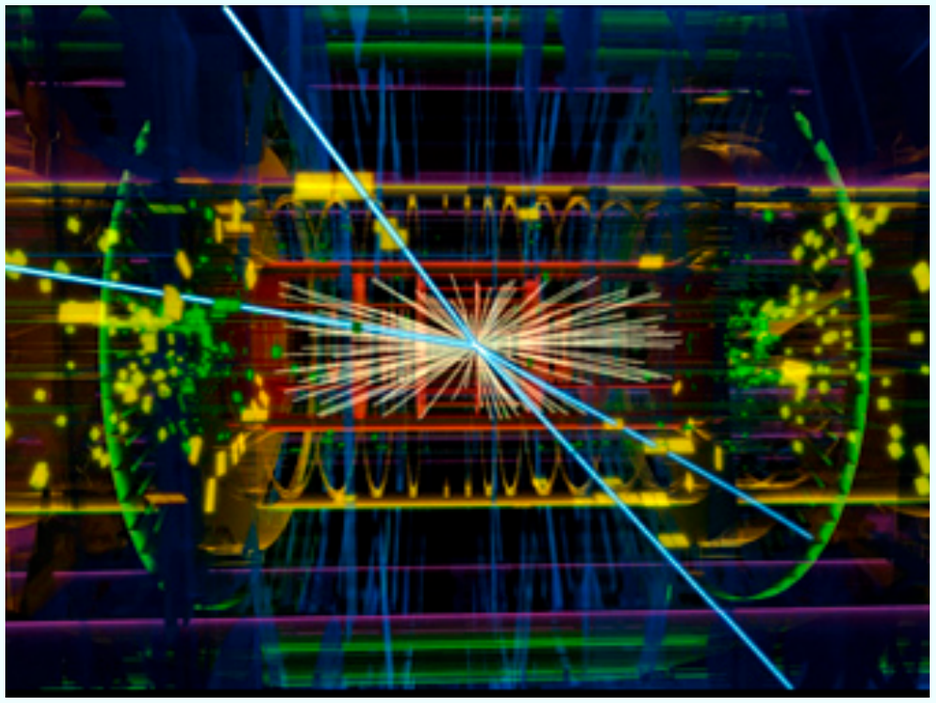
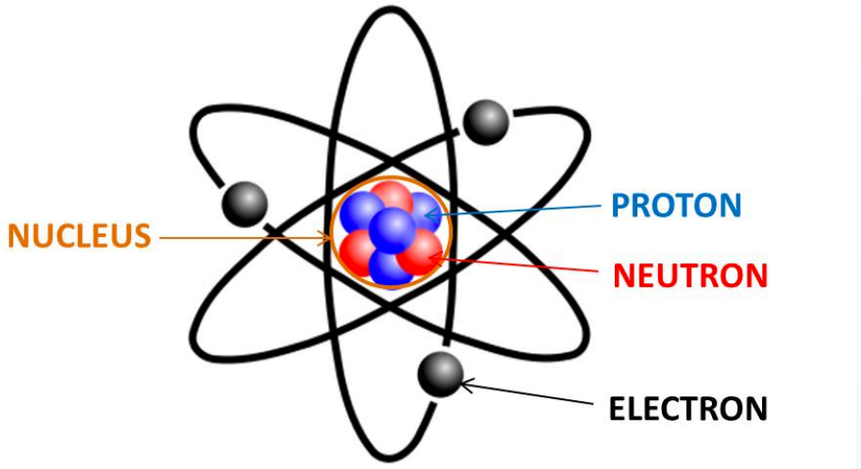


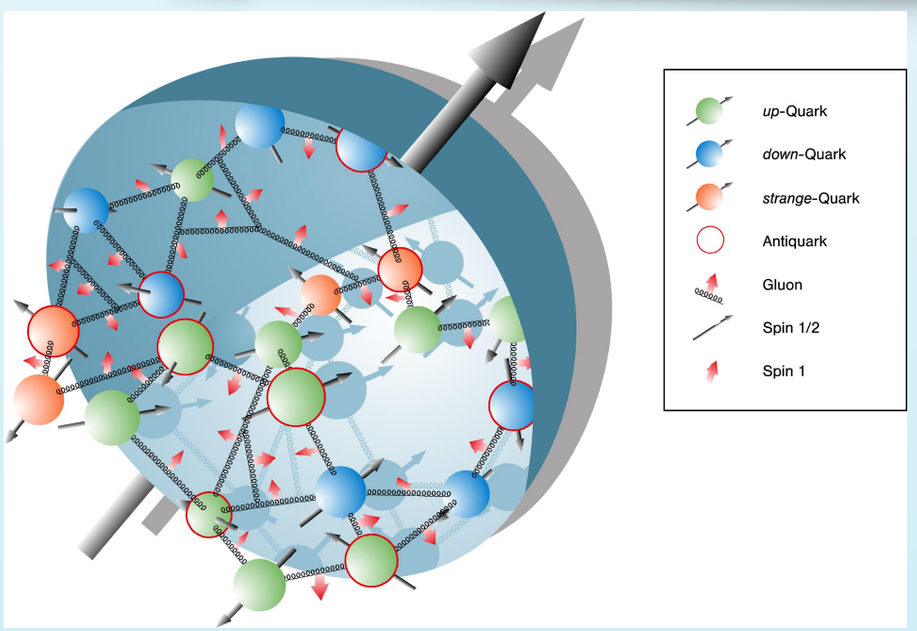
Deciphering the secret code of Nature: From the Higgs particle to gravity waves

Juan Rojo
VU Amsterdam & Theory group, Nikhef

International School of Den Haag
Den Haag, 21/11/2017



Deep into the mysteries of matter



The Stuff of Matter

☑ A **table**, a **cell phone** and a **squirrel** look very different … but ultimately, they are composed by the **same kind of building blocks:** we call them **atoms**

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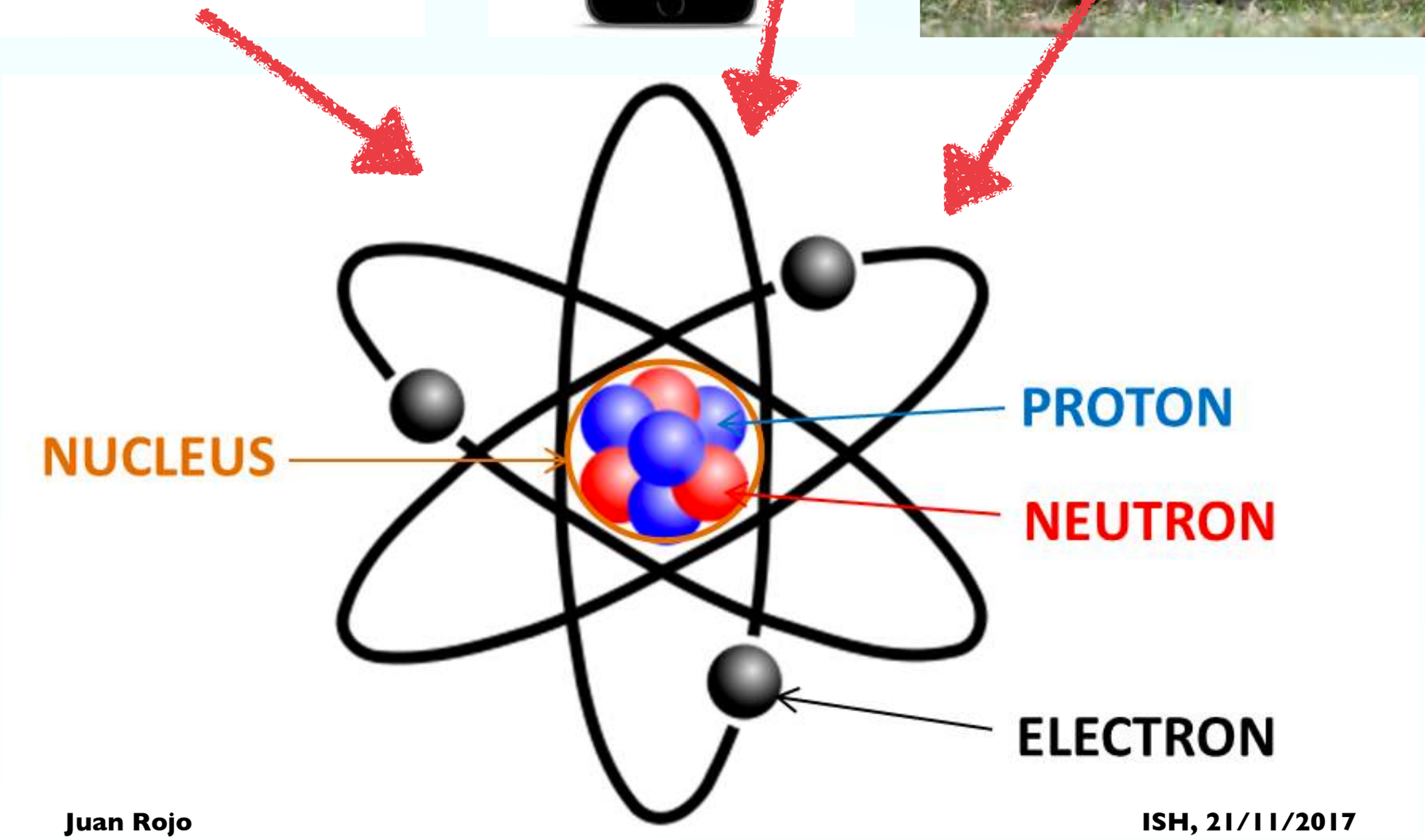

How small are atoms?

A squirrel has a length of **10 centimeters ….**

How small are atoms?

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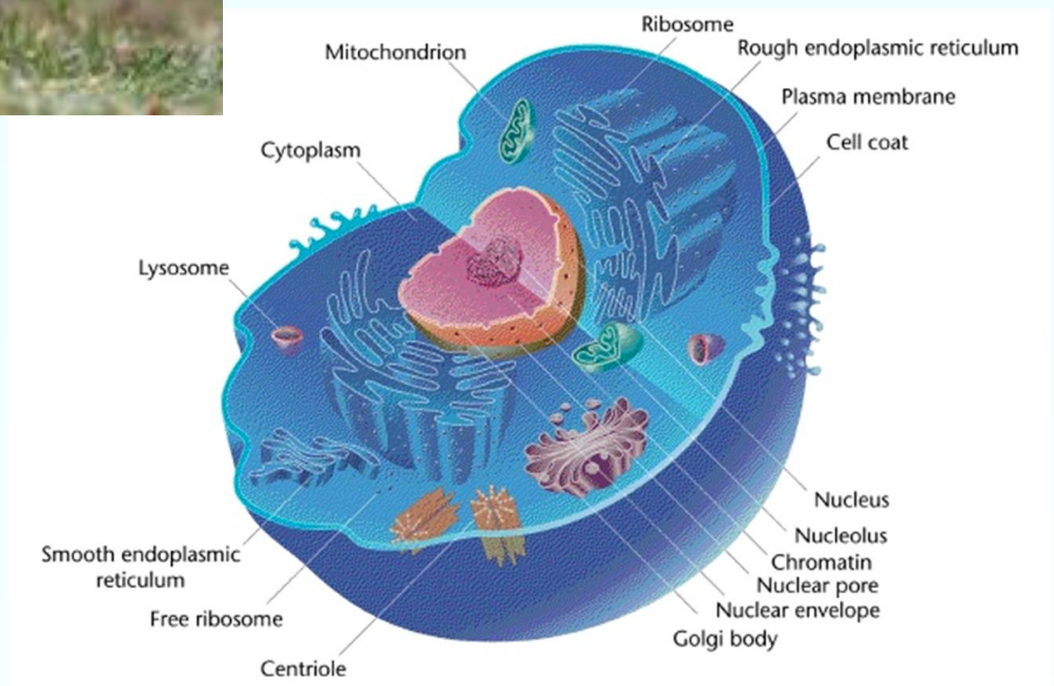
All animals are composed by **cells,** of size 10 **micrometers: 10000 times smaller …..**



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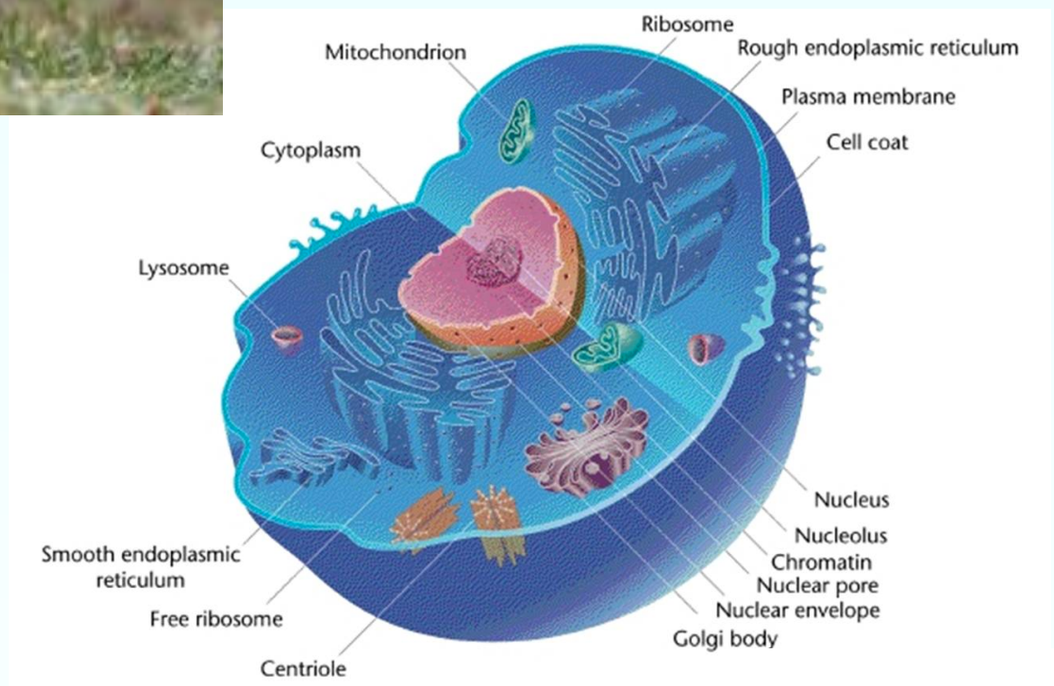
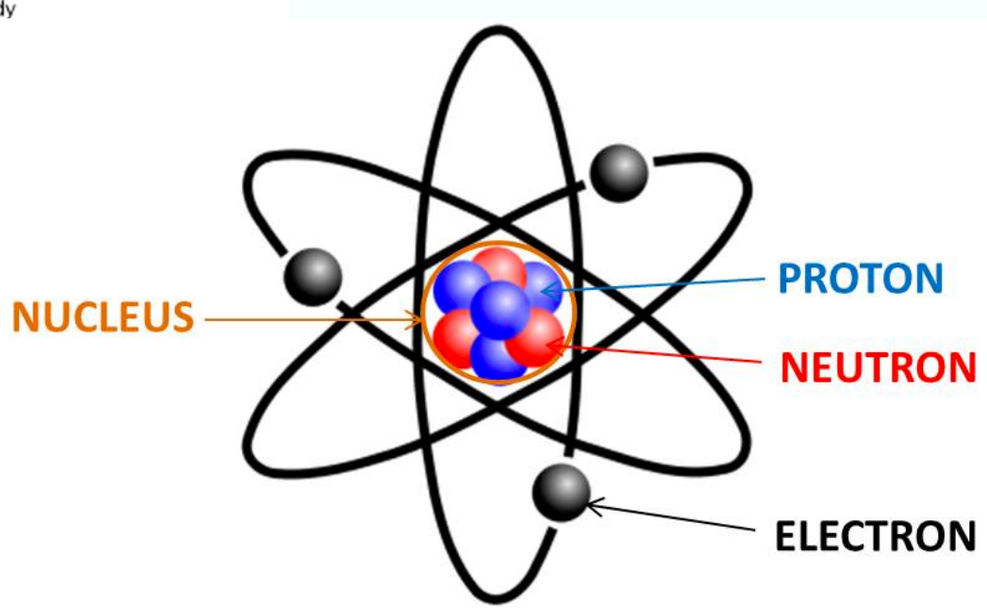
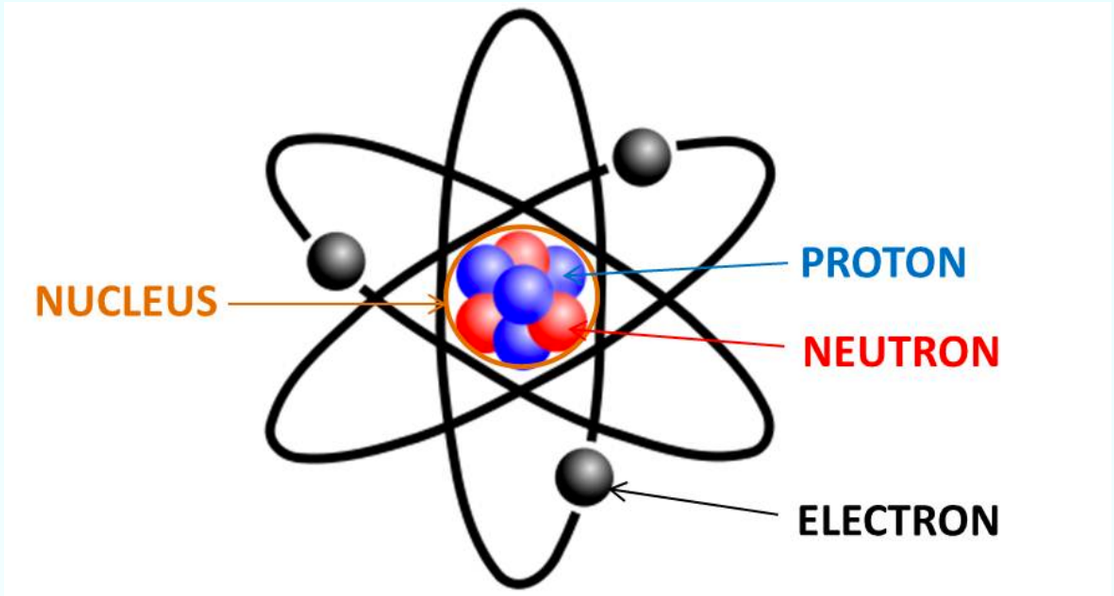


The size of an atom is **0.1 nanometers, 1000 million times smaller!** Atoms are very small!



From atoms to protons to quarks

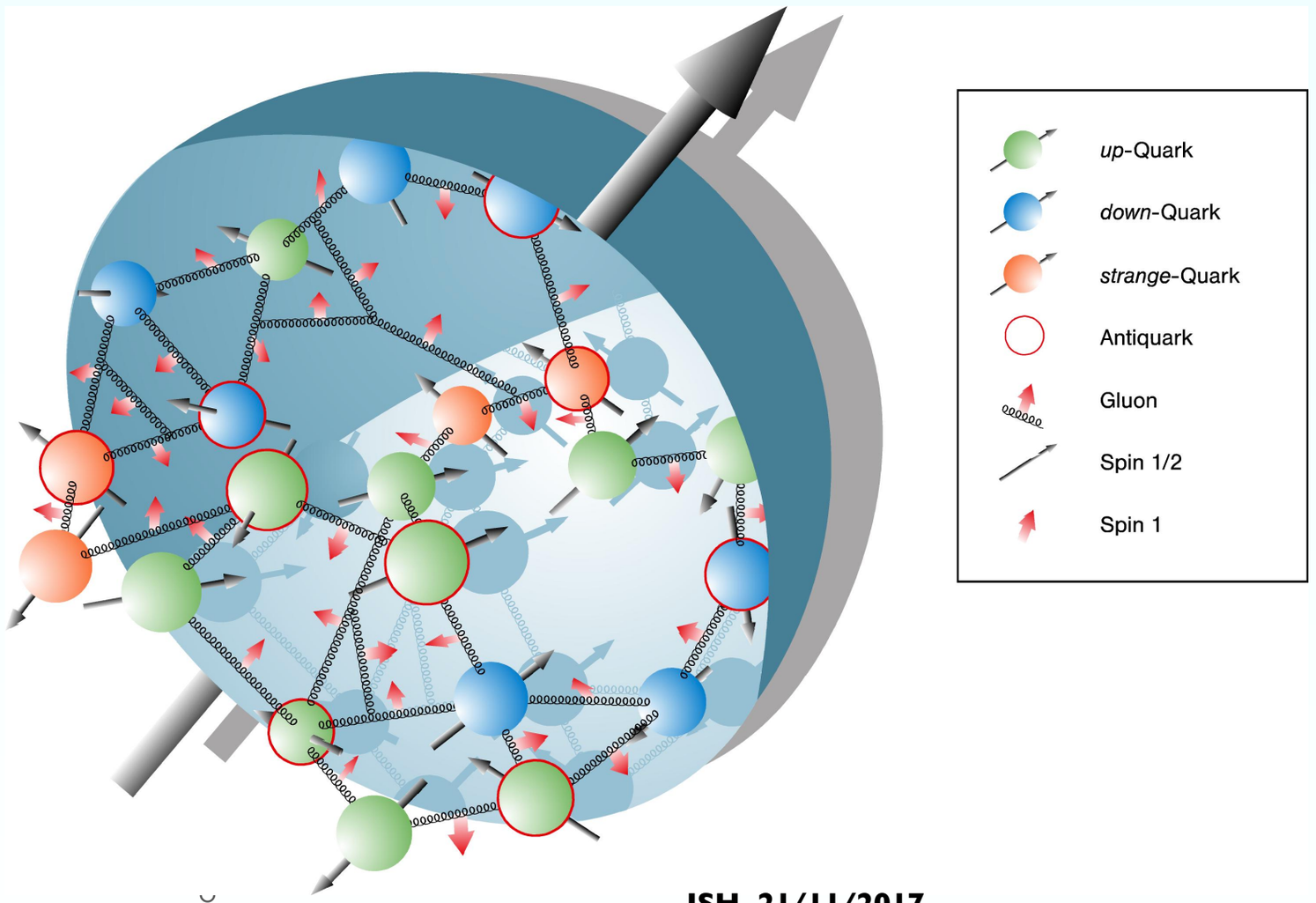


Atoms themselves have even smaller constituents: **protons, neutrons and electrons**

Protons are 10000 times smaller than atoms!

Even the tiny protons have **smaller constituents:** we call them **quarks and gluons**

Are there **more, even smaller, particles** that we can find? We need **to build gigantic experiments** to answer this!

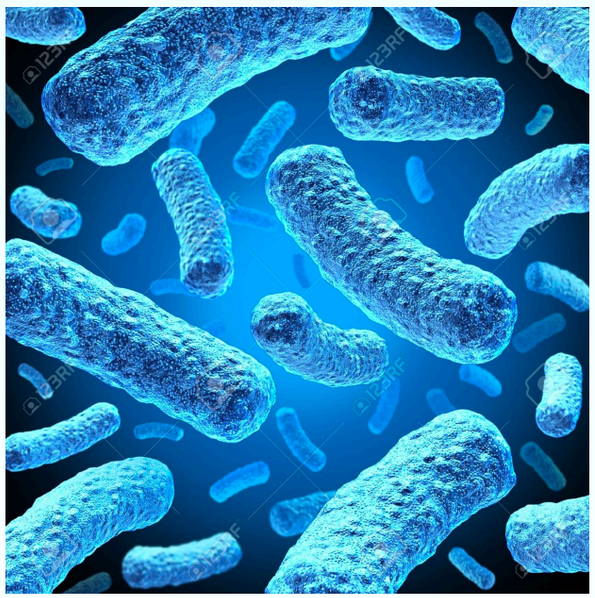


From galaxies to quarks

To grasps the **immensity and smallness of the length scales involved**, it is useful to work with **orders of magnitudes** and **exponential notation**

$$\mathbf{L \approx 10^{M}\ meters}$$

bacterium L = 0.00001 meters



bacterium M = -5

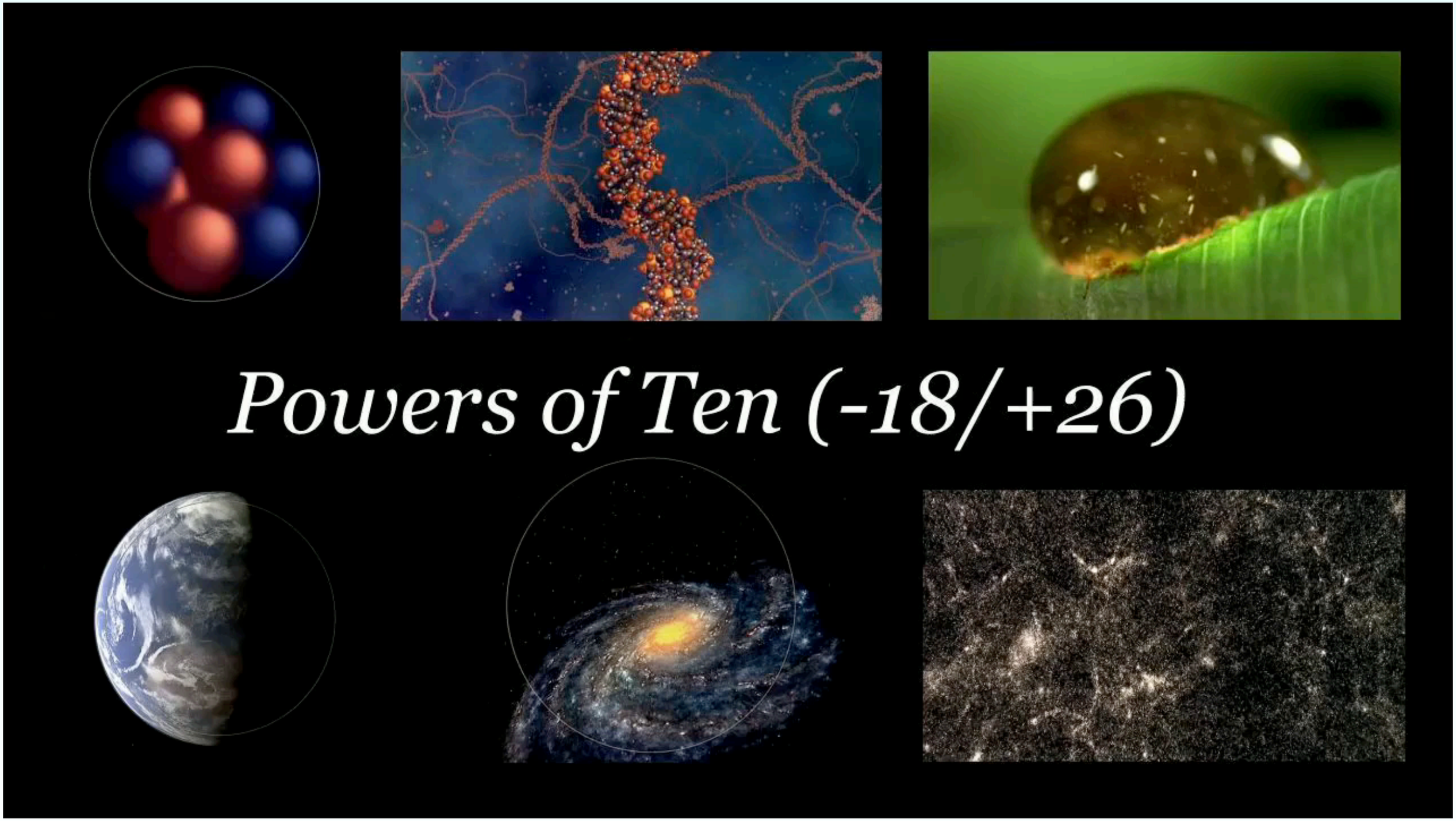
Lamborghini L = 3 meters

Lamborghini M = 0

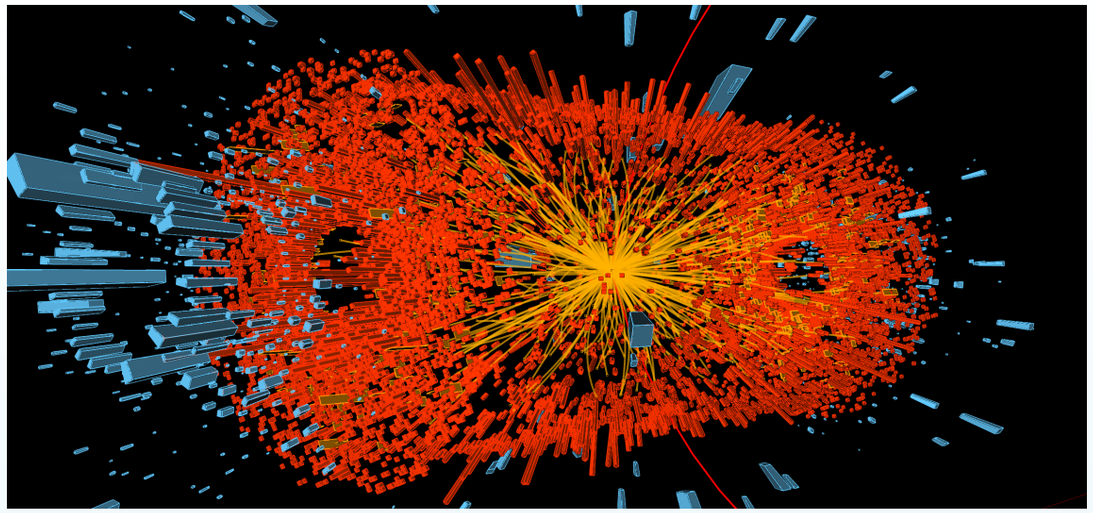
The size of a bacterium is smaller **by 5 orders of magnitude** as compared a typical car

Ourselves, a table and a car all have lengths of the same order of magnitude

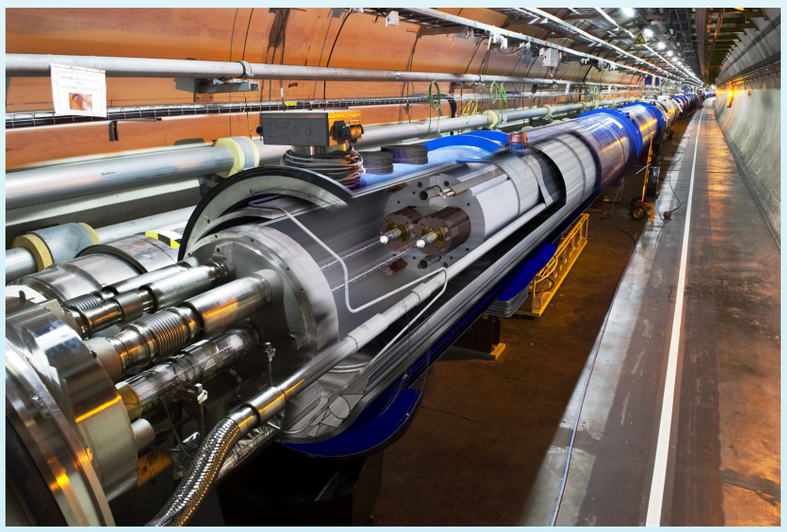
From galaxies to quarks



https://www.youtube.com/watch?v=bhofN1xX6u0



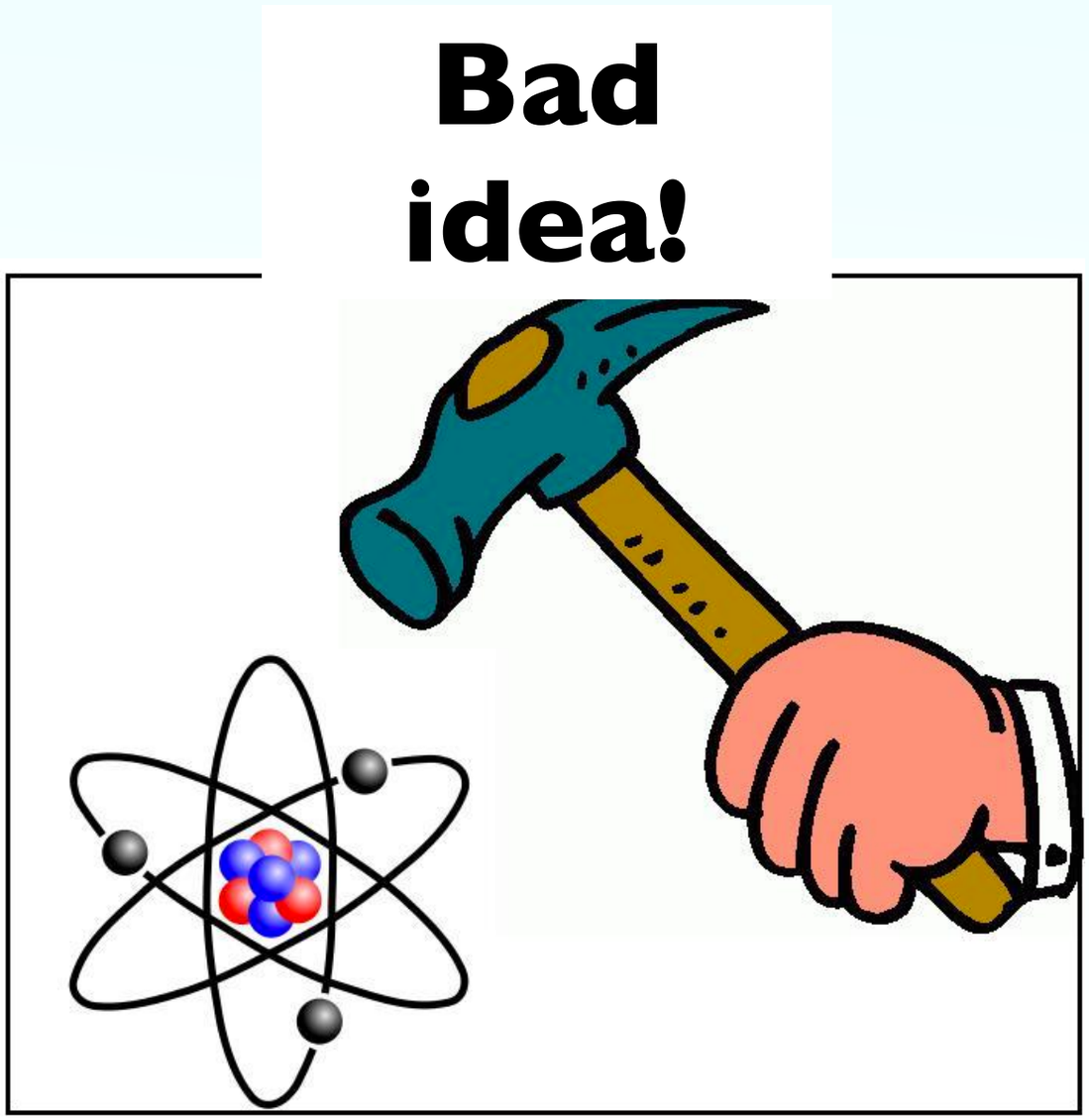
Exploring the secret code of Nature at the Large Hadron Collider



High energy colliders

The idea behind **high-energy colliders** is very simple!

📌We want to see **what is inside protons**: we need to **break them**. How we do this?

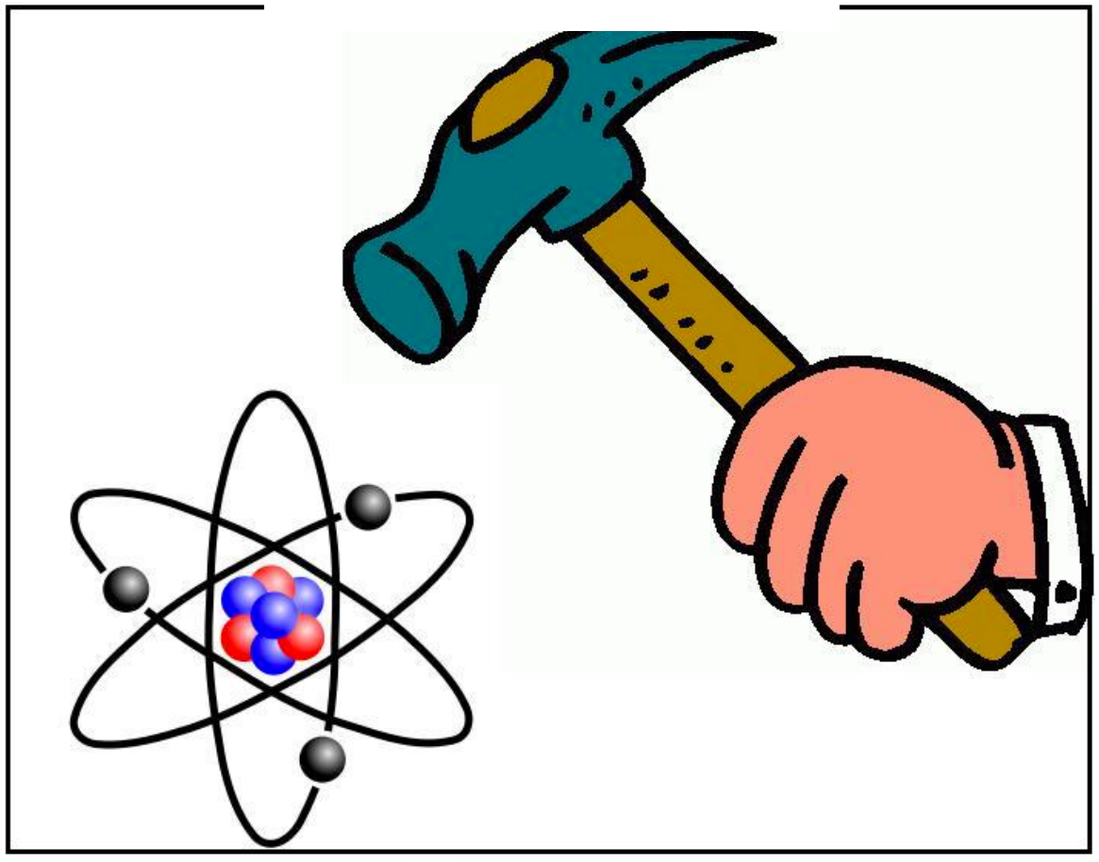


High energy colliders

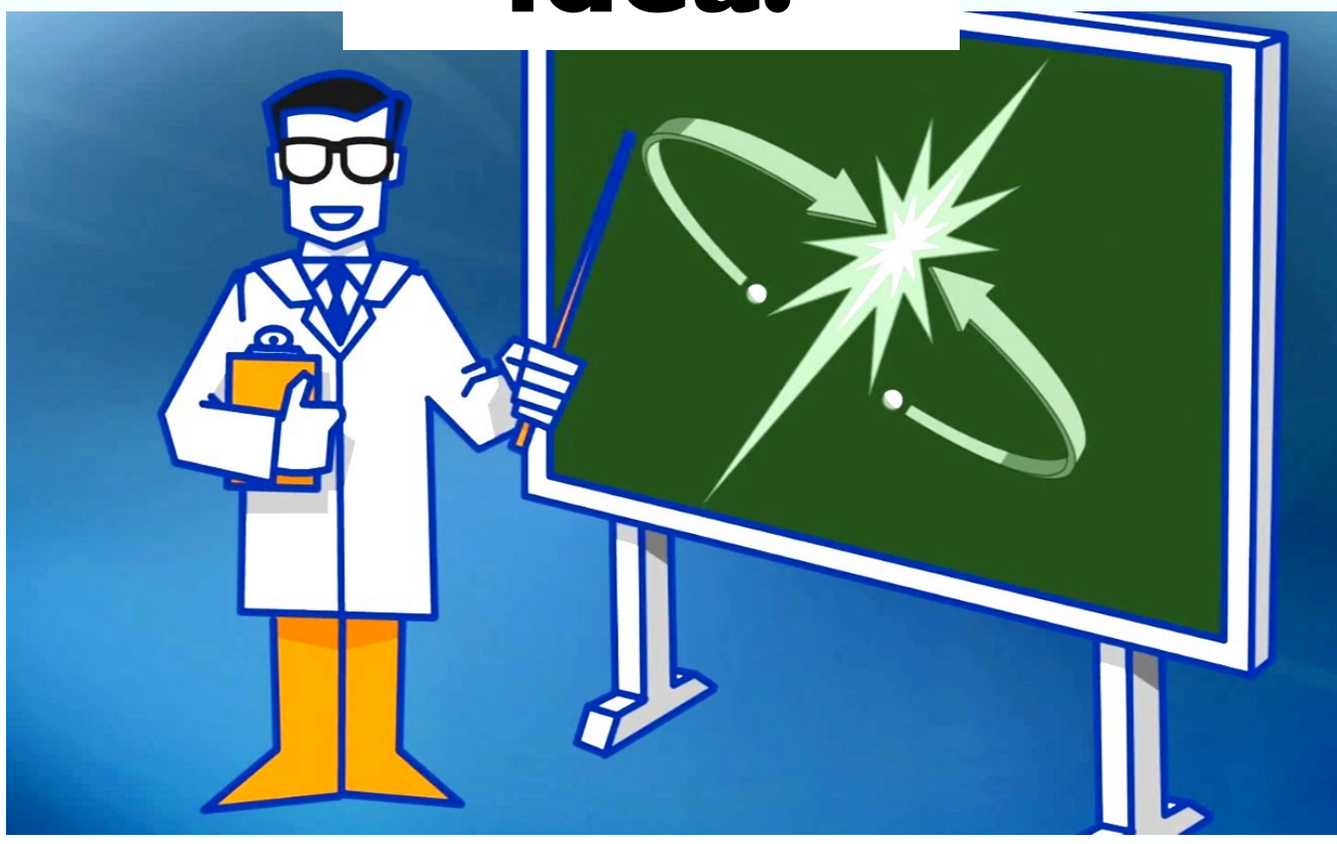
The idea behind **high-energy colliders** is very simple!

- We want to see **what is inside protons**: we need to **break them**. How we do this?
- We make protons **go very fast**, and then collide them: by looking at the r**esults of the collision,** we can understand the stuff protons are made of, if there are new particles or forces ….
- Since protons are very small, we need **extremely high energies to see inside them**: modern colliders are **gigantic machines**!

Bad idea!

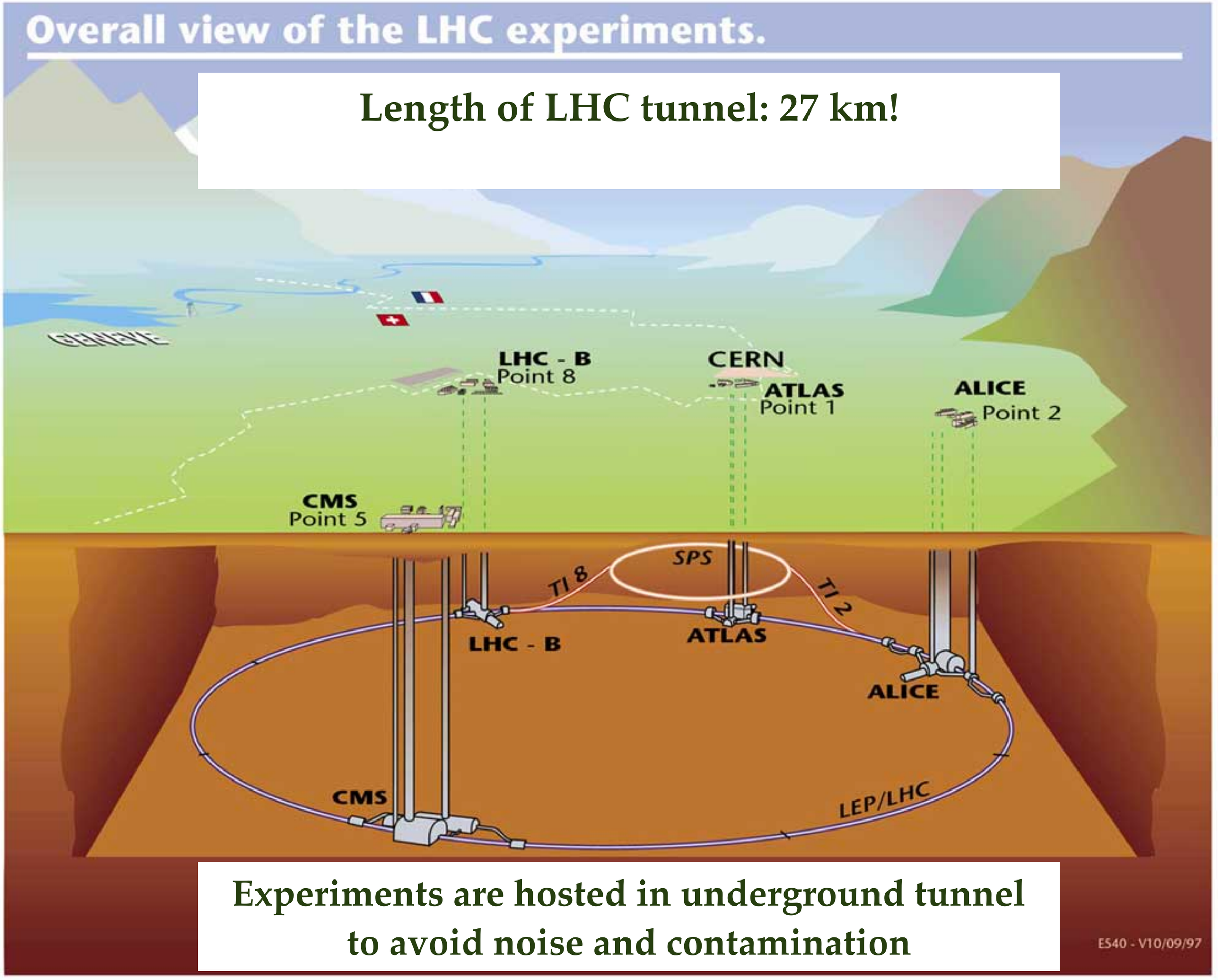


Good idea!



The Large Hadron Collider

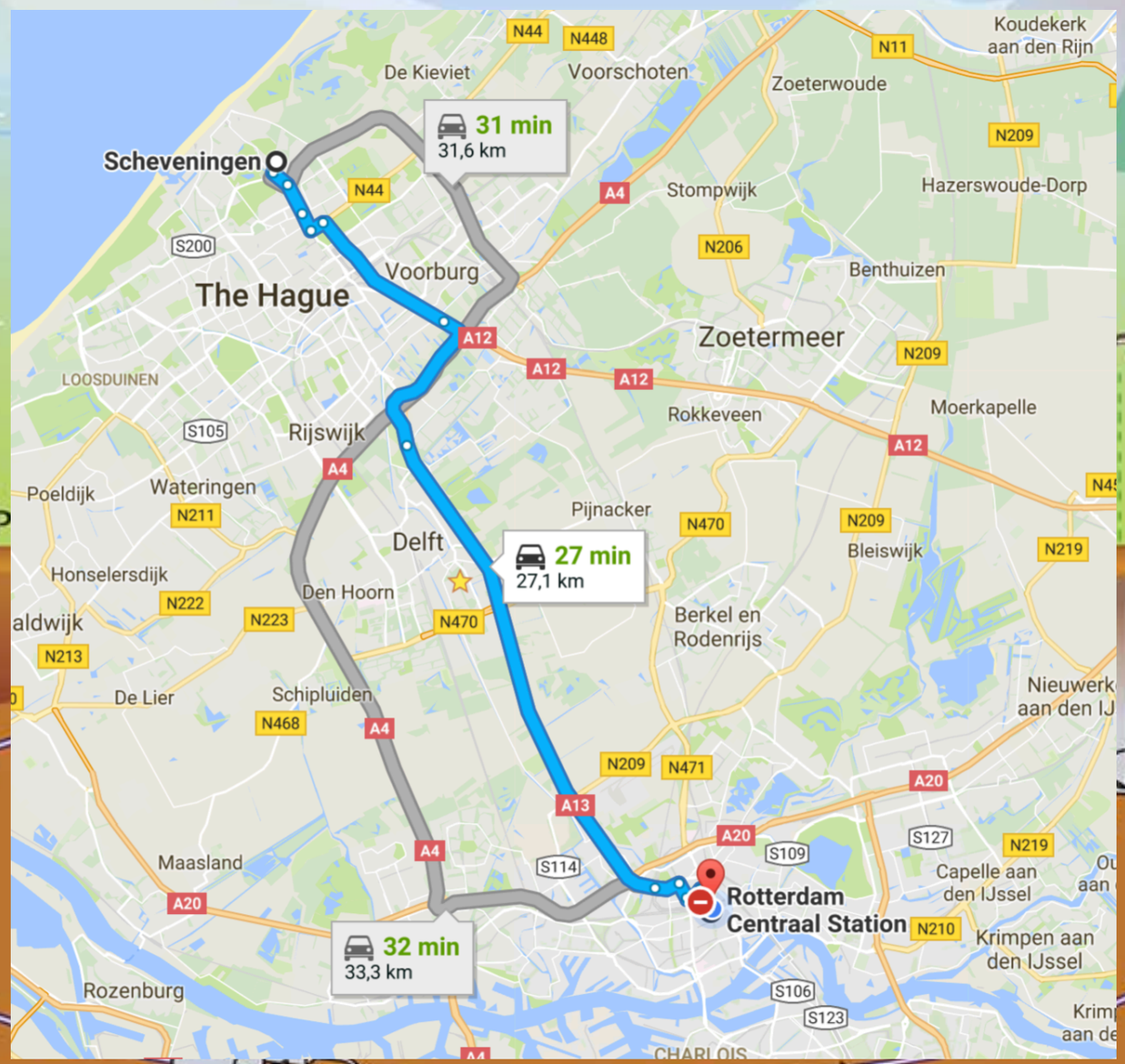
- ☑ The LHC is the **most powerful particle accelerator ever build by mankind**
- ☑ Hosted by CERN in Geneva, the LHC is composed by a **massive 27 km long tunnel** with **four gigantic detectors**


Overall view of the LHC experiments.
Length of LHC tunnel: 27 km!
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
Experiments are hosted in underground tunnel
to avoid noise and contamination
ES40 - V10/09/97

Overall view of the LHC experiments.

Length of LHC tunnel: 27 km!

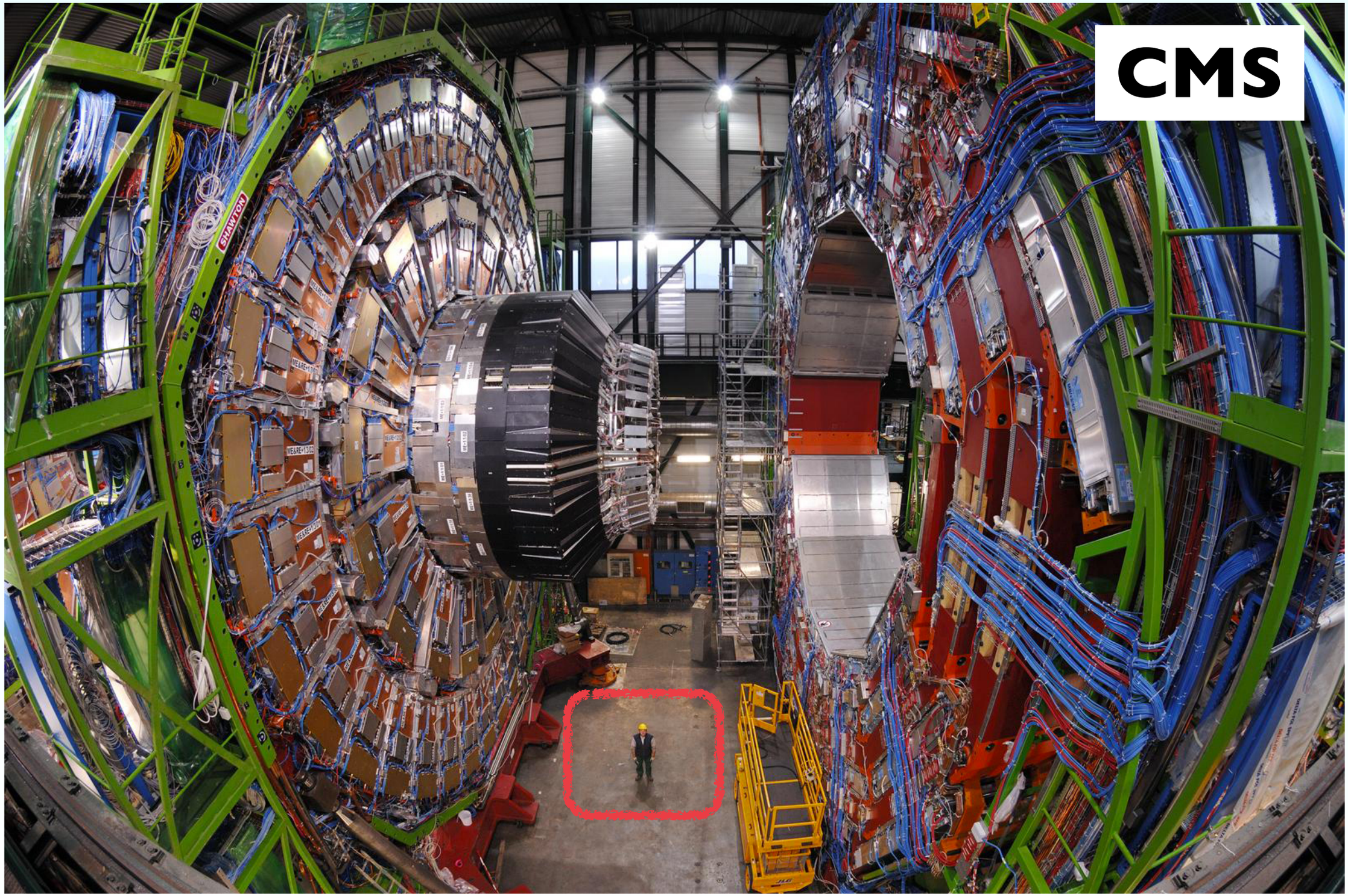
Same distance as from Rotterdam to Scheveningen



Experiments are hosted in underground tunnel to avoid noise and contamination

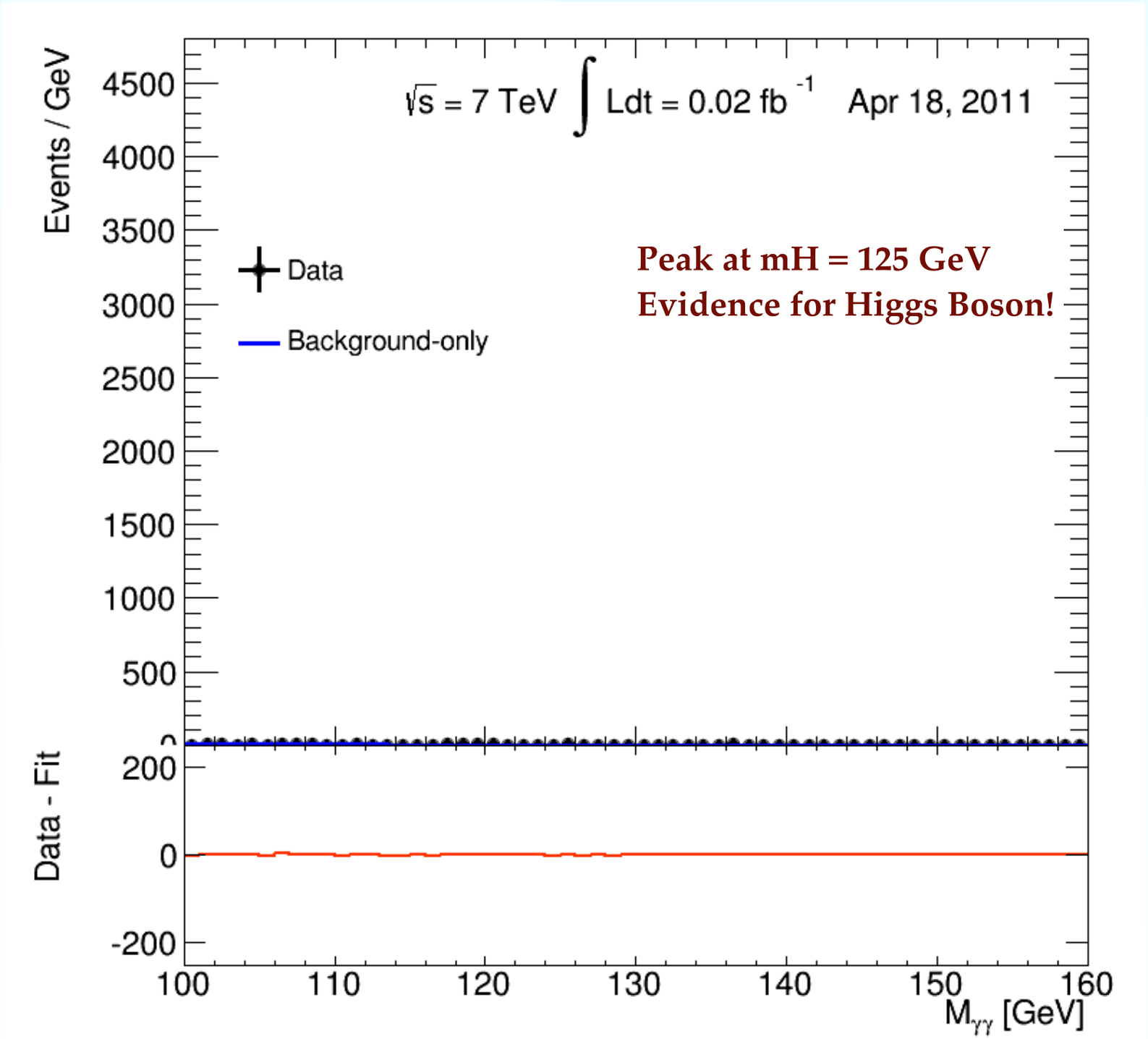
The LHC detectors

Where proton beams cross and **collisions take place**, huge detectors measure the products of the collision in an attempt to understand **the laws of Nature at the smallest distances**



Discovering New Particles

☑ At the LHC, we search for new **Fundamental Particles,** like the recently discovered **Higgs Boson,** by **looking for deviations** with respect known processes



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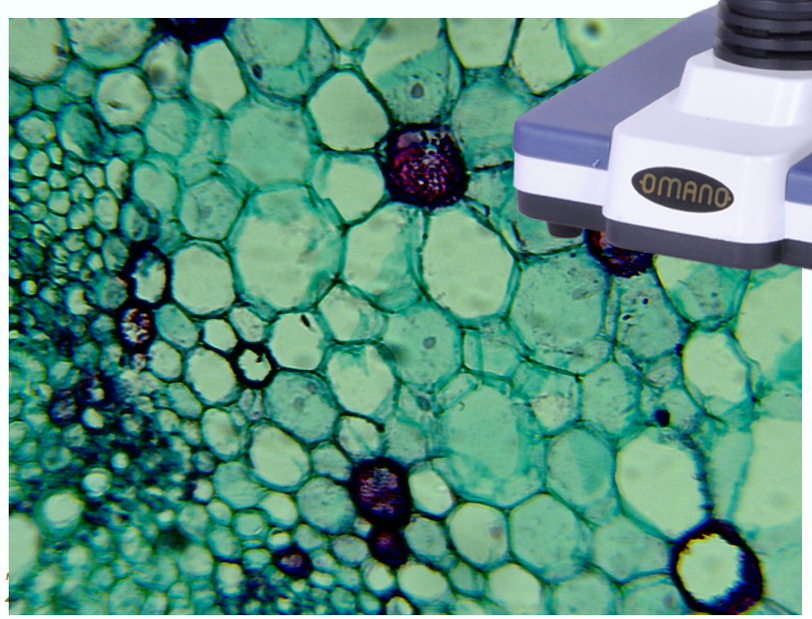
Remarkable facts about the LHC

☑ The LHC is the **most powerful microscope ever constructed**, able to see the smallest things ever seen by mankind!

Just as I can use a **microscope to see cells ….**



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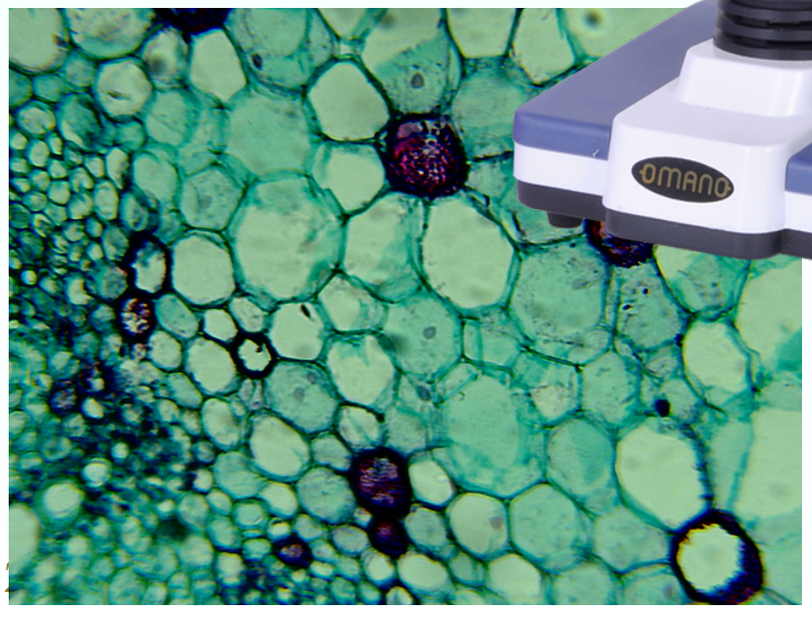
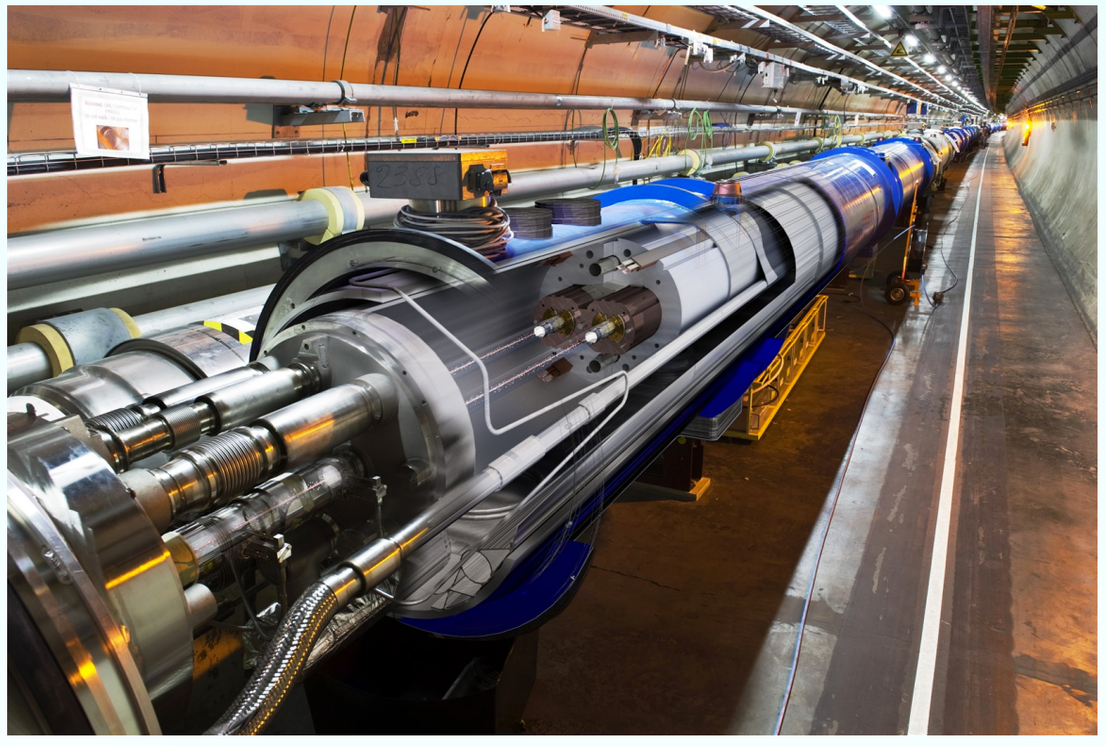
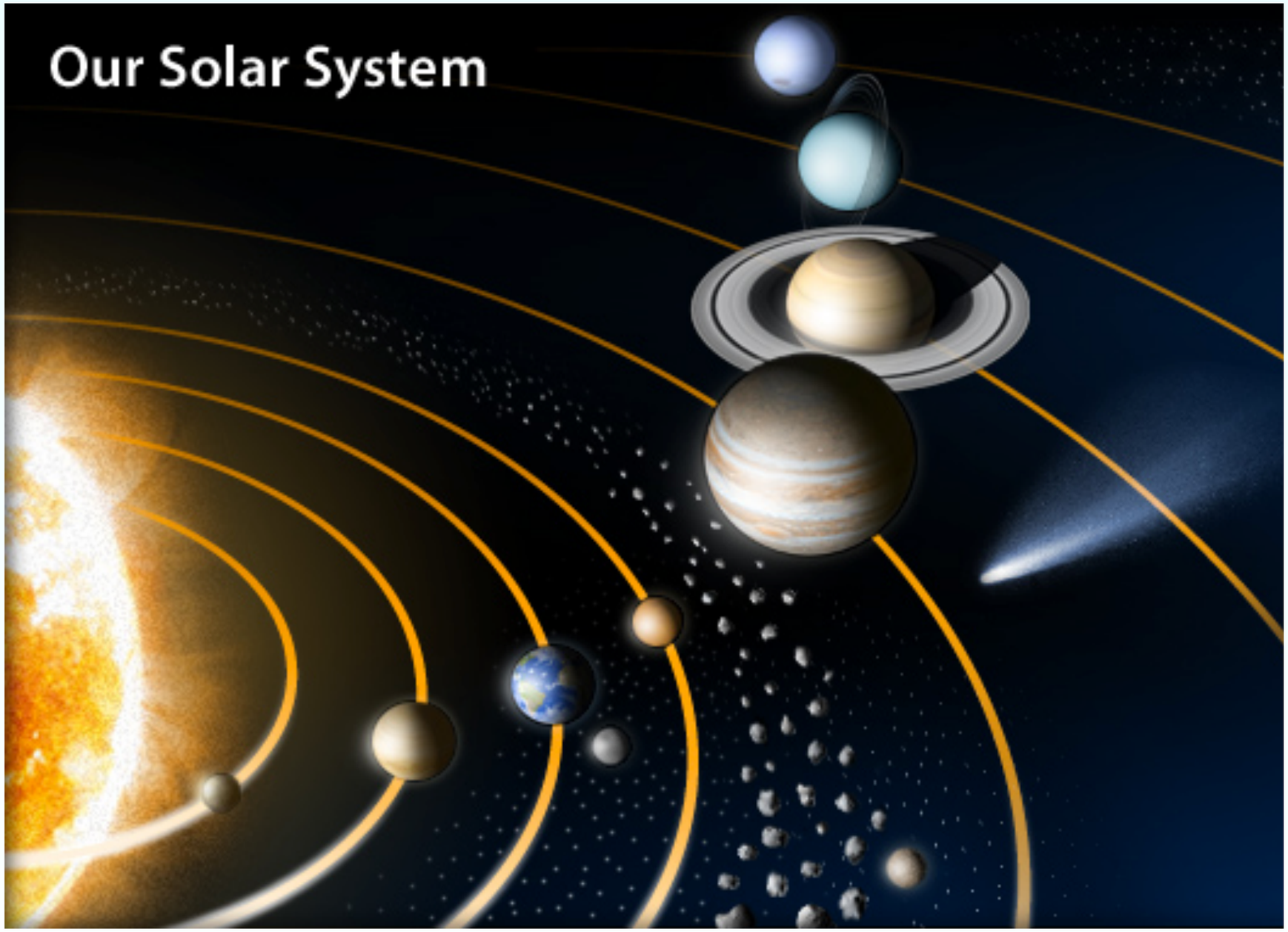


… I can use the LHC **to see new fundamental particles**



Remarkable facts about the LHC

☑ The **emptiest place in the Solar System:** vacuum in the beam pipe similar to **interplanetary space**



Remarkable facts about the LHC

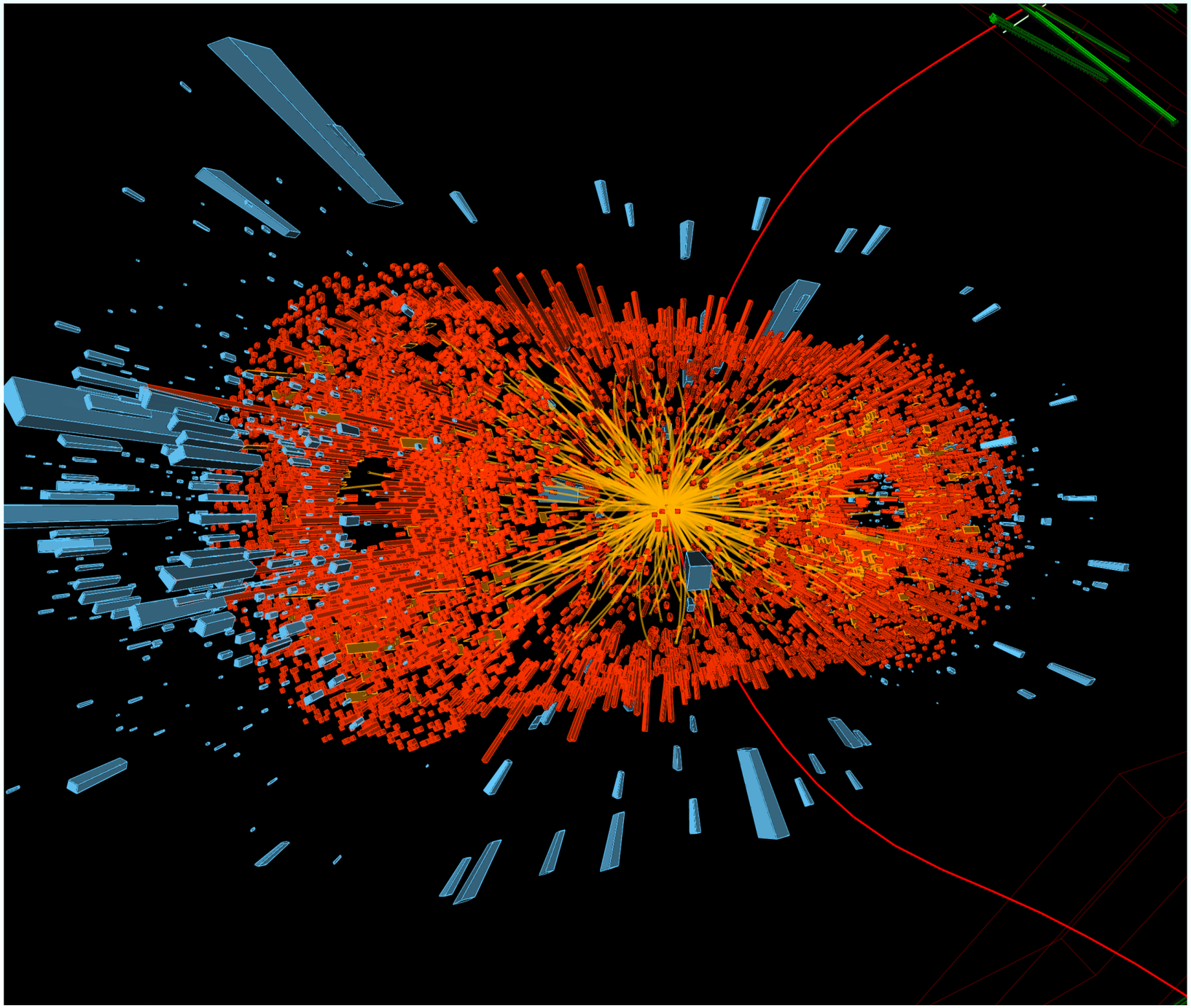
☑ One of **coldest places in the Universe:** the LHC magnets are kept at only **1.9 degress** above absolute zero, **colder than interstellar space!**

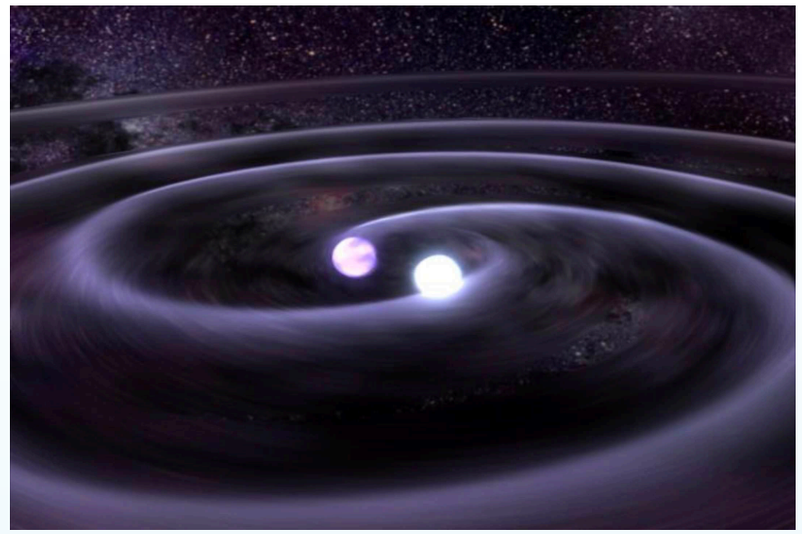
Remarkable facts about the LHC

☑ The **data volume** recorded is like reading **10,000 times the full Encyclopedia Britannica - each second!**

Remarkable facts about the LHC

☑ One of **hottest places in the Galaxy:** collisions generate a temperature **billions of times larger than the Sun,** reproducing conditions of **early Universe**





Gravitational waves:
The symphony of space-time

This is not science fiction!

Has anyone seen this movie? What happened in this particular part?

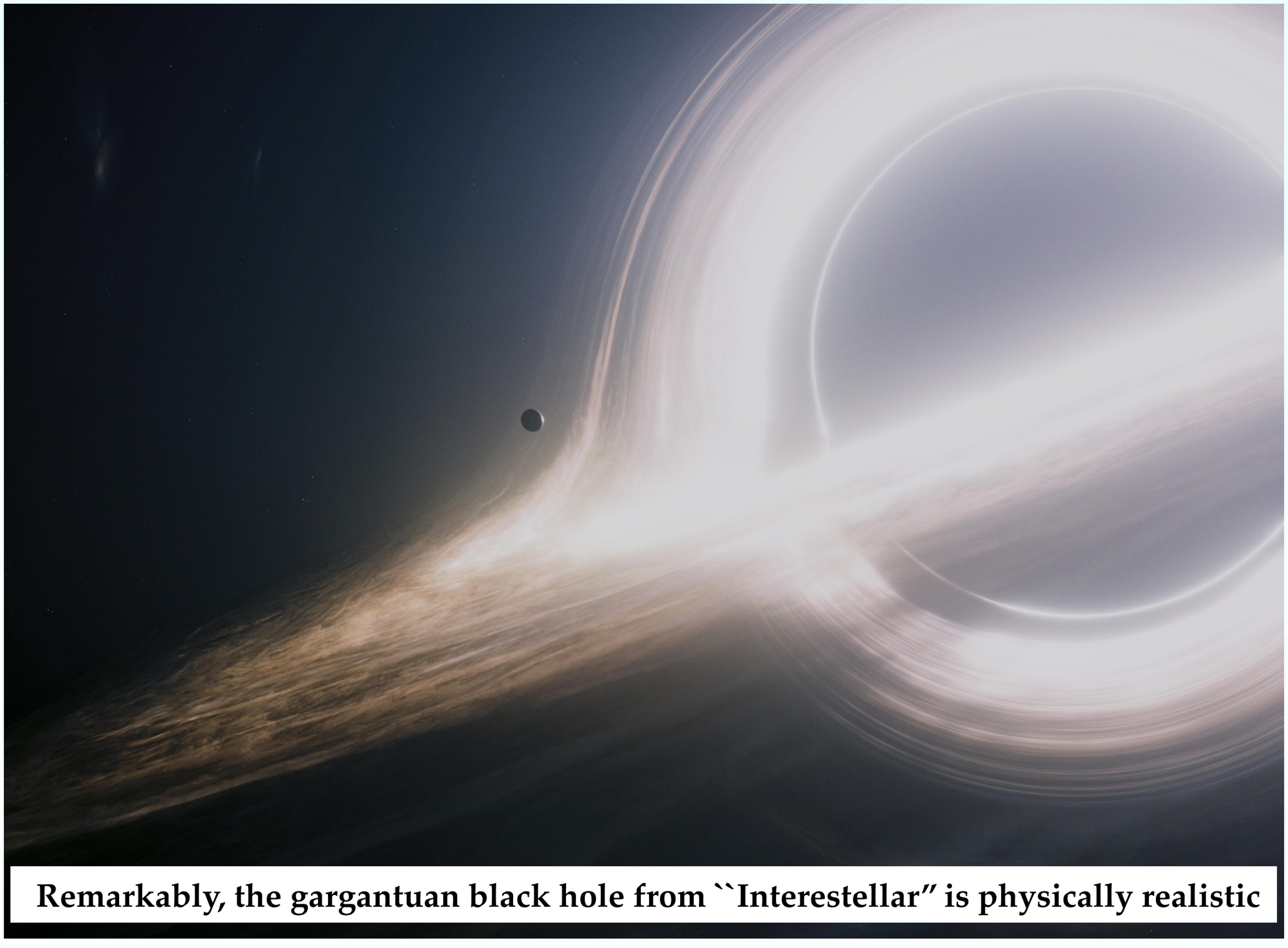
This is not science fiction!

Einstein's theory of General Relativity describes *gravity* as **deformations of space-time**

Massive enough bodies, such as black holes, deform space-time and **slow the local time**

This is not science fiction!

Black holes are one of the most fascinating objects in the Universe:
nothing can escape from their attraction, not even light!

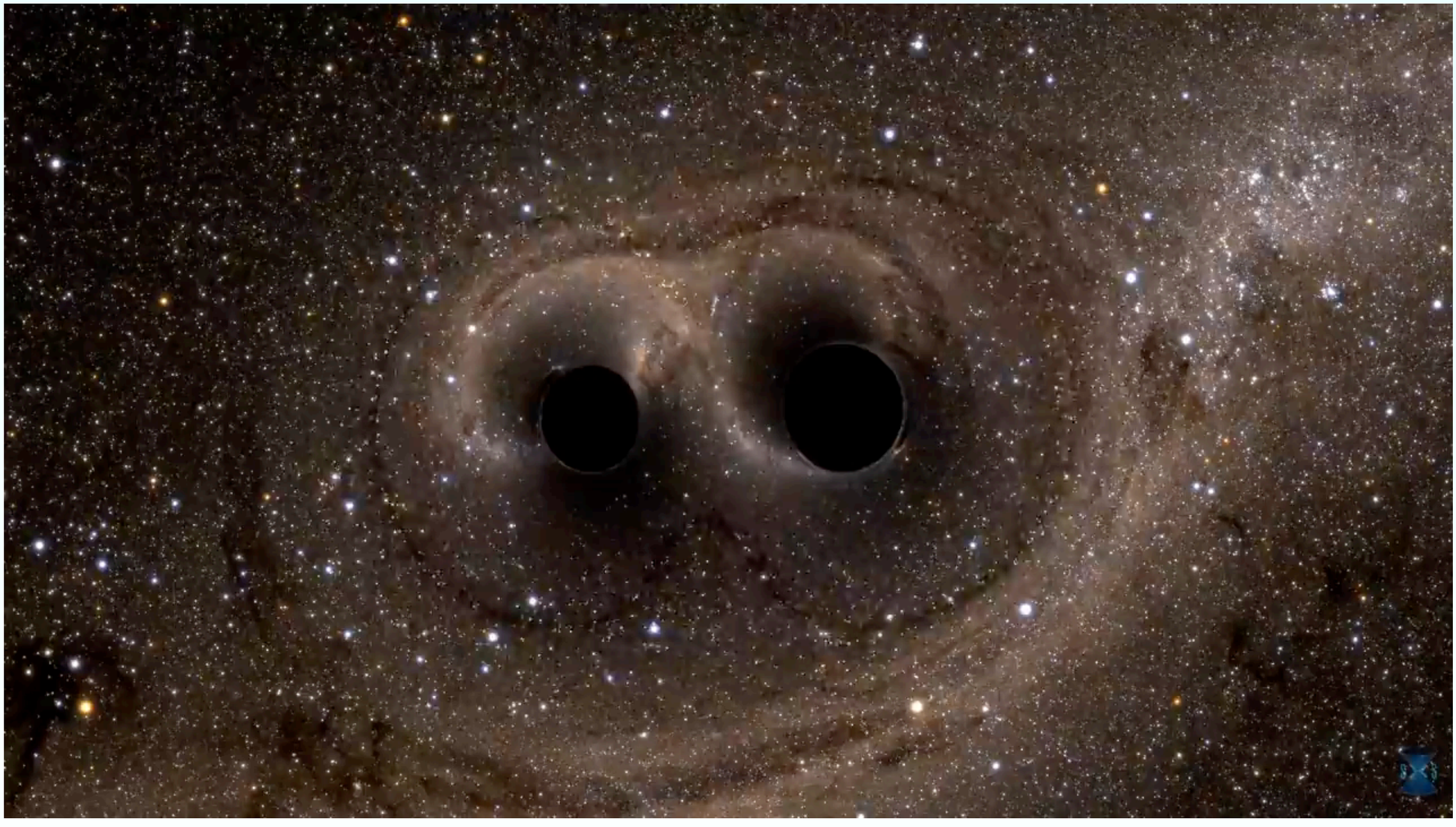


Remarkably, the gargantuan black hole from ``Interestellar" is physically realistic

When worlds collide

Black holes can be found in **pairs**, remnants from binary star systems

Black hole mergers are some of the most cataclysmic events that take place in the Universe

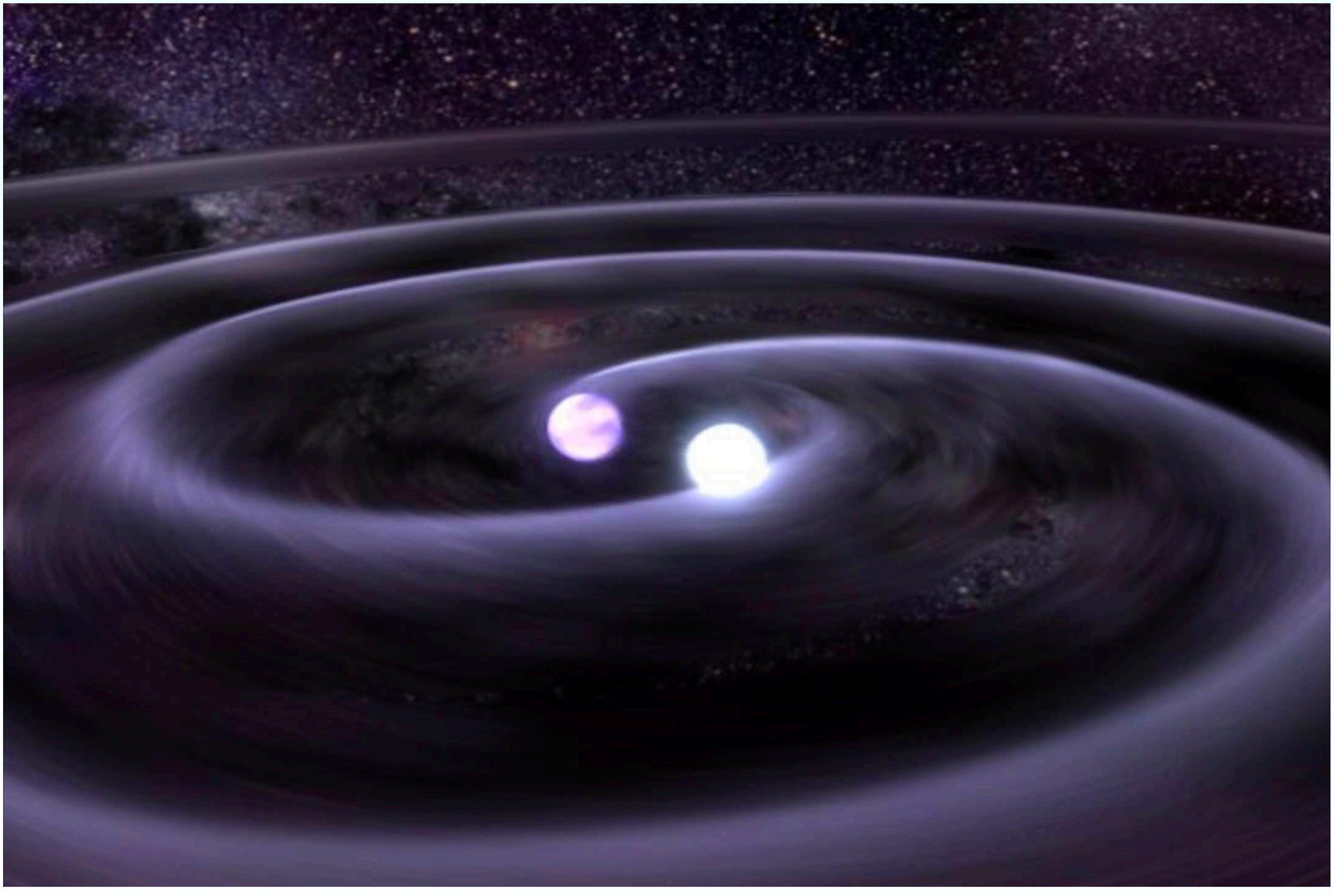


If a black hole is, well, black, then how is all this energy released?

In terms of gravitational waves, ripples of space-time itself!

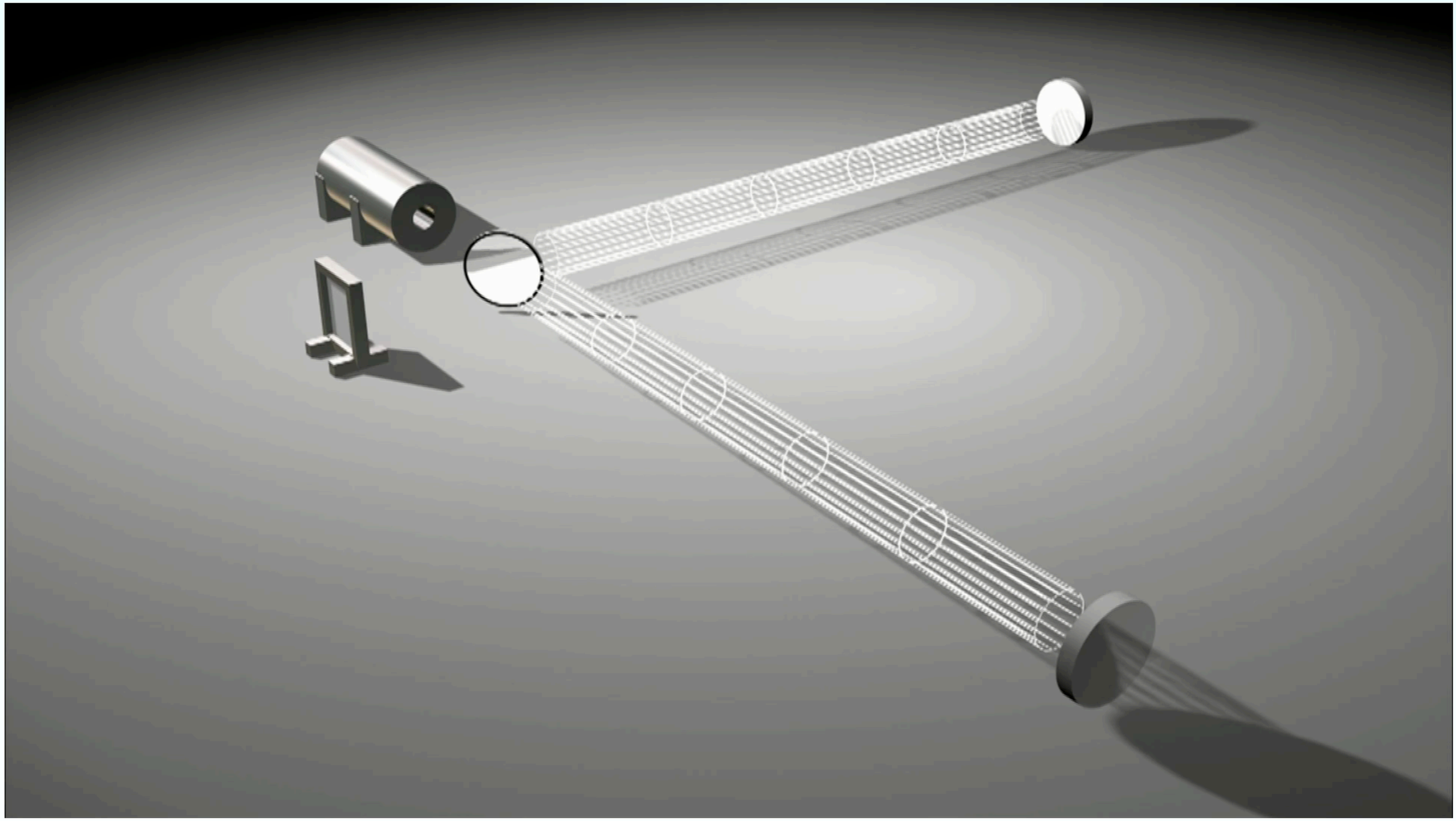
When worlds collide

Gravitational waves, unlike matter waves, do not propagate on top of something space-time itself oscillates, propagating energy across the universe



When worlds collide

Gravitational waves can be detected with **ultra-precise laser interferometers**



Need to measure length variations of less that 1/1000 of a proton size in the interferometer arms of 4 km each!

Useless science?

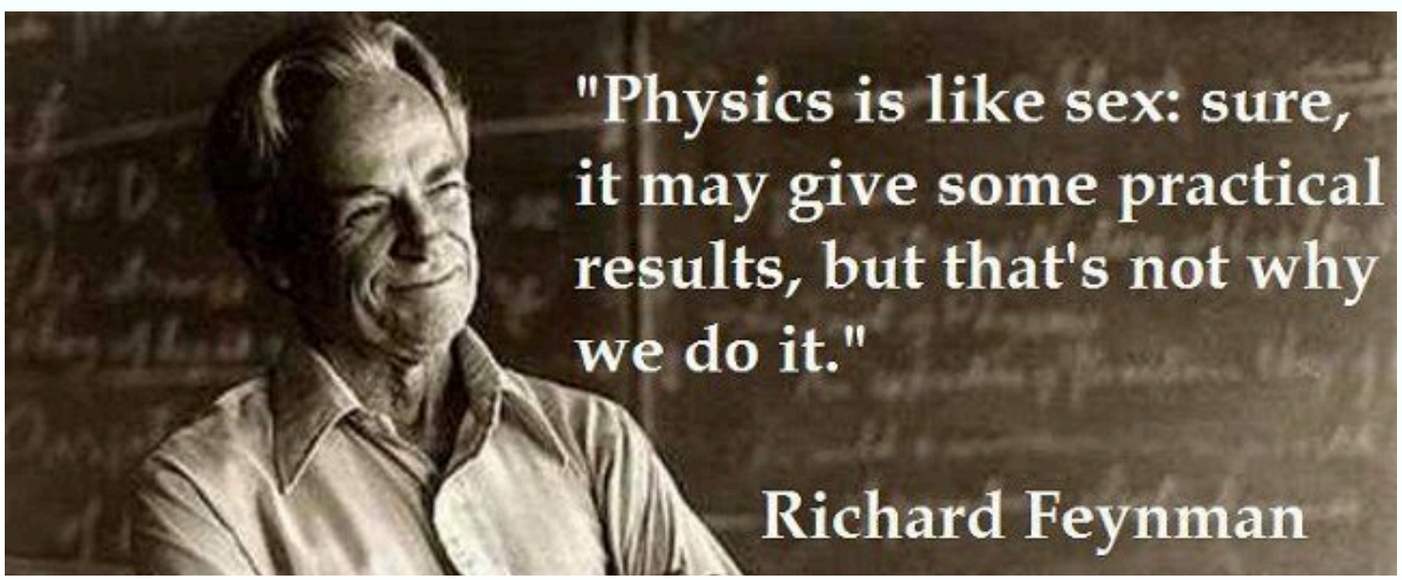
Useless science?

The main driver beyond fundamental science is **sheer curiosity,** our **intrinsic fascination to understand what we are made of**, where we come from, where are we going

In that sense, this new knowledge has all to do with honour and country but it has nothing to do directly with defending our country ***except to help make it worth defending***

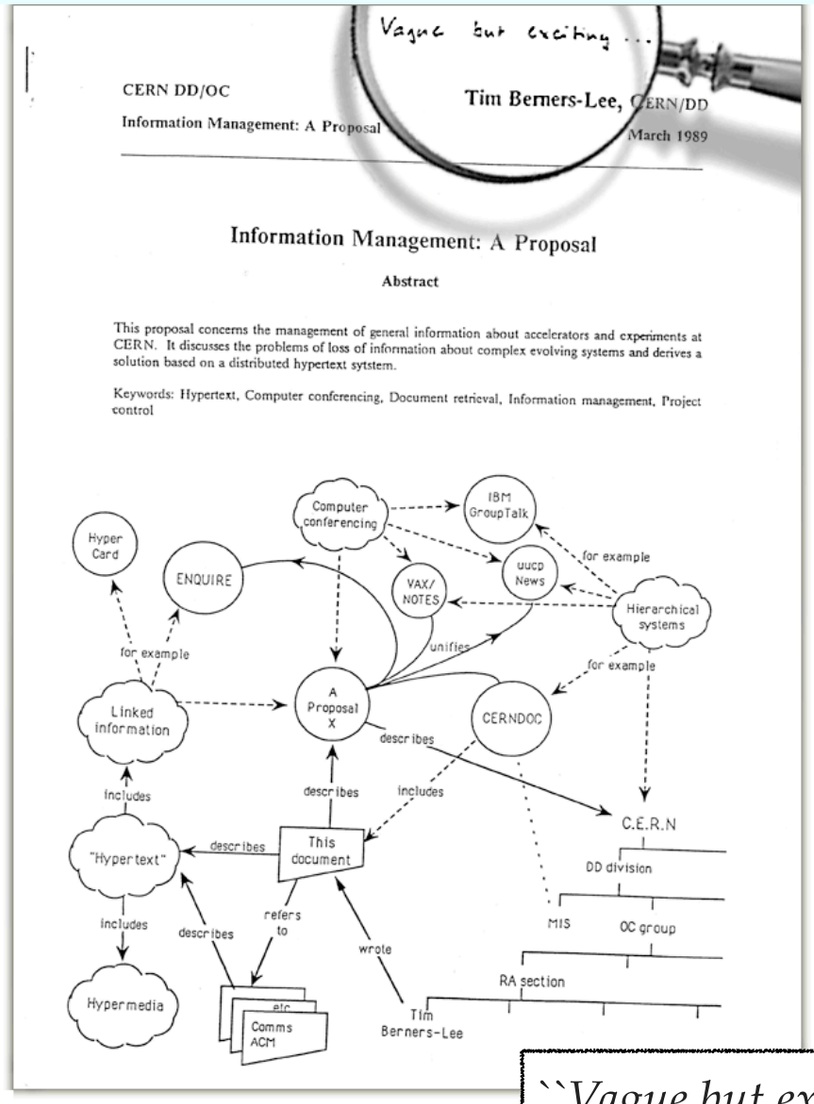
The physicist Robert Wilson, when asked by the U.S. Congress about practical applications of particle physics

This said, basic research has lead to a large number of **crucial practical applications**, many of them shaping the modern world - from **Internet** to the **GPS**



Where the web was born!

I am old enough to remember a **world without Internet!** (or even without smartphones ….)



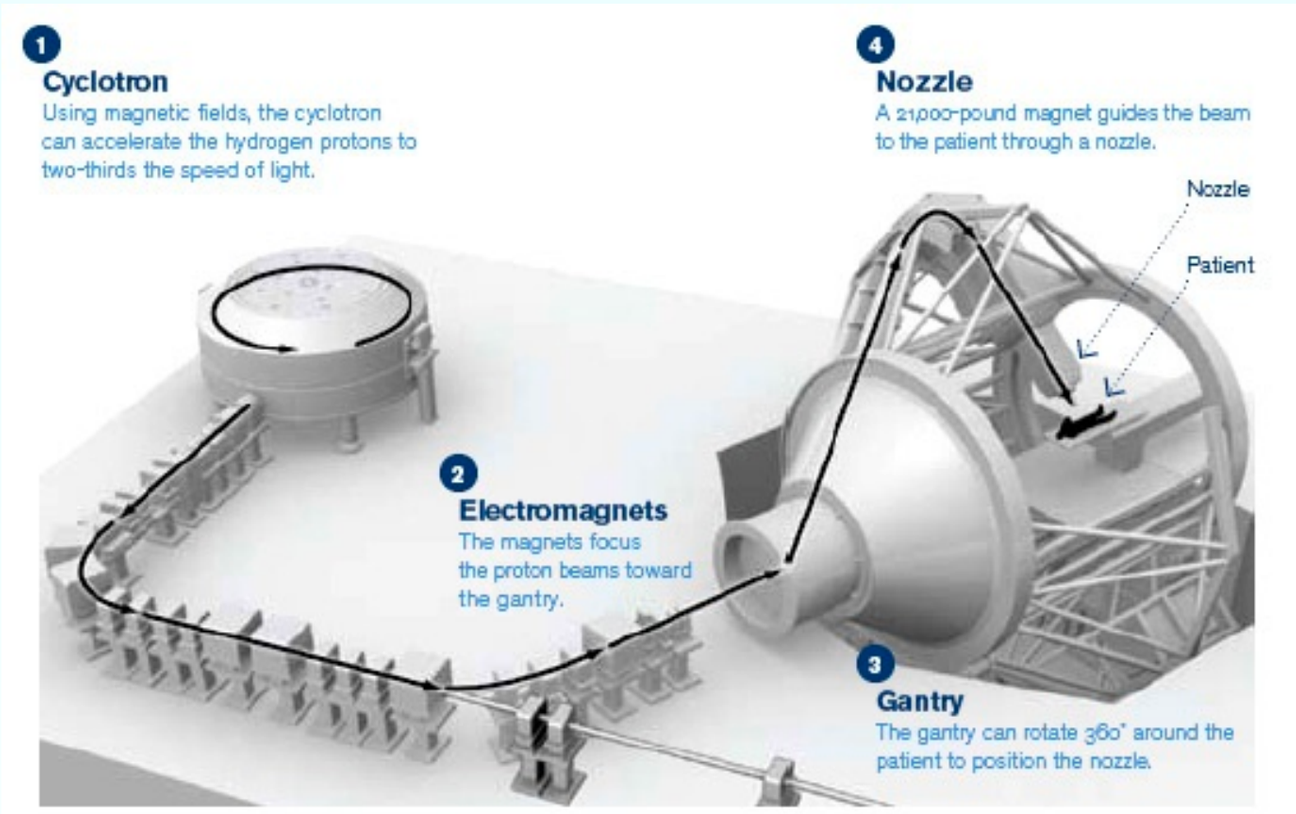
``Vague but exciting…"

The World Wide Web was first started by **Tim Berners-Lee, a CERN software engineer** aiming to streamline the communication between CERN scientists and researchers

In the U.S.A. alone, Internet-related economic sectors amount to **$966 billion** (6% of total economy)

Proton therapy

A **collimated beam of high energy protons** is used to irradiate diseased tissue

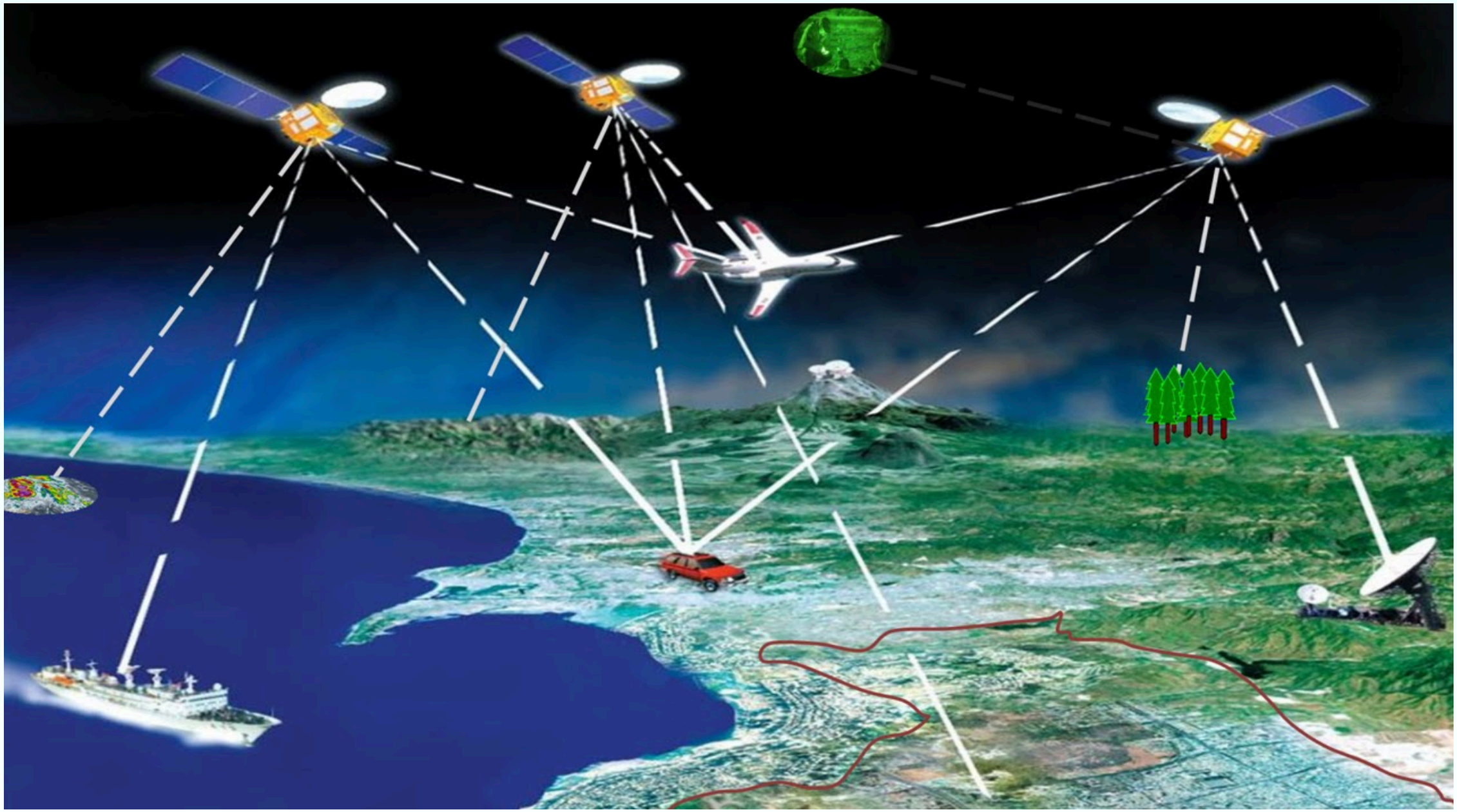


Uses **particle accelerators** to deliver precise doses, well-focused on diseased tissues like tumors and with minimal spill over to healthy tissues

Around **100 facilities of proton therapy** spread all over the world

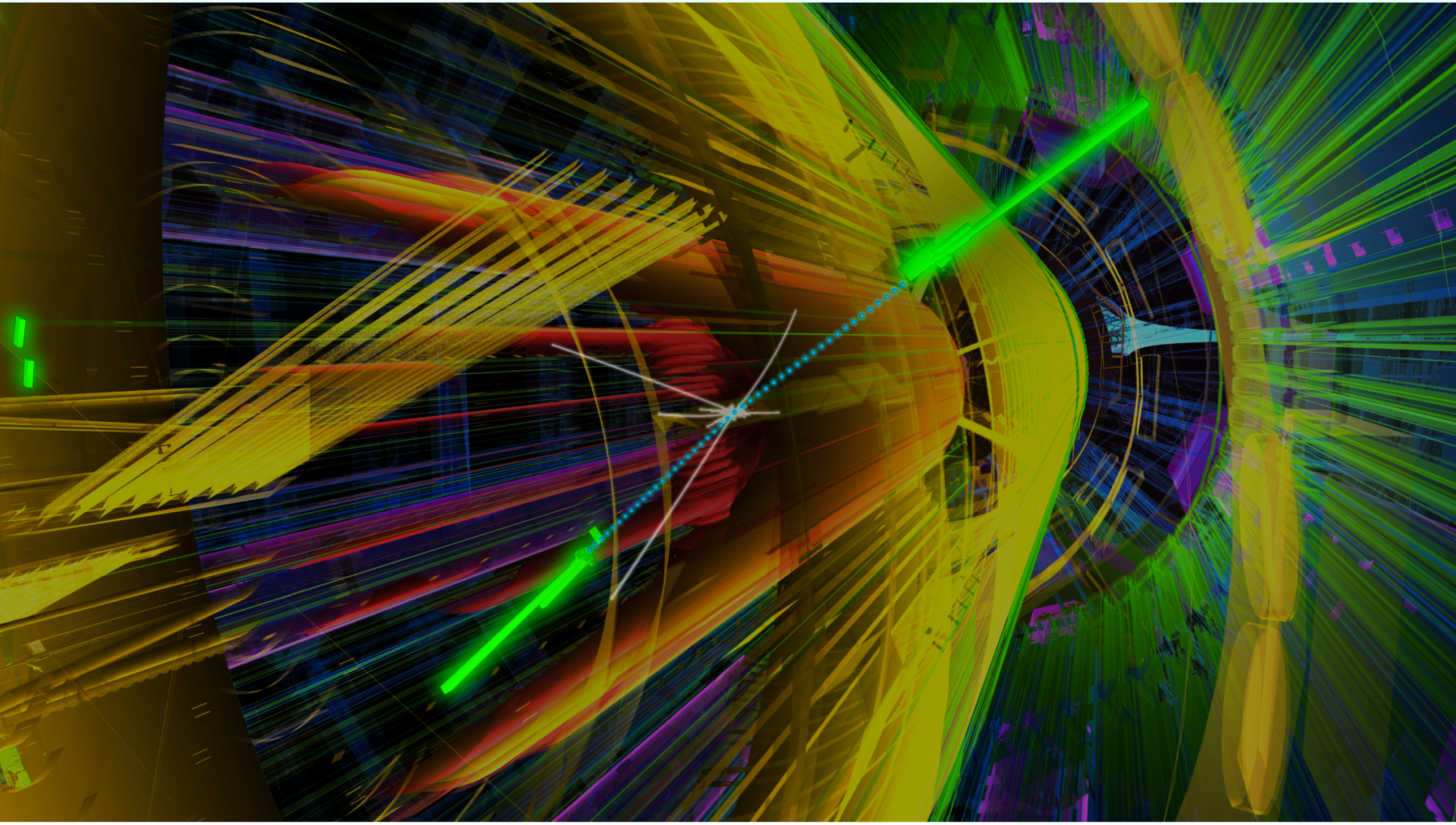
Global Positioning System

A system of connected satellites that, once accounted for the effects of **Einsteins's Special and General Relativity**, allow determining our position with an accuracy of a few meters



Remember to **thank Einstein** next time you find your way using Google Maps!

Fascinating times for high-energy physics!



Stay tuned for new discoveries!

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