

# The secret code of Nature: Unveiling the secrets of elementary particles

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*This presentation will be interactive ....  
so please have your cell phones ready!*

*We will use the MentiMeter!*



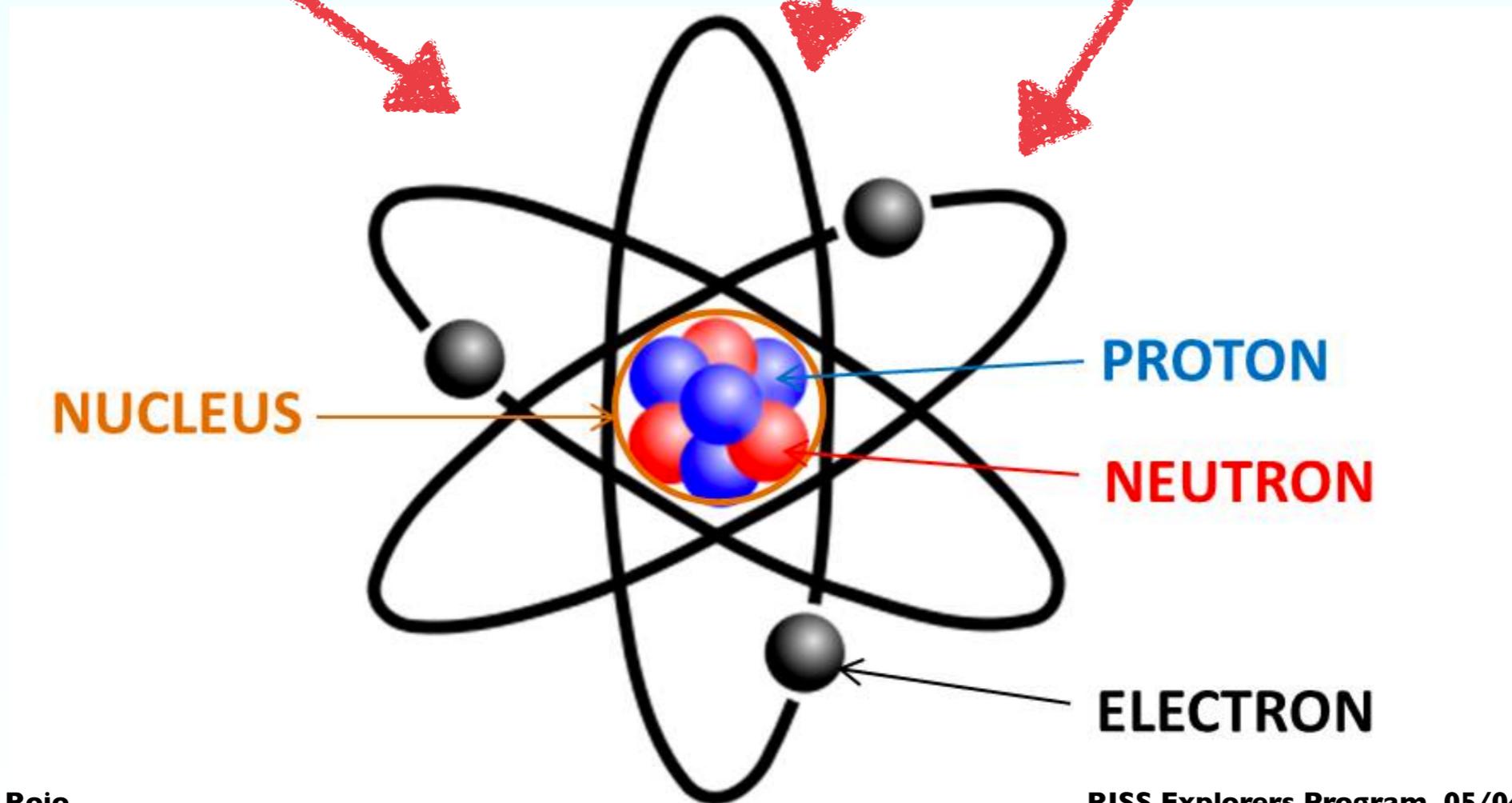
# The Stuff of Matter

- ☑ 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**



# 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



# *How small is an atom?*

# How small are atoms?



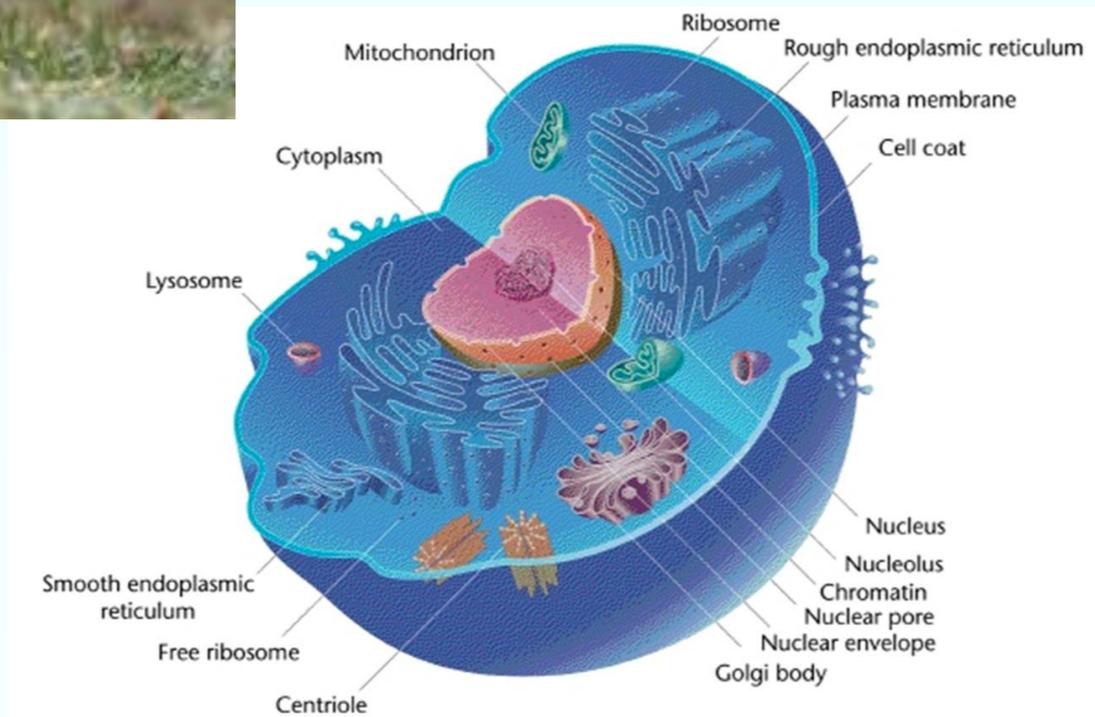
A squirrel has a length of **10 centimeters** ....

# How small are atoms?



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

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

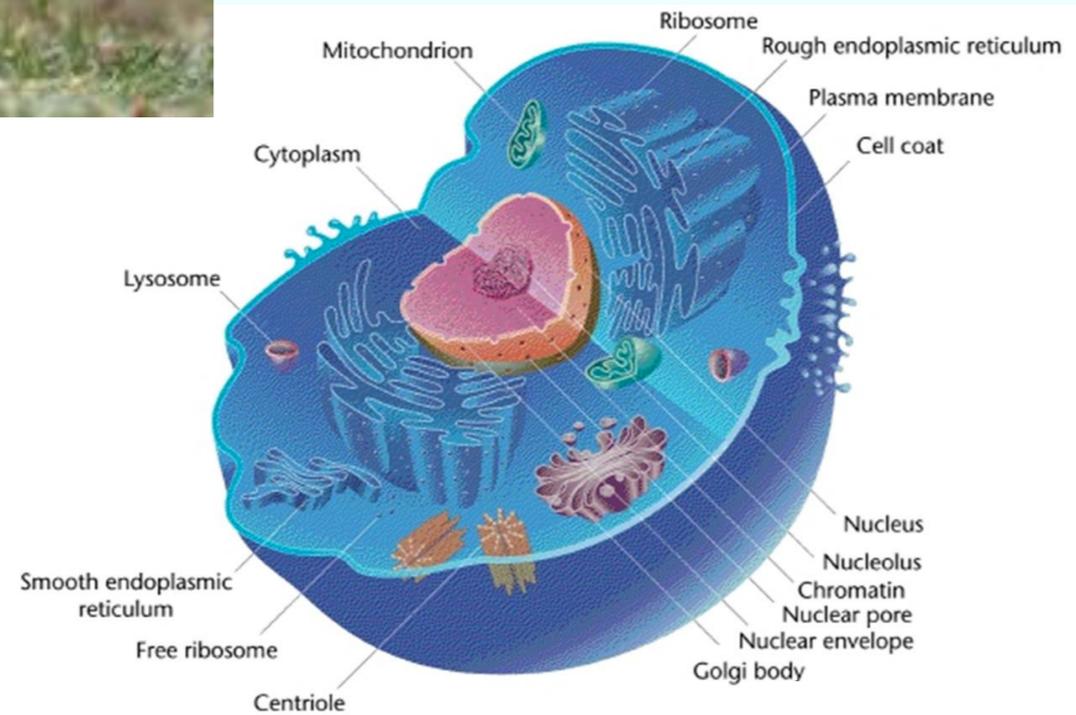


# How small are atoms?

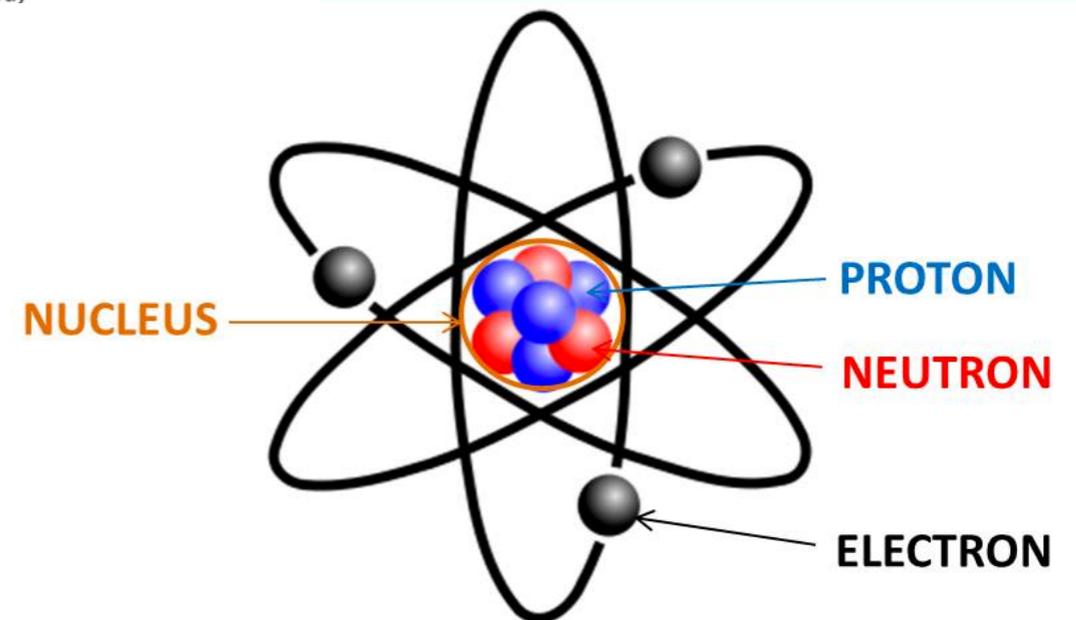


A squirrel has a length of **10 centimeters ....**

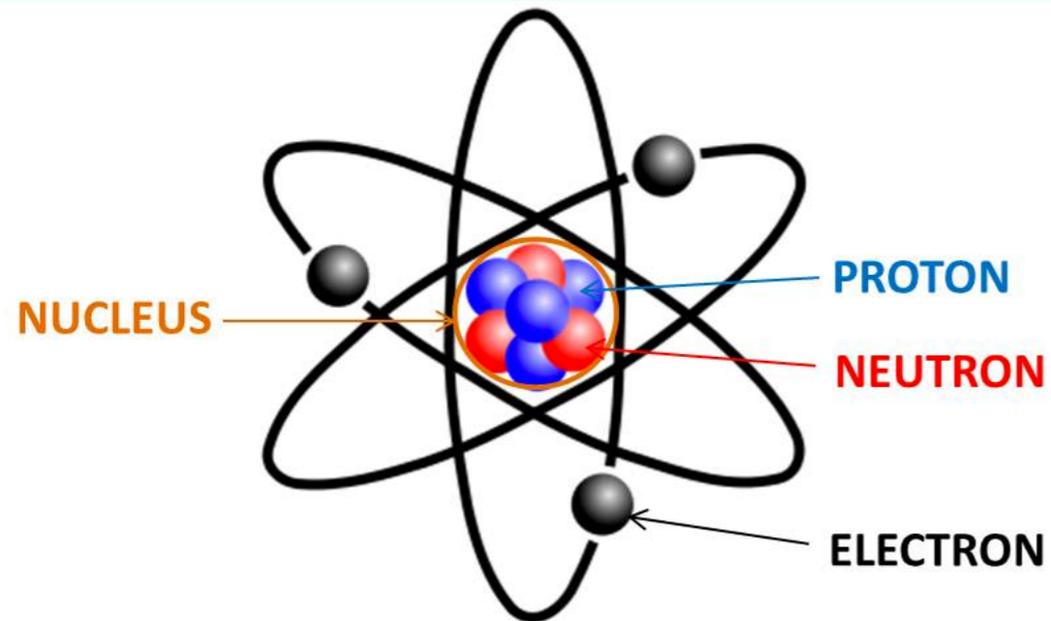
All animals are composed by **cells**, of size **10 micrometers: 10000 times smaller .....**



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



# From atoms to protons to quarks

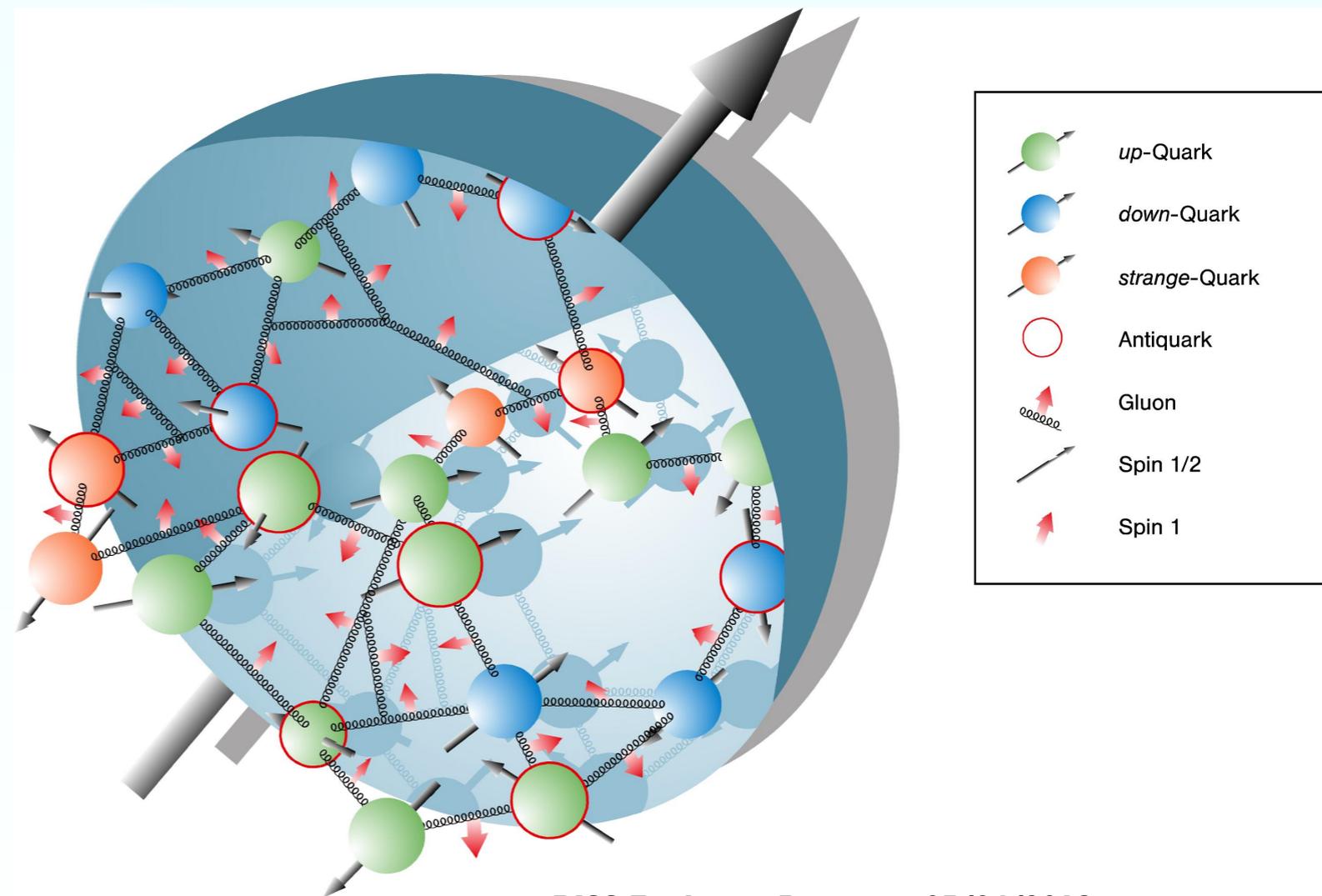


Atoms themselves have even smaller constituents: **protons, neutrons and electrons**

**Protons are 10000 times smaller than atoms!**

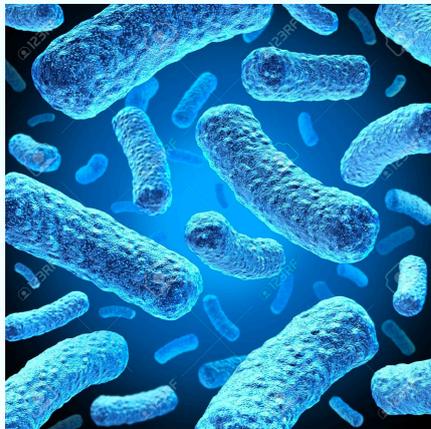
Even the tiny protons have **smaller constituents**: we call them **quarks and gluons**

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

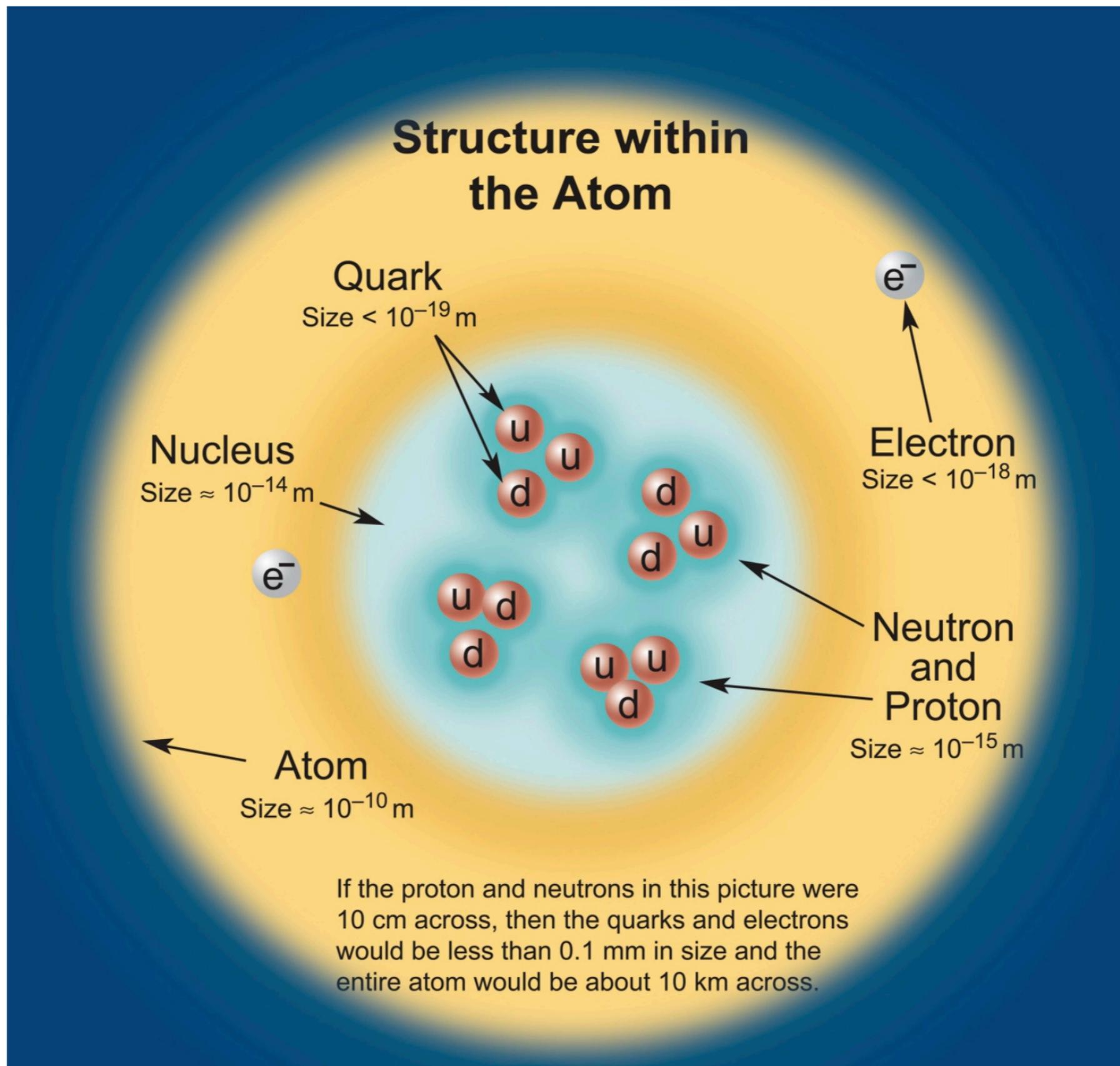


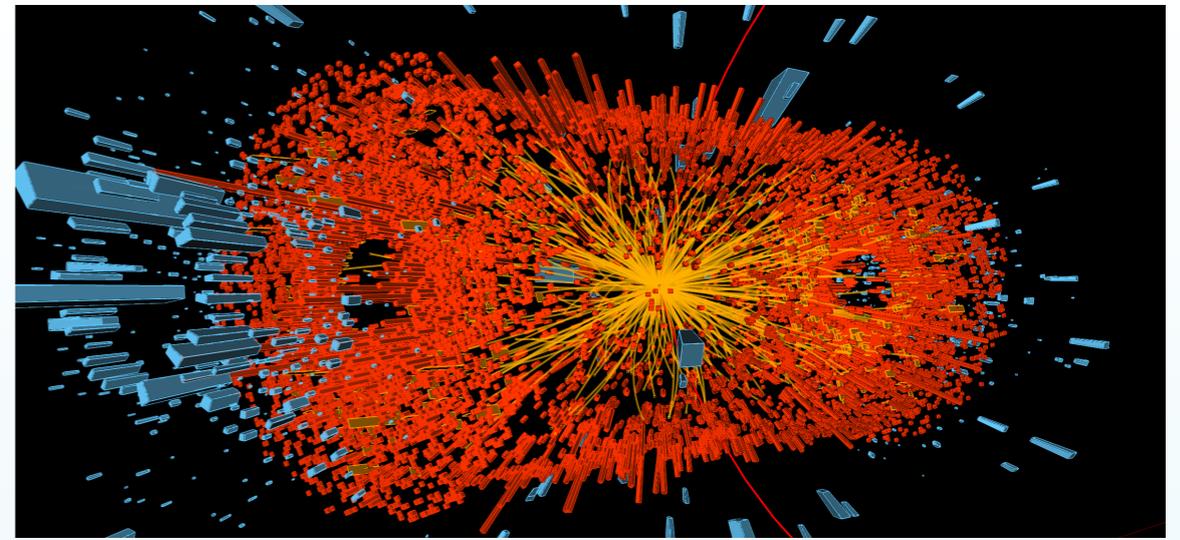
# From galaxies to quarks

**Bacterium**

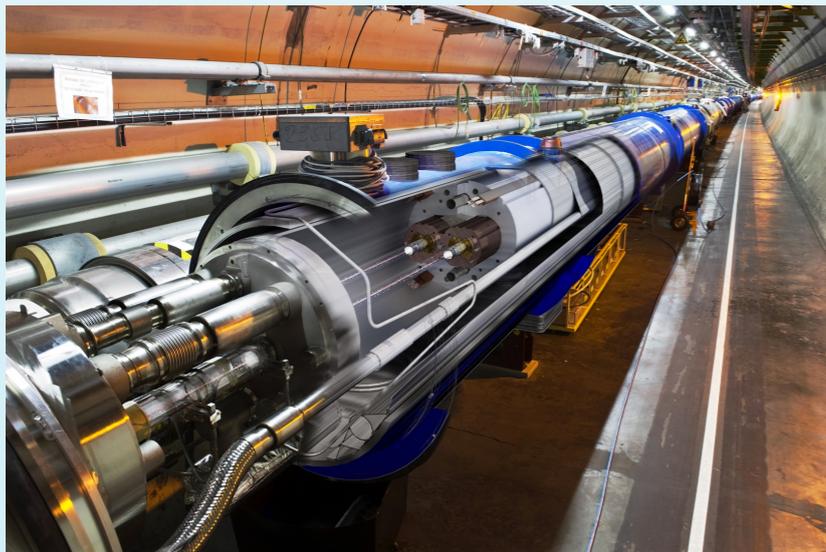


**Size =  $10^{-5}$  m**





# Exploring the secret code of Nature at the Large Hadron Collider



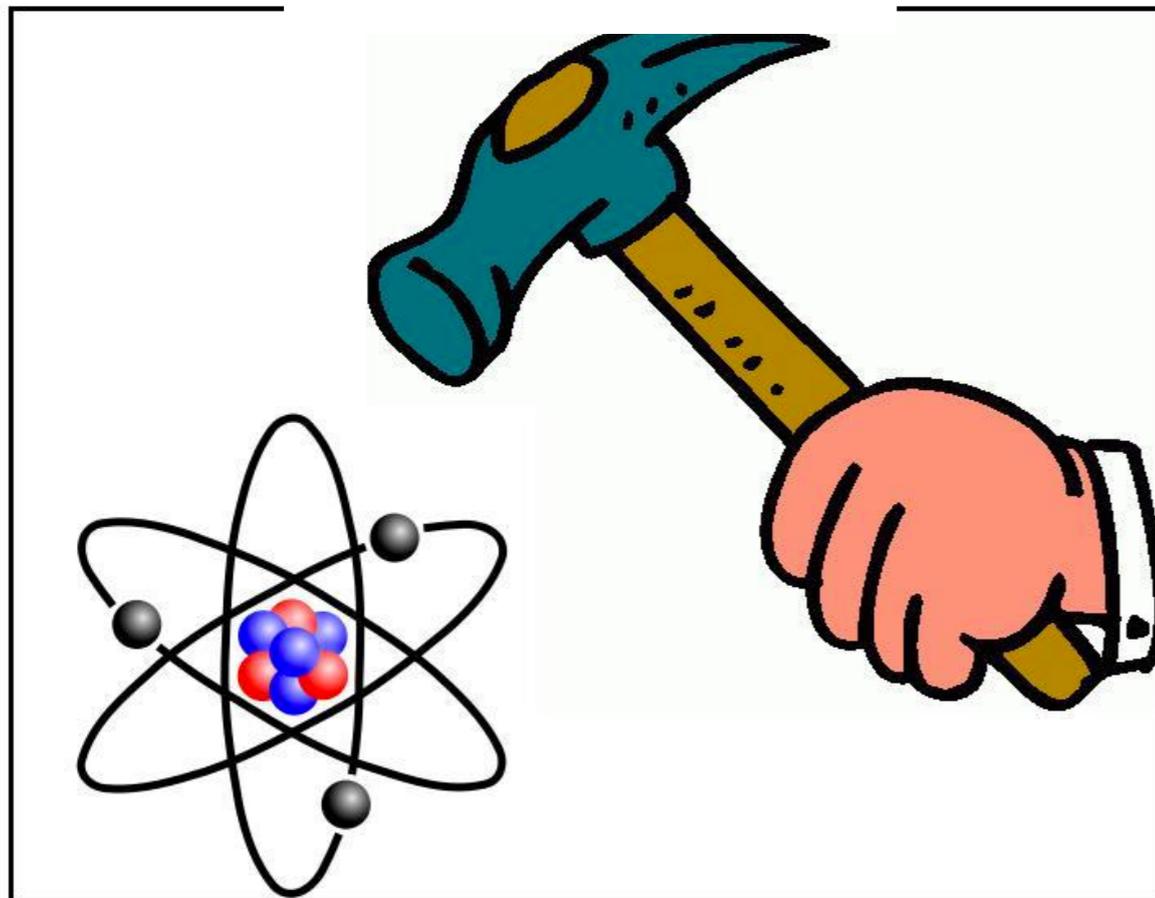
*How can we look inside tiny  
particles such as protons?*

# 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?

**Bad  
idea!**

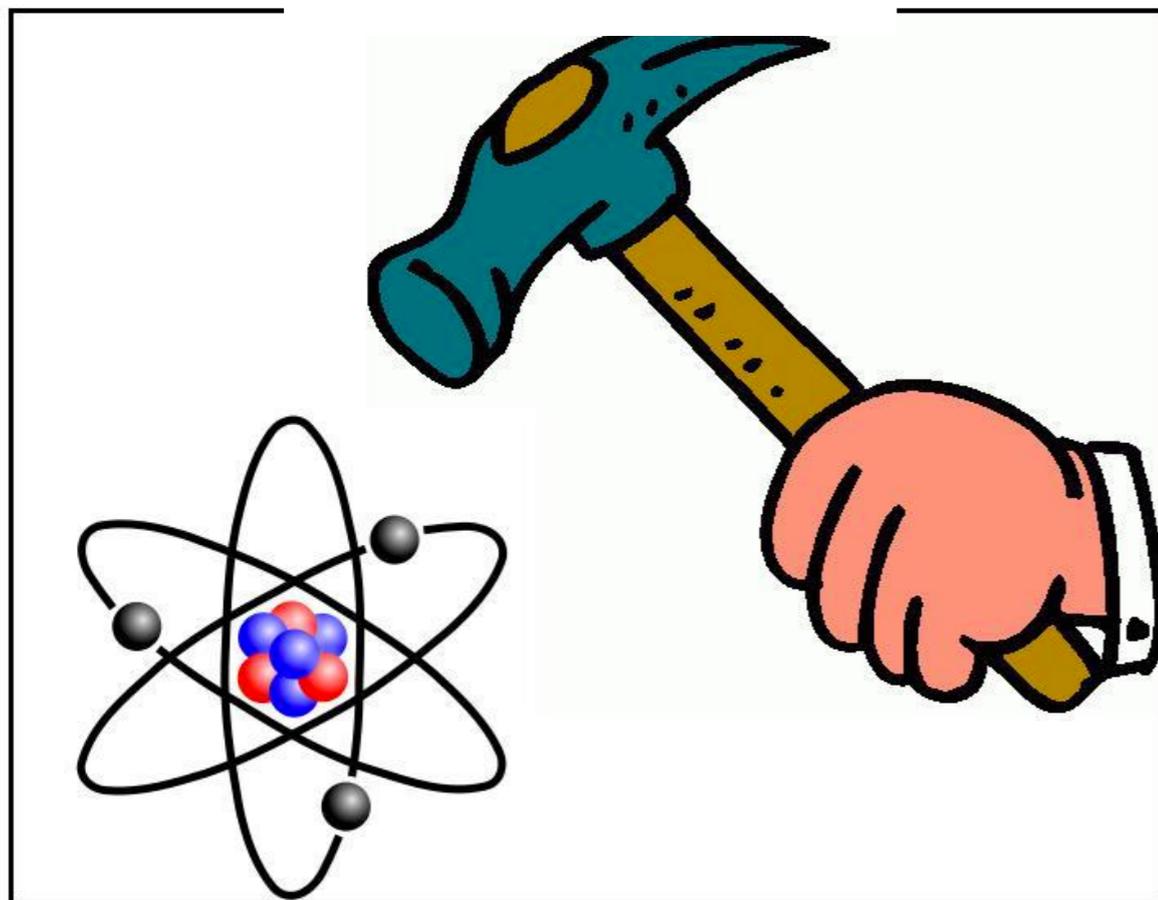


# High energy colliders

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 **results 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!**



Juan Rojo

**Good  
idea!**



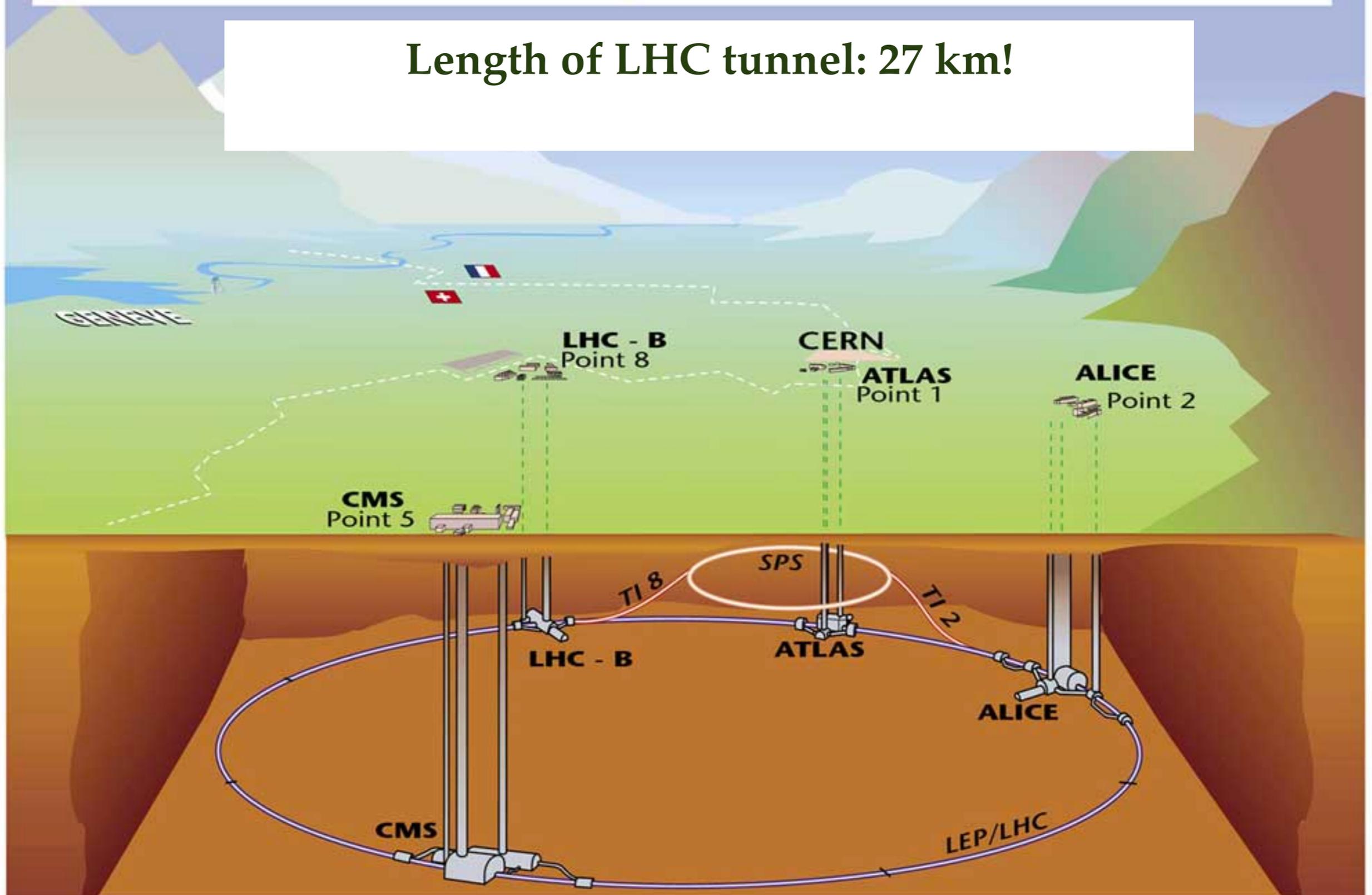
# The Large Hadron Collider

- ✓ 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!

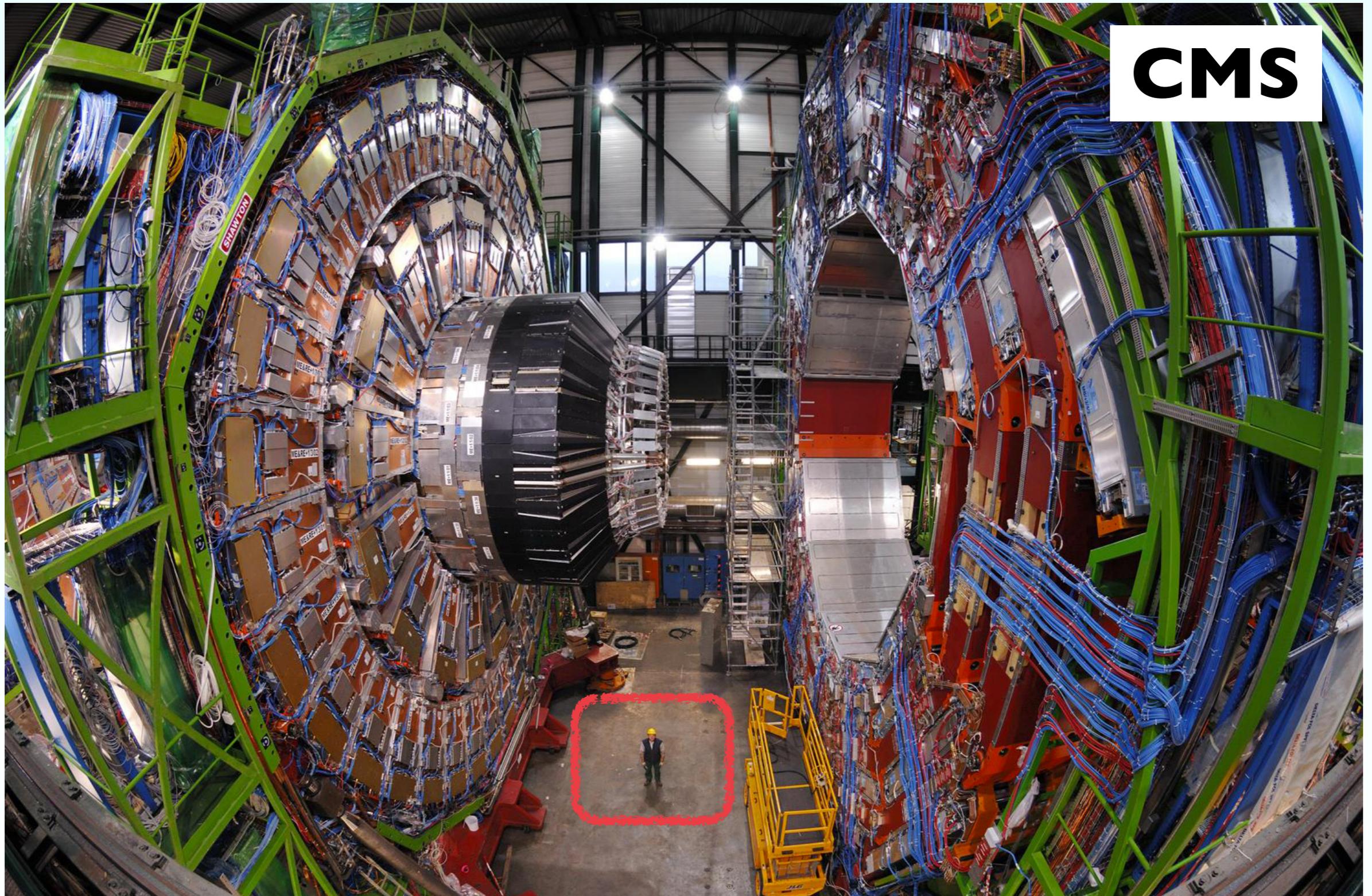


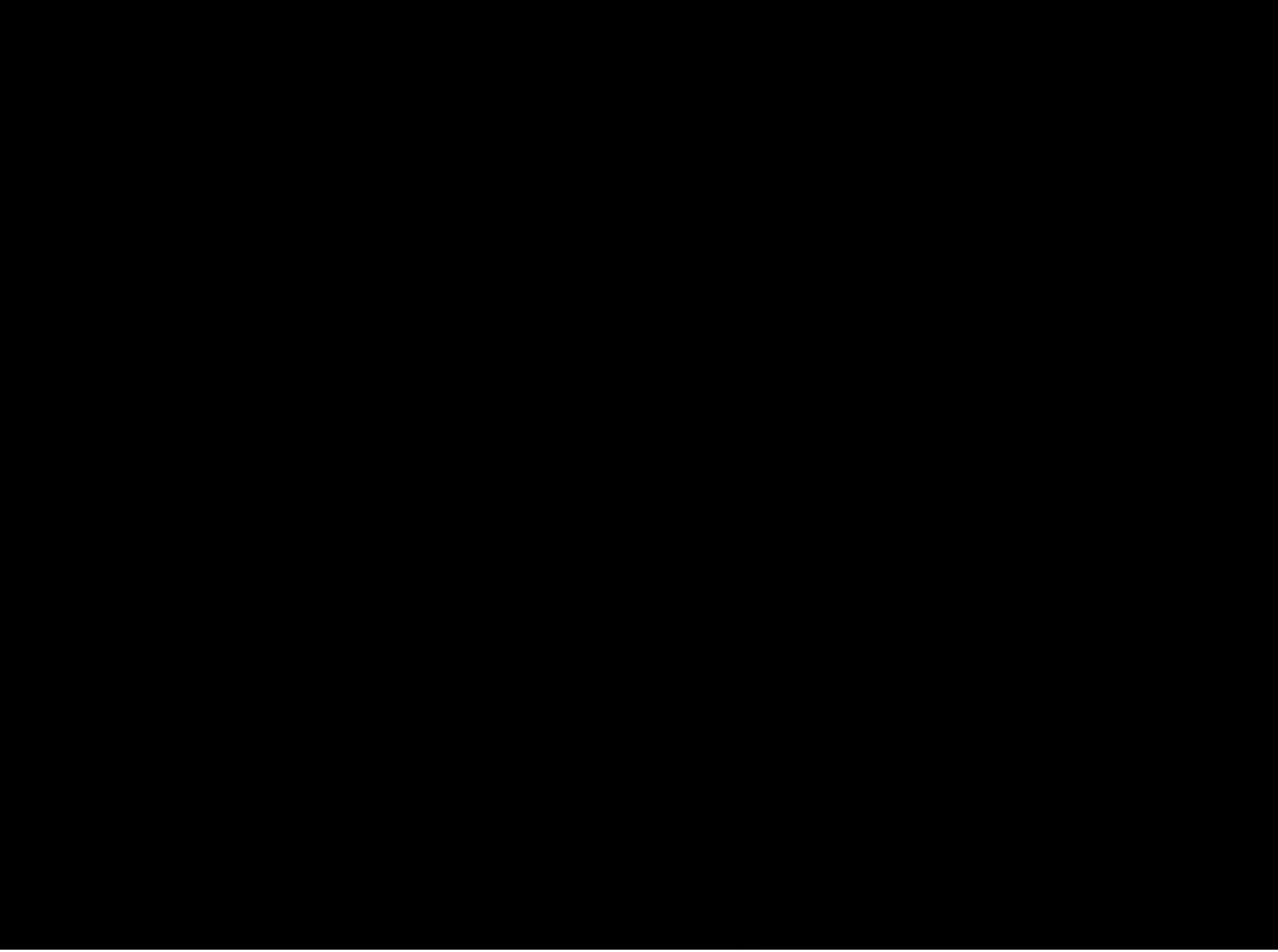
Experiments are hosted in underground tunnel to minimise disruption (+ reduce real state costs!)



# The LHC detectors

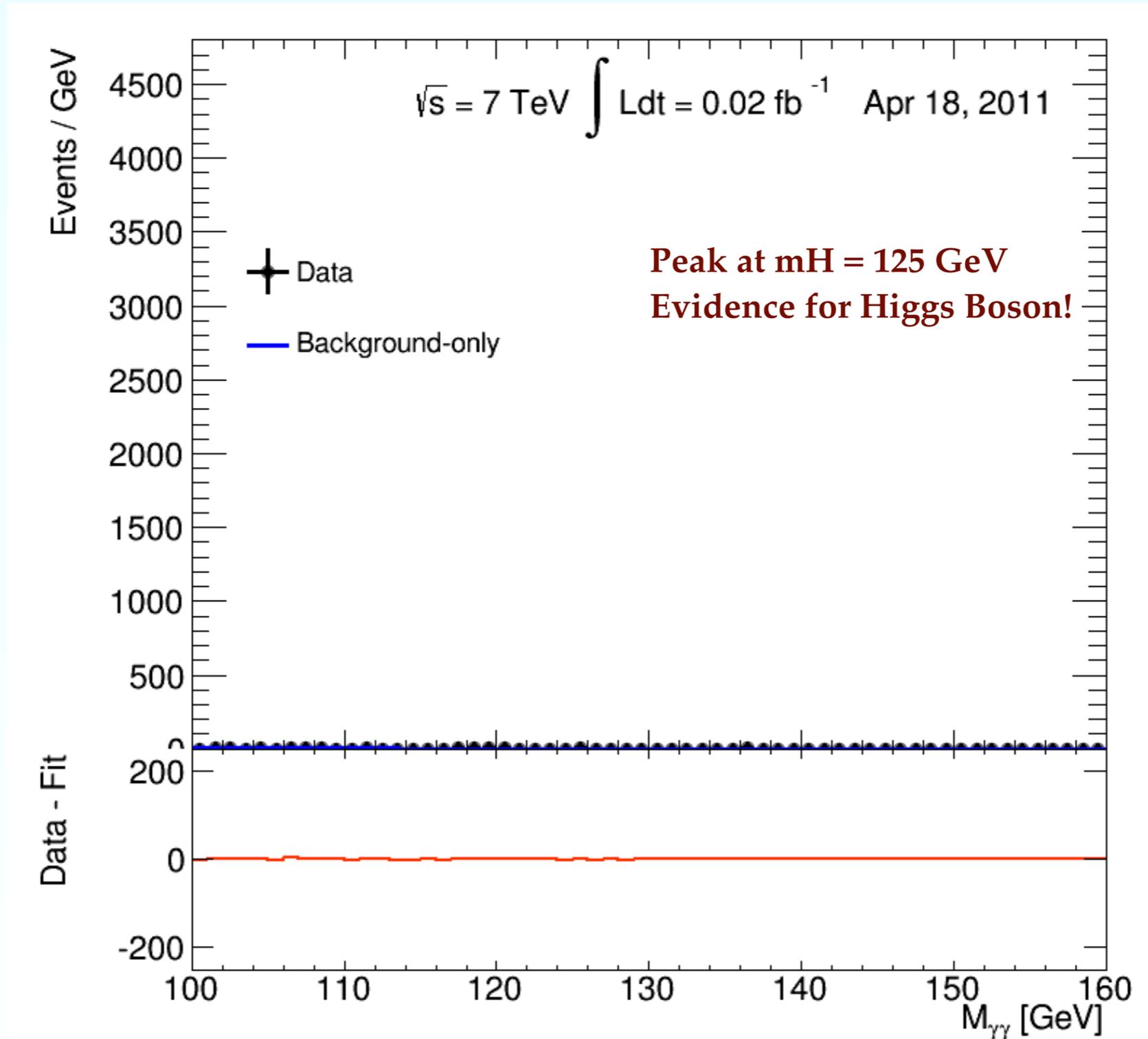
Where proton beams cross and collisions take place, huge detectors measure the products of the collision in an attempt to understand the laws of Nature at the smallest distances





# 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



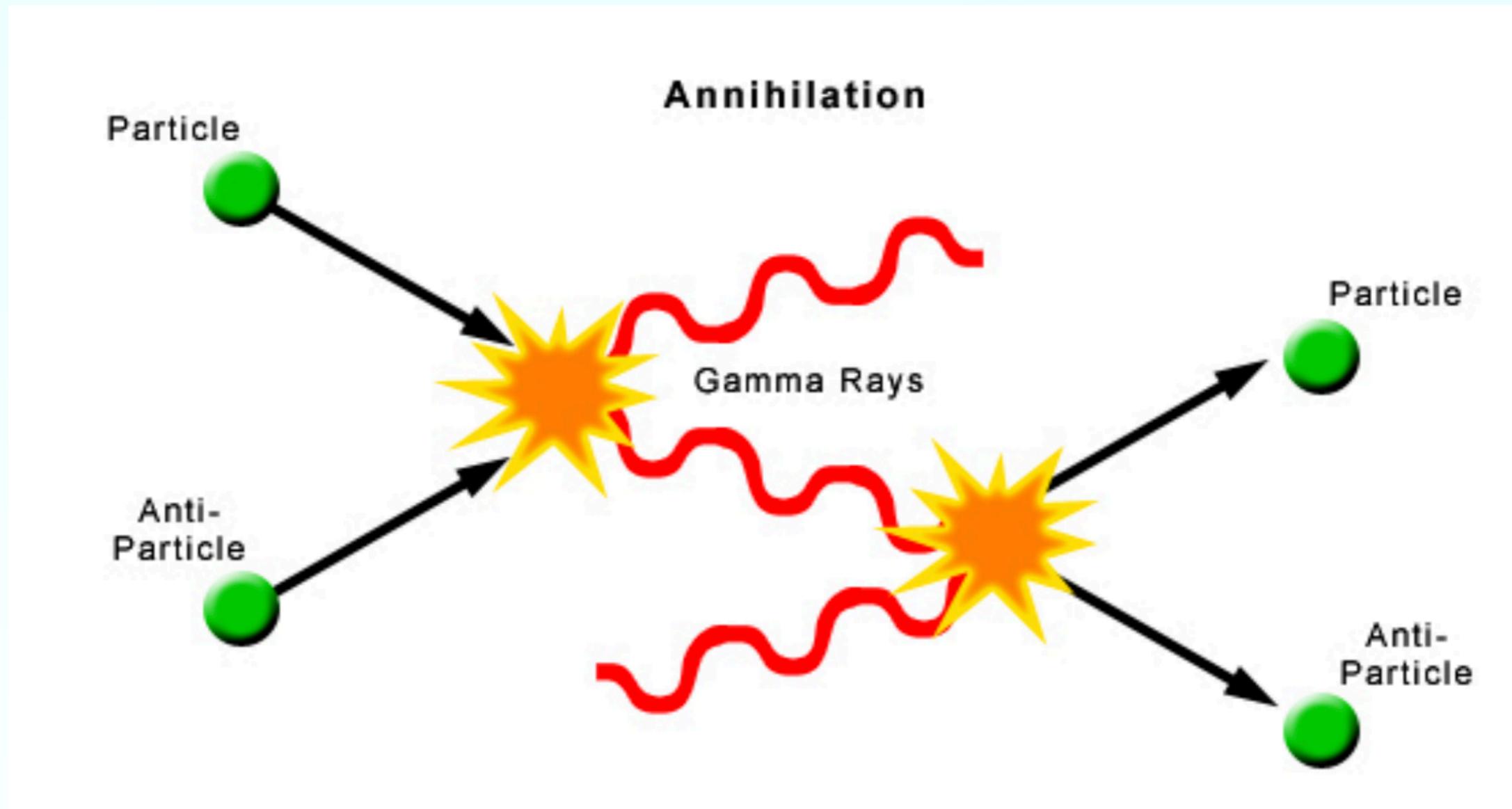
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# Antimatter matters

☑ CERN is also the world's leading producer of antimatter



Antimatter particles are just like regular particles, but with opposite charge

For example, the electron has an antiparticle called the **positron** with positive charge

When particles and anti-particles meet, they **annihilate into energy**

# Antimatter matters



# Antimatter matters

*Imagine that you had a big container full of antimatter. What can you do with it?*

# Antimatter matters

In Dan Brown's bestseller *Angels and Demons*, the perverse *Illuminati* want to steal antimatter from CERN to build a bomb to blow up the Vatican. This bomb is supposed to carry 0.25 grams of antimatter. How much energy will be released when all this antimatter is annihilated in the contact with normal matter? We can easily compute it using special relativity:

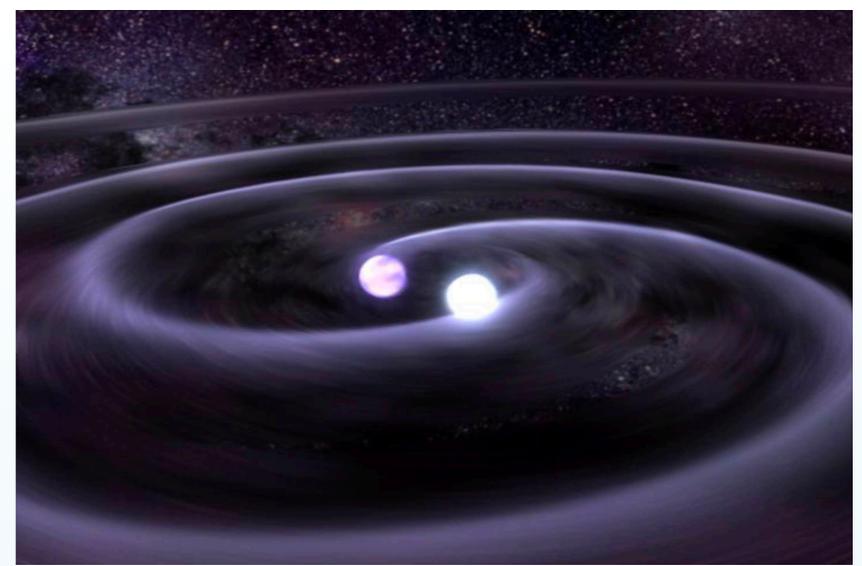
$$E = mc^2 = (2 \times 2.5 \times 10^{-4} \text{ kg}) \times (3 \times 10^8 \text{ m/s})^2 \simeq 5 \times 10^{13} \text{ J} = 50 \text{ TJ}, \quad (2.36)$$

where the factor 2 arises from the contribution of the 0.25 g of normal matter which annihilate with the antimatter in the bomb. This is about the same energy released by the atomic bomb dropped on Hiroshima ( $\simeq 63 \text{ TJ}$ ). So indeed antimatter seems to be a very powerful weapon!

The only downside of this malicious program is that producing antimatter is *very slow*. Even using all the accelerator complex from CERN<sup>a</sup>, at most one can produce  $10^{-12}$  grams of antimatter per year, meaning that it would take around *one billion years* to produce that much antimatter as required by the *Illuminati* dark master-plan. Of course, the same limitation affect proposals to power interstellar spaceships with antimatter engines.

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<sup>a</sup><http://angelsanddemons.web.cern.ch/antimatter/making-antimatter>

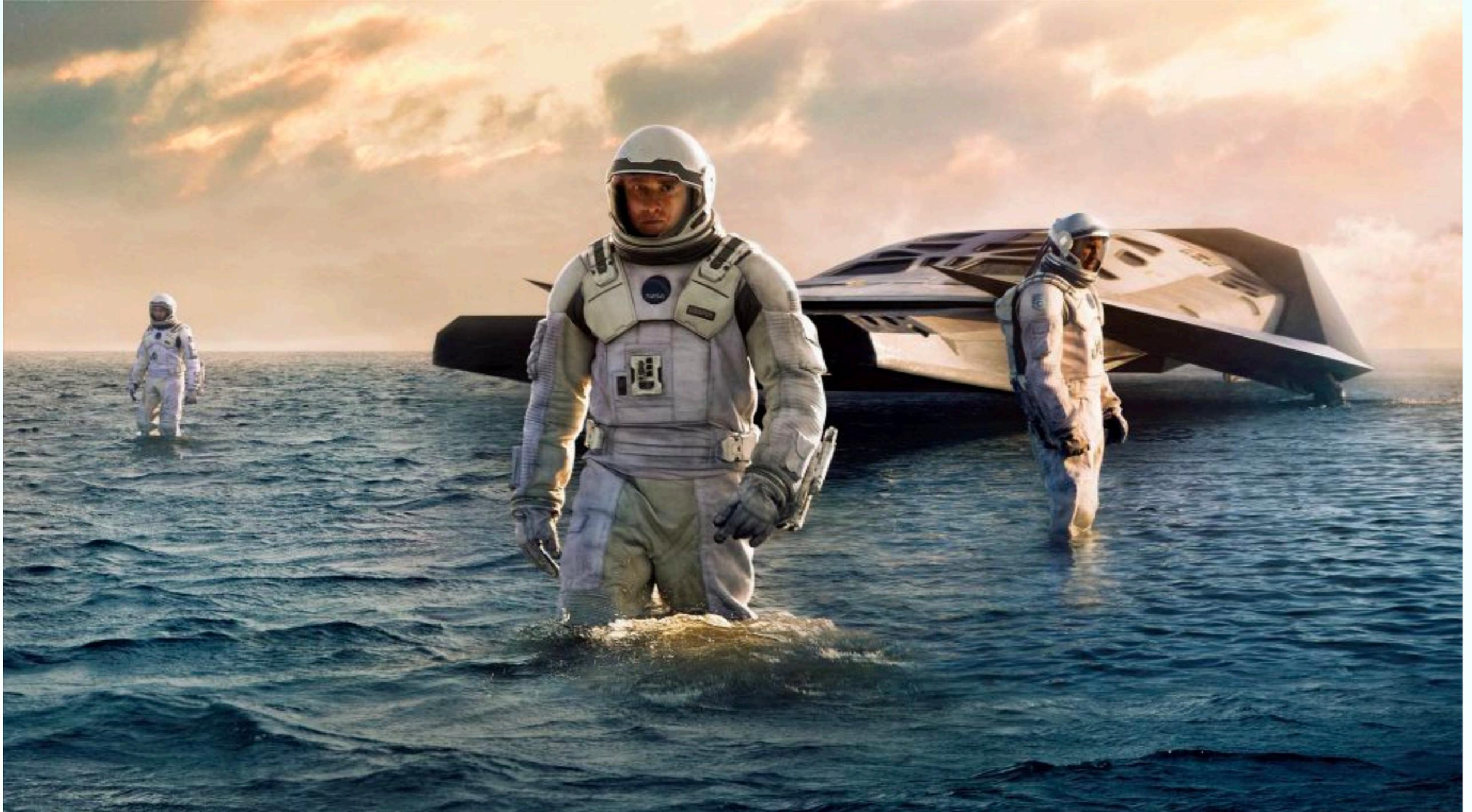


# Gravitational waves: The symphony of space-time



# This is not science fiction!

*Has anyone seen this movie?*

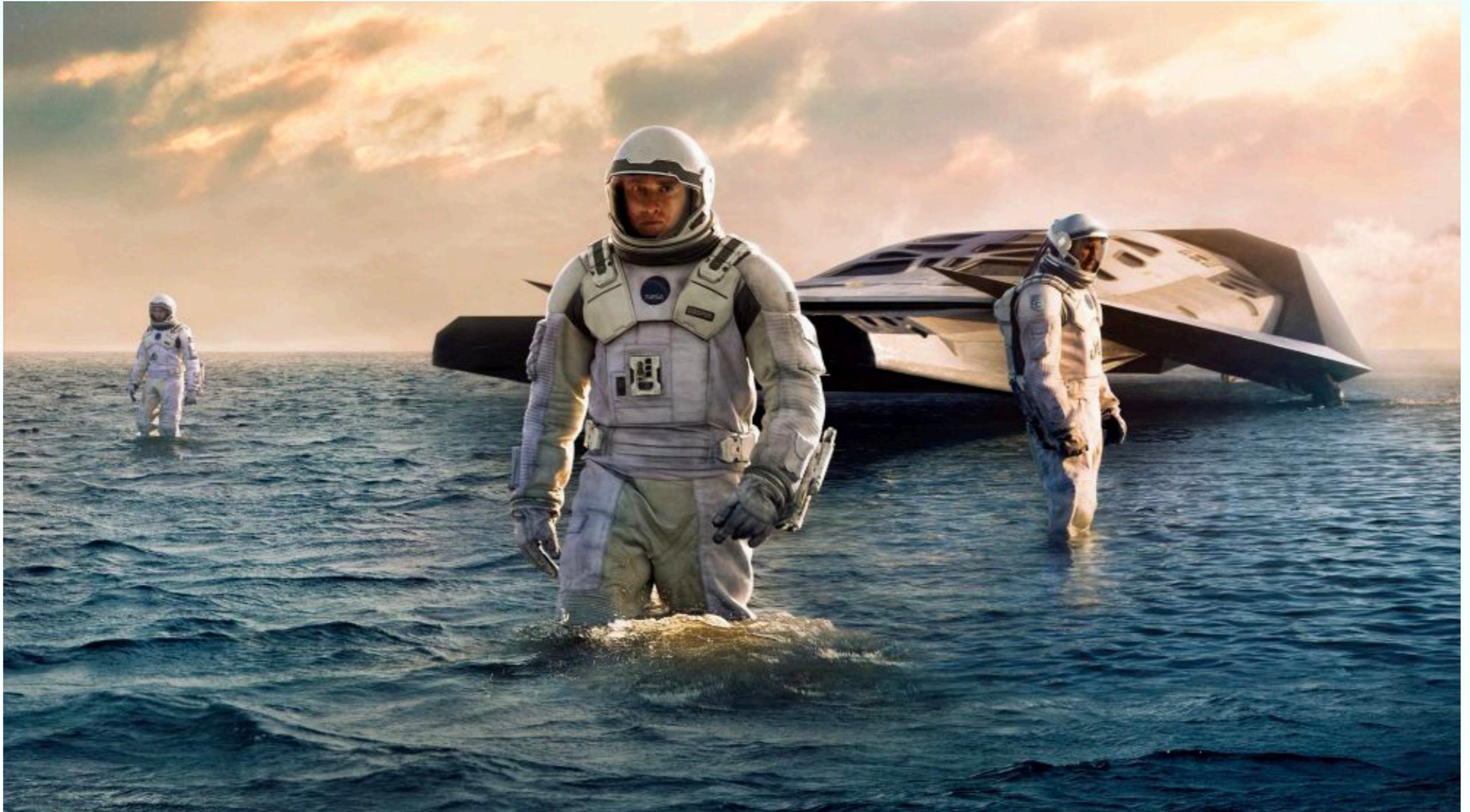


This is not science fiction!

*What happens when the Interstellar crew land on  
the first planet after crossing the wormhole?  
And why?*

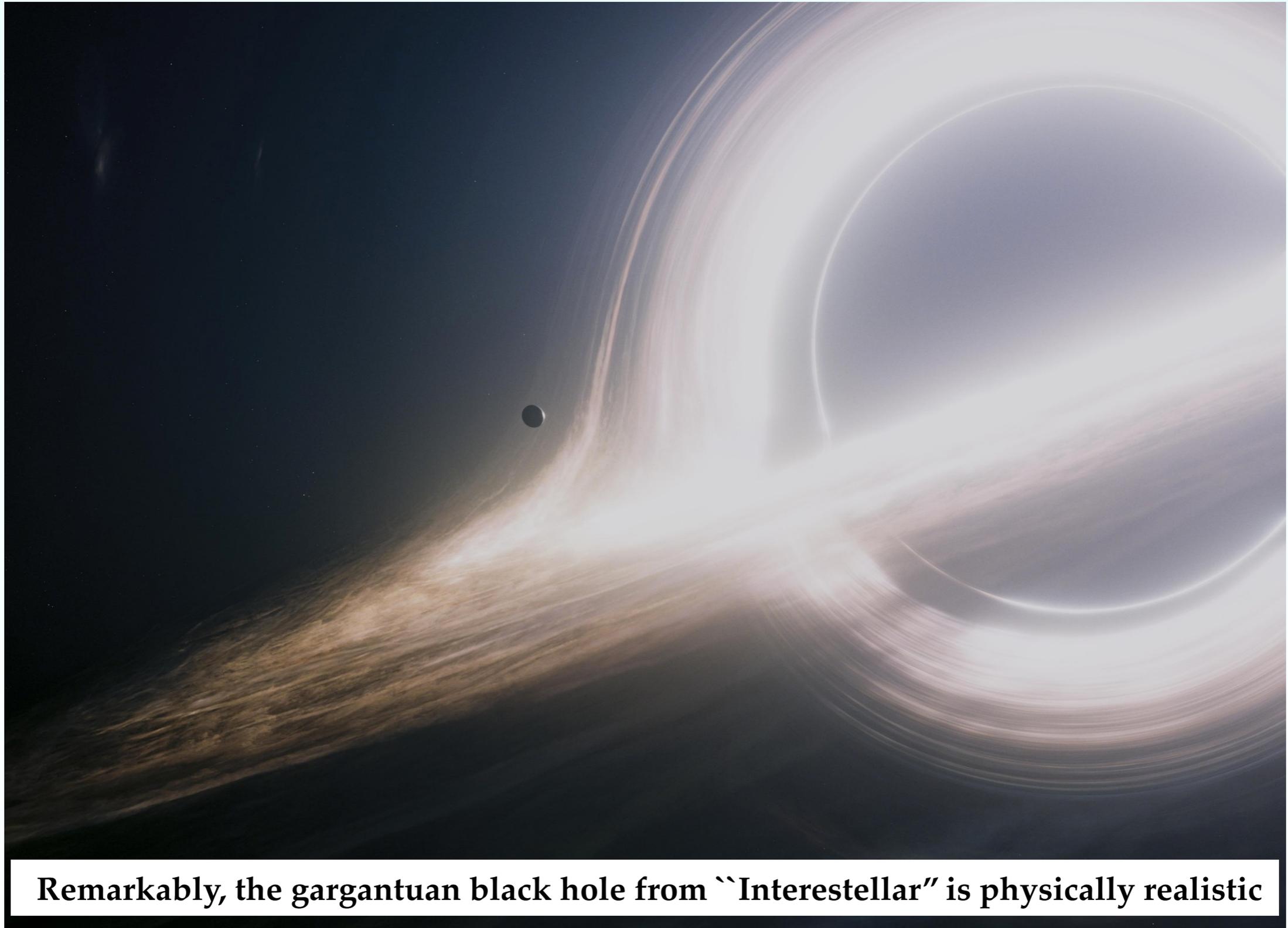
# This is not science fiction!

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!**

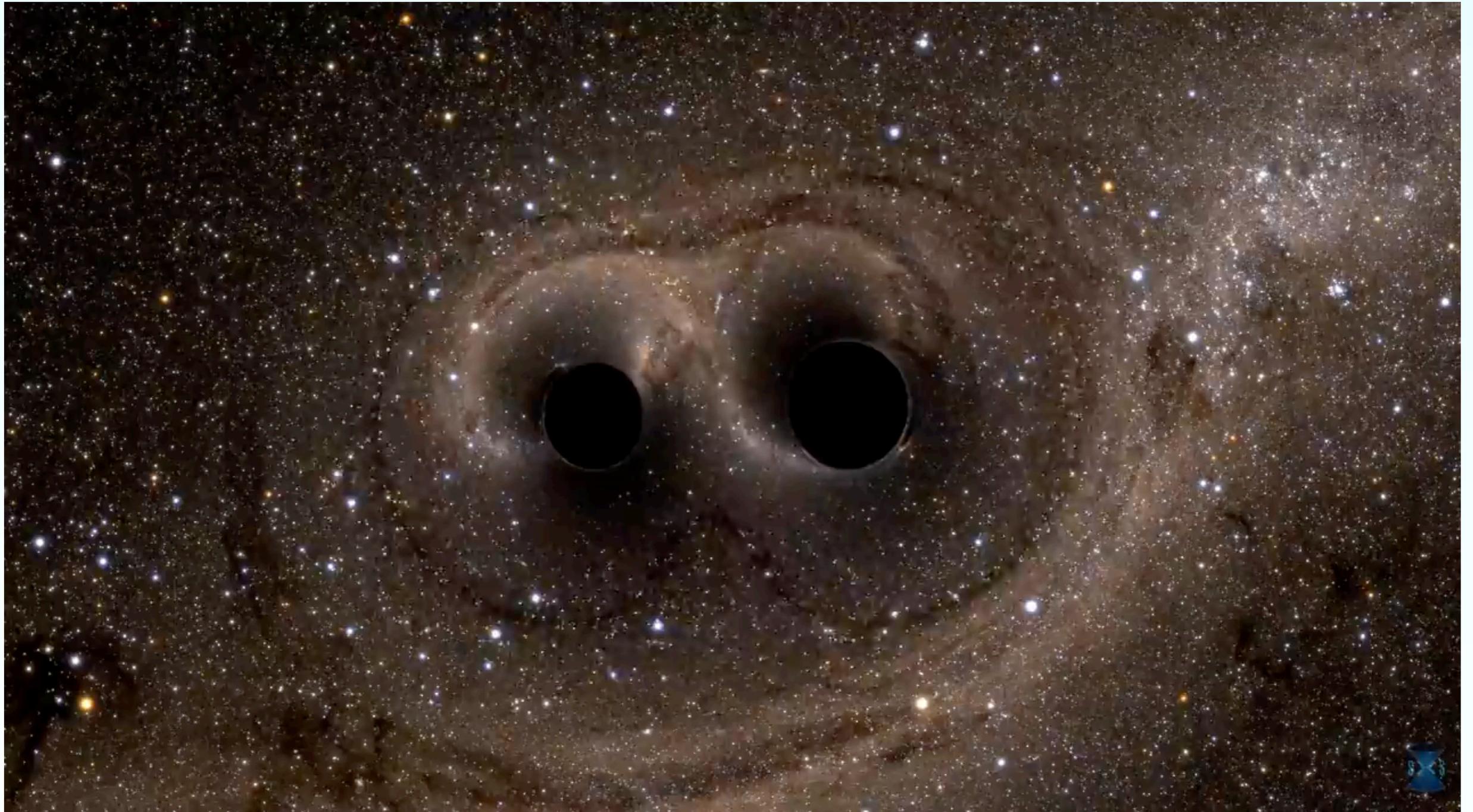


**Remarkably, the gargantuan black hole from “Interstellar” is physically realistic**

# When worlds collide

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

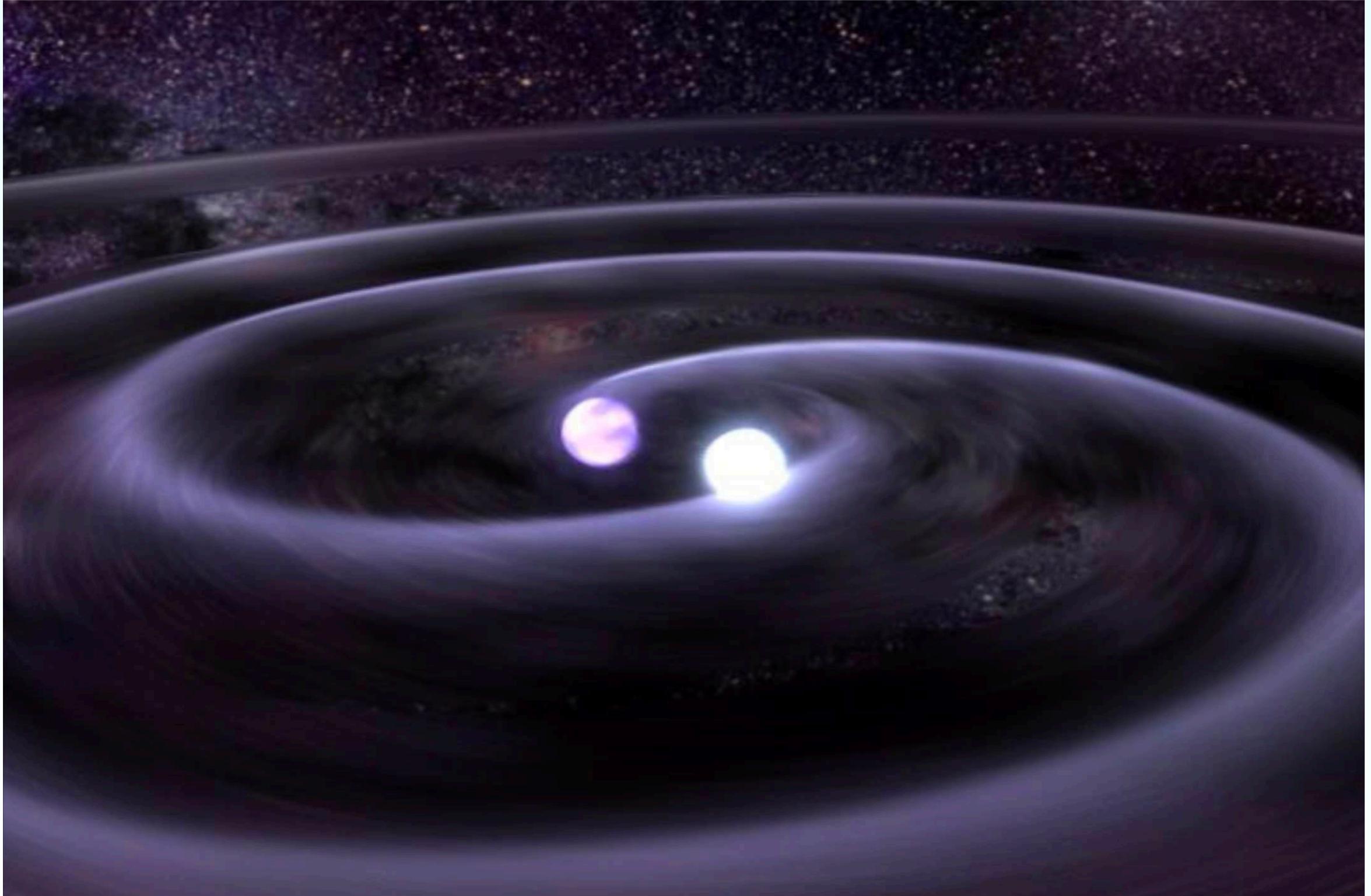
**Black hole mergers** are some of the most cataclysmic events that take place in the Universe



*If a black hole is, well, black, then how is all this energy released?  
In terms of gravitational waves, ripples of space-time itself!*

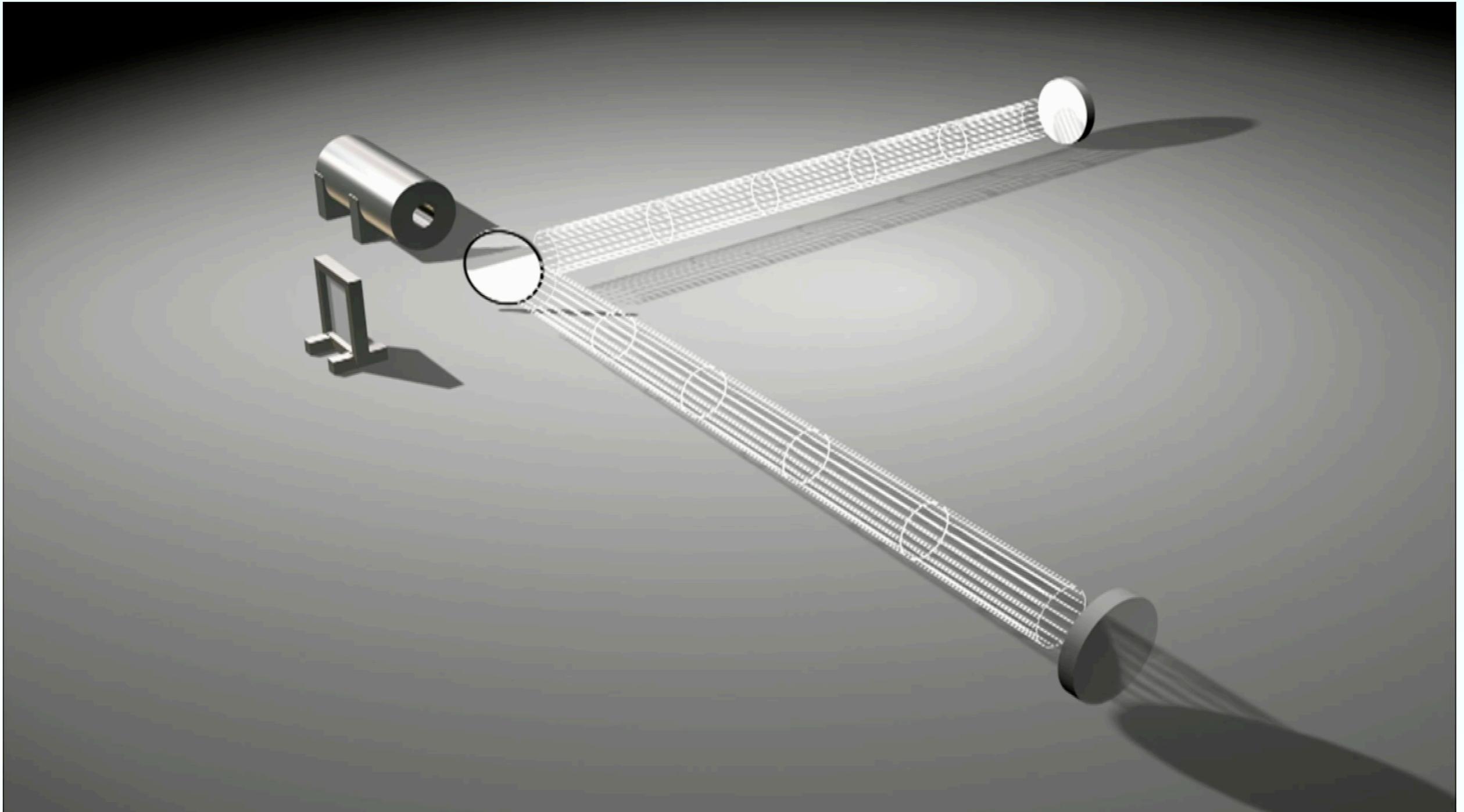
# When worlds collide

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



# When worlds collide

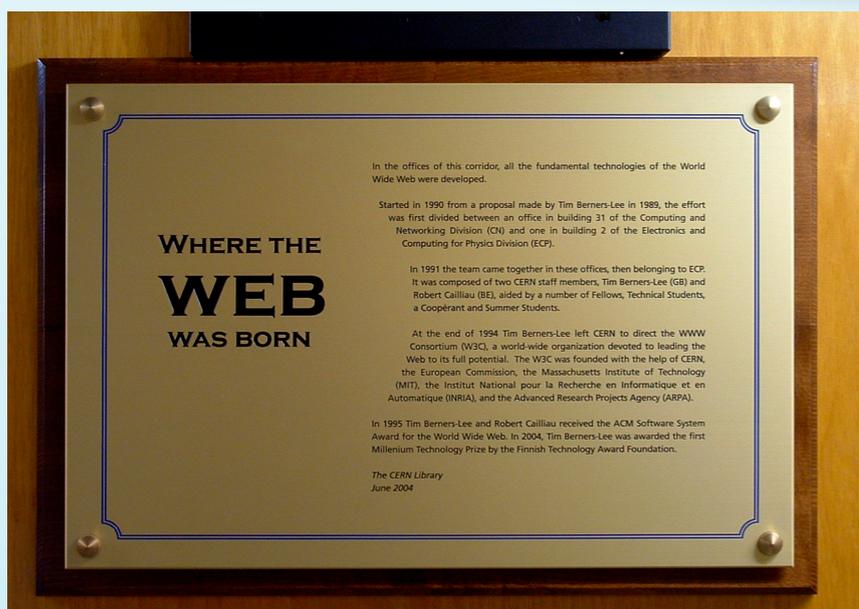
Gravitational waves can be detected with **ultra-precise laser interferometers**



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



# Useless science?



# Useless science?

*Do you think all this stuff I told you about  
is relevant for anything in the real world?*

# 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



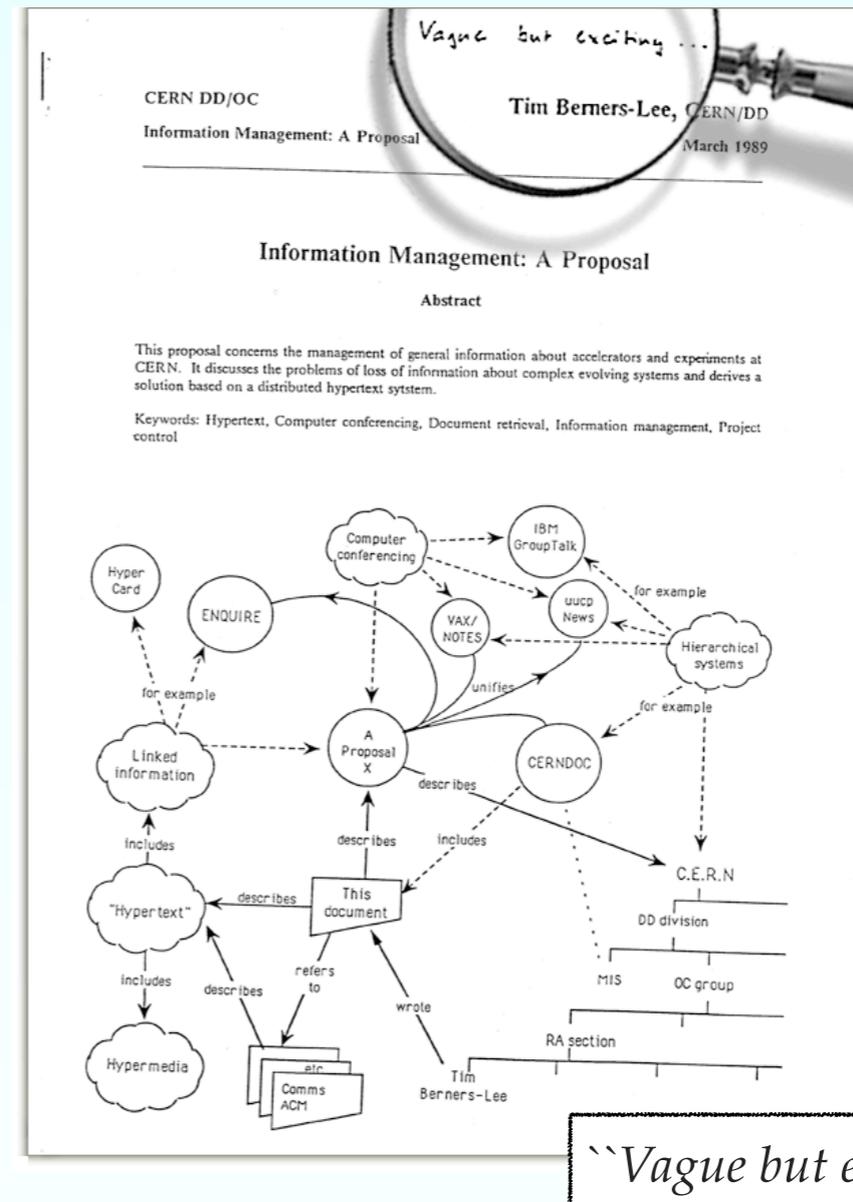
*In that sense, this new knowledge has all to do with honour and country but it has nothing to do directly with defending our country except to help make it worth defending*

*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 ....)

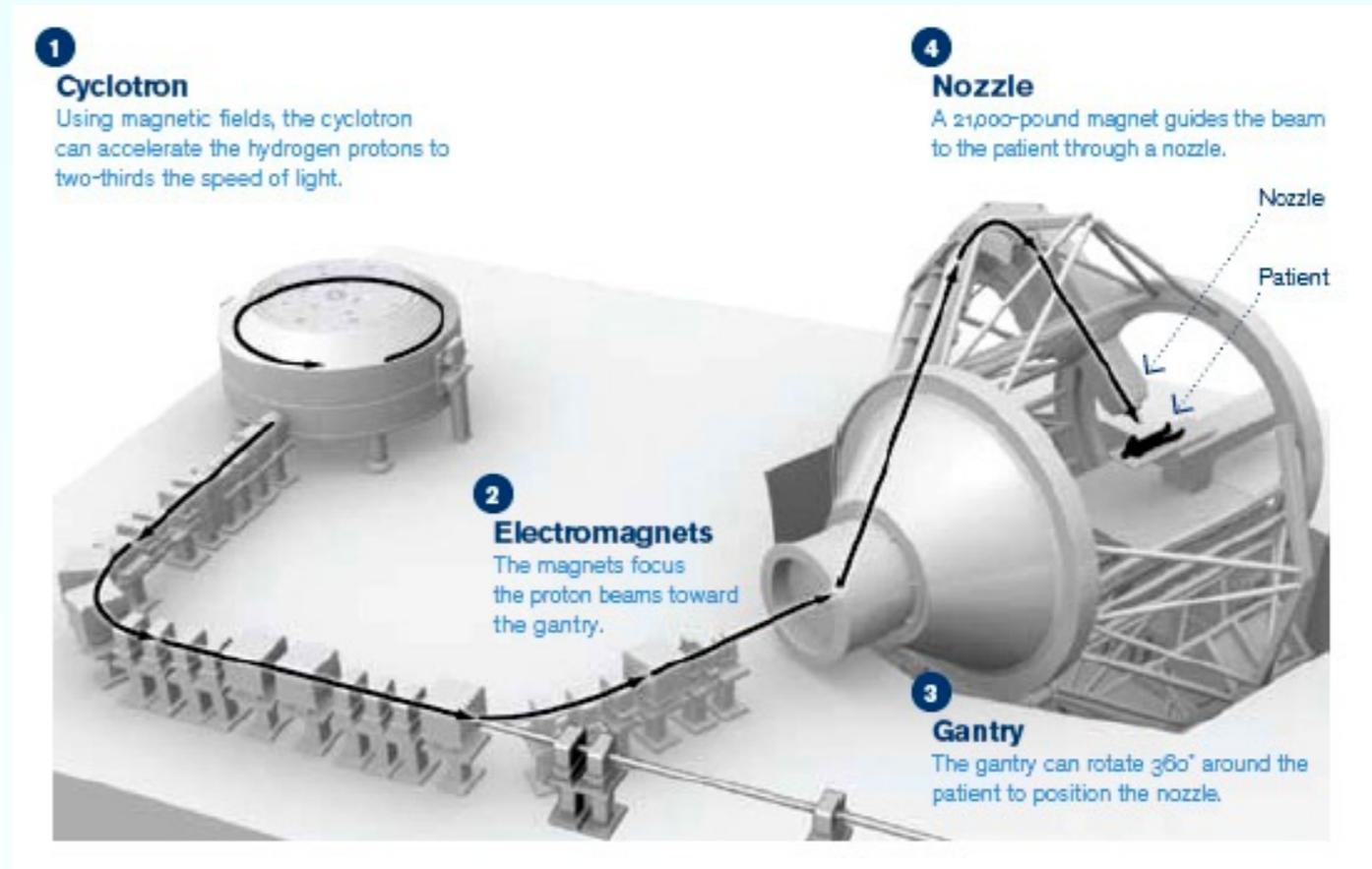


The World Wide Web was first started by **Tim Berners-Lee**, a **CERN software engineer** aiming to streamline the communication between CERN scientists and researchers

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

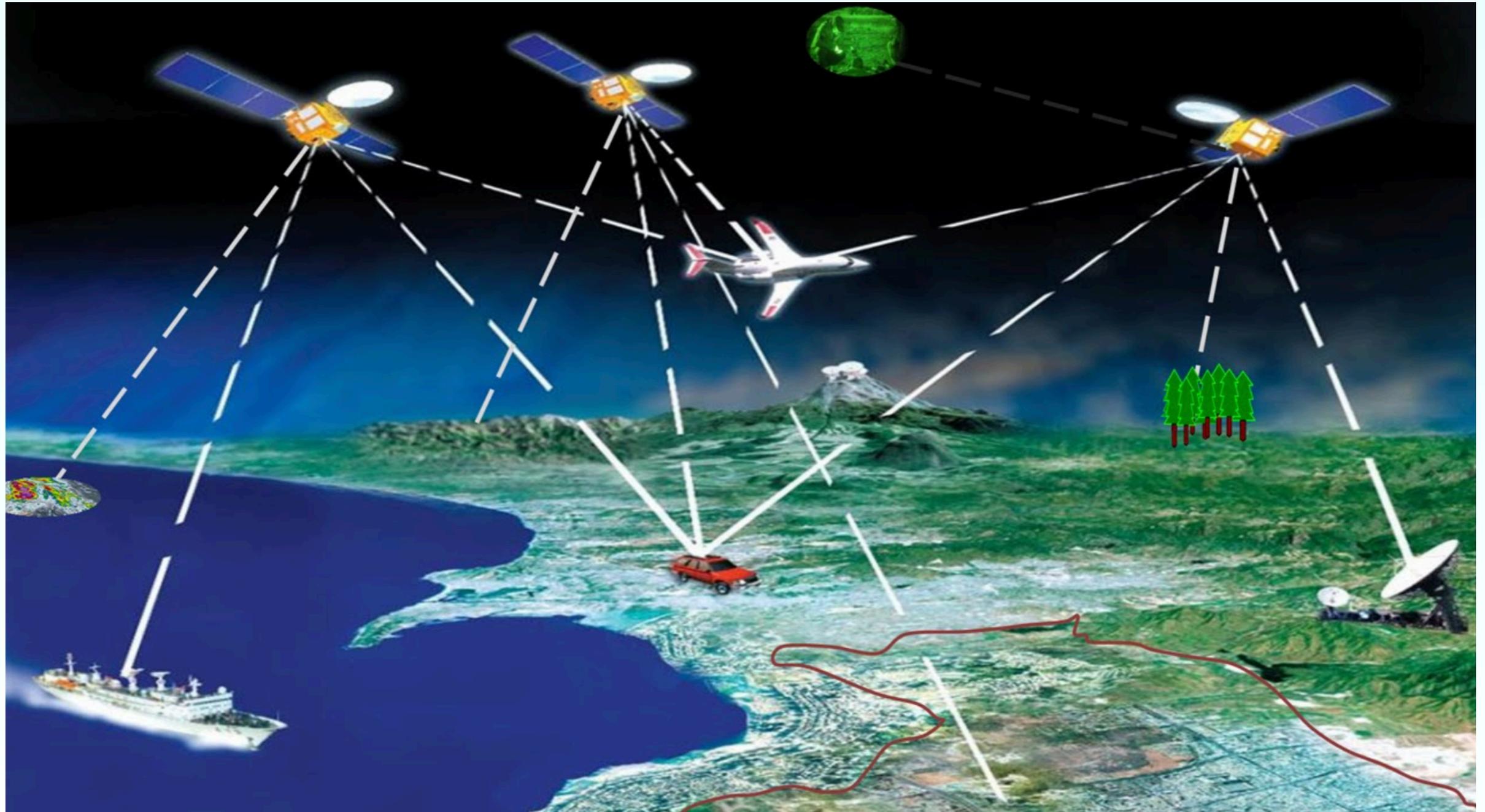


Uses **particle accelerators** to deliver precise doses, well-focused on diseased tissues like tumors and with minimal spill over to healthy tissues

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

# Global Positioning System

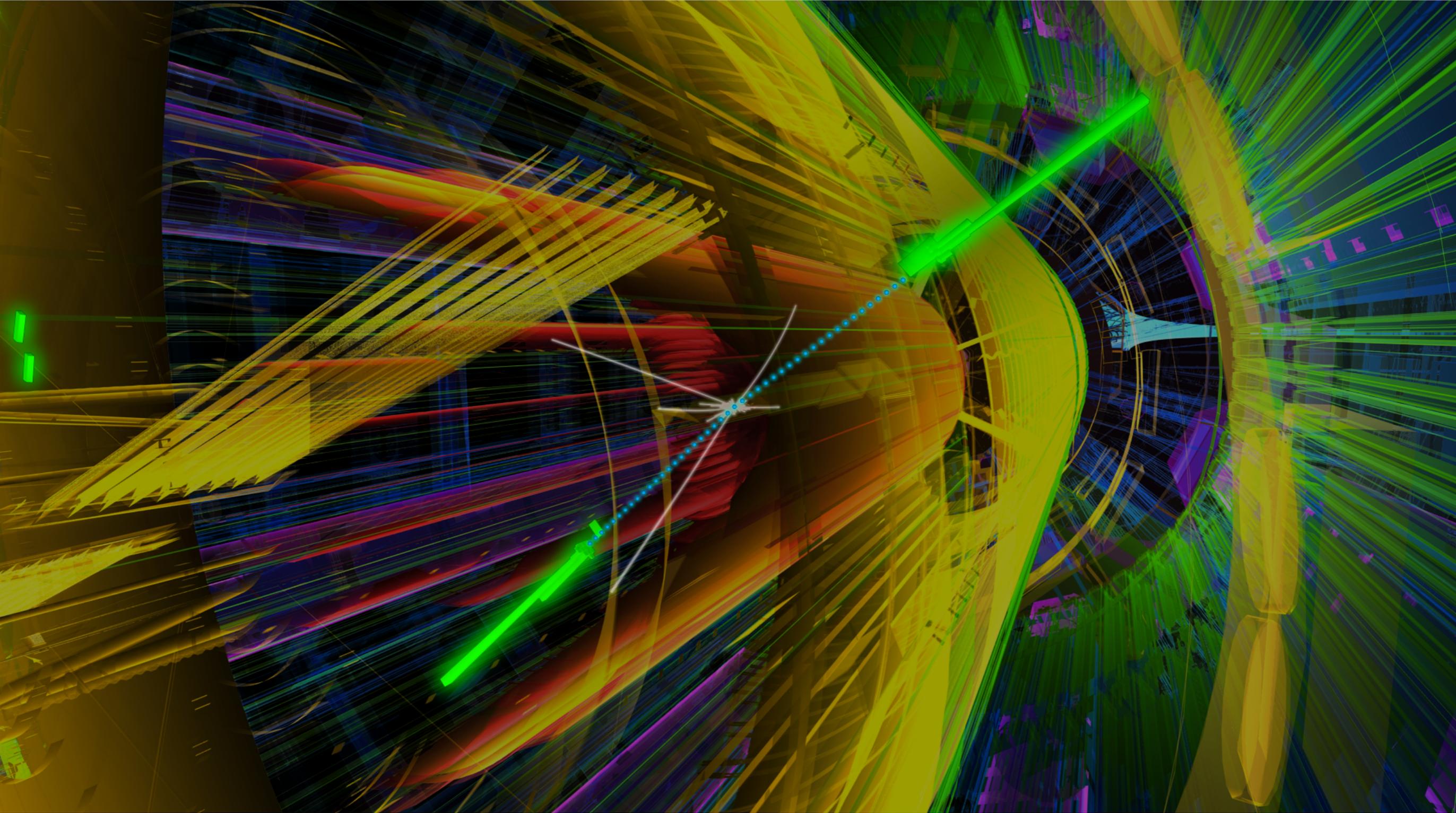
A system of connected satellites that, once accounted for the effects of **Einstein's Special and General Relativity**, allow determining our position with an accuracy of a few meters



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



# Fascinating times for high-energy physics!



## Stay tuned for new discoveries!

Fascinating times for high-energy physics!



Thanks for your attention!

Stay tuned for new discoveries!

# Extra material