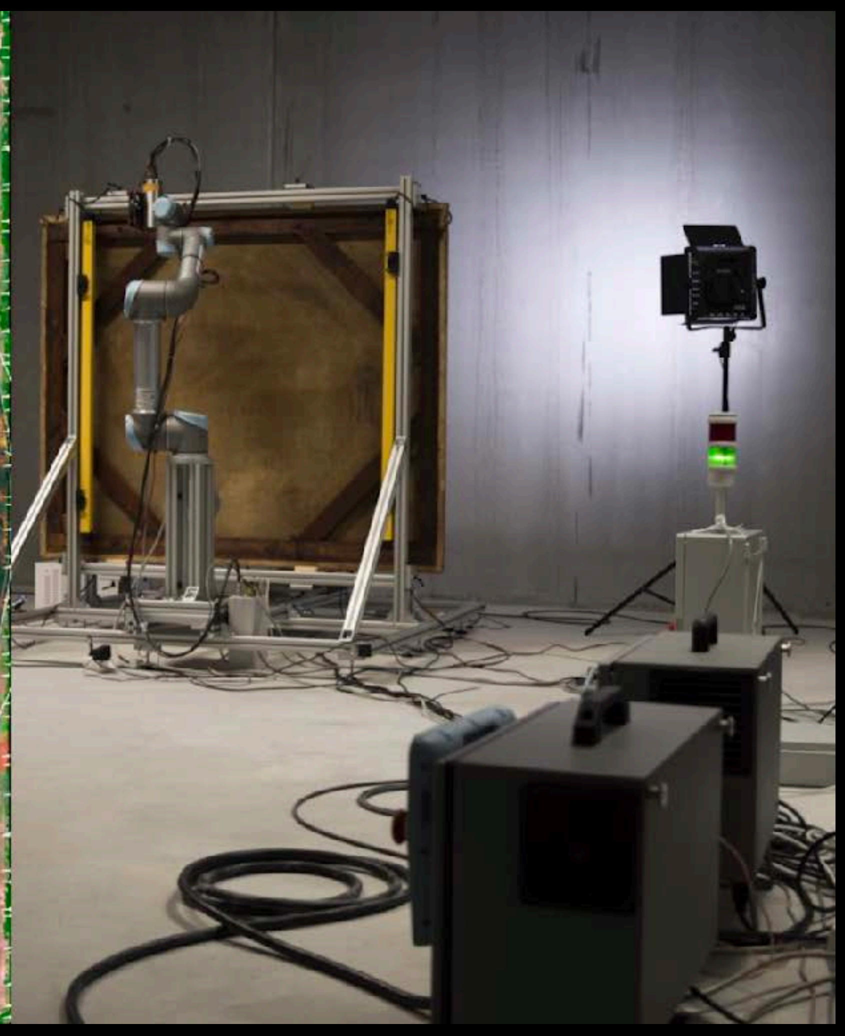


Medipix3; a CMOS pixel detector readout chip designed to be connected to a segmented semiconductor sensor.

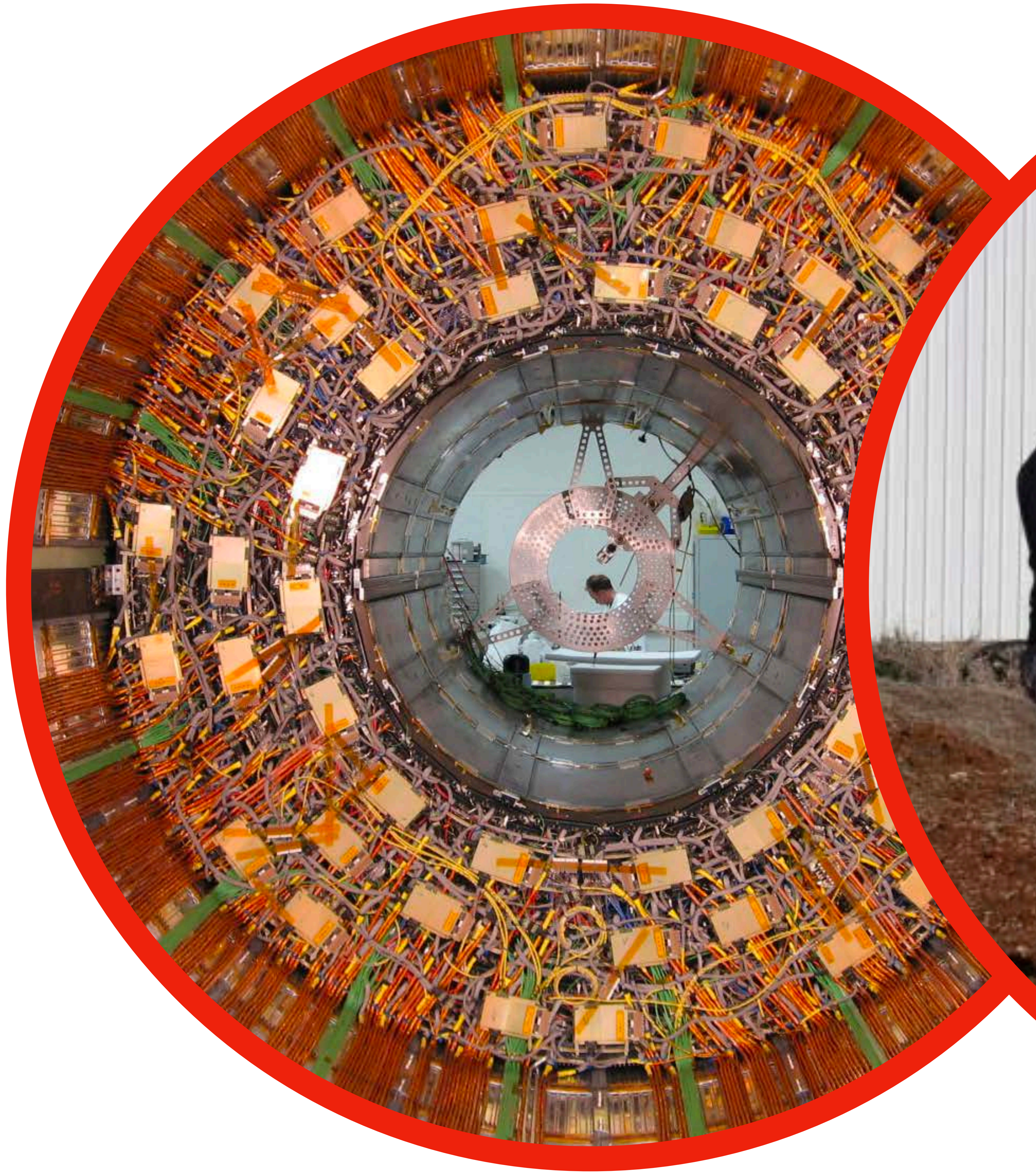


3D colour human X-ray, clinical trial

High resolution spectroscopic radiography



Blue skies research … not with imaginations/ideas

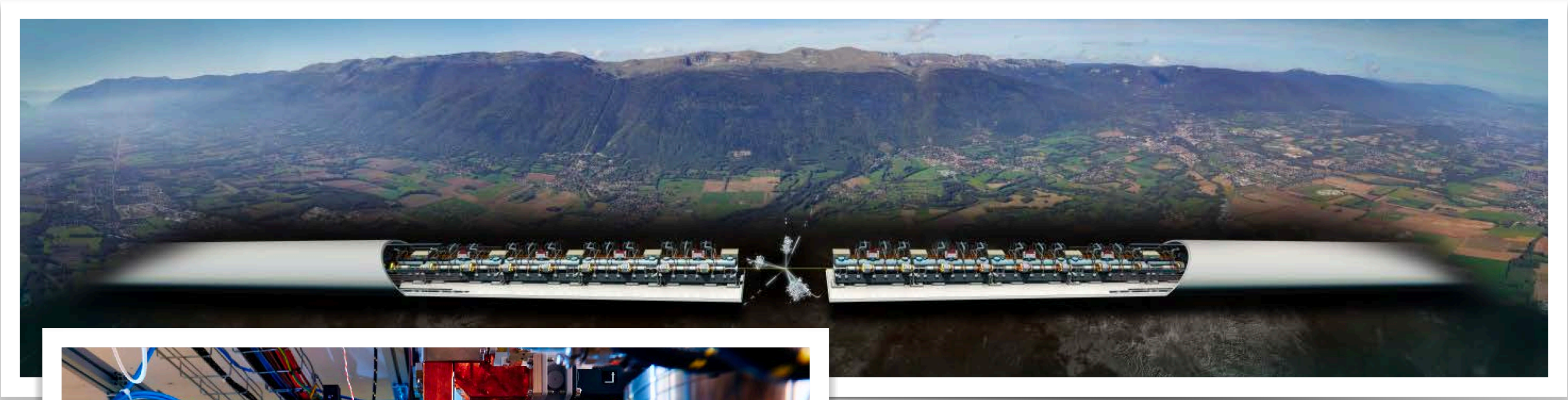


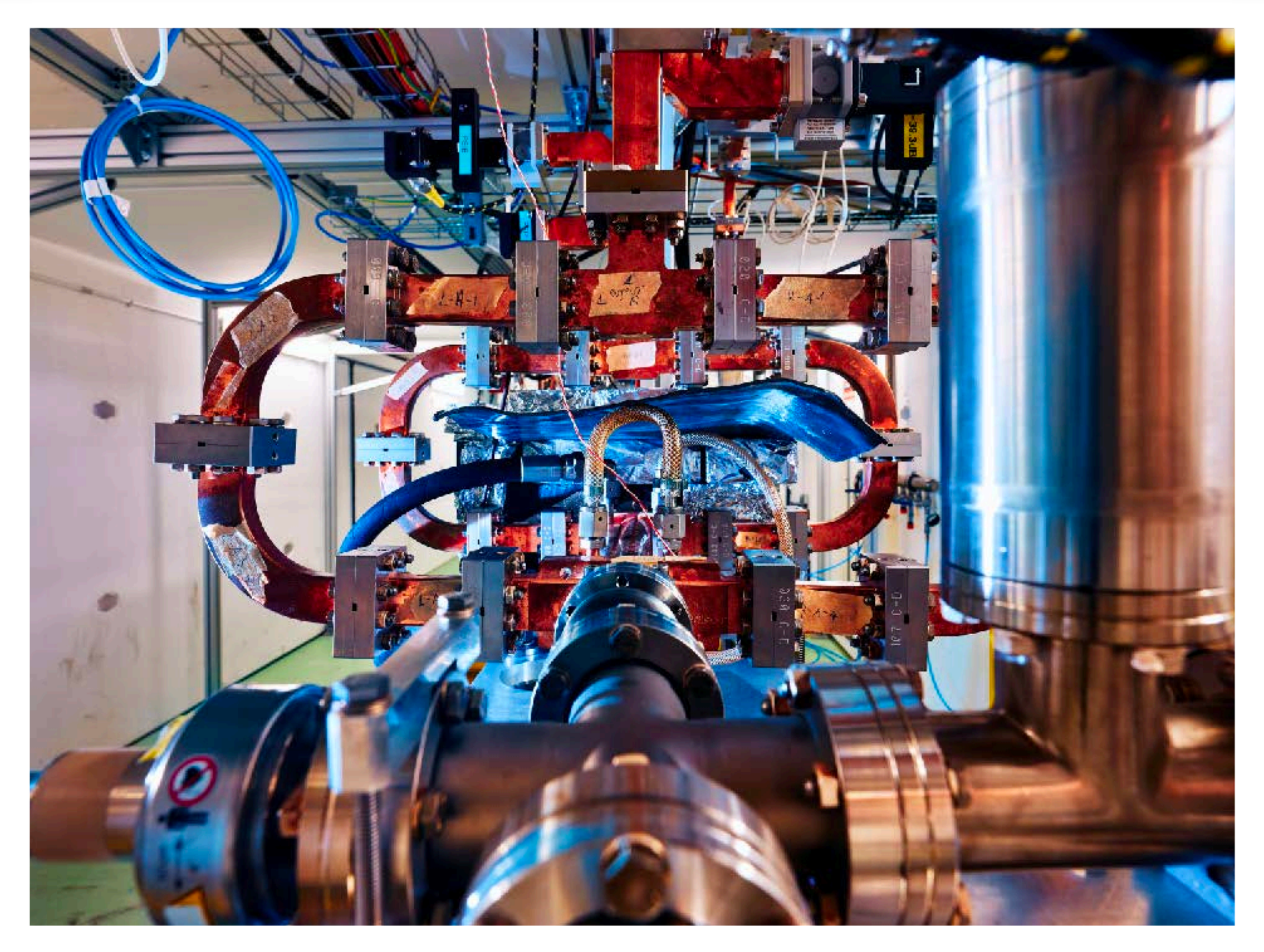
The irrigation system will use fibre optic sensors designed to measure parameters such as temperature, humidity, concentration of pesticides, fertilisers and enzymes in the soil of cultivated fields. This is the same fibre optic sensors developed by CMS experiment in order to monitor the environment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



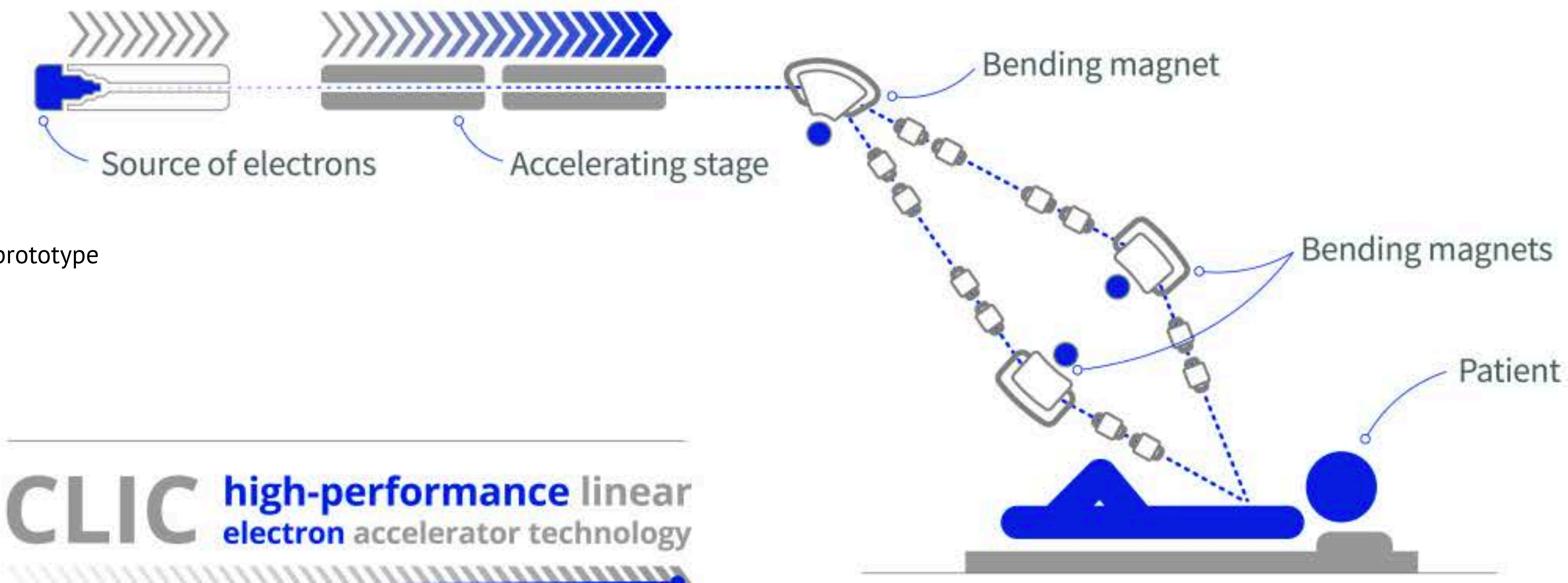


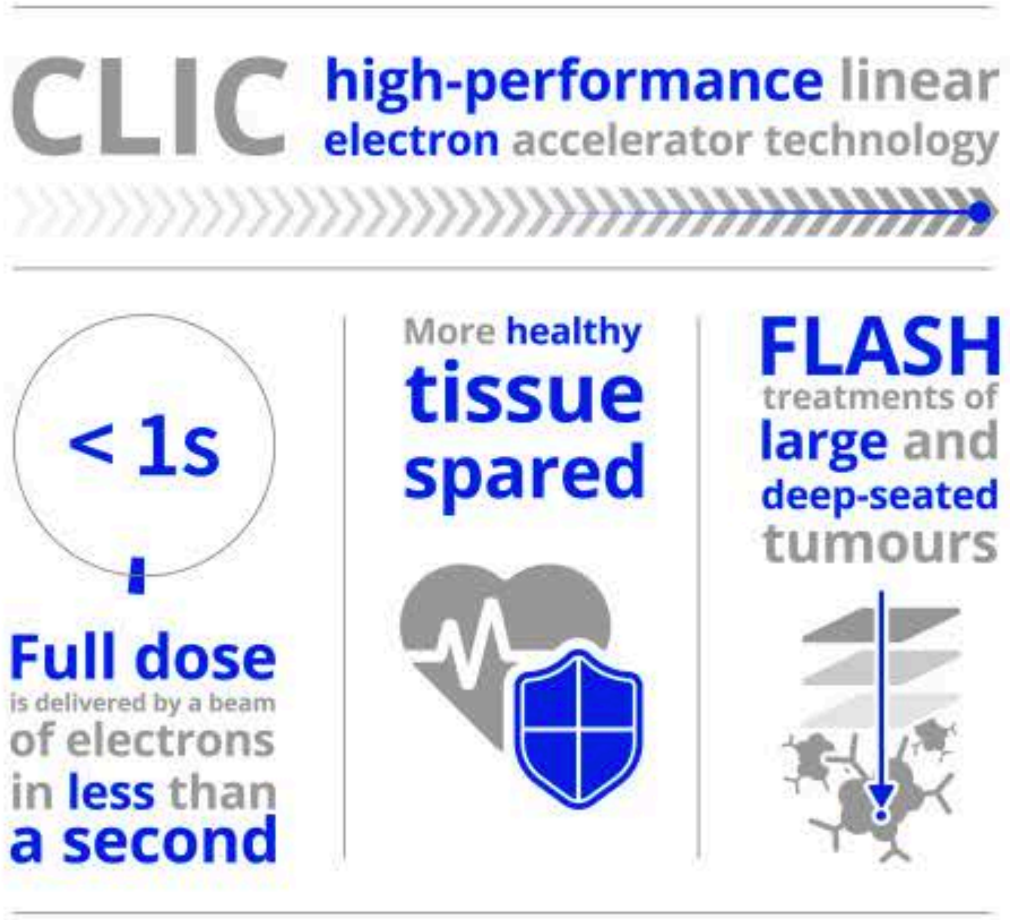
CLIC prototype

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)





Innovative Radiation Therapy with Electrons

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

CERN International Teacher Programmes

โครงการความร่วมมือไทยเซิร์น
Published by Umaratchani Kaewbutta · 23h ·

ด่วน ด่วน ด่วน หากคุณเป็นครูวิทยาศาสตร์ที่สอนระดับชั้นมัธยมศึกษาตอนปลาย ที่อายุไม่เกิน 45 ปี มีความสามารถในการสื่อสารภาษาอังกฤษได้ดี และมีความสนใจในเรื่องของฟิสิกส์อนุภาค และฟิสิกส์พลังงานสูง เราขอเชิญชวนท่านสมัครเข้าร่วมโครงการ CERN – International High School Teacher Programme 2023 และโครงการ CERN – International Teacher Weeks Programme 2023 ณ เซิร์น สมาพันธรัฐสวิส ครูวิทยาศาสตร์ที่สนใจสามารถสมัครเข้าร่วมโครงการได้ที่

โครงการ CERN HST2023 – International High School Teacher Programme 2023 (ระยะเวลา 2 สัปดาห์ ช่วงระหว่างวันที่ 2-15 กรกฎาคม 2566)
https://teacher-programmes.web.cern.ch/international-high...

CERN ITW2023– International Teacher Weeks Programme 2023 (ระยะเวลา 2 สัปดาห์ ช่วงระหว่างวันที่ 6-19 สิงหาคม 2566)
https://teacher-programmes.web.cern.ch/international...

สมัครได้ตั้งแต่บัดนี้จนถึงวันที่ 15 มกราคม 2566 ประสบการณ์อันแสนล้ำค่ารอคุณอยู่ที่สวิตเซอร์แลนด์ค๊า

CERN offers two 2-week international teacher programmes: The International High School Teacher (HST) Programme and the International Teacher Weeks (ITW) Programme. Both programmes are delivered entirely in English and are open to in-service science teachers from around the world. The goals of CERN's international teacher programmes are:

- To support teachers' professional development in the field of particle physics.
- To promote the teaching of particle physics in high schools.
- To facilitate the exchange of knowledge and experience among teachers of different nationalities.
- To stimulate activities related to the popularisation of physics within and beyond the classroom.
- To help CERN establish closer links with schools all around the world.

https://teacher-programmes.web.cern.ch/international-teacher-programmes

Until 15 January 2023!!!