

Particle Physics for Babies

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By Dr Louie Corpe



Introduction to CERN and **High Energy Particle Physics Programs** [Part 2]

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CERN Missions

Research

Seeking and finding answers to questions about the Universe

Technology Advancing the frontiers of technology

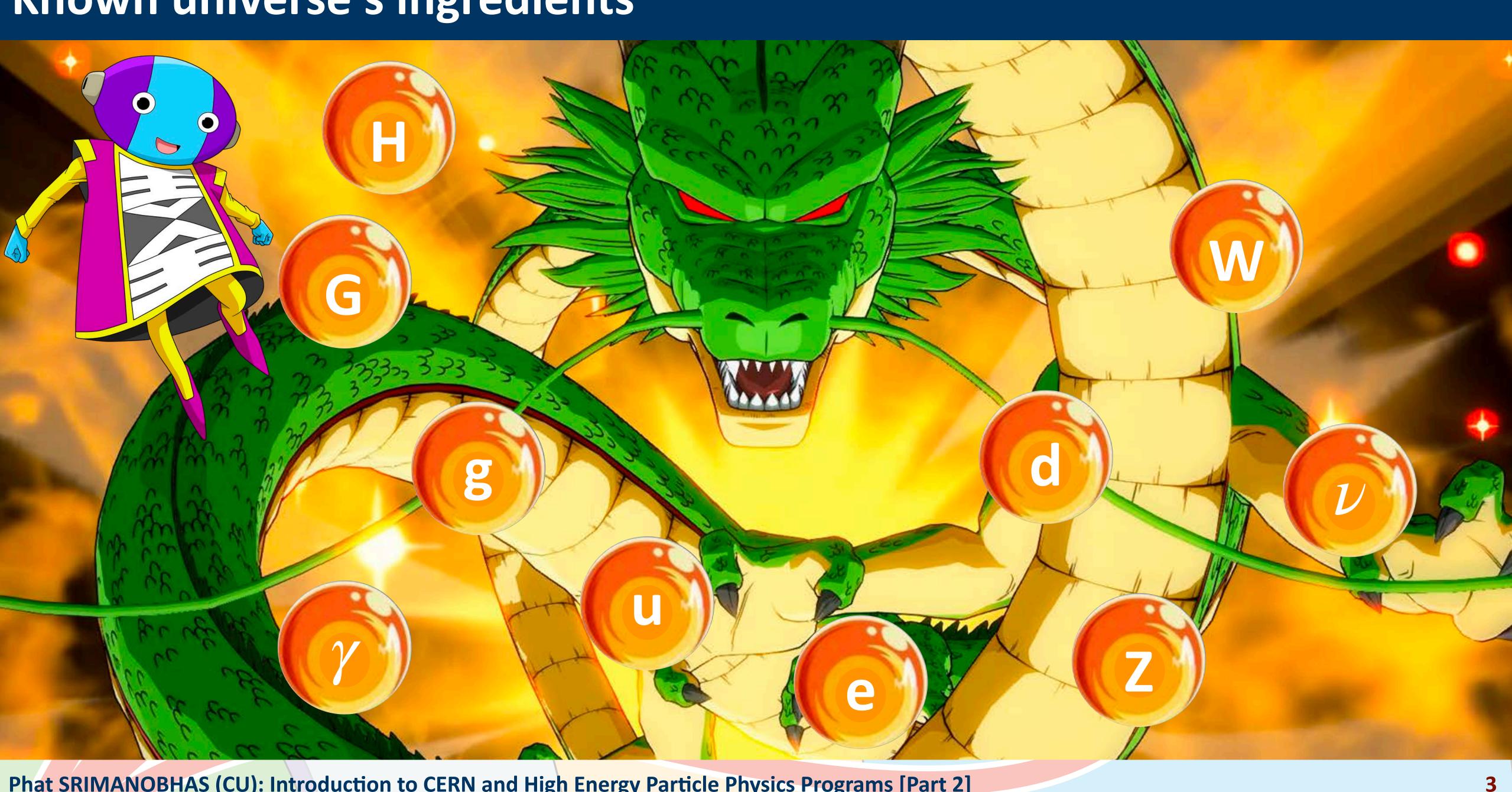
Education Training the scientists of tomorrow

Collaborating Bringing nations together through science

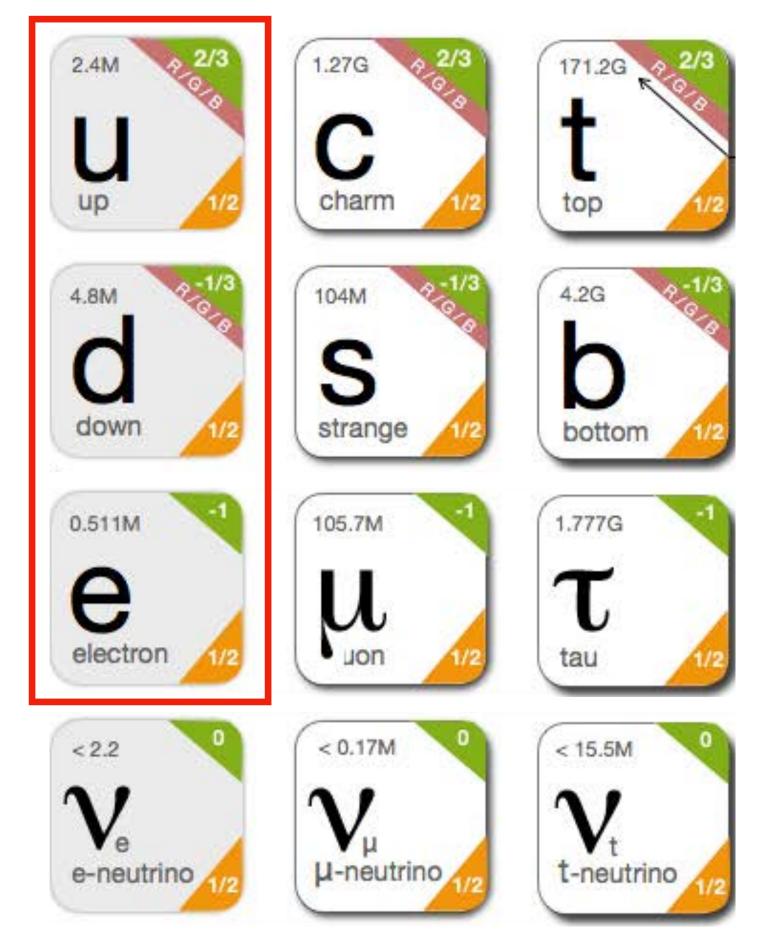




Known universe's ingredients



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



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these particles by three (out of four) fundamental forces.

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







Electromagnetic force



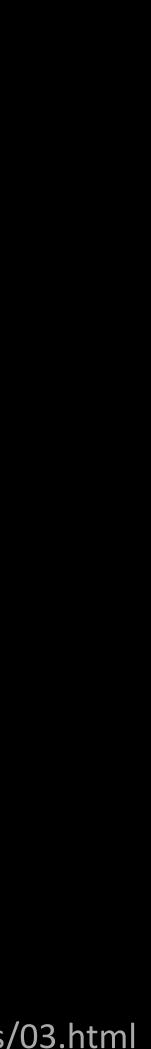
Forming atoms and molecules

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 positve charge pull in more electrons until atoms and molecules have a balance of charges.

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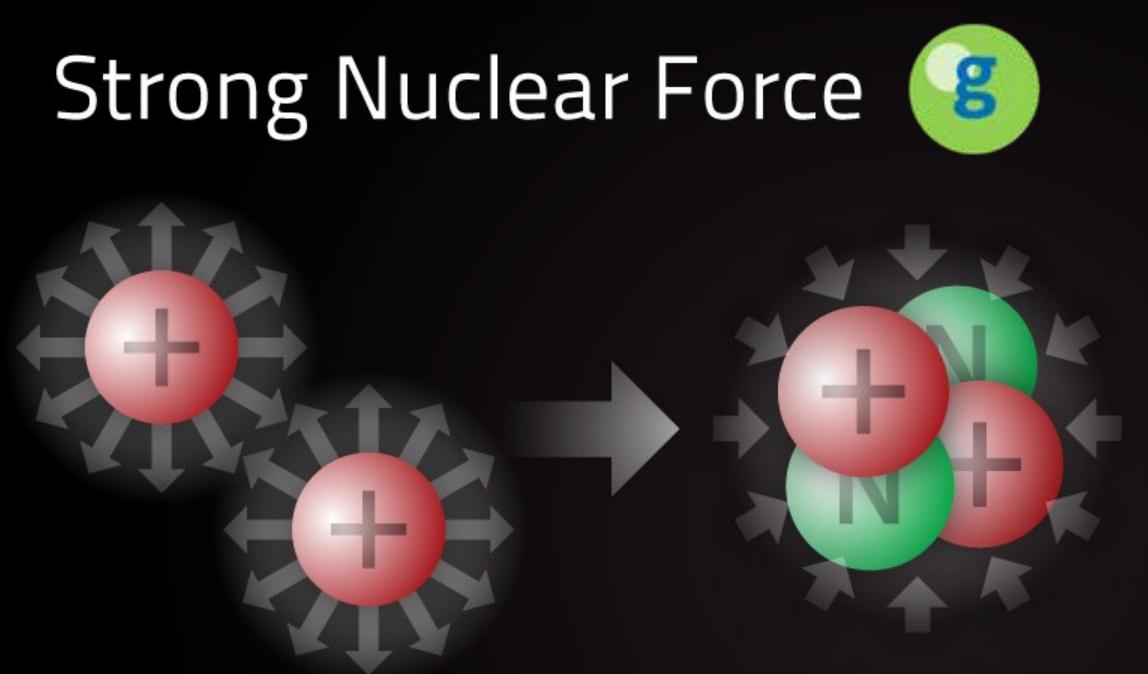
Generating light

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





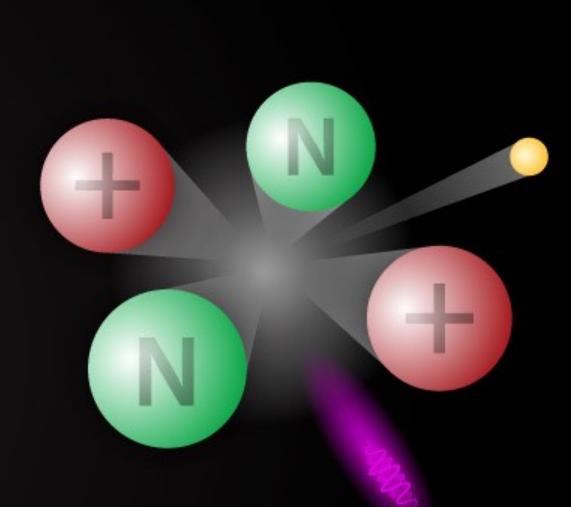
Strong nuclear force



Binding protons in atomic nuclei

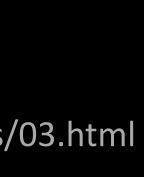
Positively charged particles naturally repel each other, it takes an extreme amount of force to hold protons together. The strong nuclear force overcomes the repulsion between protons to hold together atomic nuclei. Without the strong nuclear force, complex nuclei cannot form.

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Breaking the bond

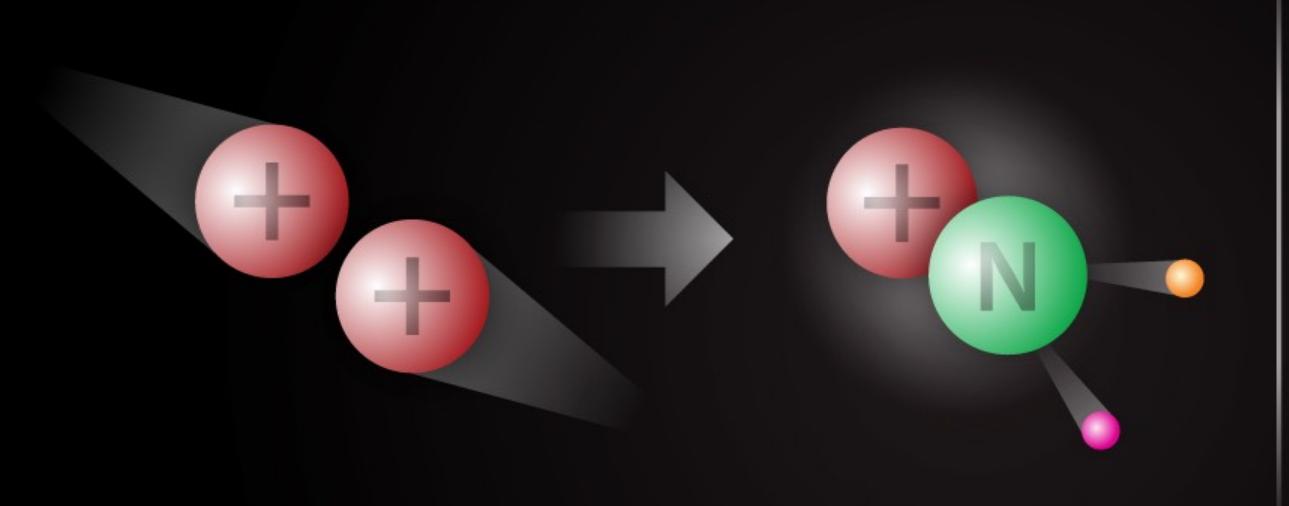
Enormous energy is released as gamma rays and nuetrinos when the strong nuclear force is broken between protons and neutrons.





Weak nuclear force

Weak Nuclear Force [🗾 🚺

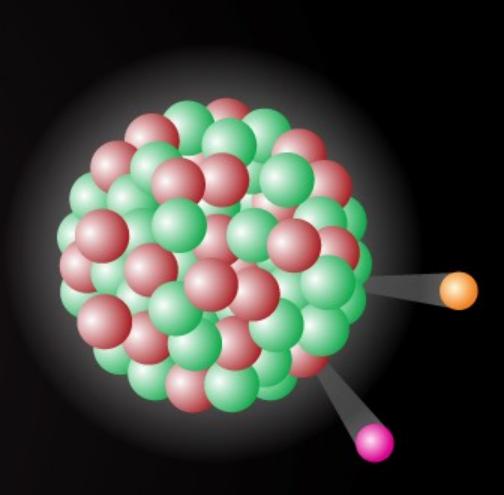


Converting protons into neutrons

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 Nuetron. Without the weak nuclear force converting protons into nuetrons, certain complex nuclei cannot form.

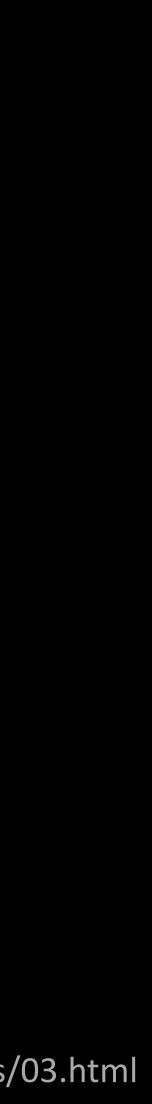
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Releasing radiation

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





Gravity

Gravity

Center of Mass

The Sun and the planets all orbit a shared center of mass

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.

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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.

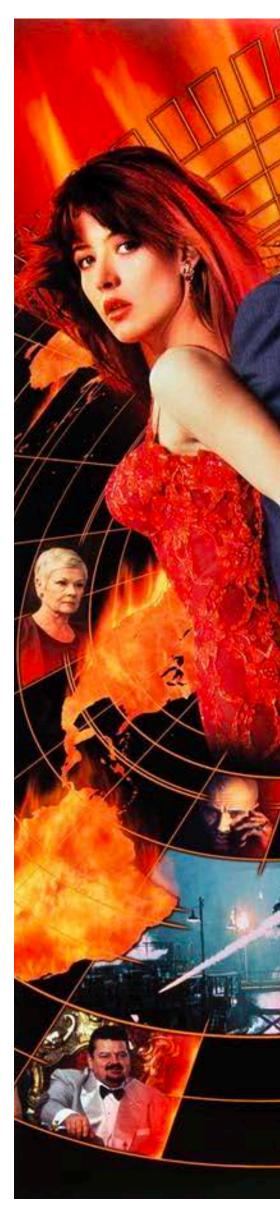




Goals of today high energy particle physics

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



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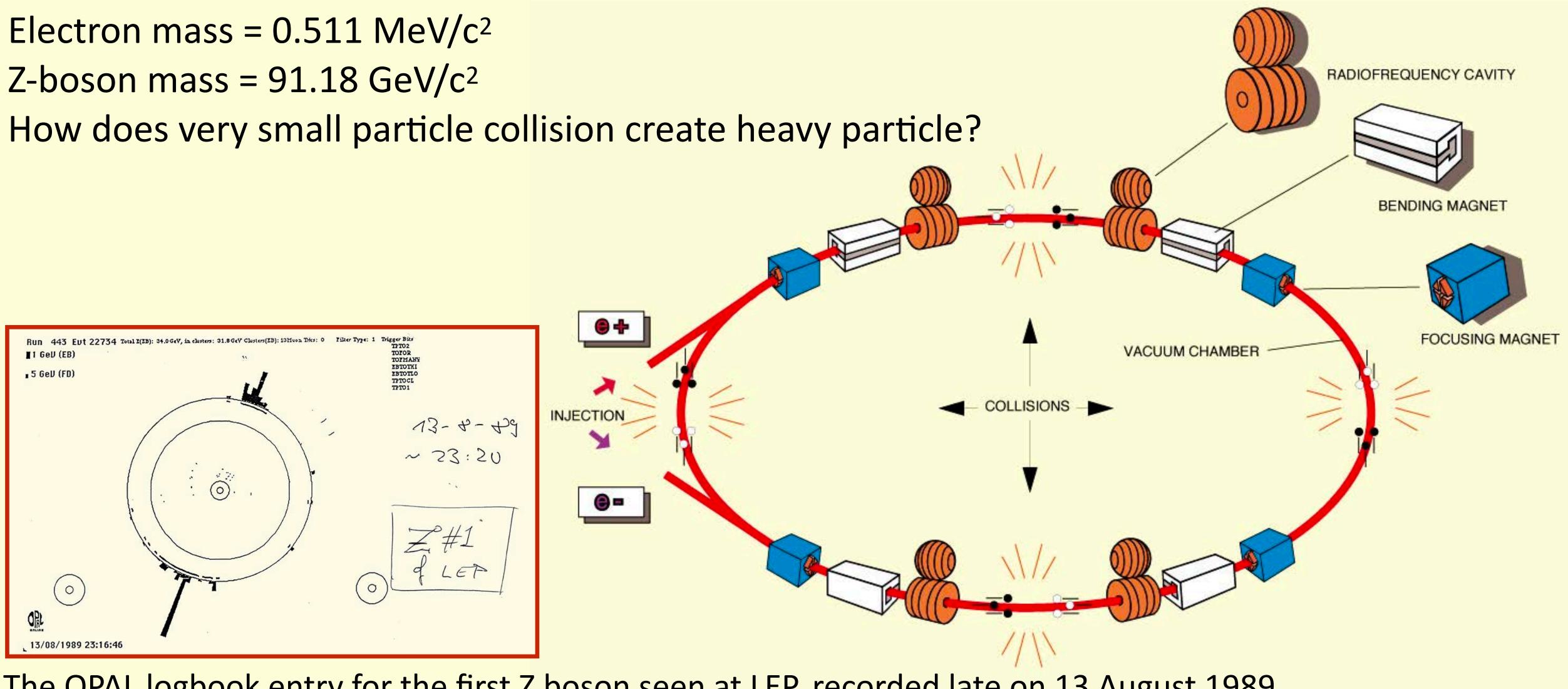
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Standard Model IS Not FI





Accelerator is our tool to find answers



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

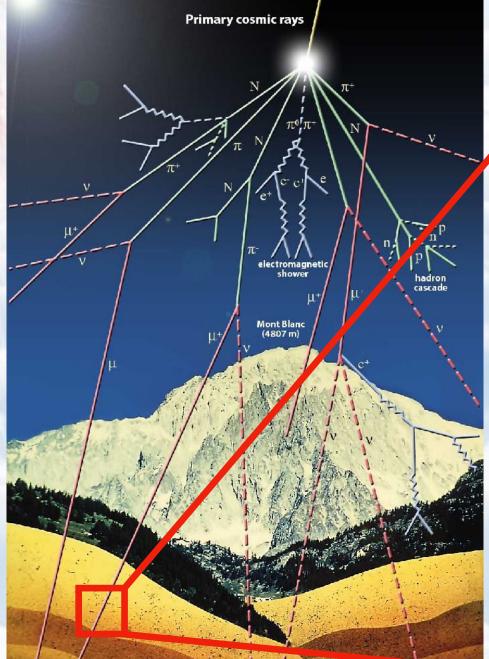


Cosmic rays: Particles from outer space accelerators

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





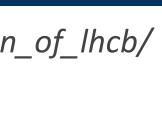
A vacuum chamber where the proton beams collide in the ISR http://cds.cern.ch/record/41966

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

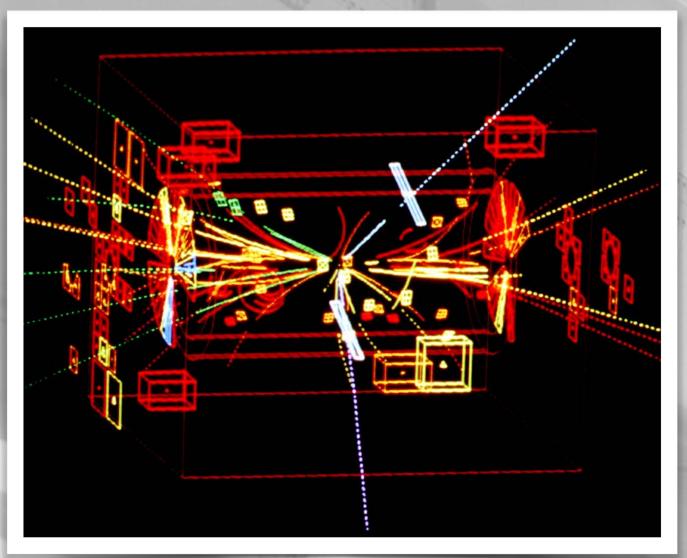
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https://www.reddit.com/r/CERN/comments/8xnwz1/the_map_of_cern_and_cutaway_illustration_of_lhcb/

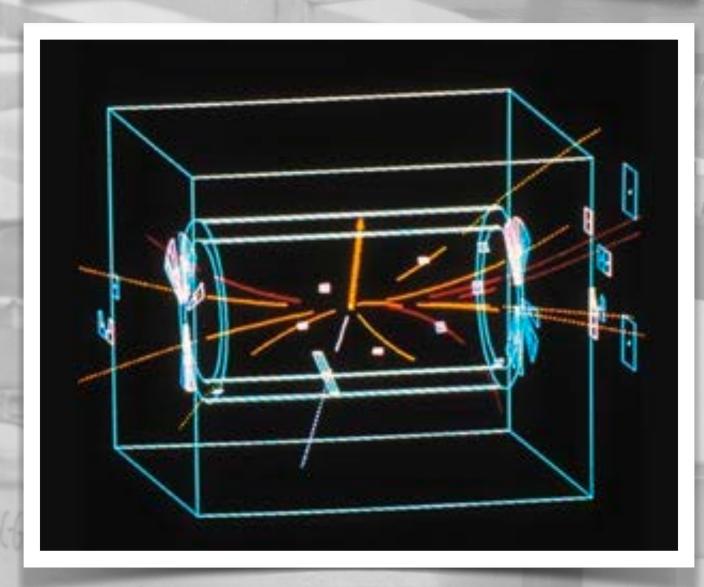




17 June 1976, SPS ... plan changed to $p\bar{p}$ collider ... discovery



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

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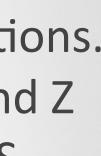
S. Weinber **Abdus Salam** S. L. Glashow (1933-202 (1926-1996)(1932-) Around 1968, theorists came up with the electroweak theory, which

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

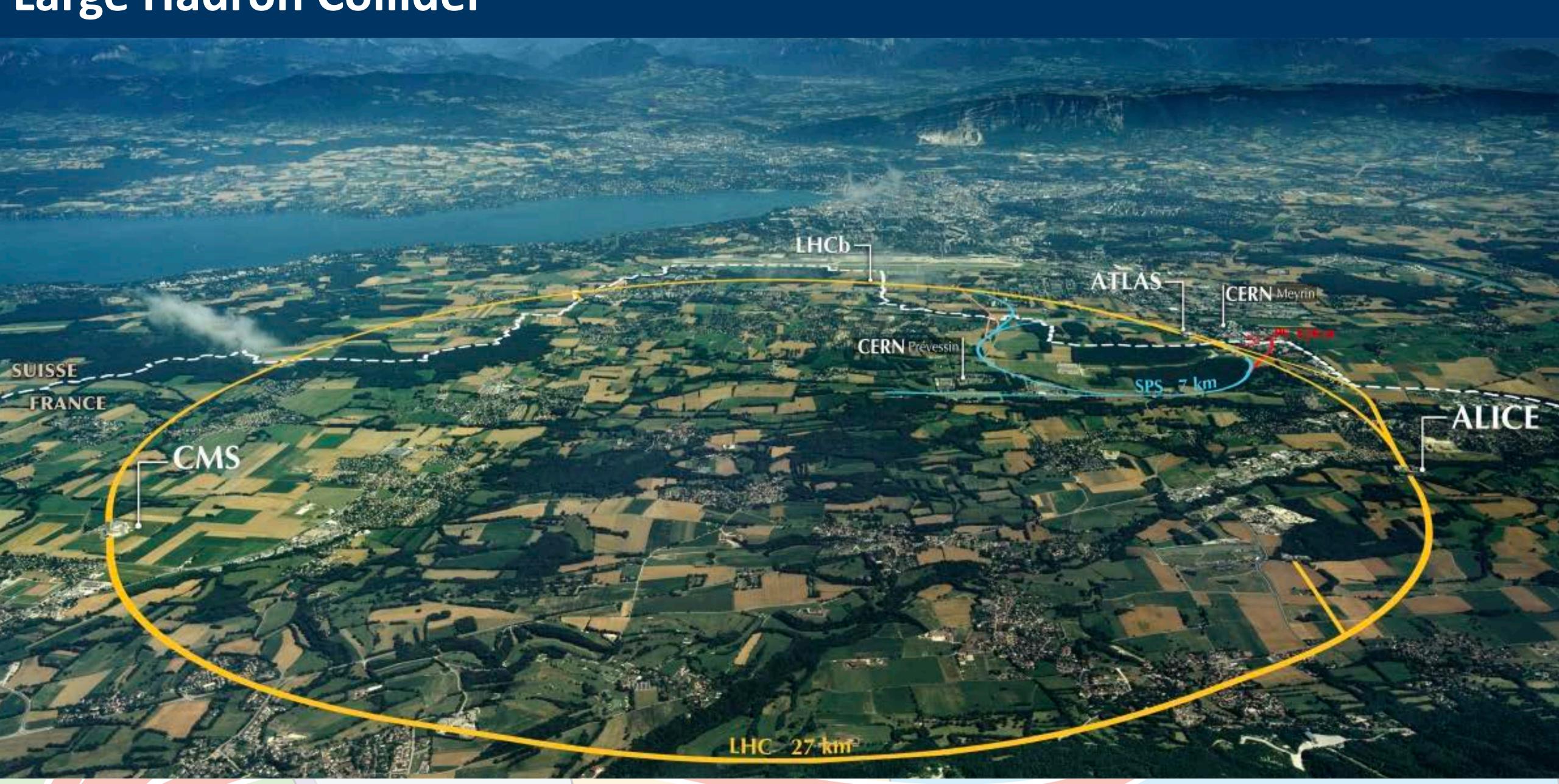
in discussion.







Large Hadron Collider





Large Hadron Collider by numbers

27KM (16 MILES) IN CIRCUMFERENCE



IN RAW DATA GENERATED BY LHC EXPERIMENTS

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

ACHIEVED BY PARTICLES

OFFOIDO INTERNAL OPERATING TEMPERATURE

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OLLISIONS

OCCUR PER SECOND

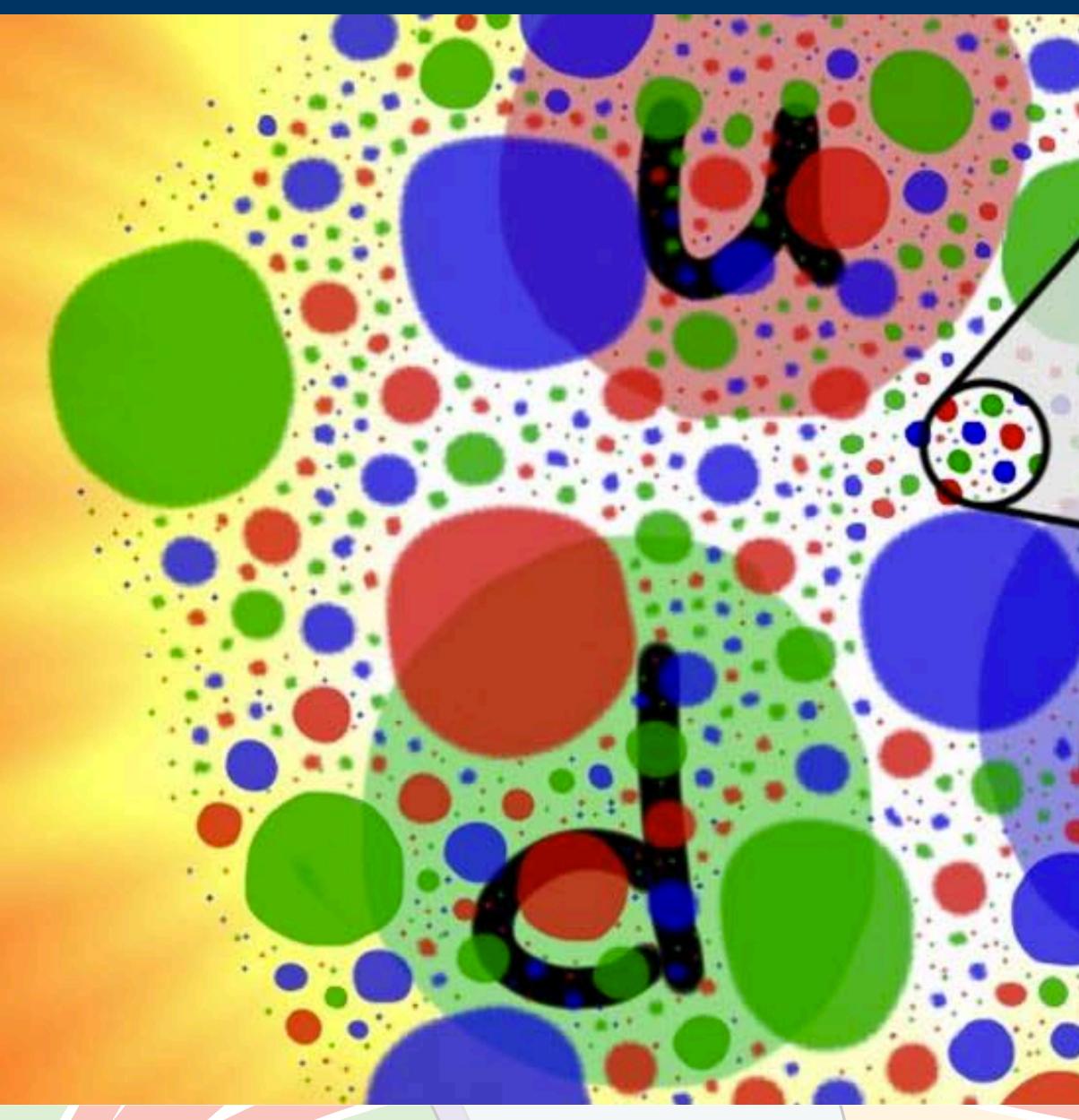
HEAT GENERATED BY COLLISIONS

CERN'S OPENSTACK CLOUD ACROSS TWO DATA CENTERS

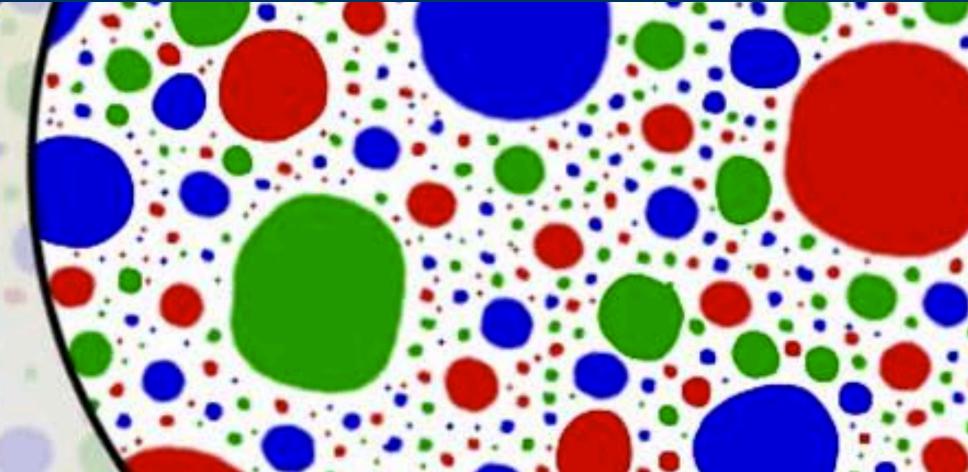


Parton - Proton

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



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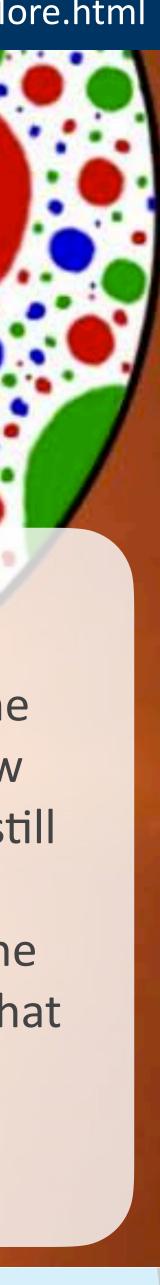


Parton

▶ 1964, Murray Gell-Mann and George Zweig

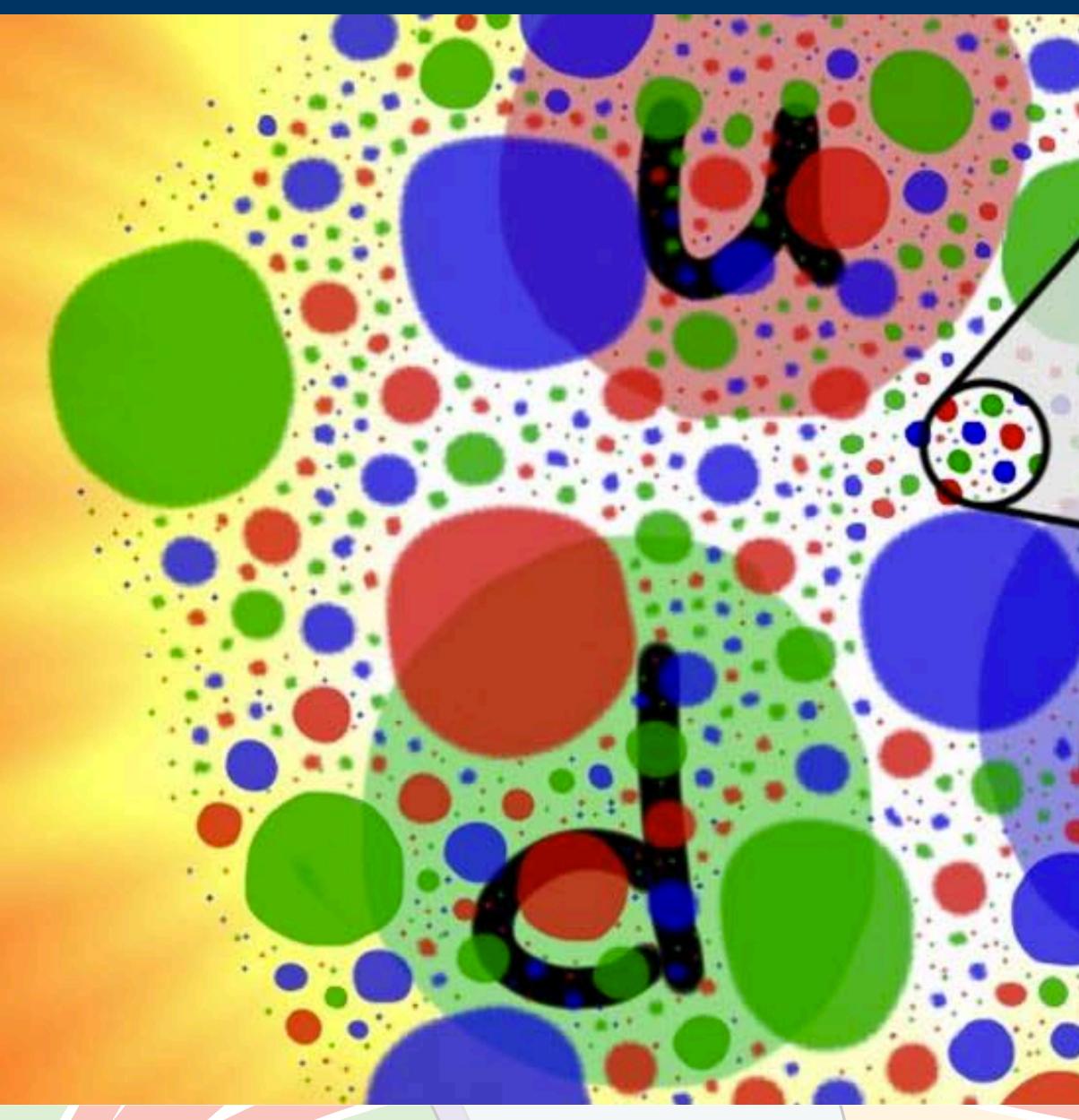
independently proposed that the proton (and also the neutron) consisted of three smaller particles. We now use Gell-Mann's name for them: quarks. They were still theoretical.

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.



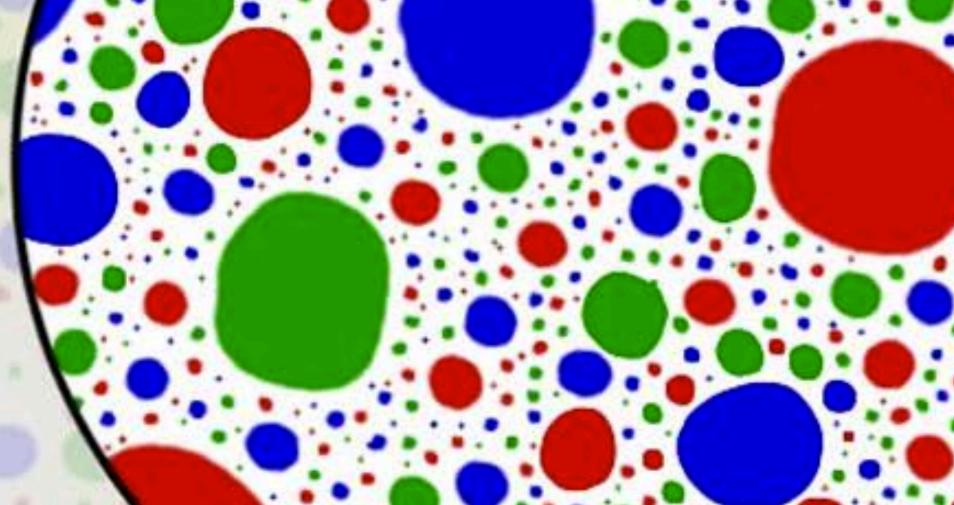
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Parton - Proton



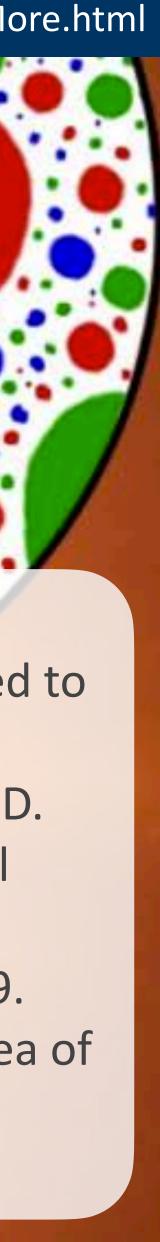
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http://www.fnal.gov/pub/today/archive/archive_2012/today12-05-04_NutshellReadMore.html



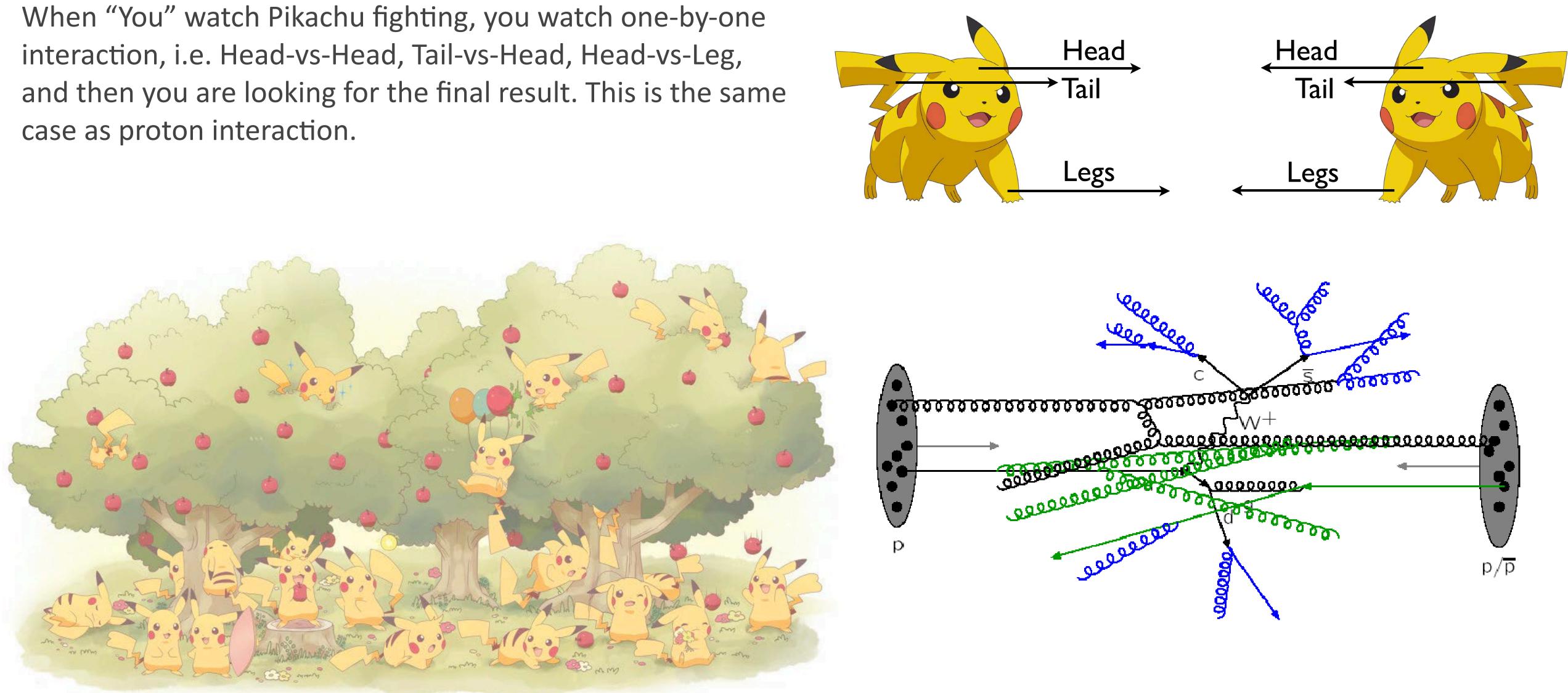
Proton

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





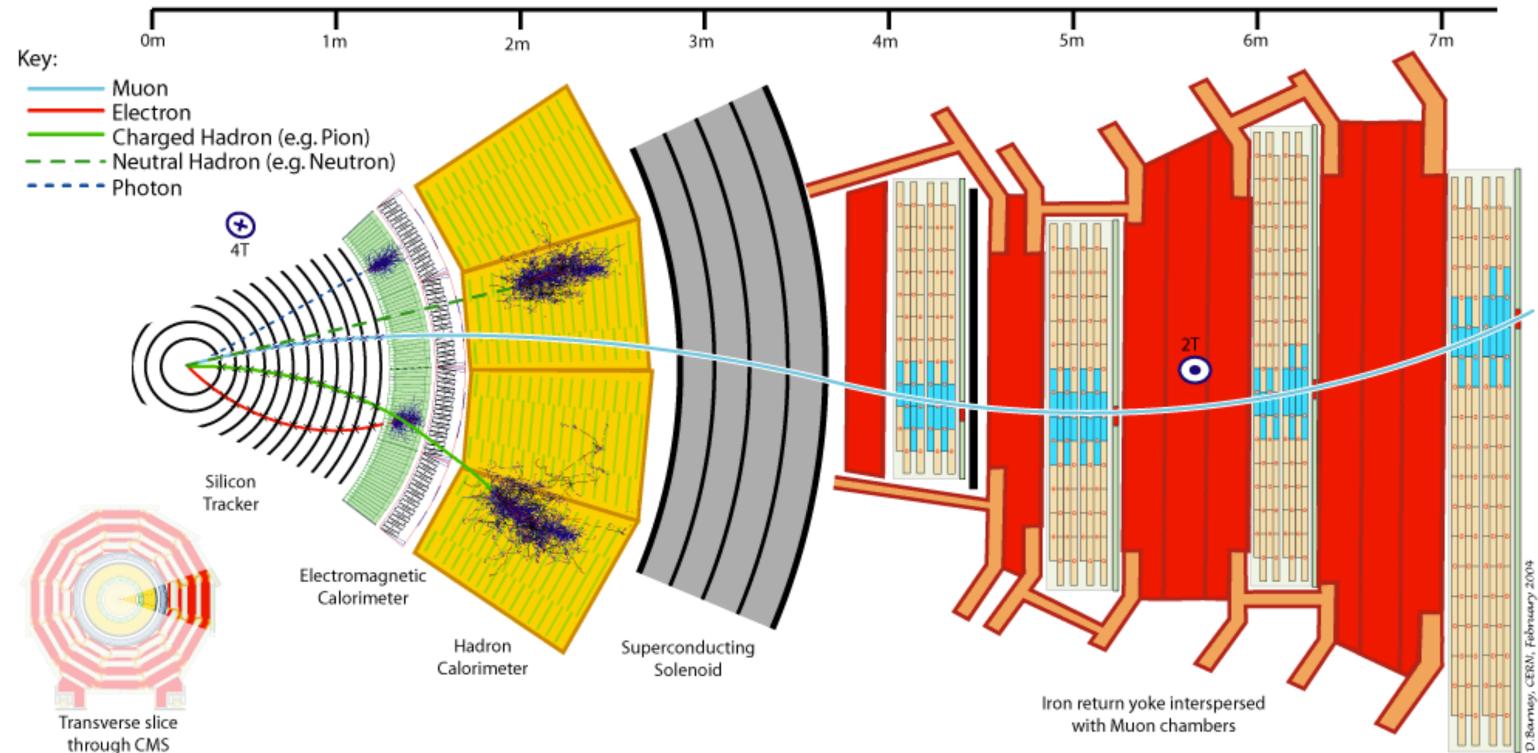
Particle detection

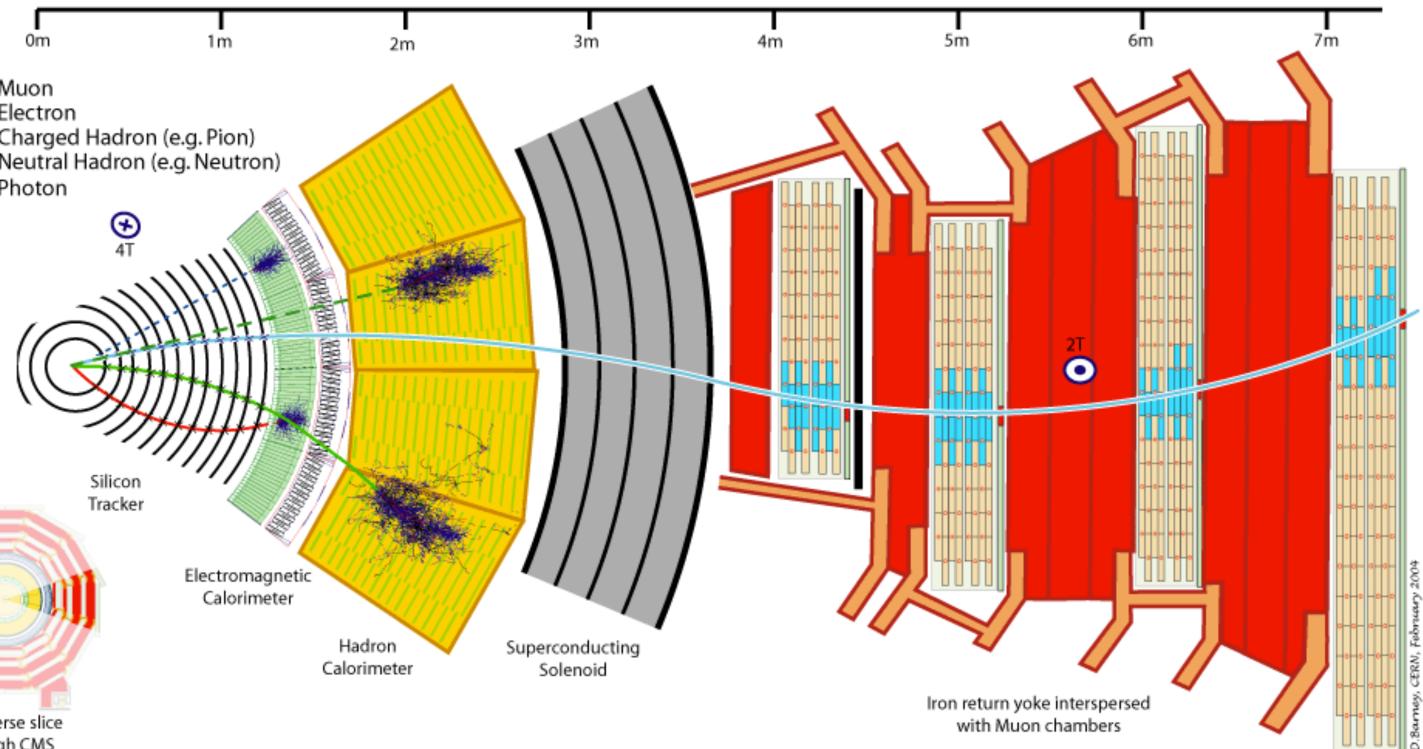
In experimental physics, a particle detector or radiation detector is an instrument used to detect, to track and to identify elementary particles by measuring one or more properties of them.

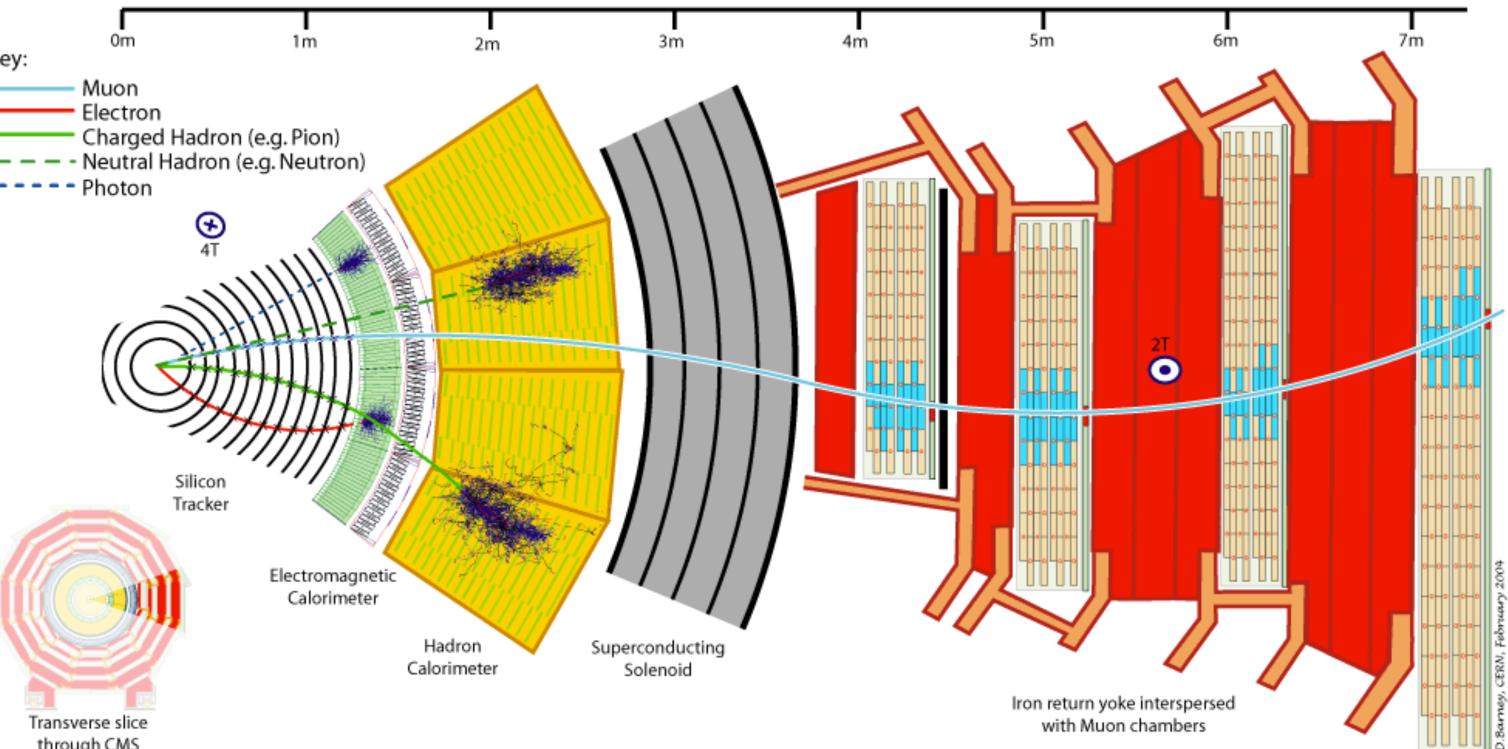
Particle detectors are devices producing an observable signal when they are crossed by a particle. Usually they are made by an active element (such that there is some interaction with the particle) and by a readout system ("forming" the signal and sending it to the data acquisition chain)

Aim: to detect as many of the stable and longlived 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

Energy gained or lost by a particle with the charge of one **electron** moving across the po tential difference of one **volt**.

ue to mass-energy equivalence, **J/c²** can be used to express mass an

=(pc²) +(mc²)²

62×10⁻³⁶ kg

e = charge of a single proton
 = smallest free electric charge
 ≠ color charge

The name of a Quark is called its flavour.

Spin is an intrinsic form of angular momentum carried by elementary particles, composite particles (hadrons), and atomic nuclei. It is similar to the angular momentum of classical mechanics, while having some significant deviations.

e. g.:

particles like **electrons** with no moment inertia also have a **spin**.

tions to reach their initial position.

some ways, spin is like a vector quantity; it as a definite magnitude, and it has a projecon of spin (quantization makes this different om the direction of an ordinary vector). The ojection of spin is always a multiple of **h**.

The spin can only be measured in 2s + 1 different directions, where s is the spin quantum number. Therefore, an electron with s = 1/2 nas only two possible directions, often referred to as up (or +) and down (or +).

reduced Planck constant **h** = 6,582 119 514 · 10 · 16 eV

Beta deca

ta decay is a form of radioactive decay. fast energetic electron or positron is called a ta ray. It only occurs among bound nucleons.

neutron breaks into a proton, ectron and an electron antine β decay

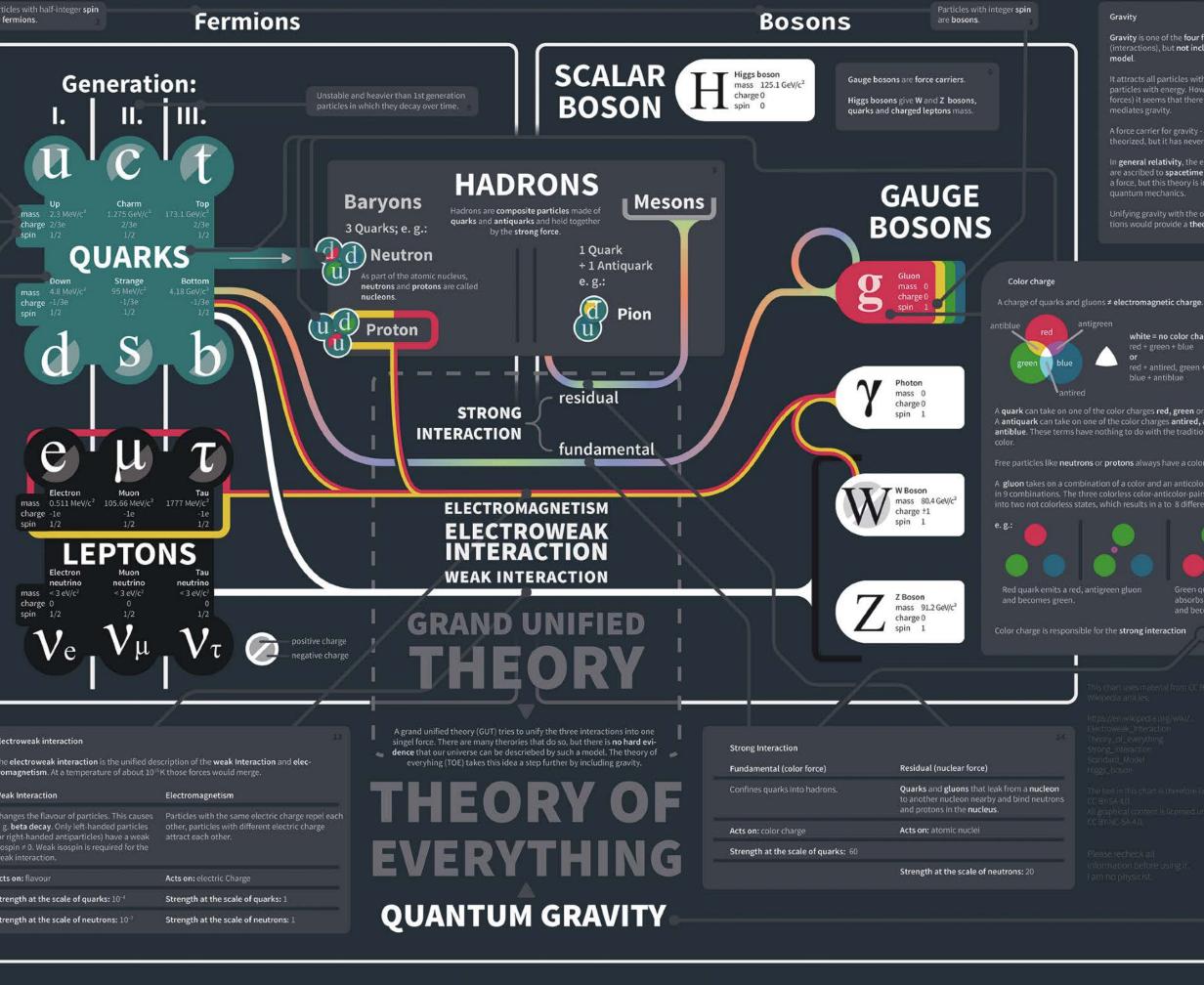
A proton breaks into a neutron, by er positron and an electron neutrino. = β* decay

positron is the antiparticle of the electron.

ion occurs.

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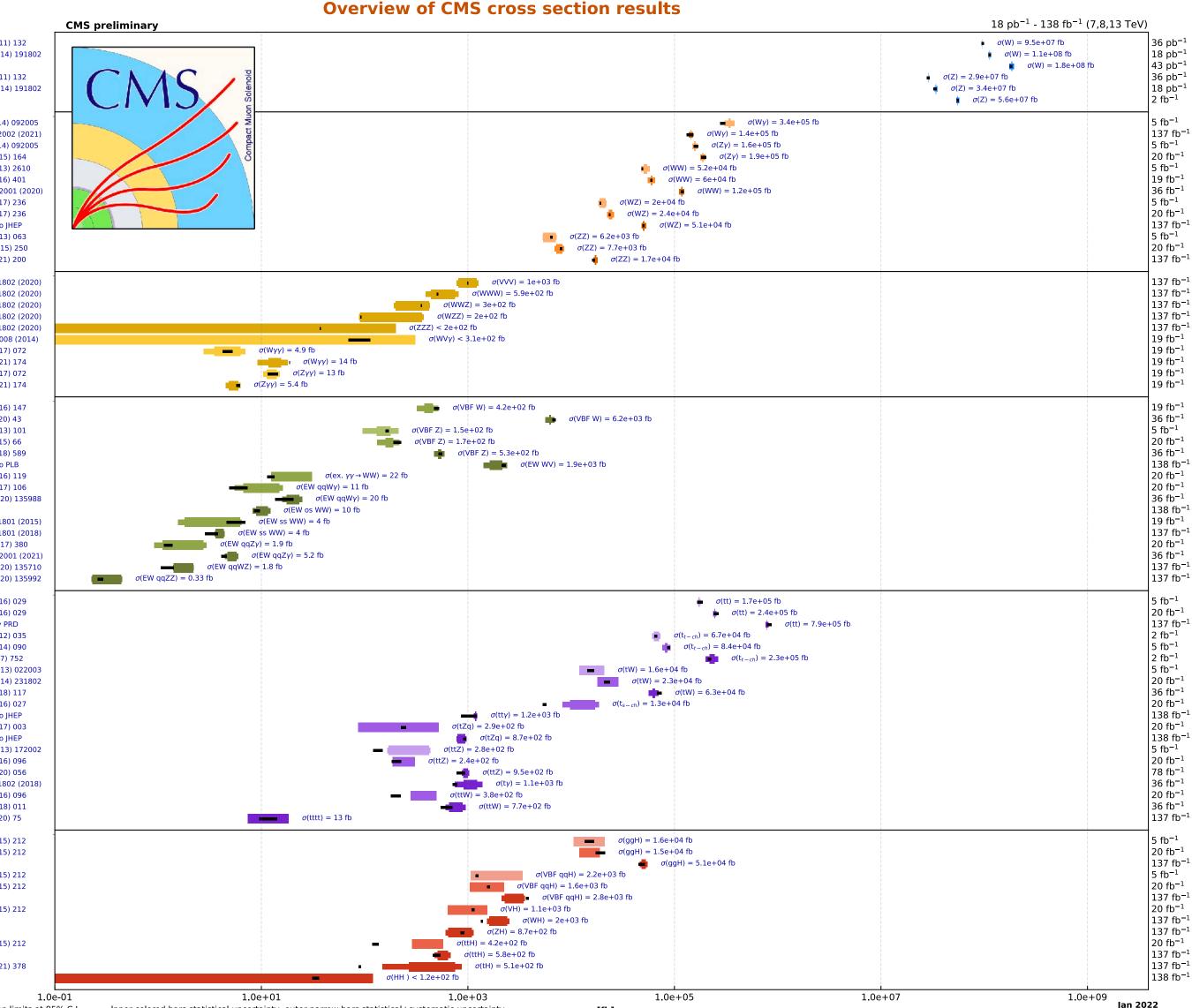
LHC with Standard Model

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

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Measured cross sections and exclusion limits at 95% C.L. See here for all cross section summary plots



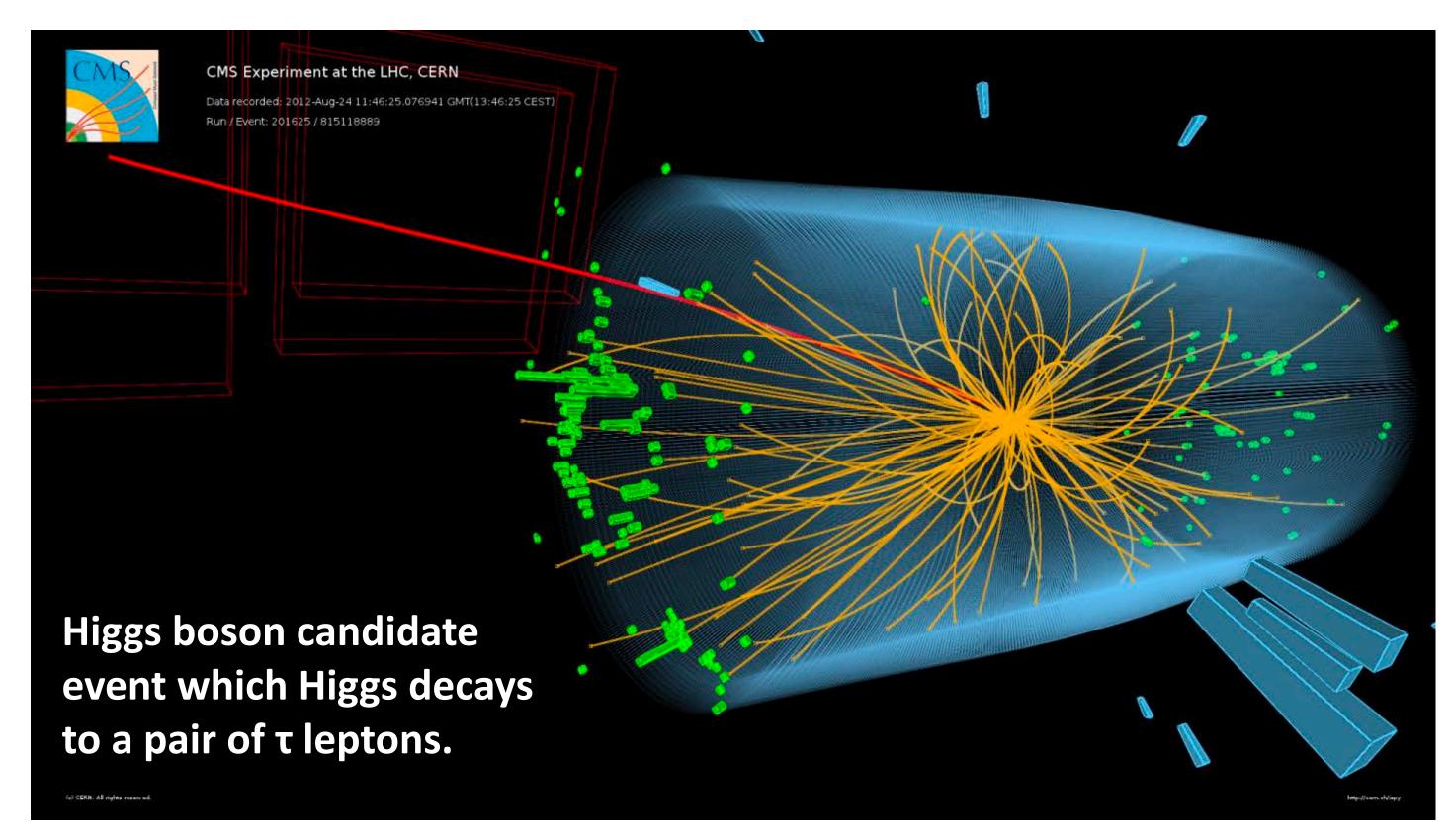
Inner colored bars statistical uncertainty, outer narrow bars statistical+systematic uncertainty σ [fb] Light colored bars: 7 TeV, Medium bars: 8 TeV, Dark bars: 13 TeV Black bar theory prediction



Mass of elementary particles?

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

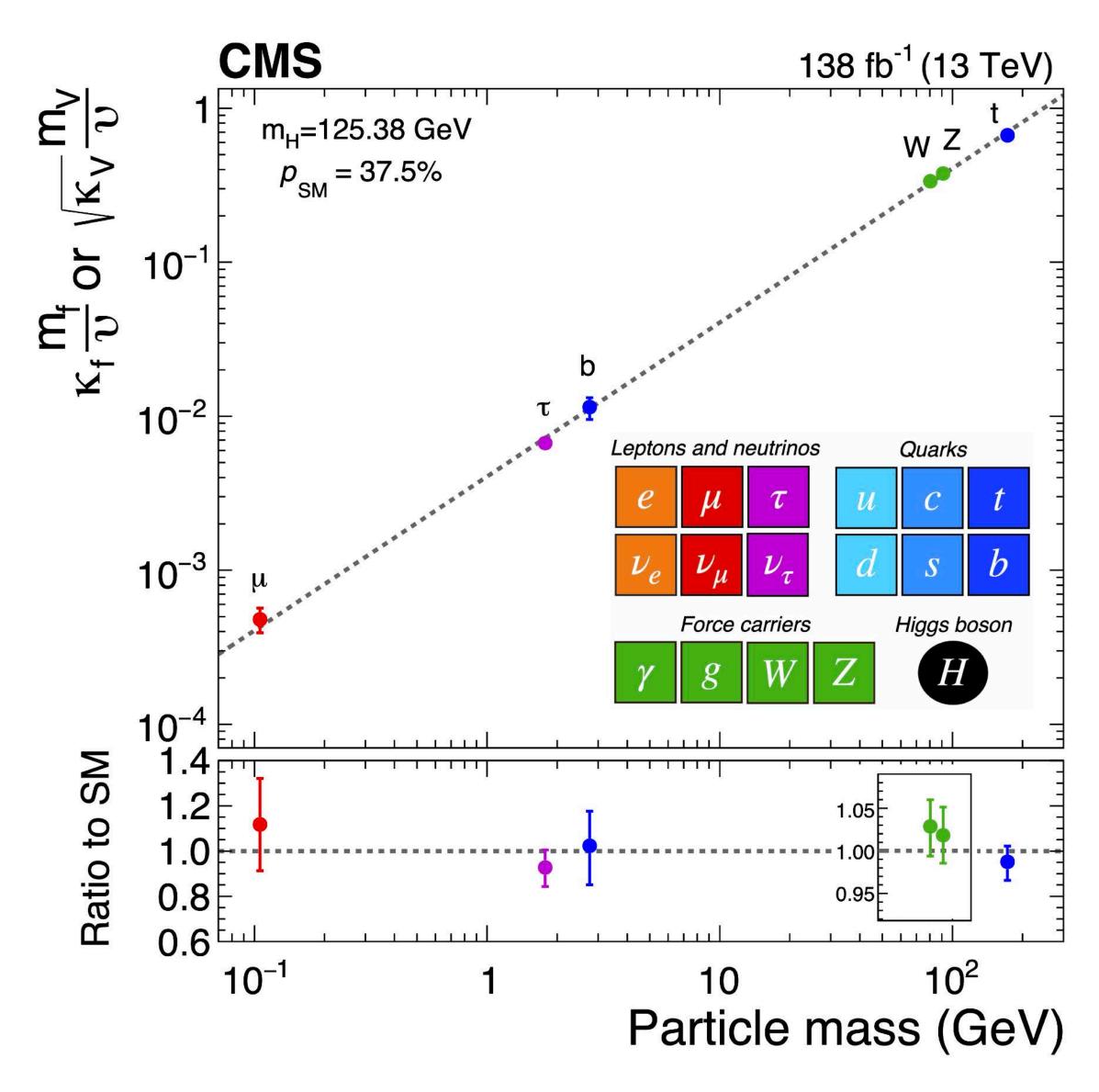
- by Robert Brout and François Englert [Phys. Rev. Lett. 13, 321];
- by **Peter Higgs** [Phys. Rev. Lett. 13, 508];
- by Gerald Guralnik, C. R. Hagen, and Tom Kibble [Phys. Rev. Lett. 13, 585].







Mass of elementary particles?



Phat SRIMANOBHAS (CU): Introduction to CERN and High Energy Particle Physics Programs [Part 2]



The Higgs boson is predicted to couple to particles (or decay into them) with a strength depending on their masses in a welldefined 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]

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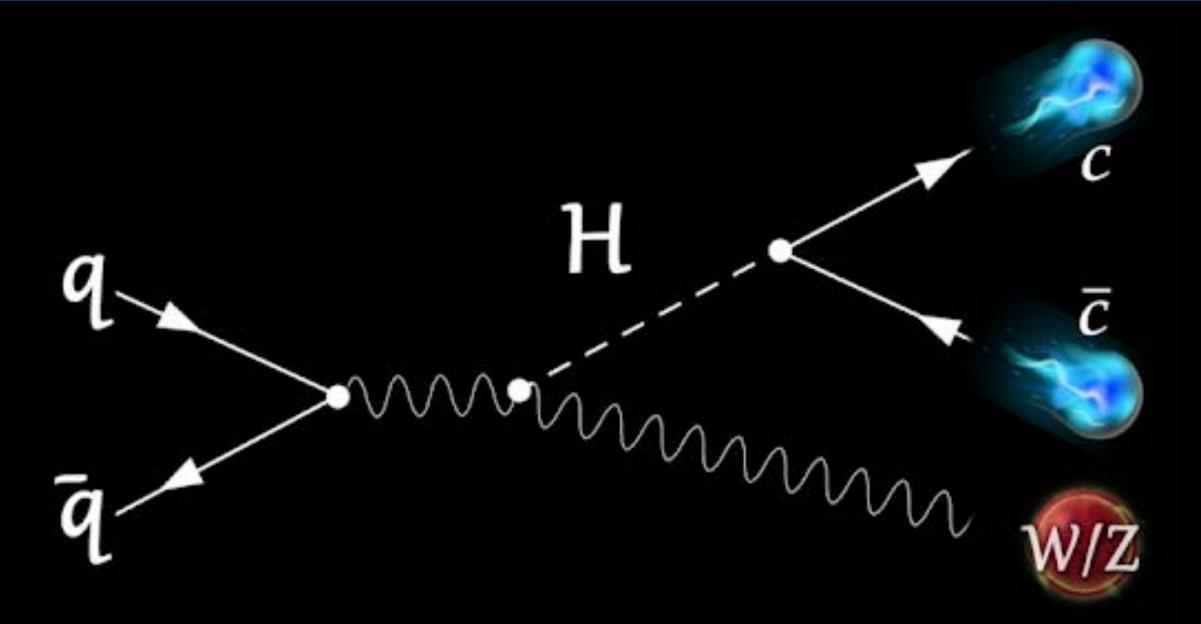
Higgs ... from search to precision measurement



CMS Experiment at the LHC, CERN Data recorded: 2018-Aug-05 09:43:33.747957 GMT Run / Event / LS: 320854 / 196048575 / 115

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.

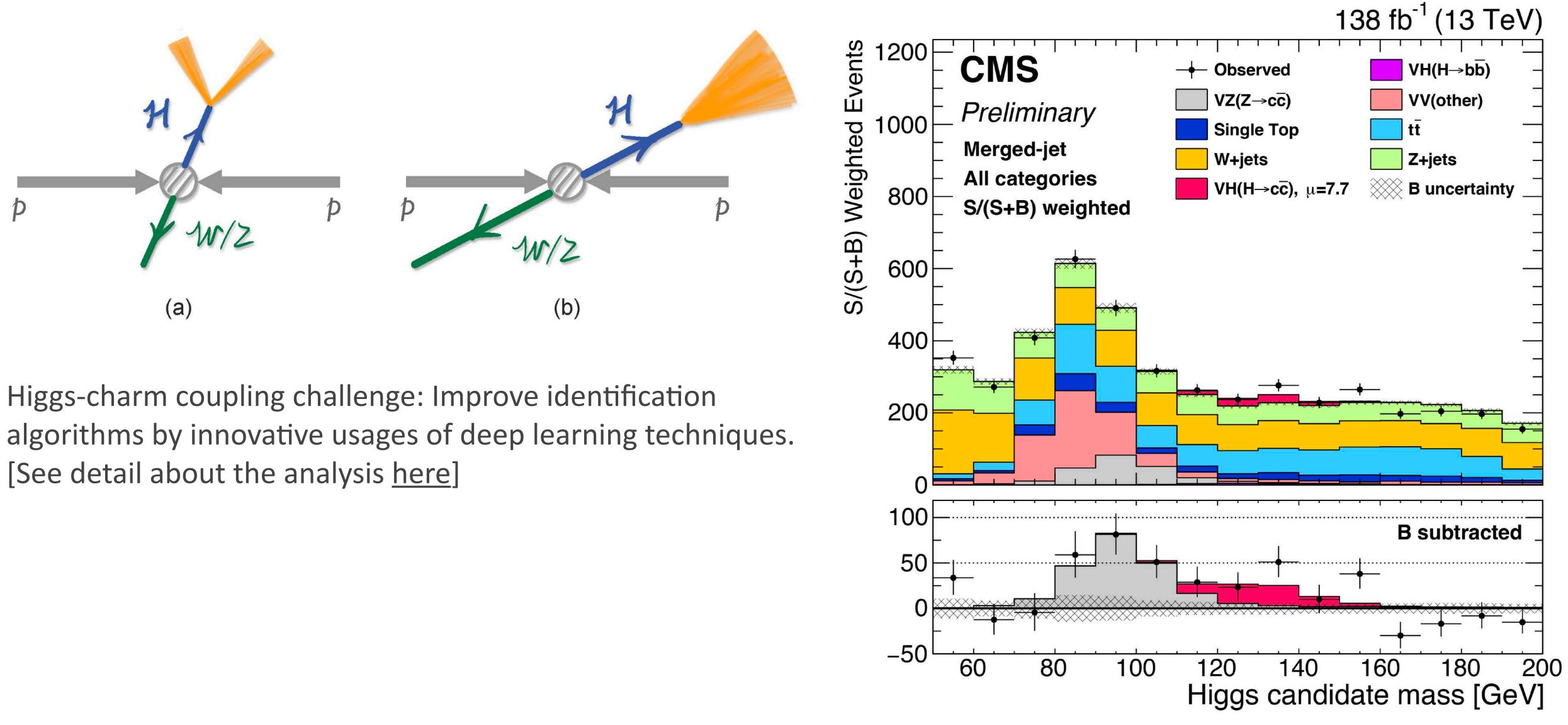








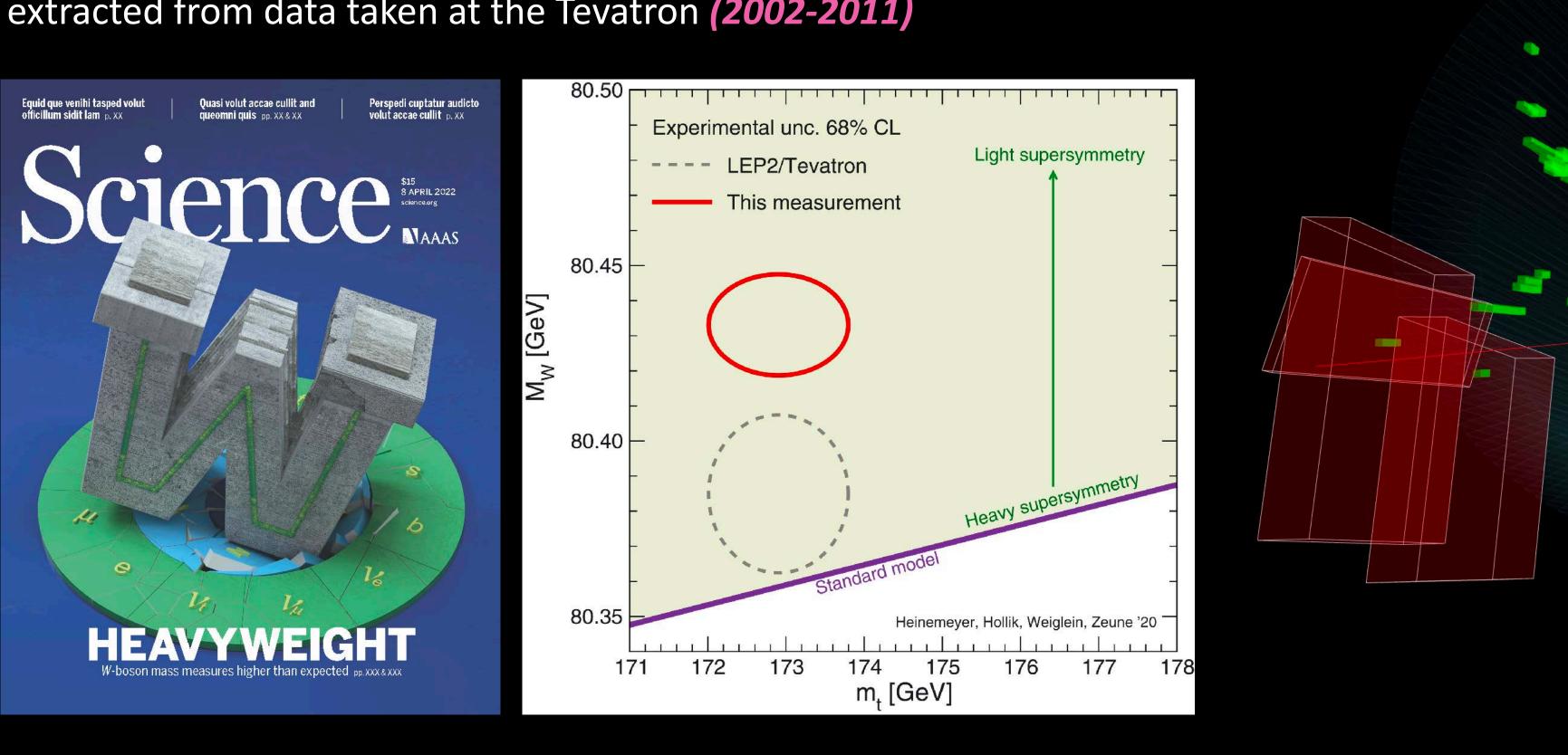
Higgs ... from search to precision measurement





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)



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

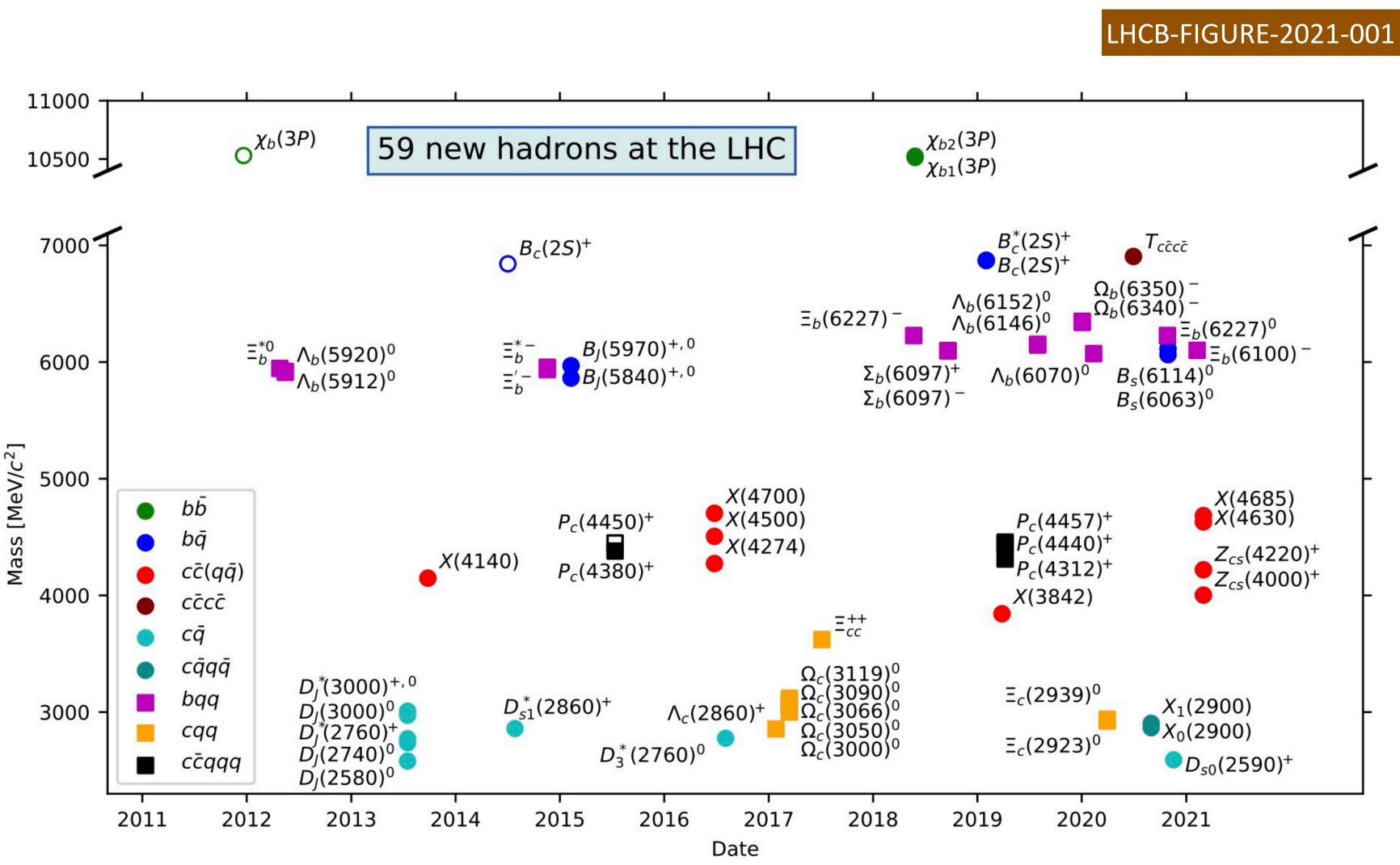


26

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

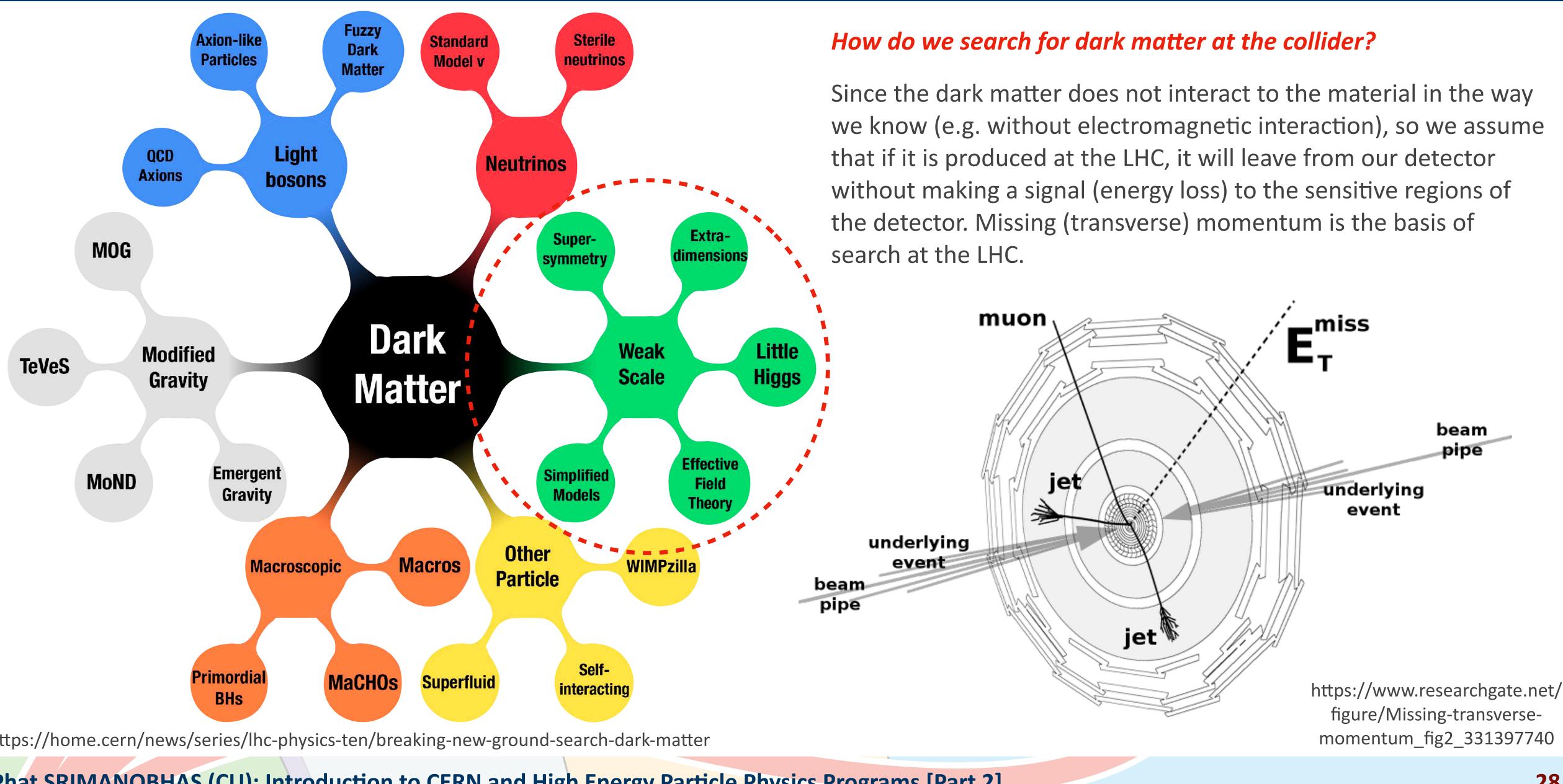
Quantum chromodynamics (or QCD) is still on very solid footing

- 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.





Exotic searches: Dark Matter searches at collider



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

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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

28

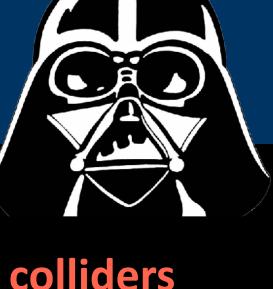
Exotic searches: Darth Vader Dark Matter



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

 $E_{\pi}^{miss} = 1.9 \text{ TeV}$ jet $p_{T} = 1.9 \text{ TeV}$

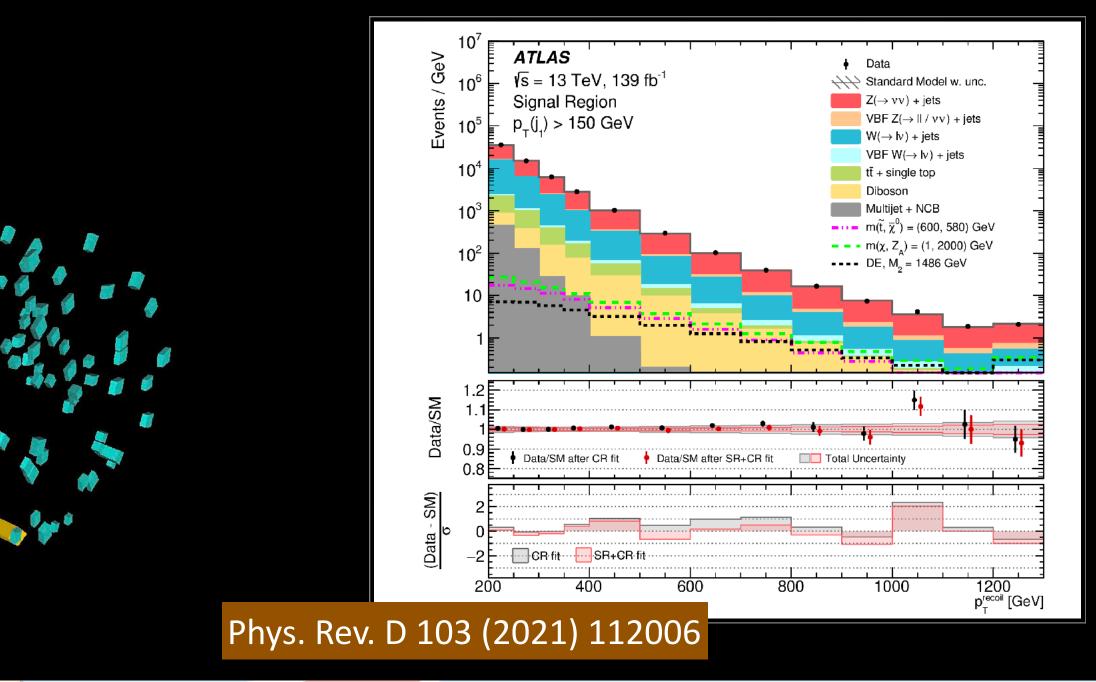




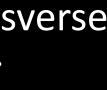
Type of DM-candidate events we study at the colliders

• 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









Exotic searches: Darth Vader Dark Matter

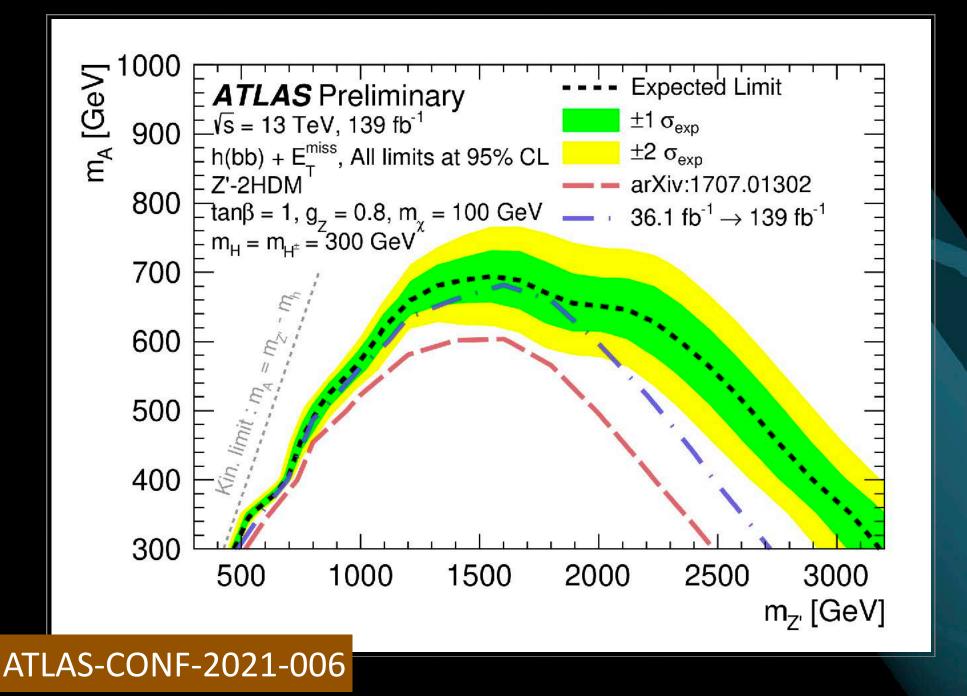


Type of DM-candidate events we study at the colliders

• two-Higgs-doublet model (2HDM)

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

• Example: extension with Z' then $Z' \rightarrow Ah; A \rightarrow DM+DM$



Phat SRIMANOBHAS (CU): Introduction to CERN and High Energy Particle Physics Programs [Part 2]

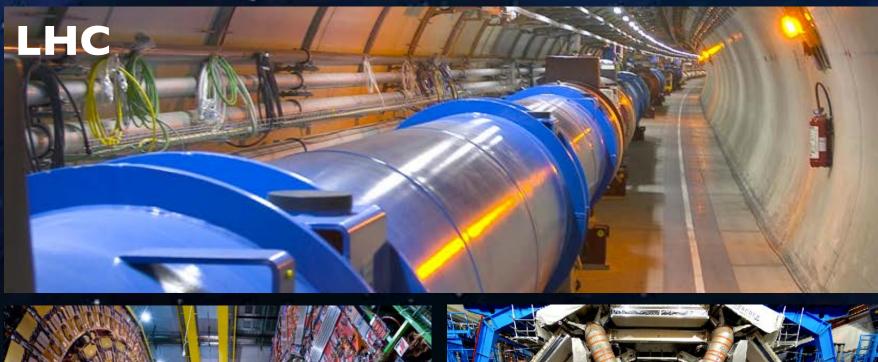


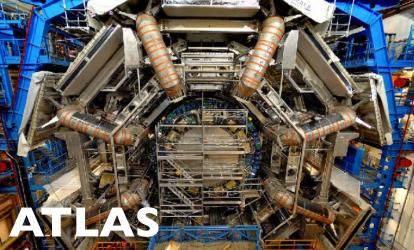


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Dark matter searches

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





Dark Matter-nucleus scattering COUPP

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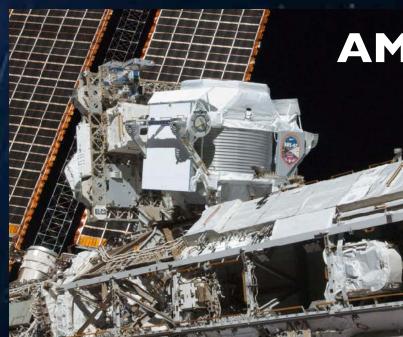
Collider

Observe DM annihilation products



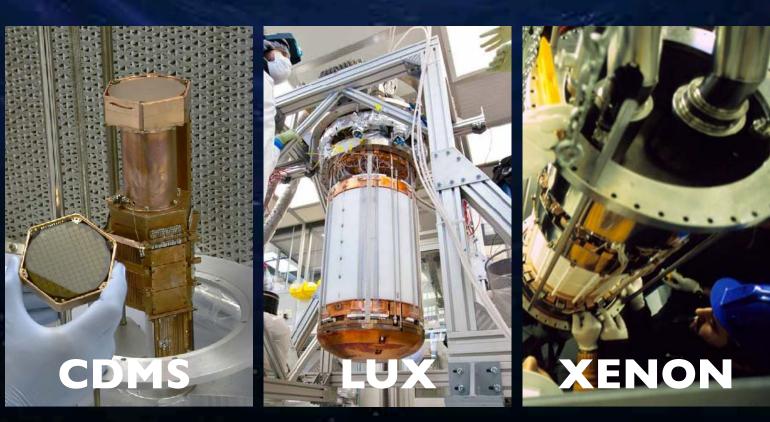


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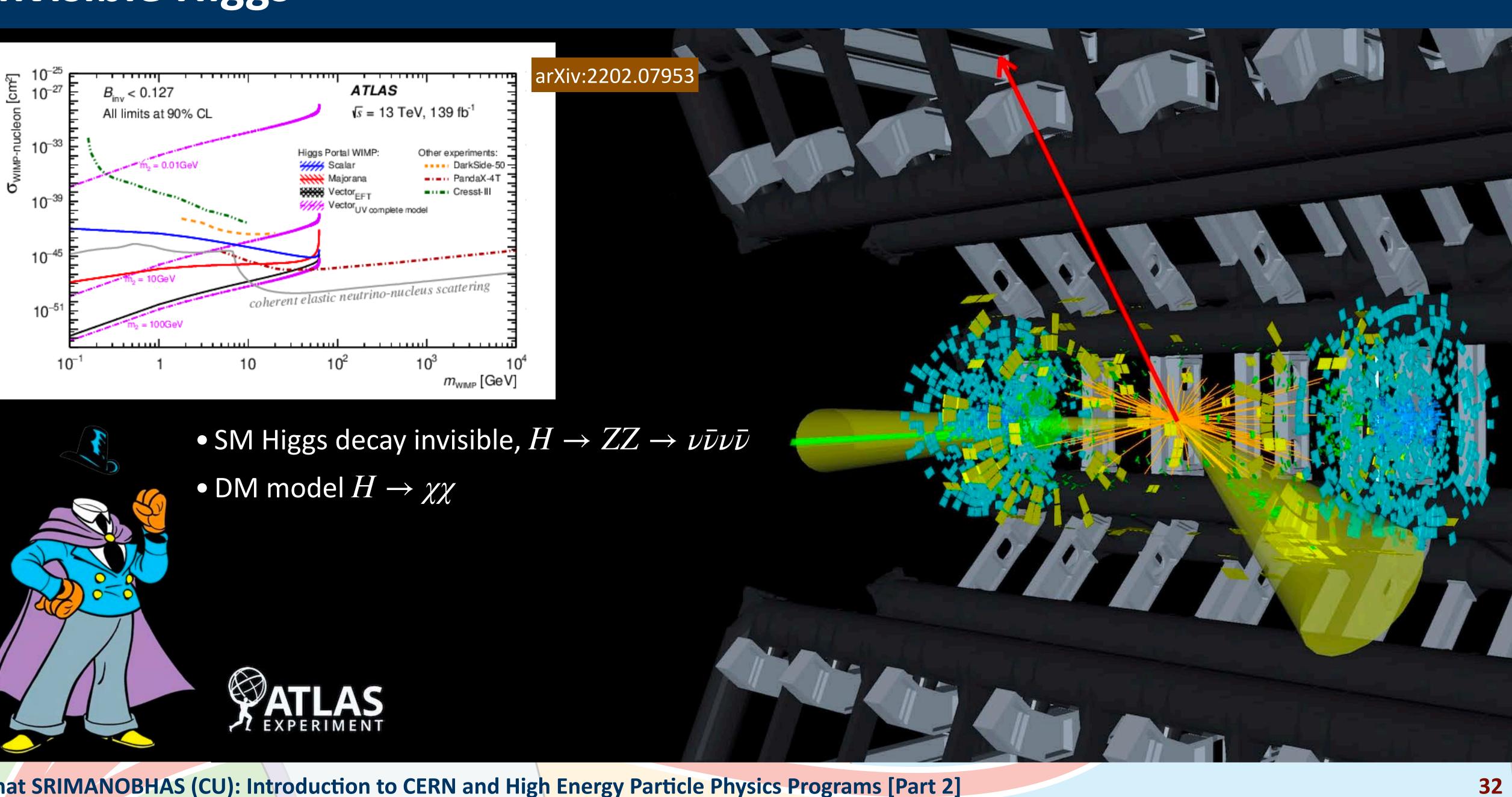


Indirect detection

Direct detection



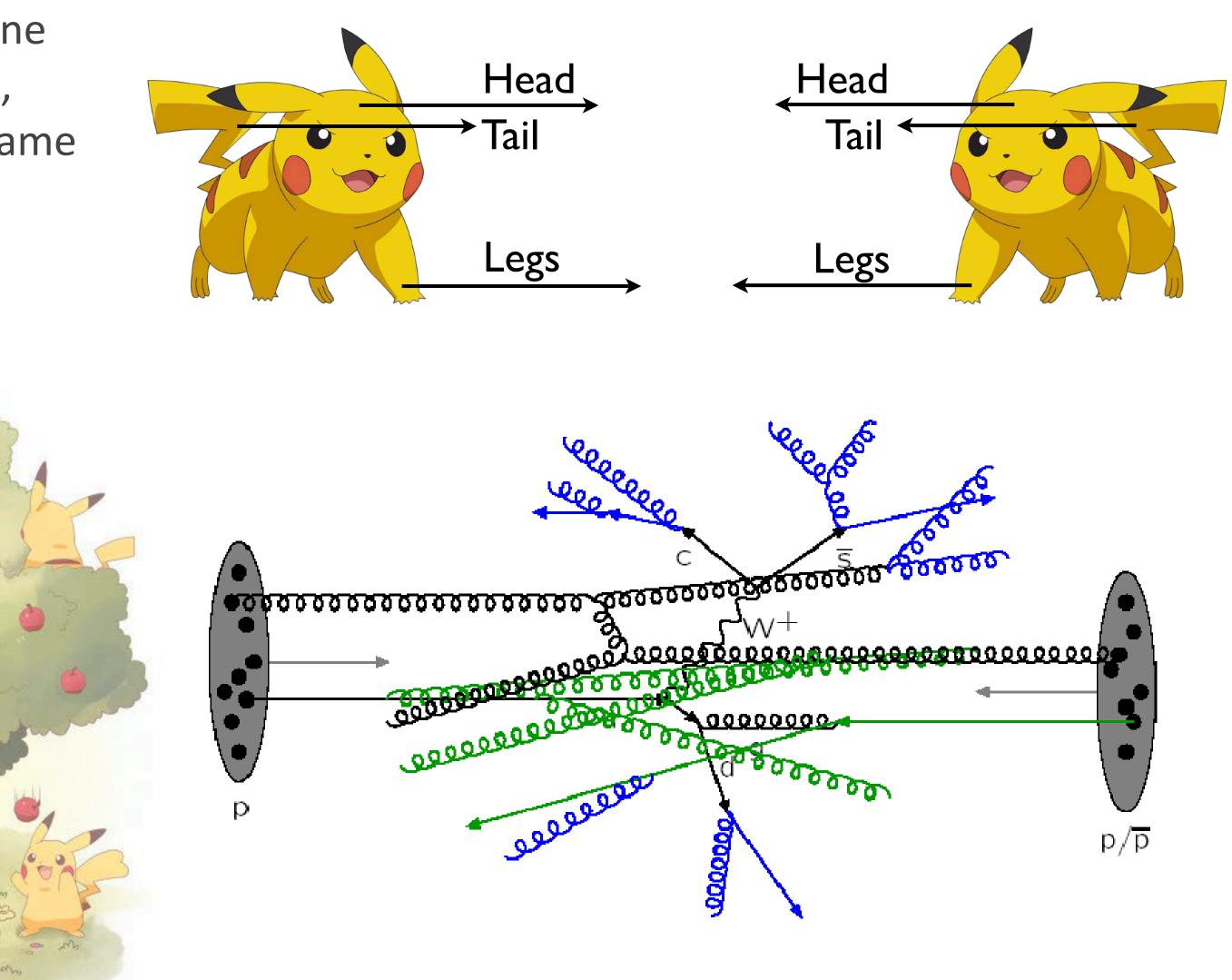
Invisible Higgs





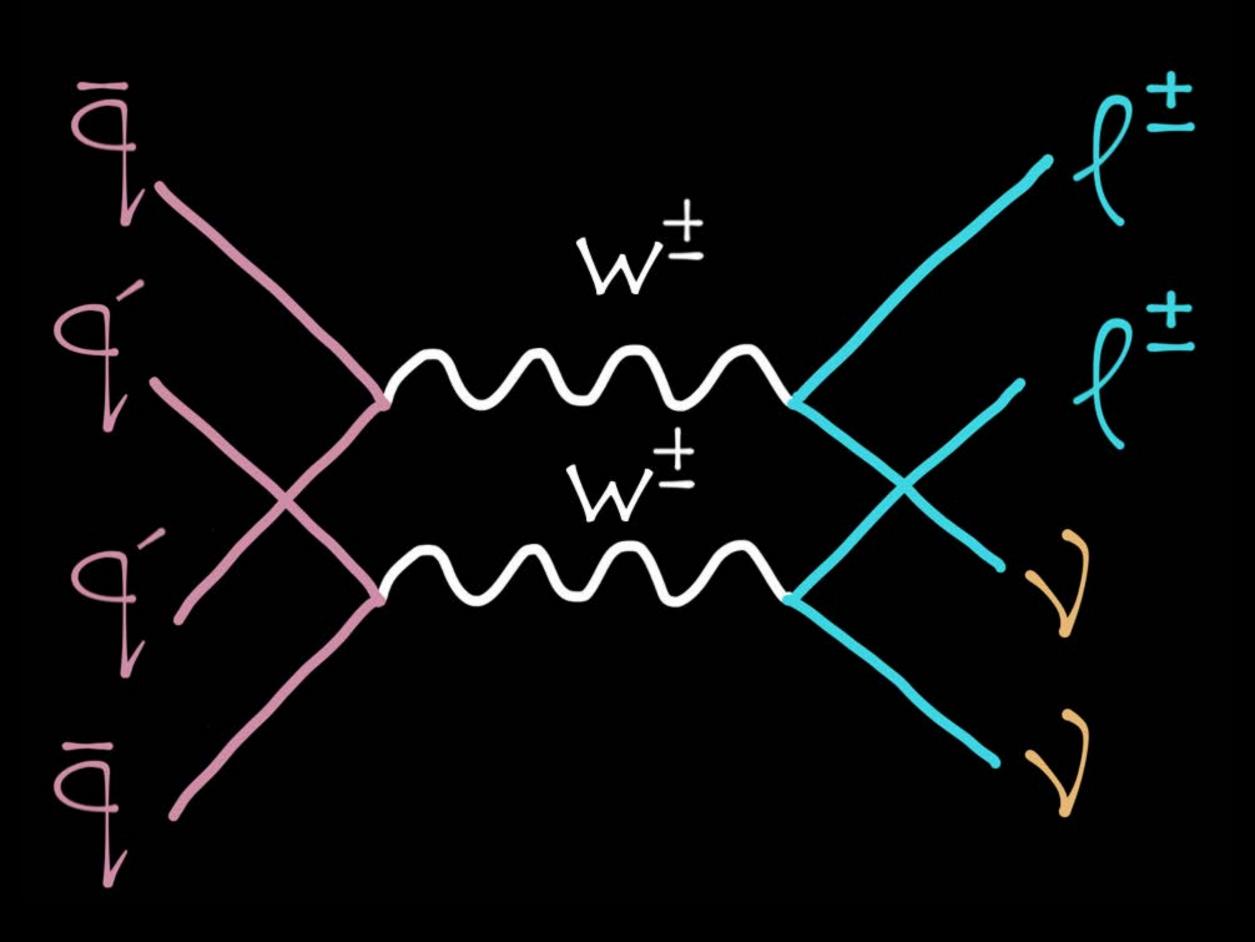
Proton collision

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



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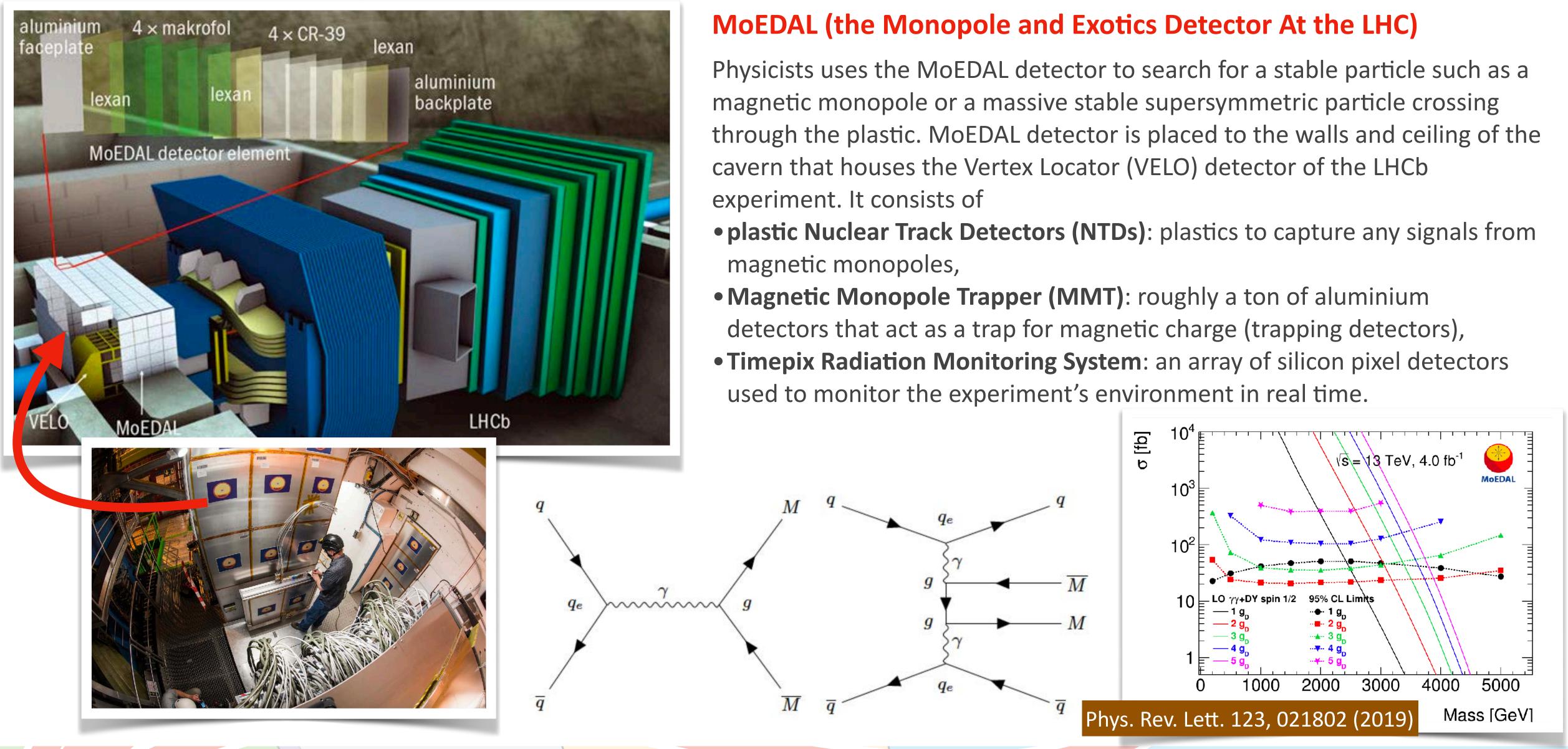


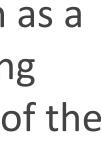
CMS Experiment at the LHC, CERN Data recorded[,] 2017-Nov-10 10:58:32 136704 GMT Run / Event / LS: 306459 / 2221501824 / 2004





Small experiments but big Physics potentials at the LHC



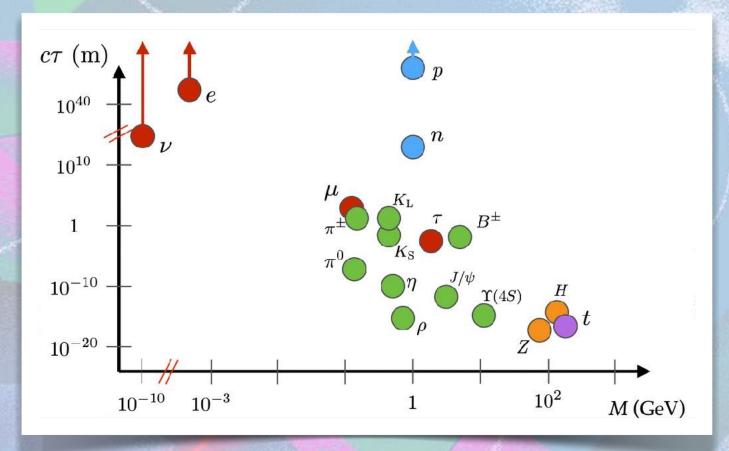




Exotic searches: Long-lived particles

When produced particles will not decay immediately ...

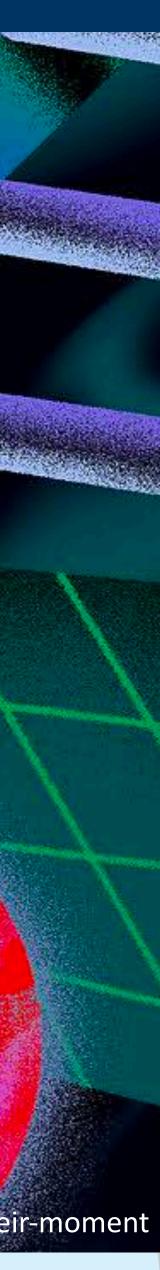
In high energy particle physics experiments, physicists often assumes that new massive particles produced in particle collisions would decay immediately, closed to their points of origin, e.g. Higgs boson. However, we also know that there are particles which have long lifetimes, e.g. muons which can 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?

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



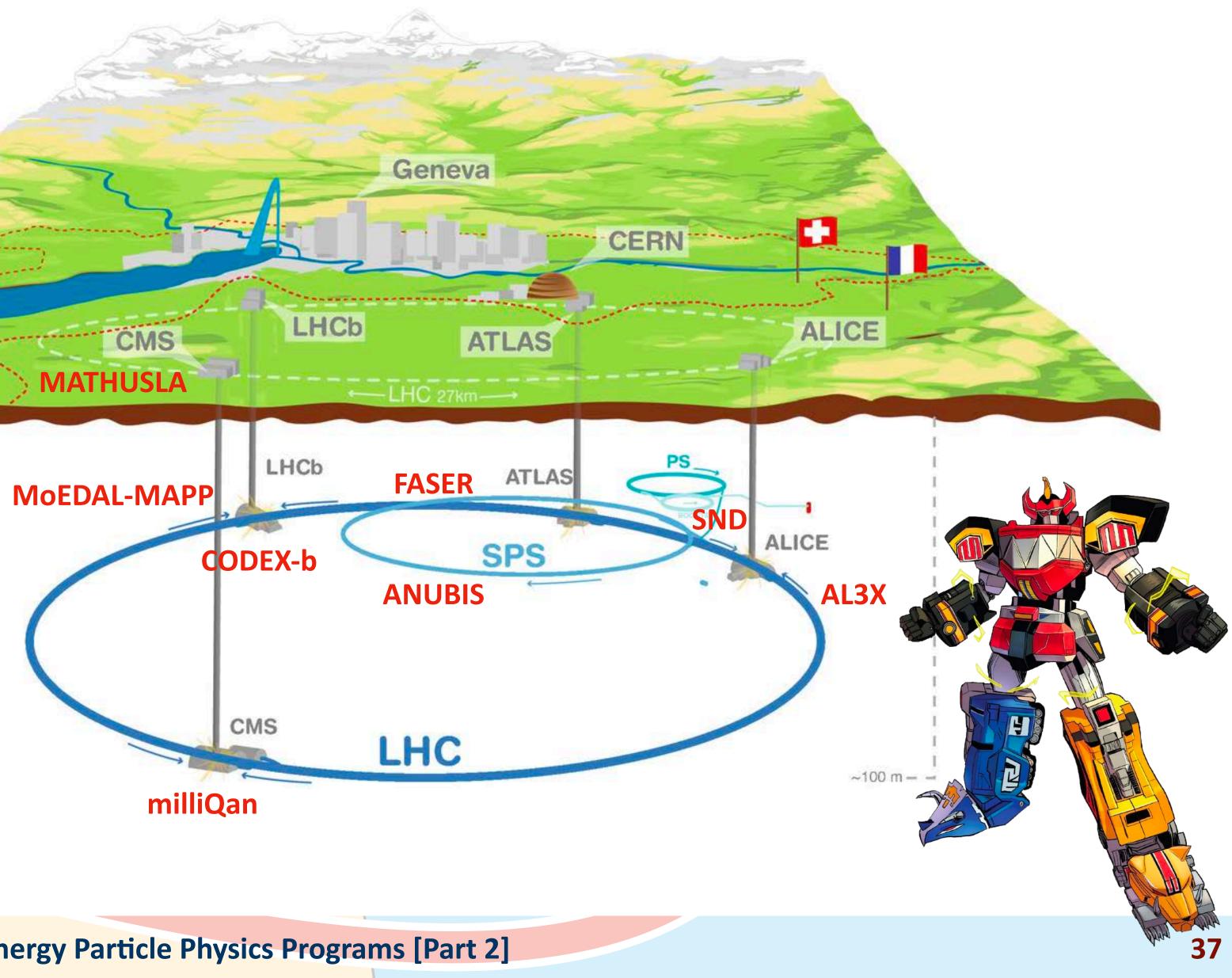


Power Detector Rangers: To search for Long-lived particles

Several small experiments around LHC to search for LLPs

- FASER (Approved): with a volume of ~1 m³ will be installed 480 m downstream from the ATLAS interaction point
- MATHUSLA: large scale surface detector instrumenting ~8×10⁵ m³ above ATLAS or CMS
- **CODEX-b**: ~10³ m³ detector to be installed in the LHCb cavern
- AL3X to use a cylindrical ~900 m³ 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

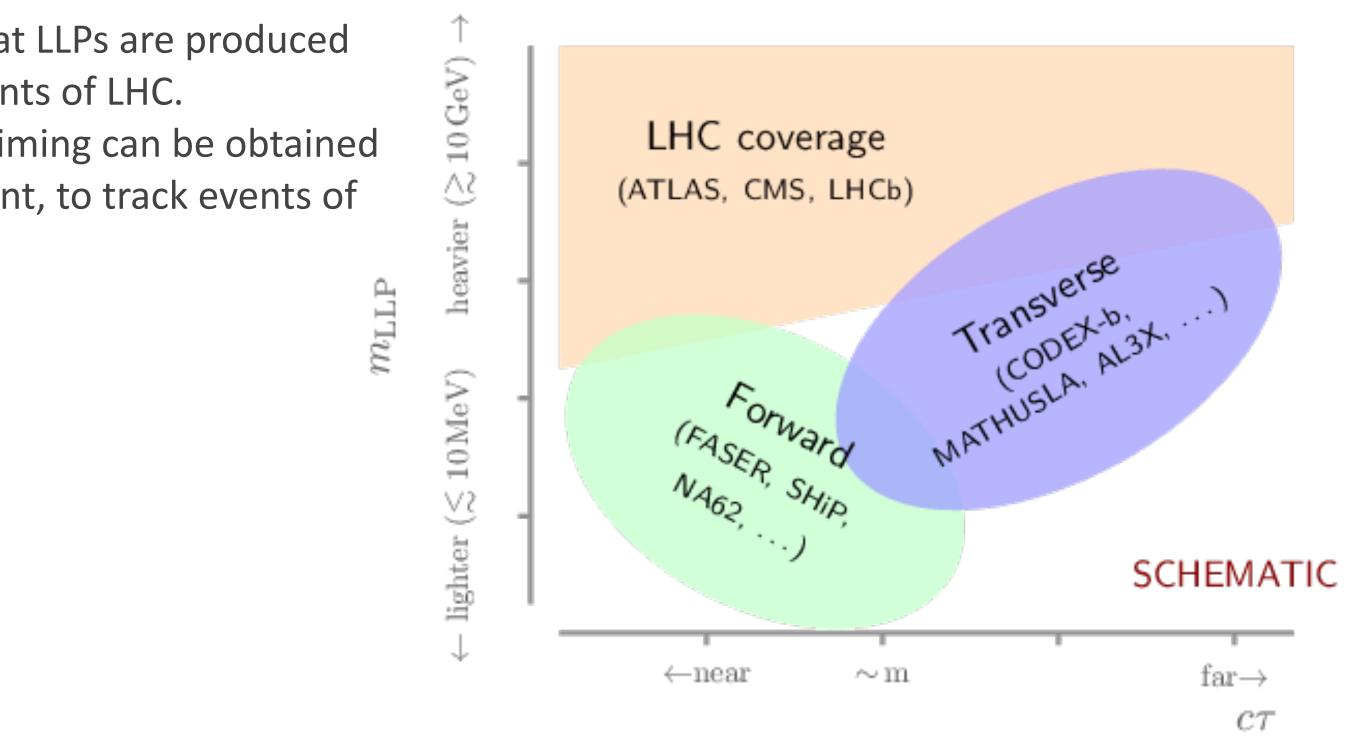


Why do we need detector rangers to search for LLP?

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)



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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 Scinti. Scinti. 0.5T magnet Scinti. 0.5T magnet 0.5T magnet Decaying to e⁺e⁻ pair Tracker Calorimeter Tracker Tracker LHC tunnel charged particles (P<7 TeV) forward jets neutrino, dark photon LHC magnets 100 m of rock p-p collision at IP 480 m



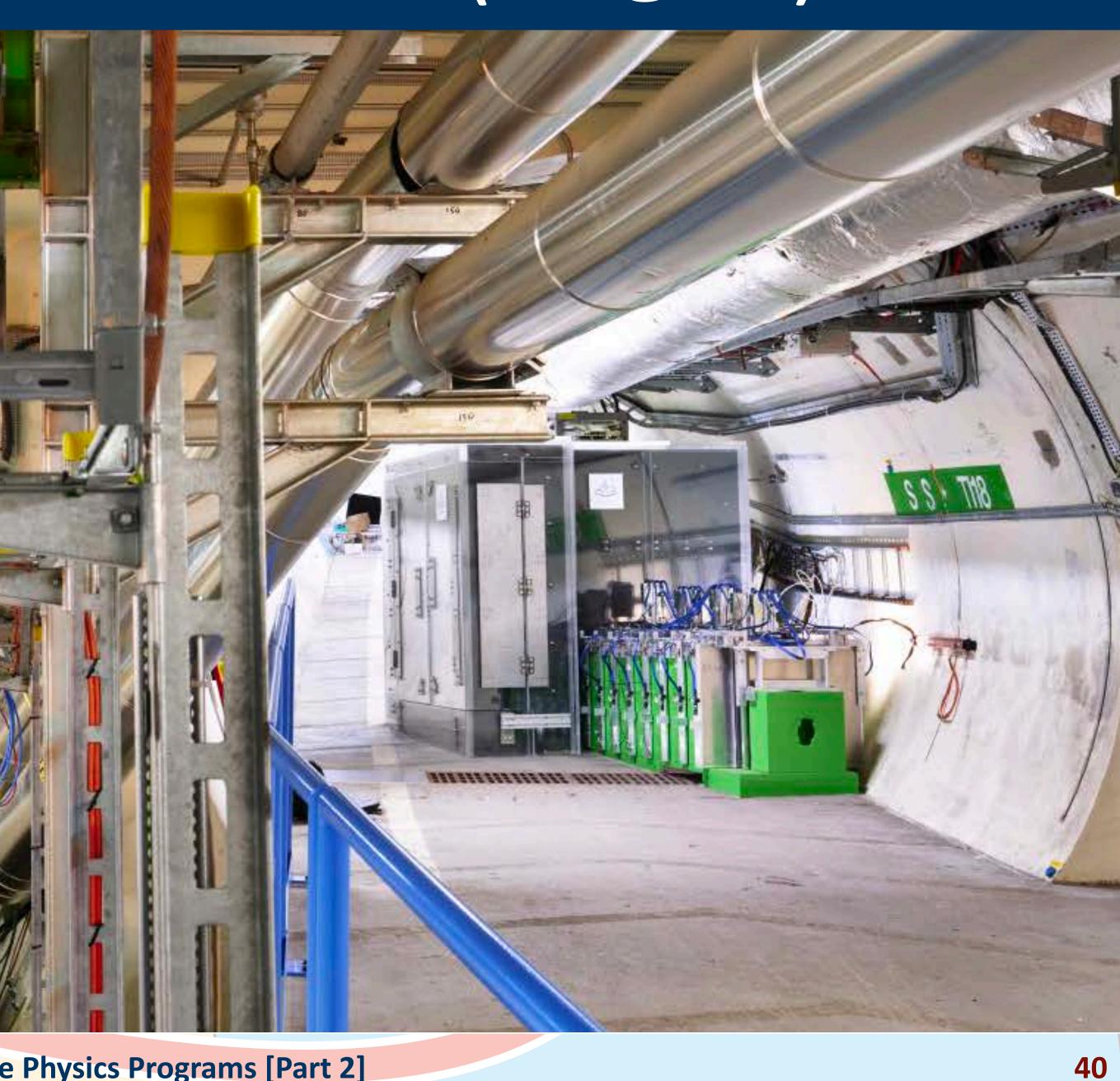




The Scattering and Neutrino Detector at the LHC (SND@LHC)

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.

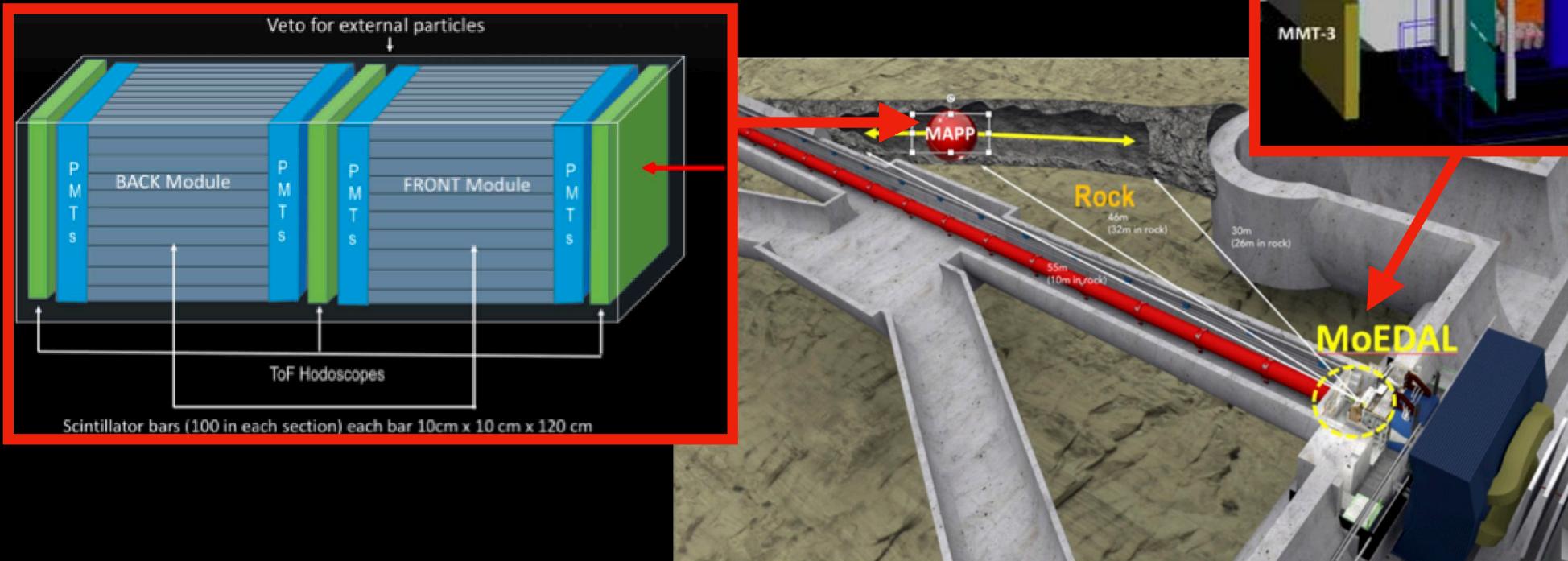
SND@LHC consists of a neutrino target followed downstream by a device to measure the neutrino energy and to detect muons (the heavier cousins of electrons) that are produced when neutrinos interact with the target.

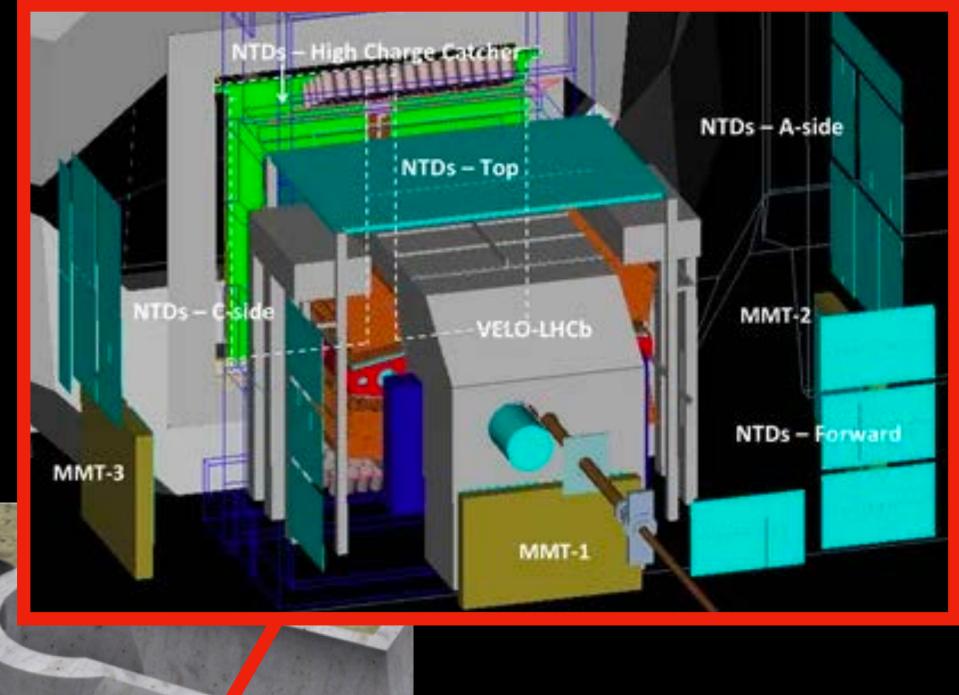


MoEDAL Apparatus for Penetrating Particles (MAPP)

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





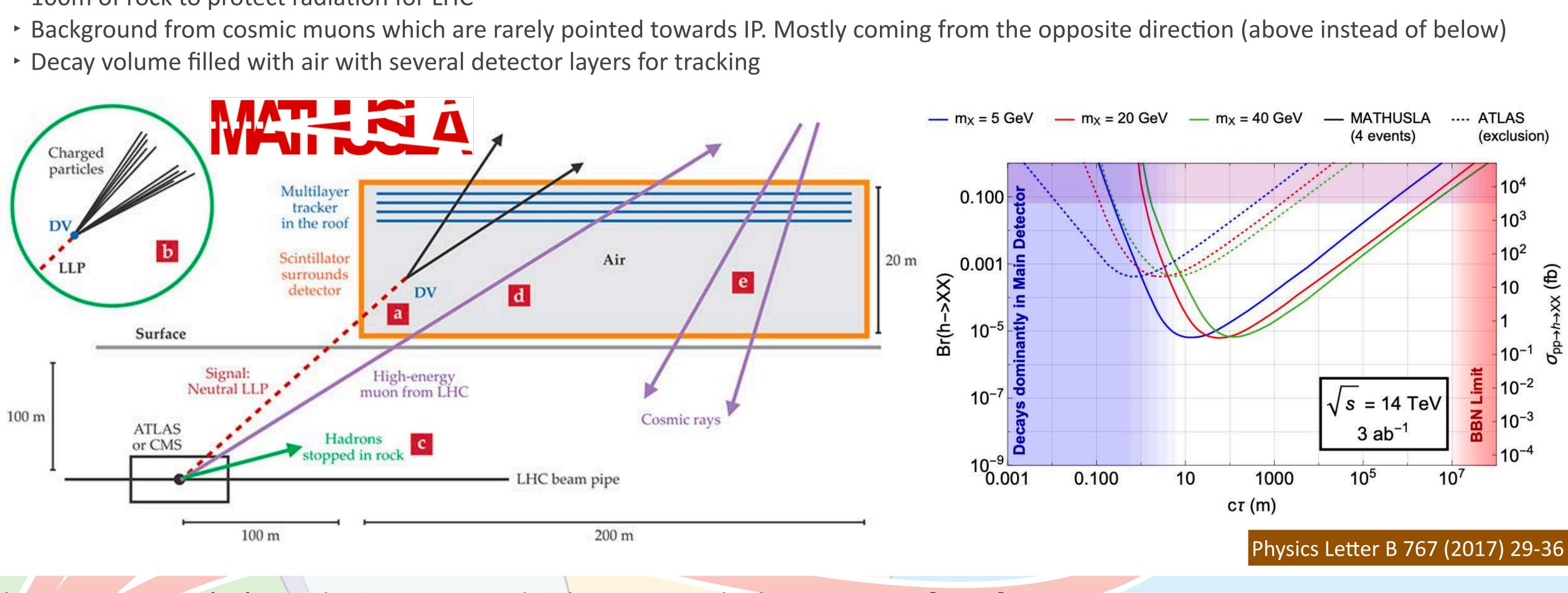


MAssive Timing Hodoscope for Ultra-Stable neutral pArticles (MATHUSLA)

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:

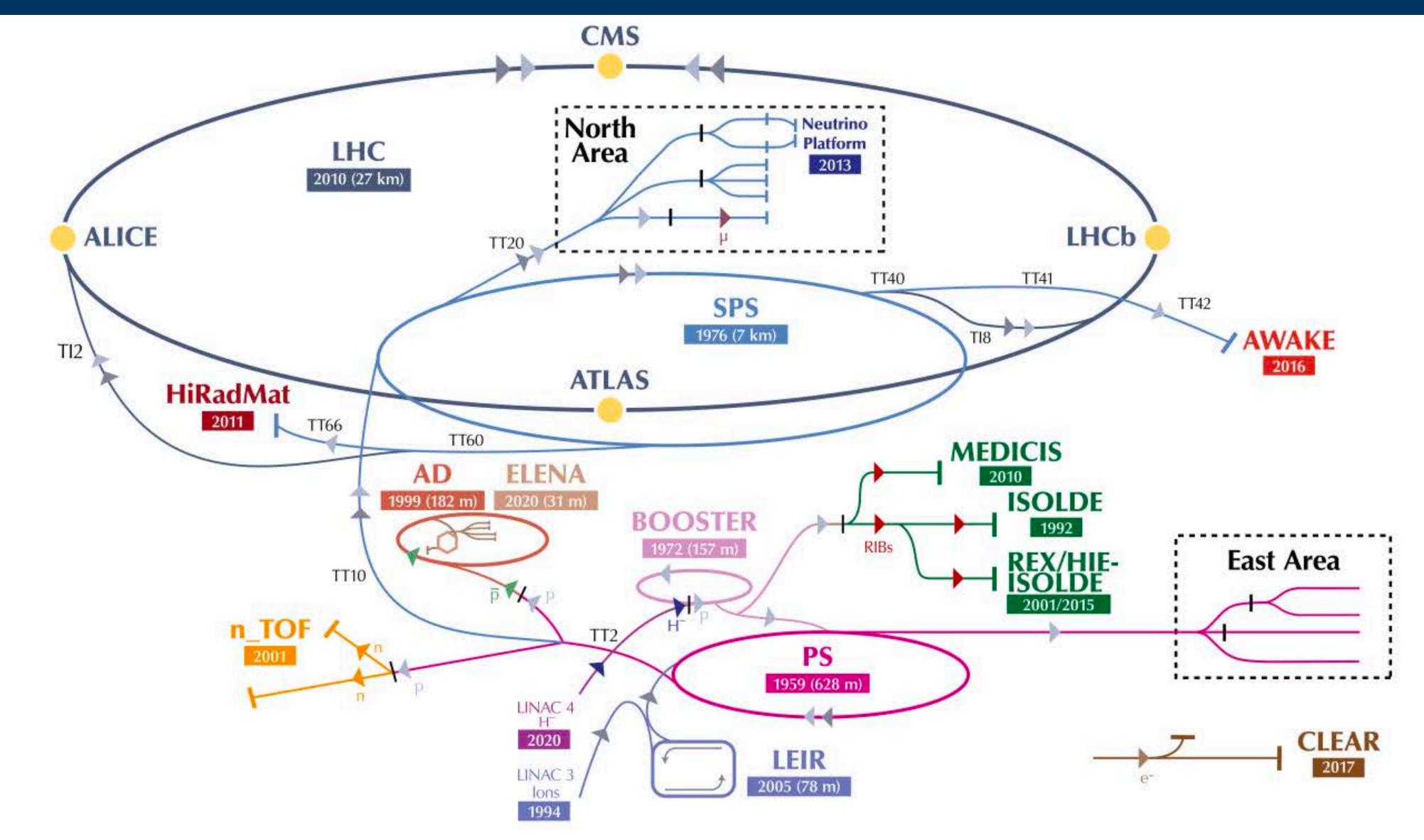
- No additional tunnel
- 100m of rock to protect radiation for LHC







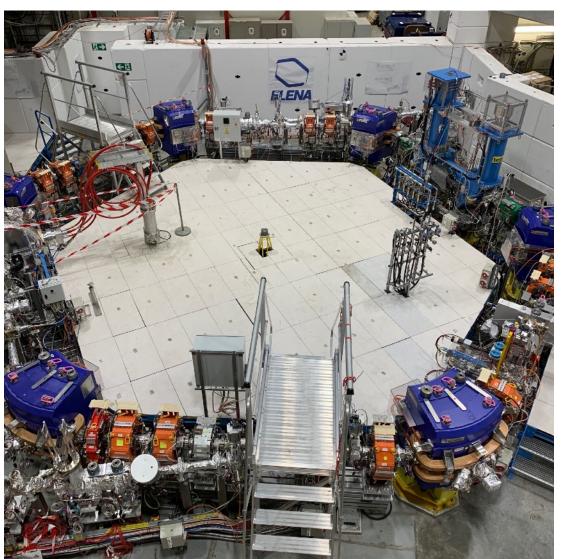
CERN accelerator complex: Not only LHC





Not only accelerate, but also decelerate



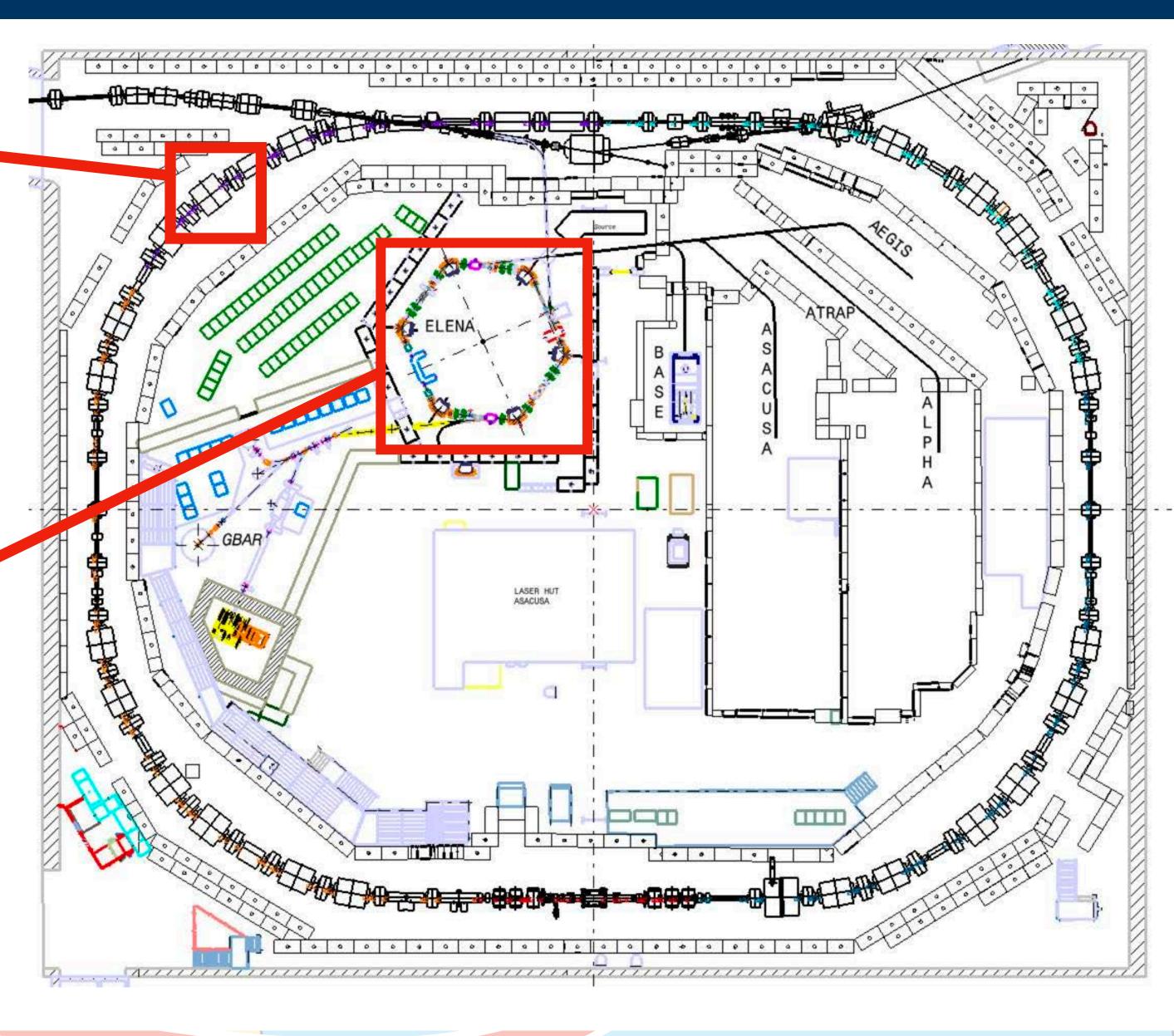


Antiproton Decelerator (AD)

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



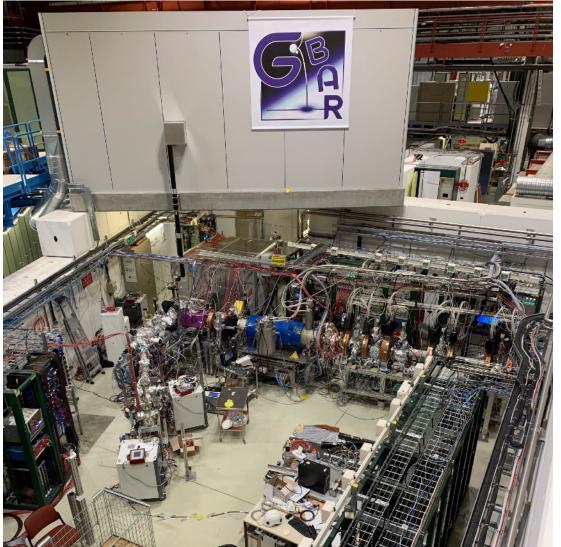


To study anti-matter



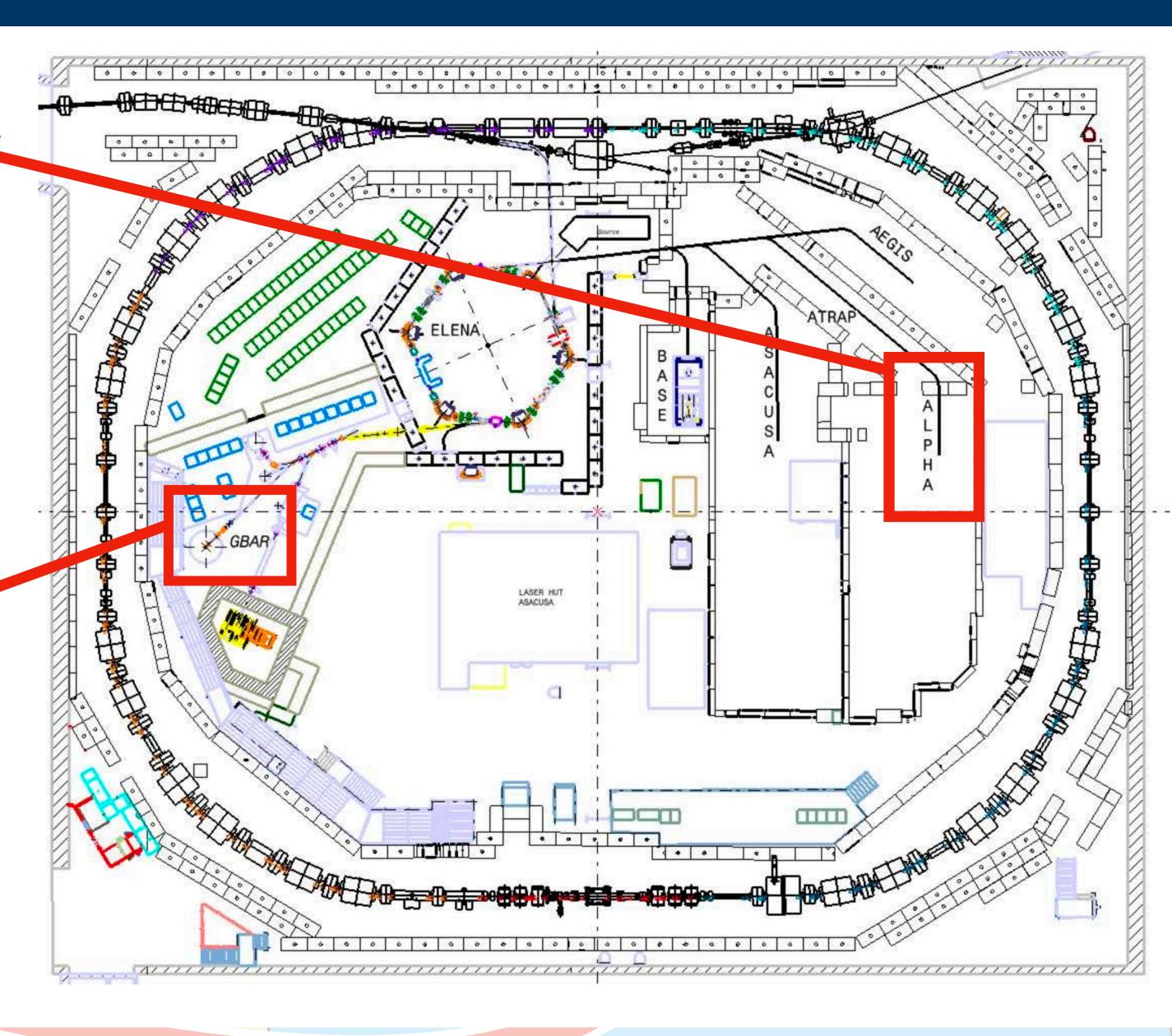
Antihydrogen Laser Physics Apparatus 🔫 (ALPHA)

create, capture and then cool antihydrogen to use for experiment



Gravitational **Behaviour of Antimatter at Rest** (GBAR)

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





To study links between cosmic rays and cloud formation

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CLOUD

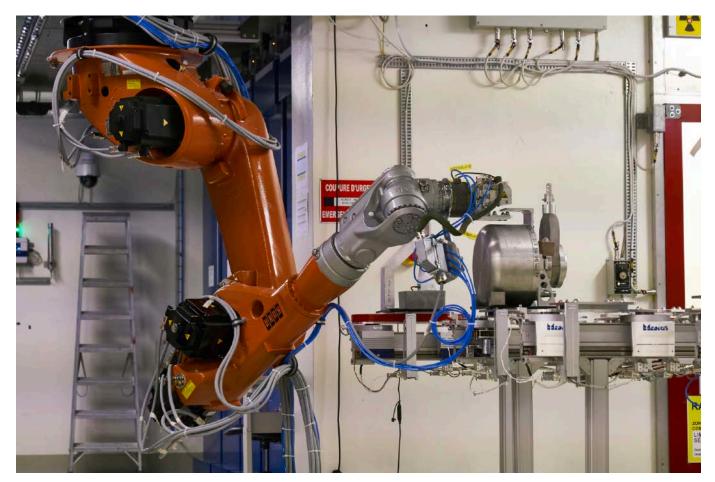
Could there be a link between galactic cosmic rays and cloud formation? An experiment at CERN is using the cleanest box in the world to find out.





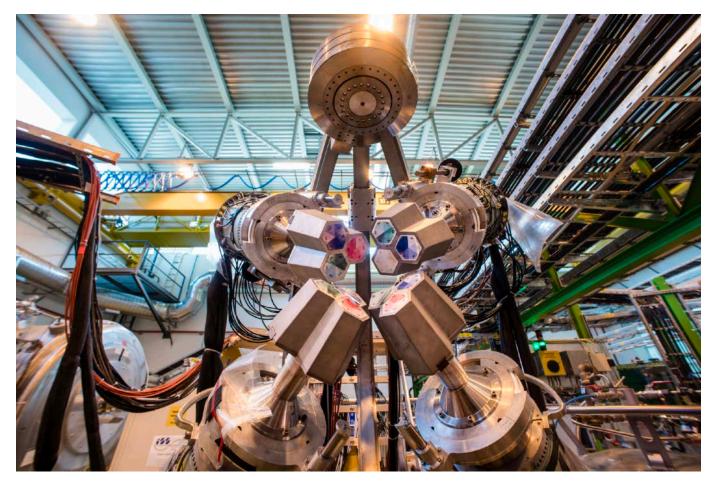


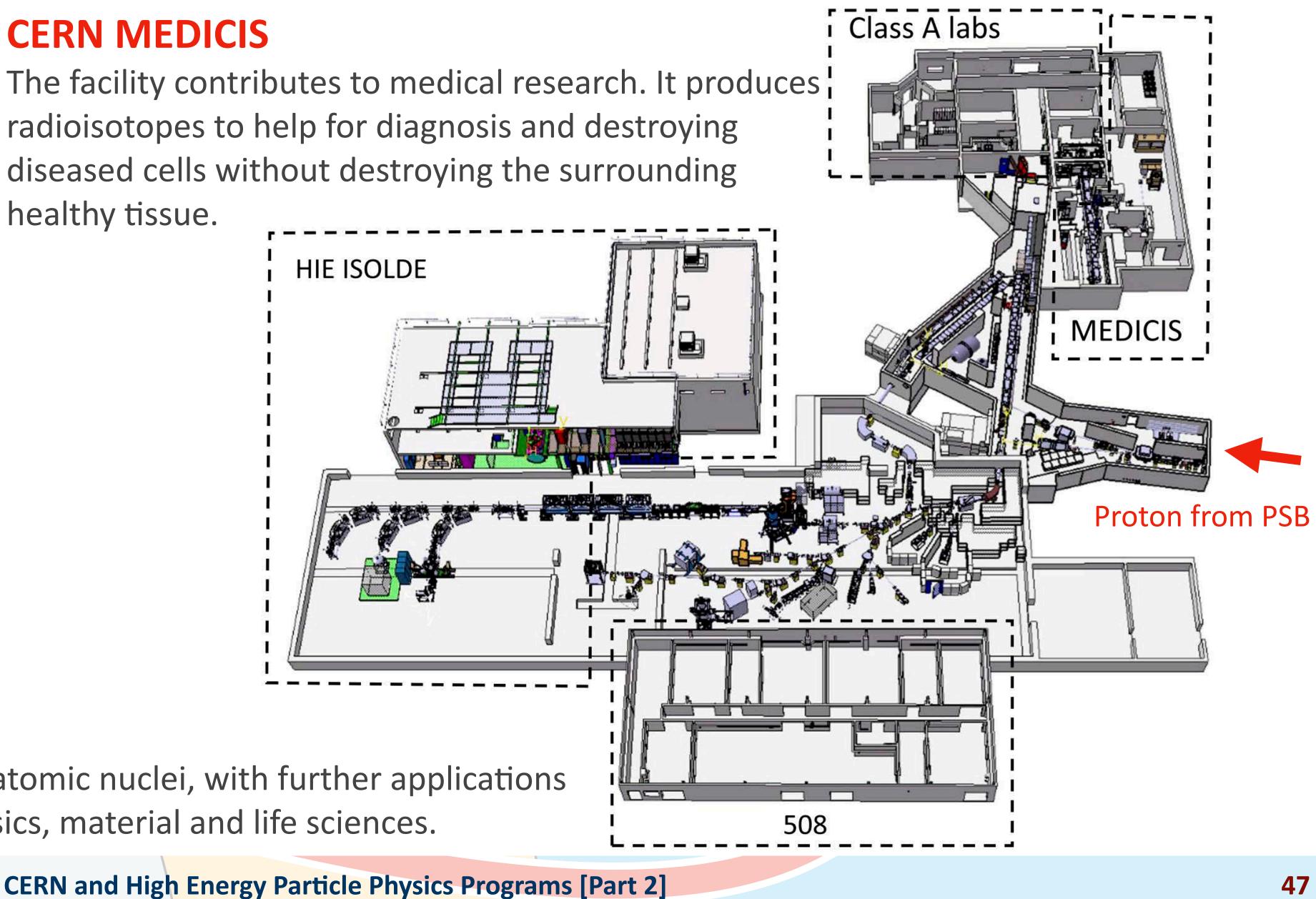
To study on radioisotopes and applications, e.g. medical applications



CERN MEDICIS

healthy tissue.





ISOLDE

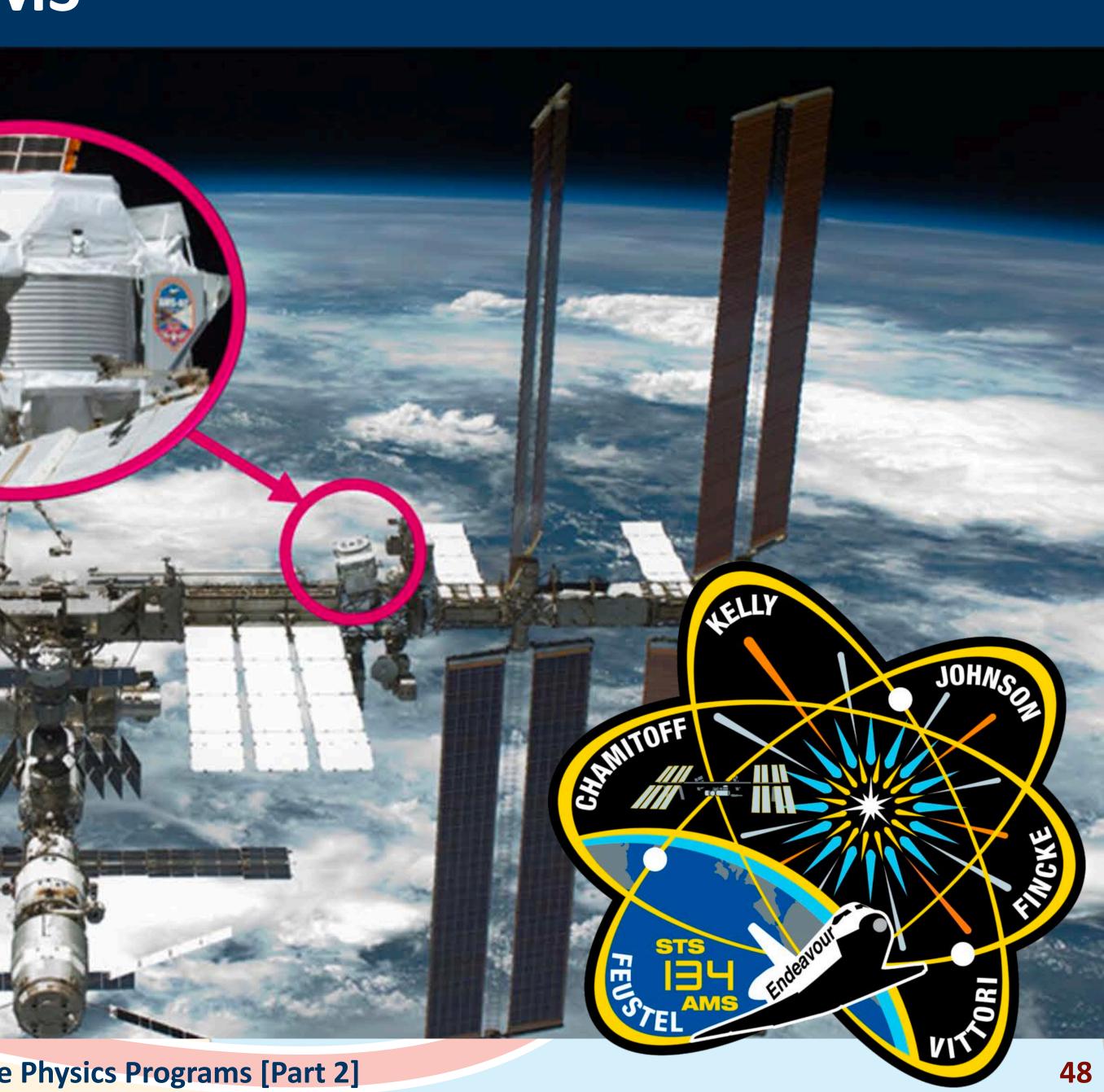
ISOLDE studies the properties of atomic nuclei, with further applications in fundamental studies, astrophysics, material and life sciences.

External experiments at CERN: AMS

AMS

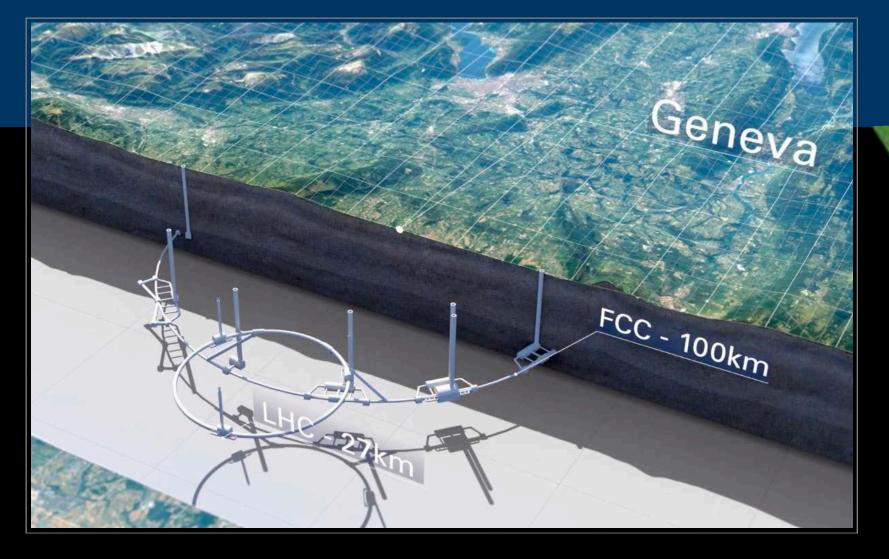
The Alpha Magnetic Spectrometer looks for dark matter, antimatter and missing matter from a module on the International Space Station.

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.



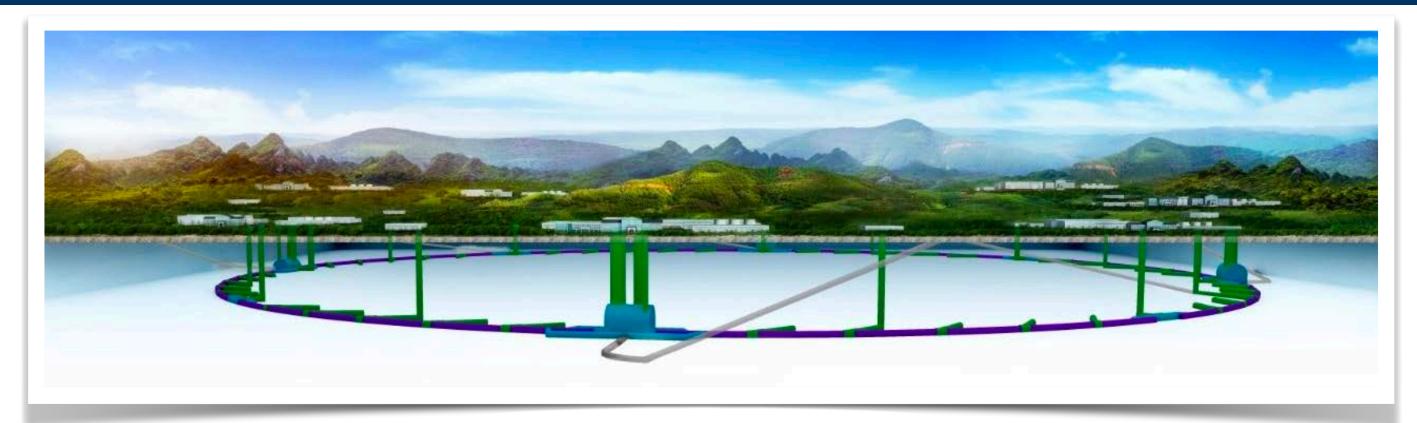
Beyond LHC

- 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 (pp)



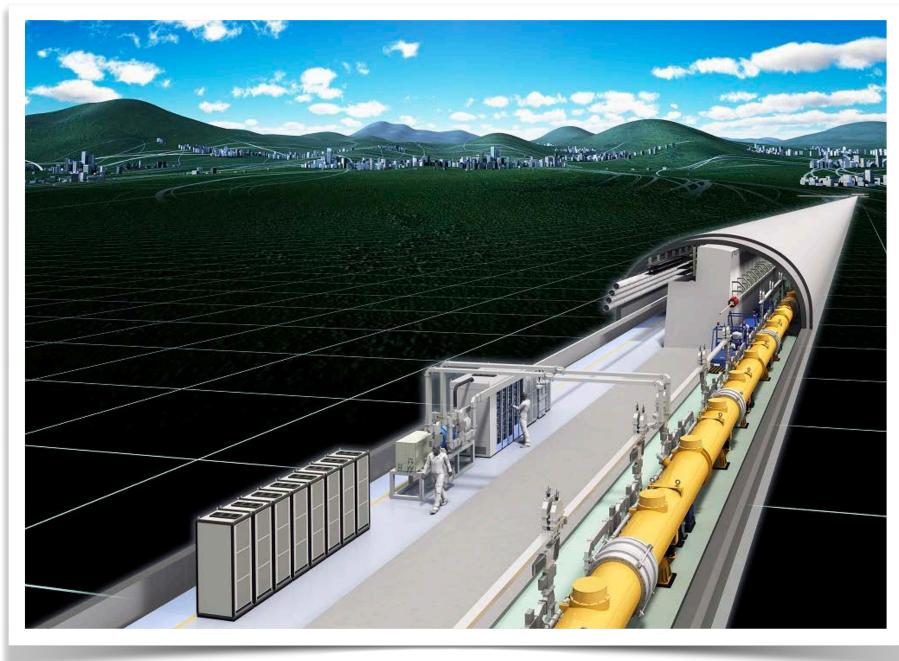


Beyond LHC: Precision Measurement



CEPC (Circular Electron Positron Collider), China

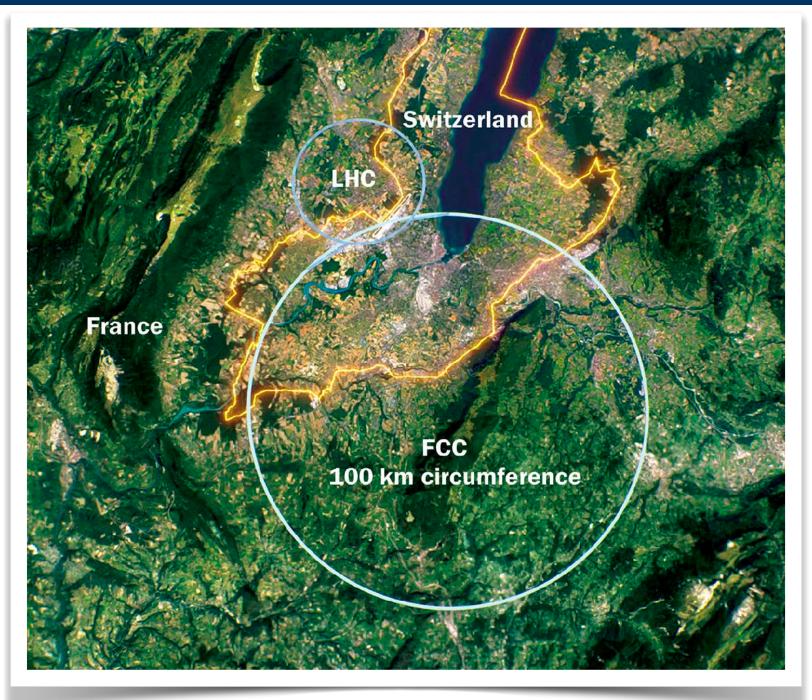
International Linear Collider (ILC)



Compact Linear Collider (CLIC)



Phat SRIMANOBHAS (CU): Introduction to CERN and High Energy Particle Physics Programs [Part 2]

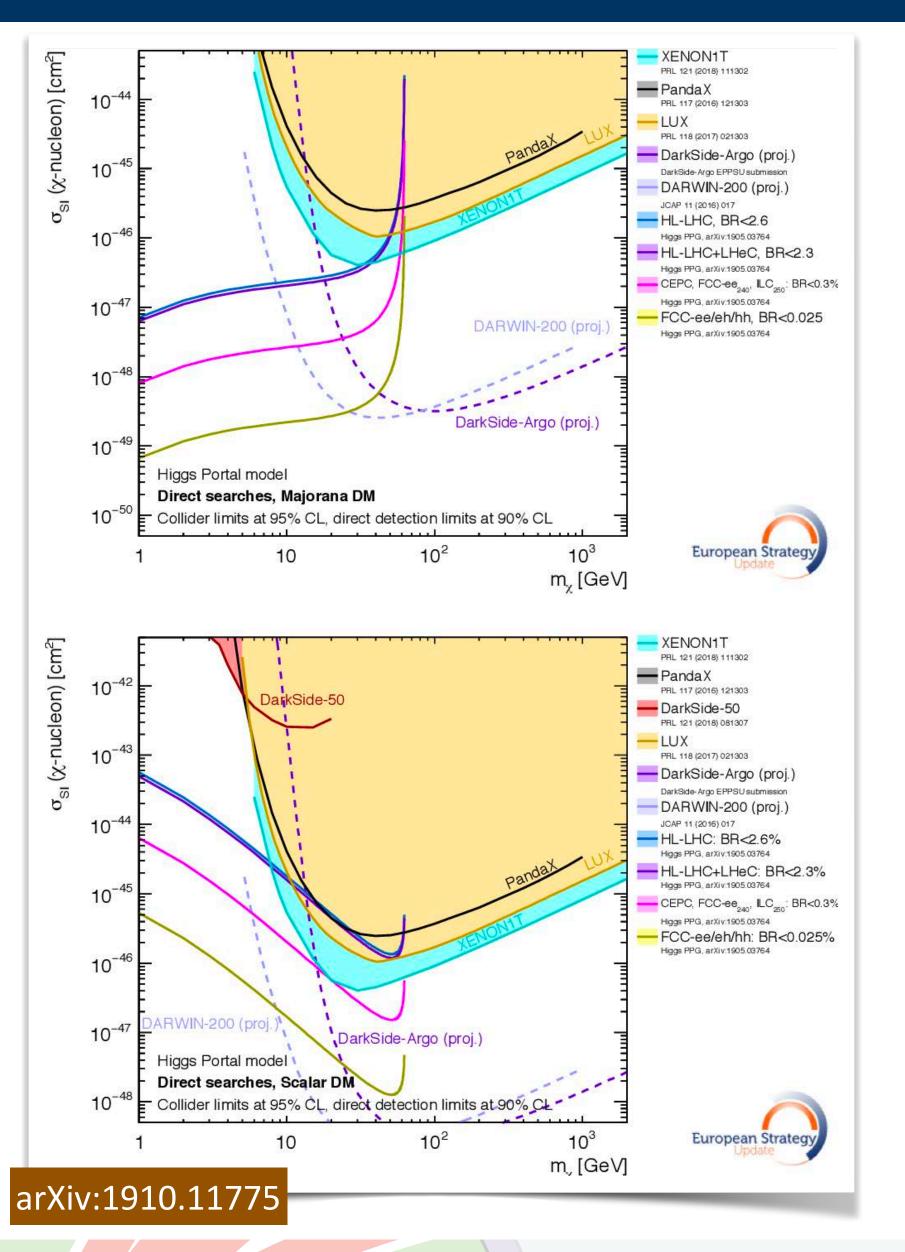


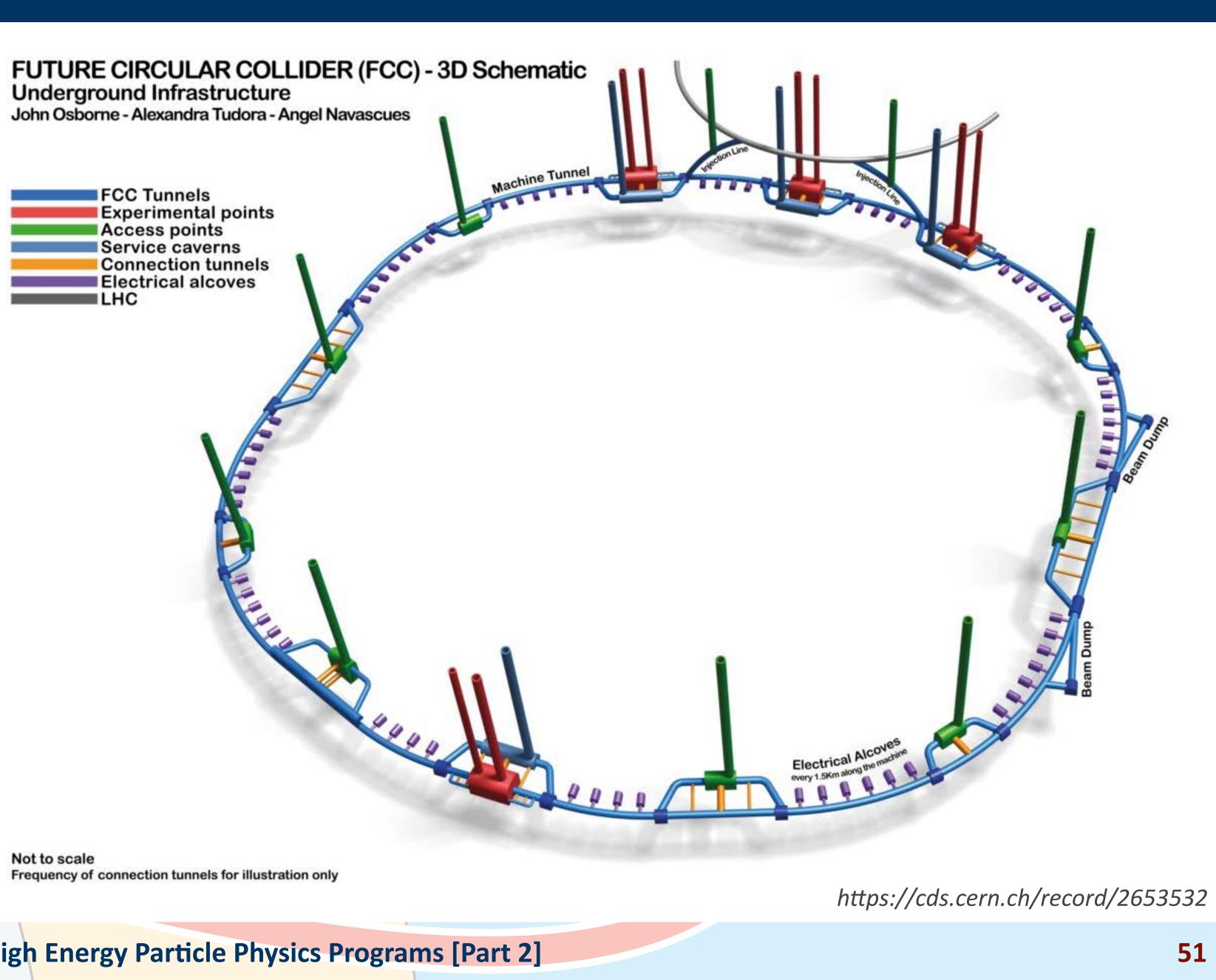
Future Circular Collider (FCC) - ee, **Switzerland-France**

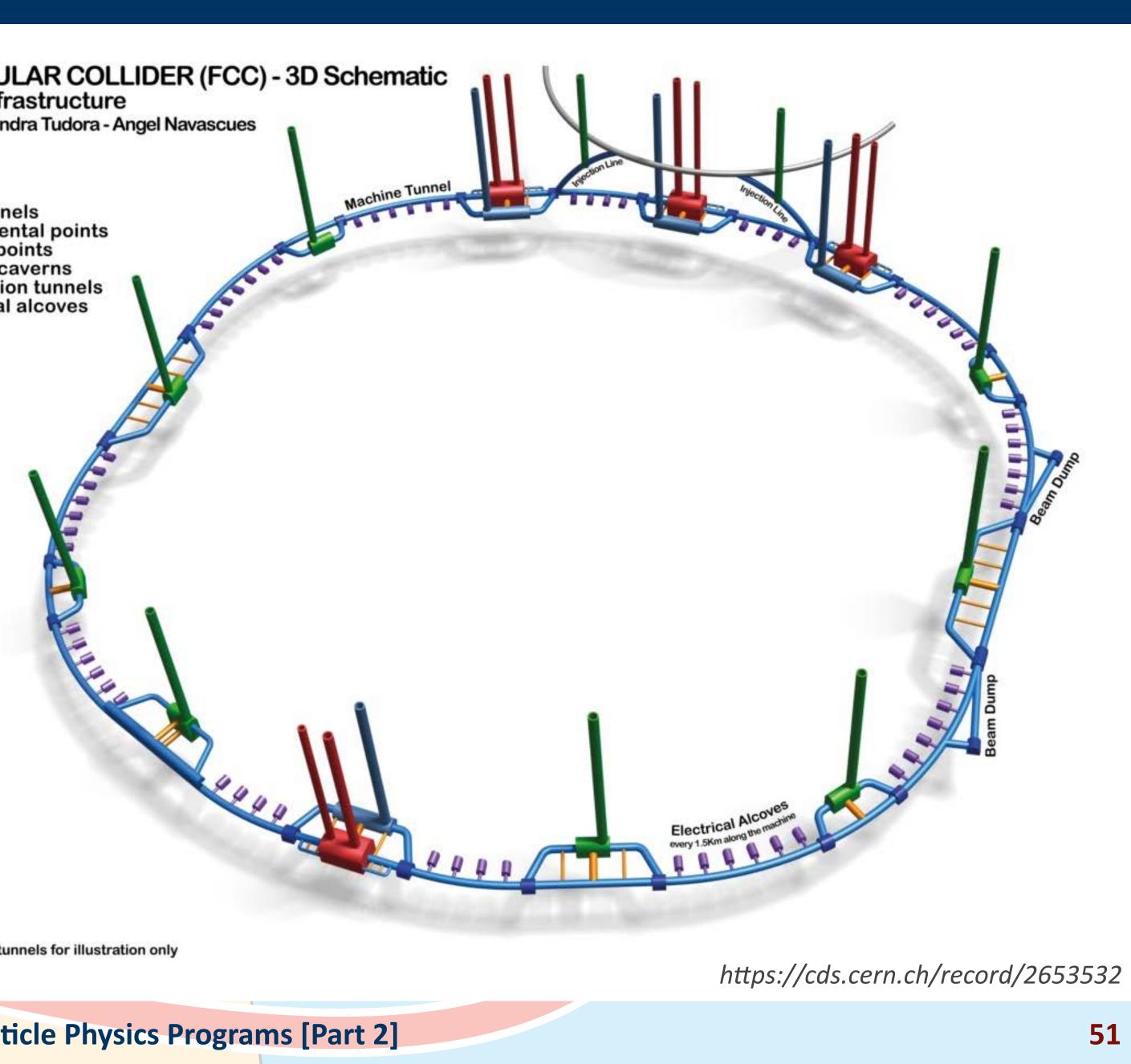




Beyond LHC: 100 TeV pp Collider







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 μ 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.

Target Collisions lead to muons with energy of about 200 MeV.

In a dozen turns, accelerate muons to 20 GeV.

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

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

Compressor Ring Reduce size of beam.

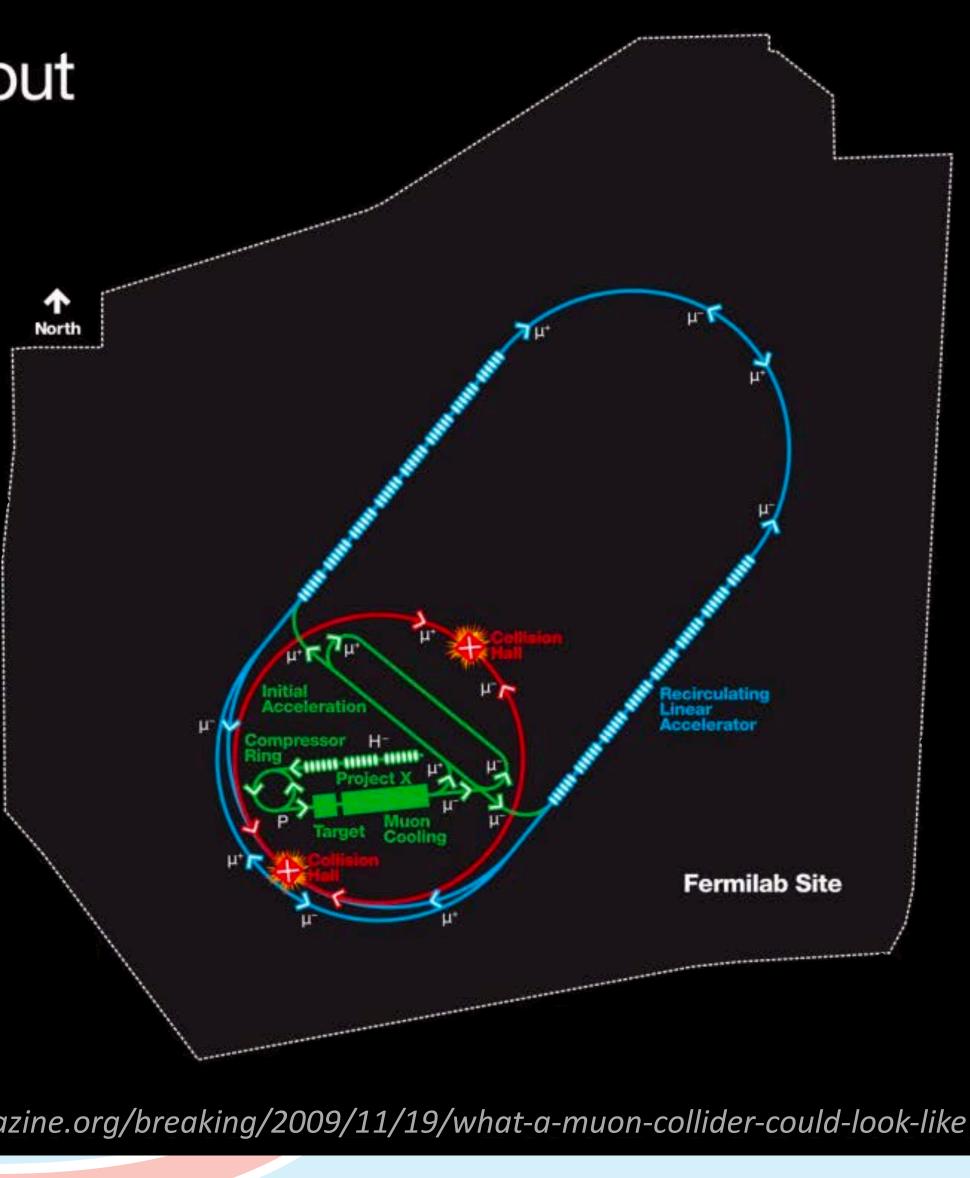
Muon Capture and Cooling

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

Initial Acceleration

Recirculating Linear Accelerator

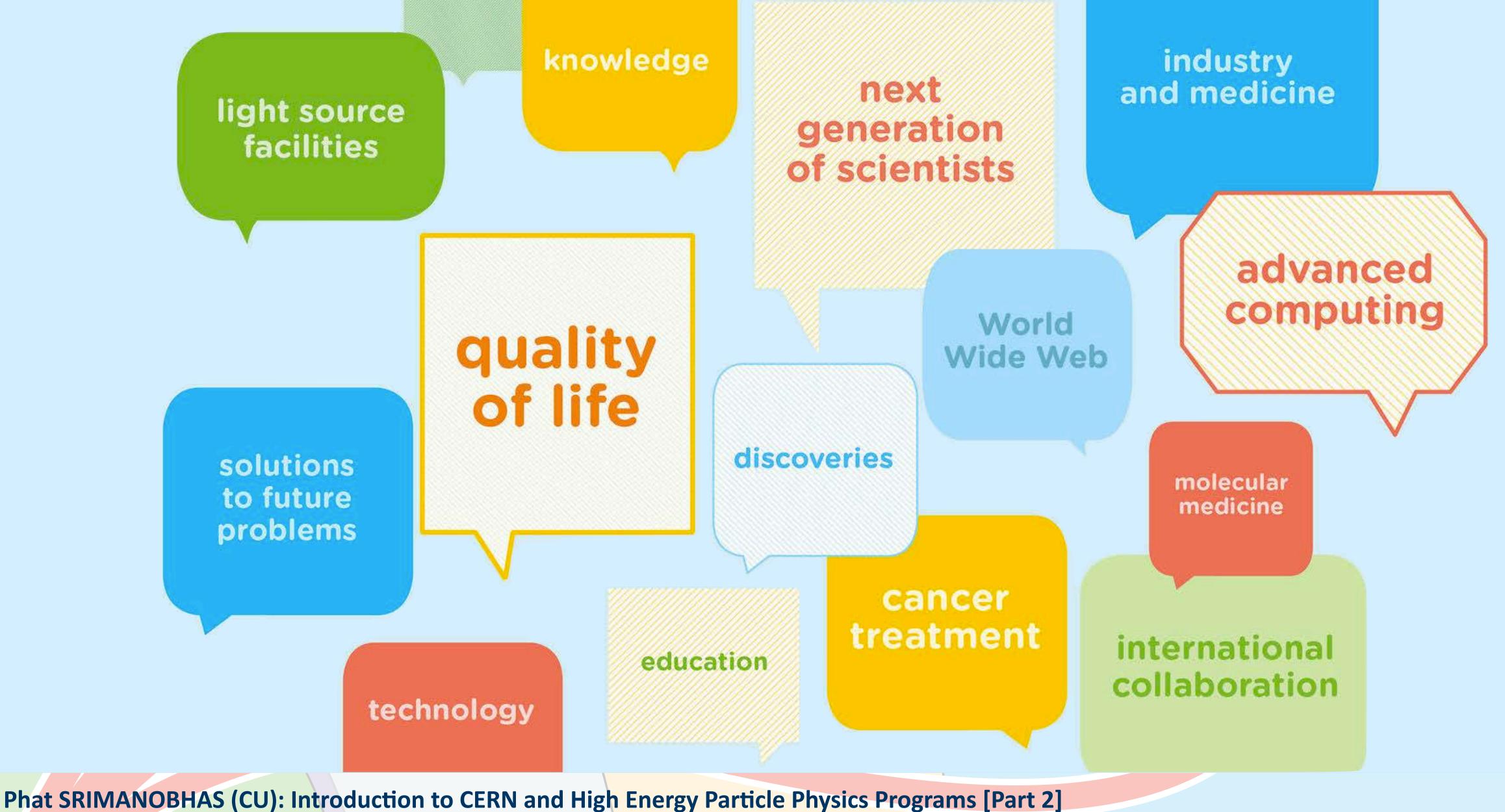
Collider Ring



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

Why particle physics matters

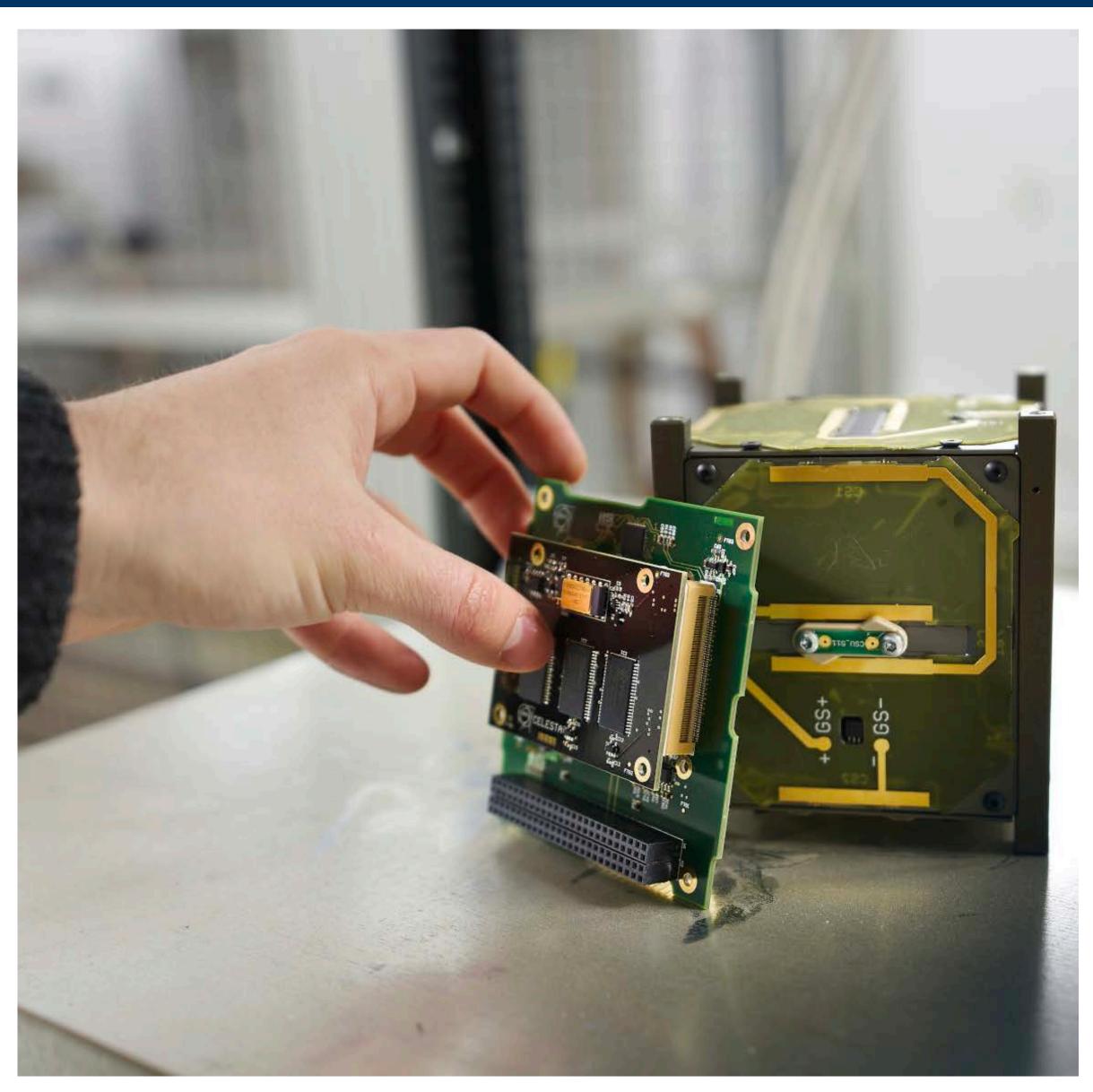


http://www.symmetrymagazine.org/article/october-2013/why-particle-physics-matters



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CERN latchup and radmon experiment student satellite



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Ref: <u>here</u>

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).

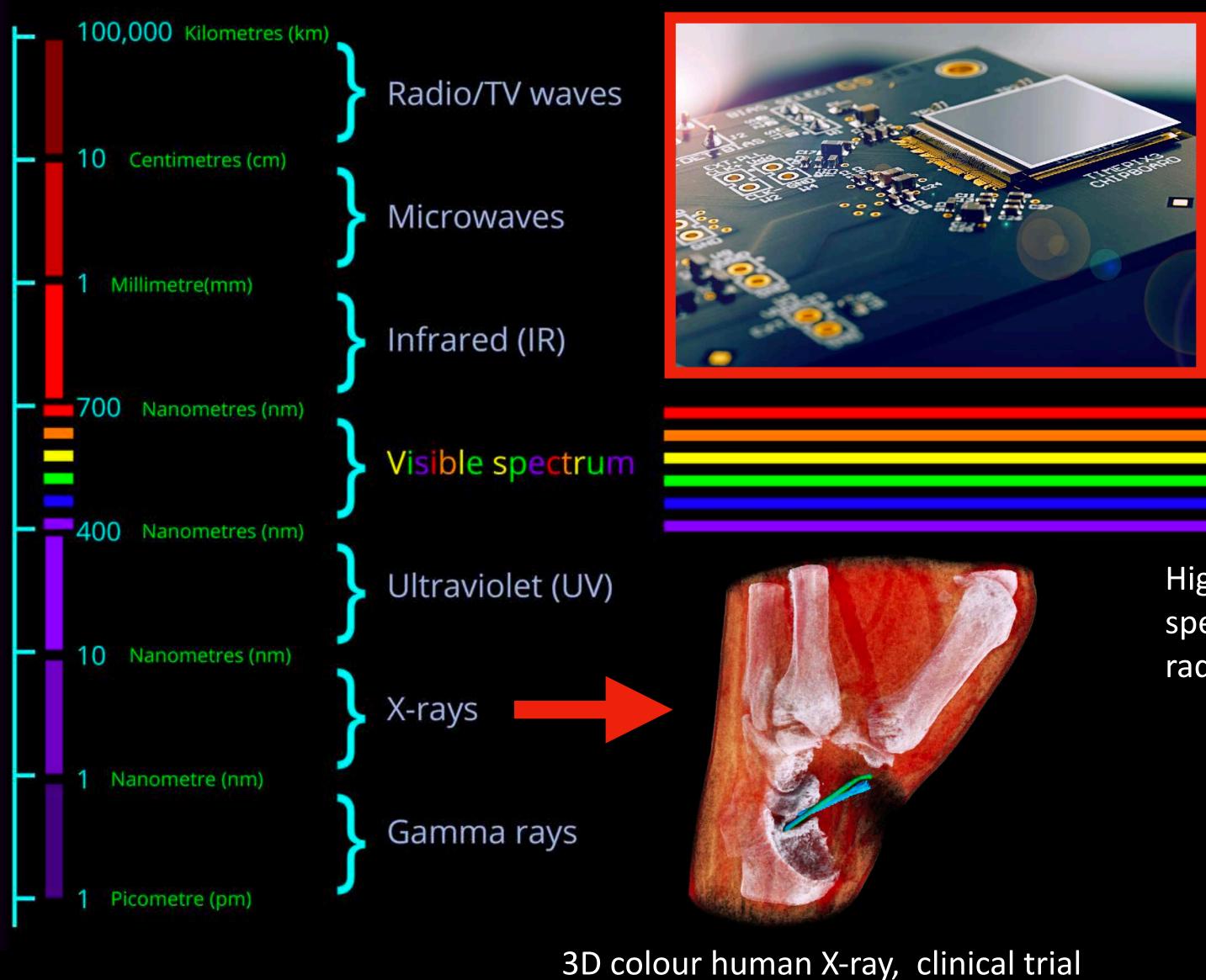


Dipole antenna system. Each antenna unfolds up to 55cm in length Standard format structure Solar panel Payload Electrical power system **UHF/VHF** radio Flight control computer





Blue skies research ... not with imaginations/ideas



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

High resolution spectroscopic radiography









Blue skies research ... not with imaginations/ideas



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

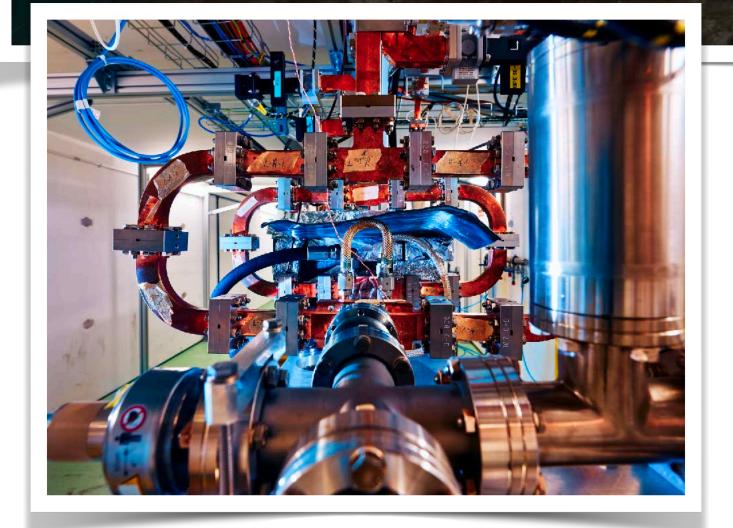
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The irrigation system will use fibre optic sensors designed to measure parameters such as temperature, humidity, concentration of pesticides, fertilisers and enzymes in the soil of cultivated fields. This is the same fibre optic sensors developed by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



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".



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.

CLIC prototype

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

