

THE KIND OF PHYSICS THAT WE DO AT FERMILAB

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A little about me



- Born in Quito, Ecuador (Andes mountains). I have seen a Galapagos tortoise but have never been to the islands.
- I liked chemistry and physics in high school but I did not know that being a physicist was possible until my physics teacher told me.
- I got my undergraduate degree from Ecuador's public university (only two colleges offer a degree in physics). My thesis advisor got me in touch with people at Fermilab.

My journey in the US



- Intern at Fermilab @ 2015.
- PhD @ Johns Hopkins (Baltimore, Maryland), 2016 - 2020
- Now I am a Fermilab postdoc. I use accelerator experiments to search for possible dark matter particles and to investigate the properties of the Higgs boson.



Fermilab is located in Batavia, IL.

It was founded by Robert Wilson in 1967.

It is one out of 17 national laboratories founded by the Department of Energy.

Fermilab is a particle physics laboratory.

We also do astronomy and cosmology.

We also develop particle detectors and accelerators, quantum science and technologies.

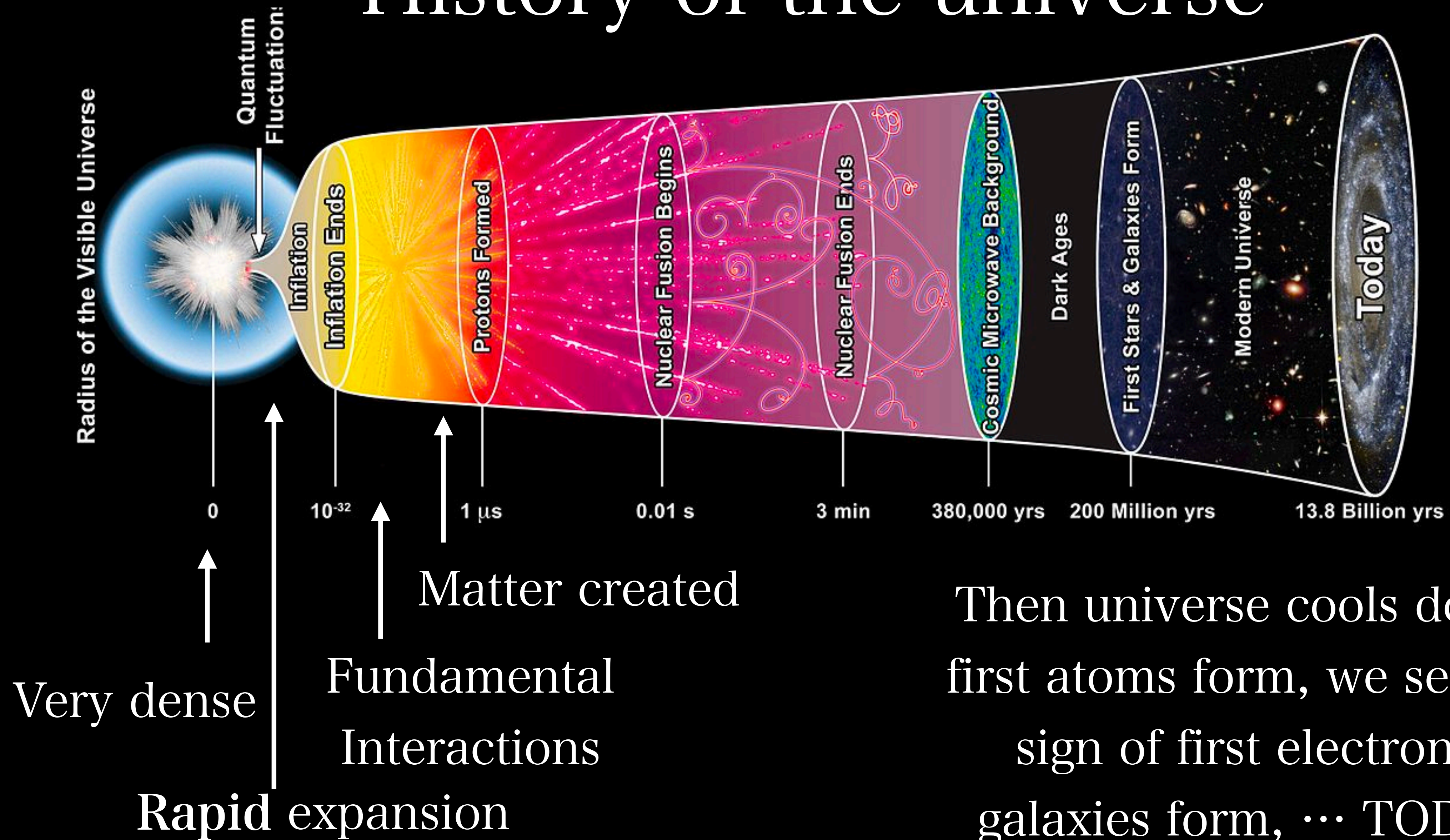
We do theory and experiment.

Where does everything come from?

What is the origin of the universe? What are the components?

We know that the Universe is 13.8 billion years old and that it is expanding (and that this expansion is accelerating).

History of the universe



Then universe cools down,
first atoms form, we see the
sign of first electrons,
galaxies form, ... TODAY

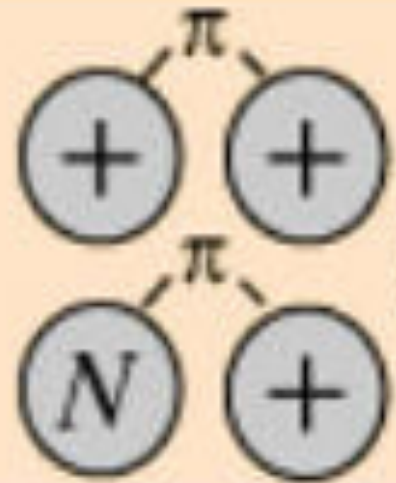
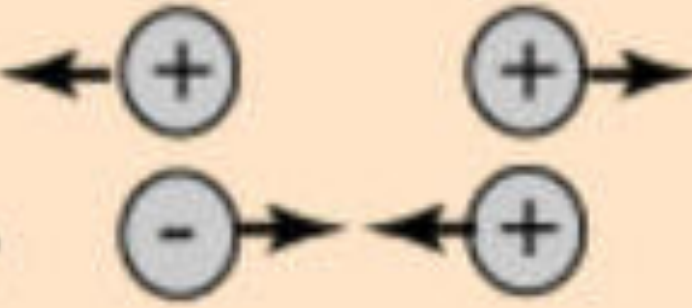
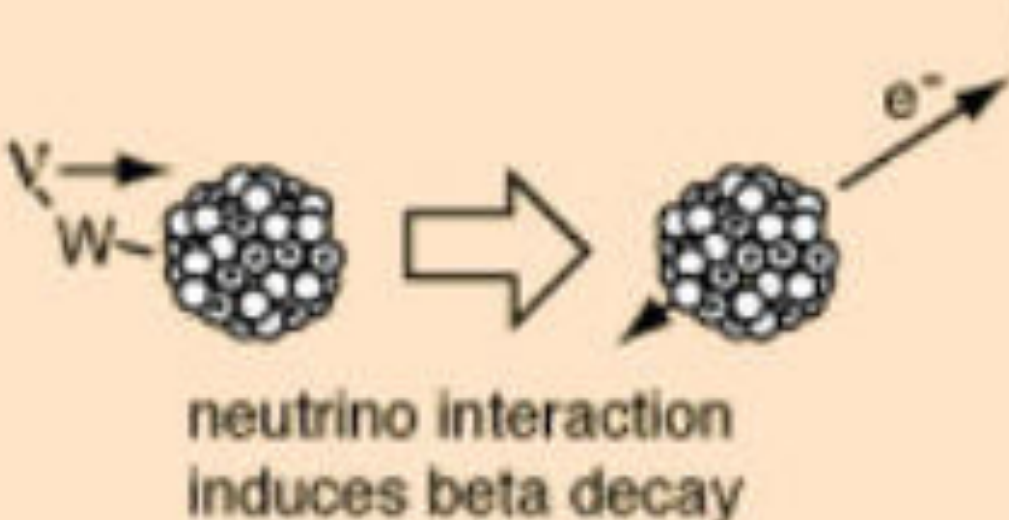
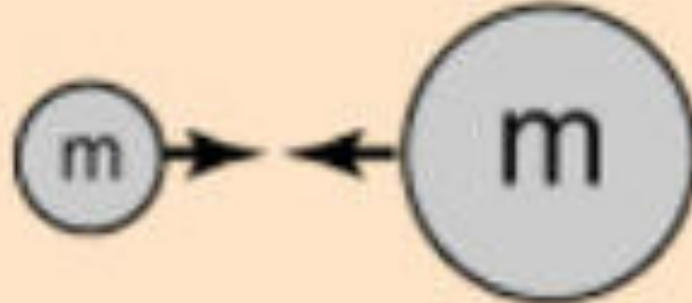
Where does everything come from?

What is the origin of the universe? What are the components?

How does everything interact?

What are the fundamental forces and what is their strength?

We know that there are four fundamental forces.

<i>Strong</i>	 <p>Force which holds nucleus together</p>	Strength 1
<i>Electro-magnetic</i>		Strength $\frac{1}{137}$
<i>Weak</i>	 <p>neutrino interaction induces beta decay</p>	Strength 10^{-6}
<i>Gravity</i>		Strength 6×10^{-39}

Where does everything come from?

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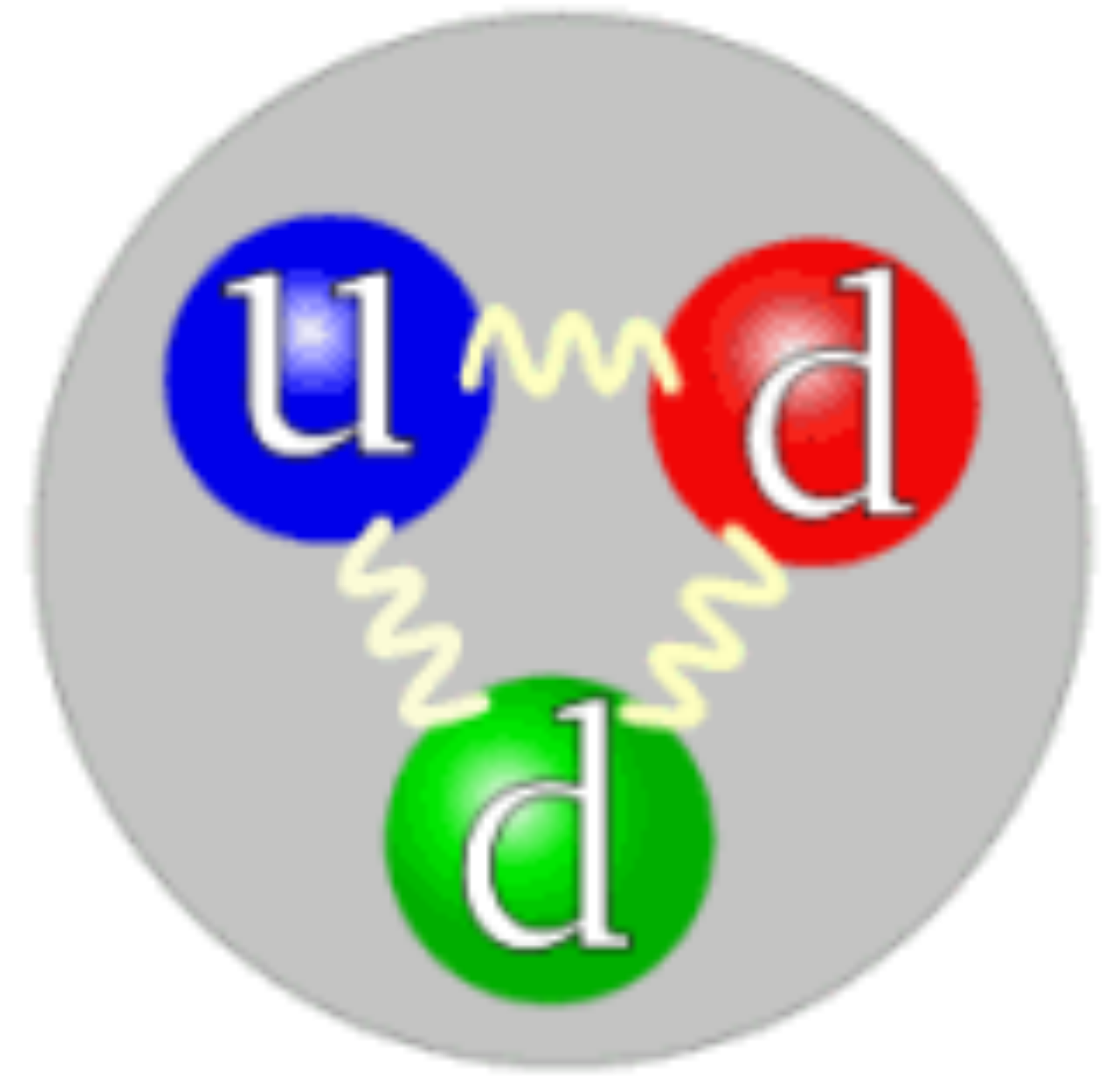
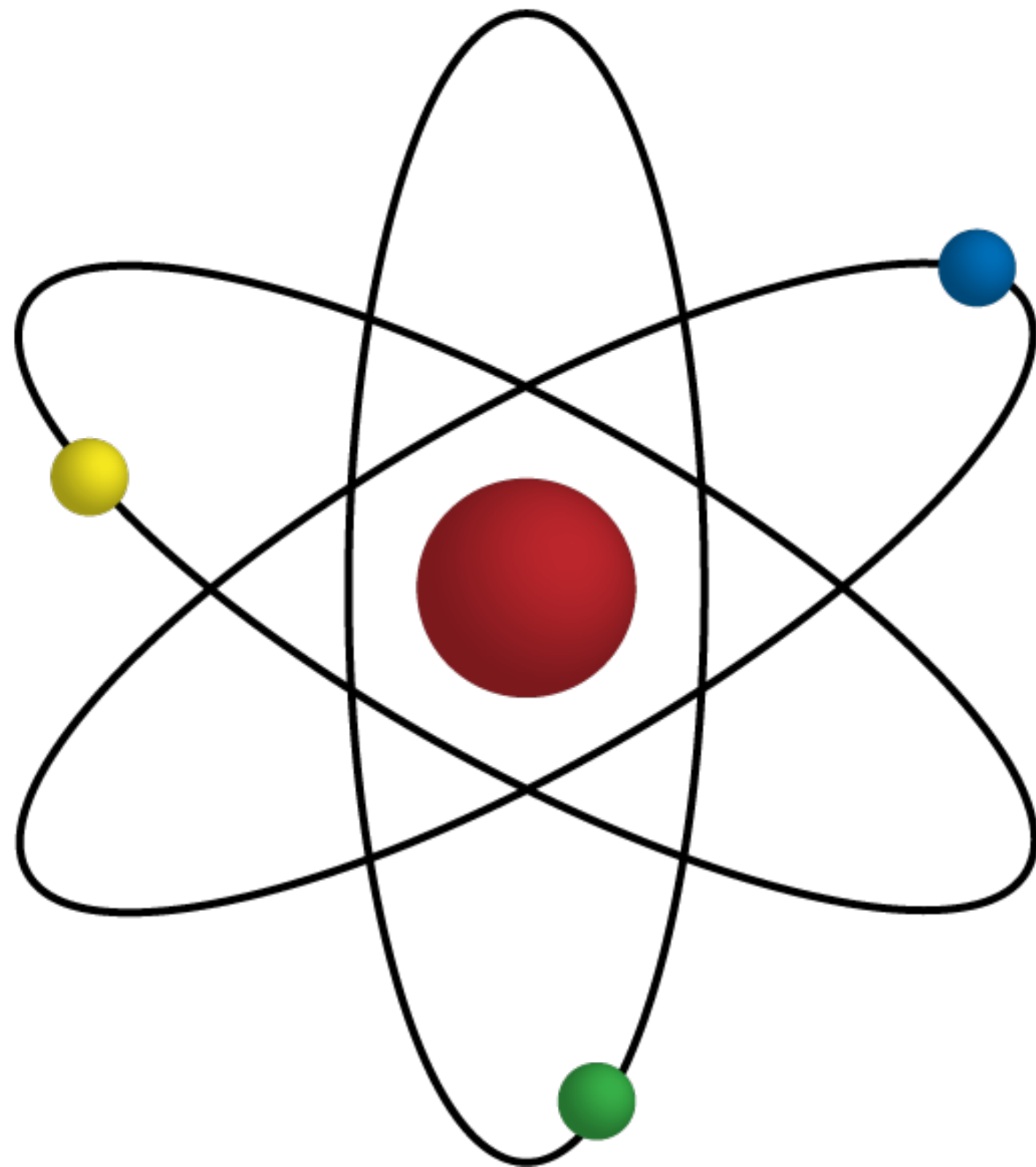
How does everything interact?

What are the fundamental forces and what is their strength?

What is stuff made off?

What are the fundamental blocks of our universe (particles)?

We know that there is a given number of elementary particles.



Electrons + Nucleus (protons/neutrons made of up and down quarks)

Up *quark*

u

c

t

g

H

Higgs
boson

Down *quark*

d

s

b

W

Electron

e

μ

τ

Z

ν_e

ν_μ

ν_τ

γ

Photon

Neutrinos

Periodic Table

1 H Hydrogen																	2 He Helium				
3 Li Lithium	4 Be Beryllium															5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesi...															13 Al Aluminium	14 Si Silicon	15 P Phospho...	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Mangane...	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germani...	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton				
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybde...	43 Tc Techneti...	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon				
55 Cs Caesium	56 Ba Barium	57 La Lanthanu...	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon				
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfor...	105 Db Dubnium	106 Sg Seaborgi...	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitneriu...	110 Ds Darmsta...	111 Rg Roentge...	112 Cn Copernic...	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovi...	116 Lv Livermori...	117 Ts Tennesse...	118 Og Oganess...				
			58 Ce Cerium	59 Pr Praseody...	60 Nd Neodymi...	61 Pm Promethi...	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinu...	65 Tb Terbium	66 Dy Dysprosi...	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium					
			90 Th Thorium	91 Pa Protactin...	92 U Uranium	93 Np Neptuniu...	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californi...	99 Es Einsteini...	100 Fm Fermium	101 Md Mendelev...	102 No Nobelium	103 Lr Lawrenci...					

Fermilab was very involved with discoveries
of particles in the last 50 years.

THE PARTICLES AND THEIR DISCOVERY

Positron, e^+ – 1932

Muon, μ^\pm – 1937

Pion, π^0, π^\pm – 1947

Kaon, K^0, K^\pm – 1947

Lambda, Λ^0, Λ^\pm – 1947

Antiproton, \bar{p} – 1955

Electron anti-neutrino, $\bar{\nu}_e$ – 1956

Muon neutrino, ν_μ – 1962

Xi, Ξ^0, Ξ^\pm – 1964

J/ Ψ – 1974

Tau, τ^\pm – 1975

Upsilon, Υ / b quark – 1977

Gluon, g – 1979

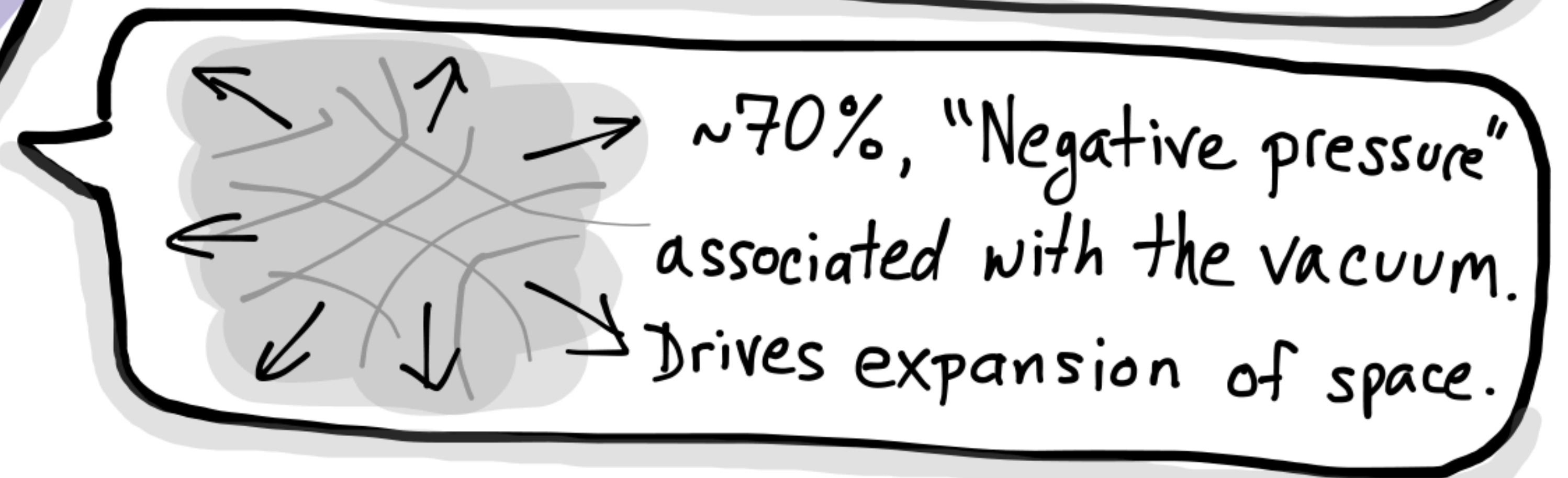
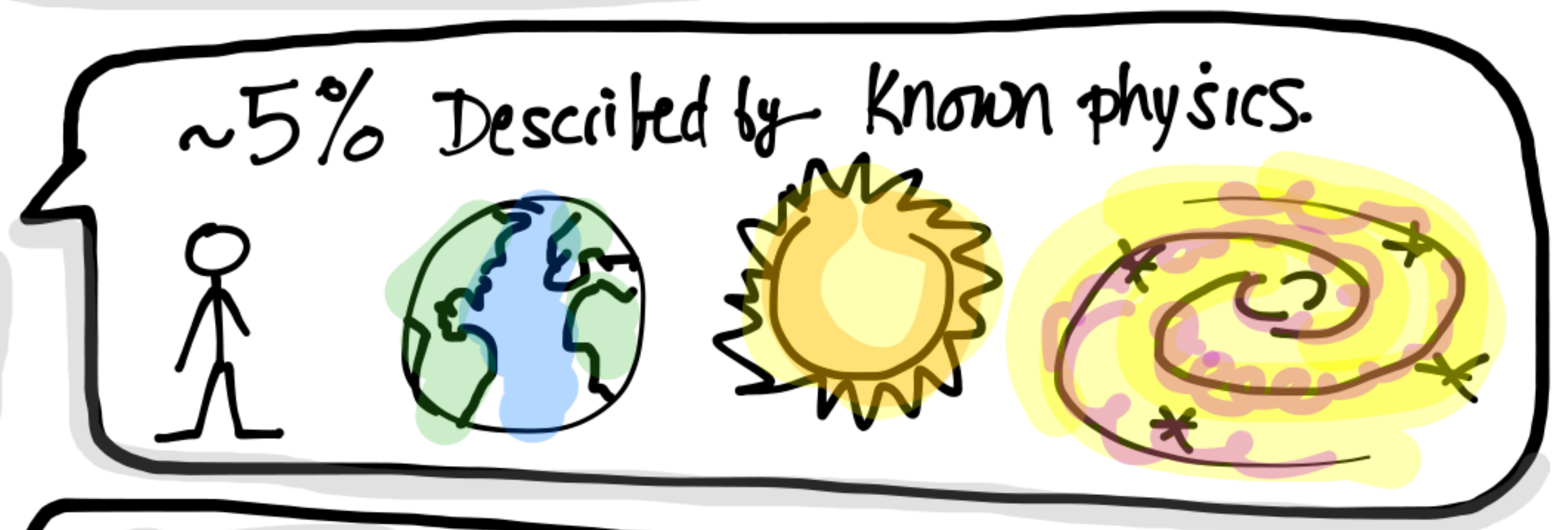
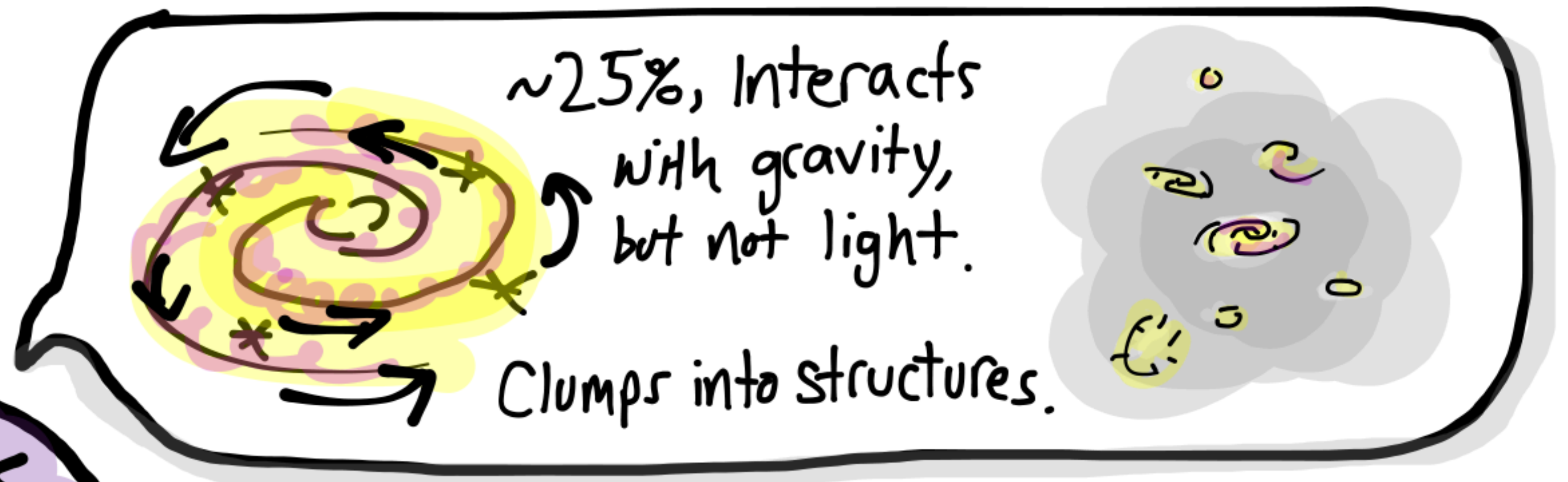
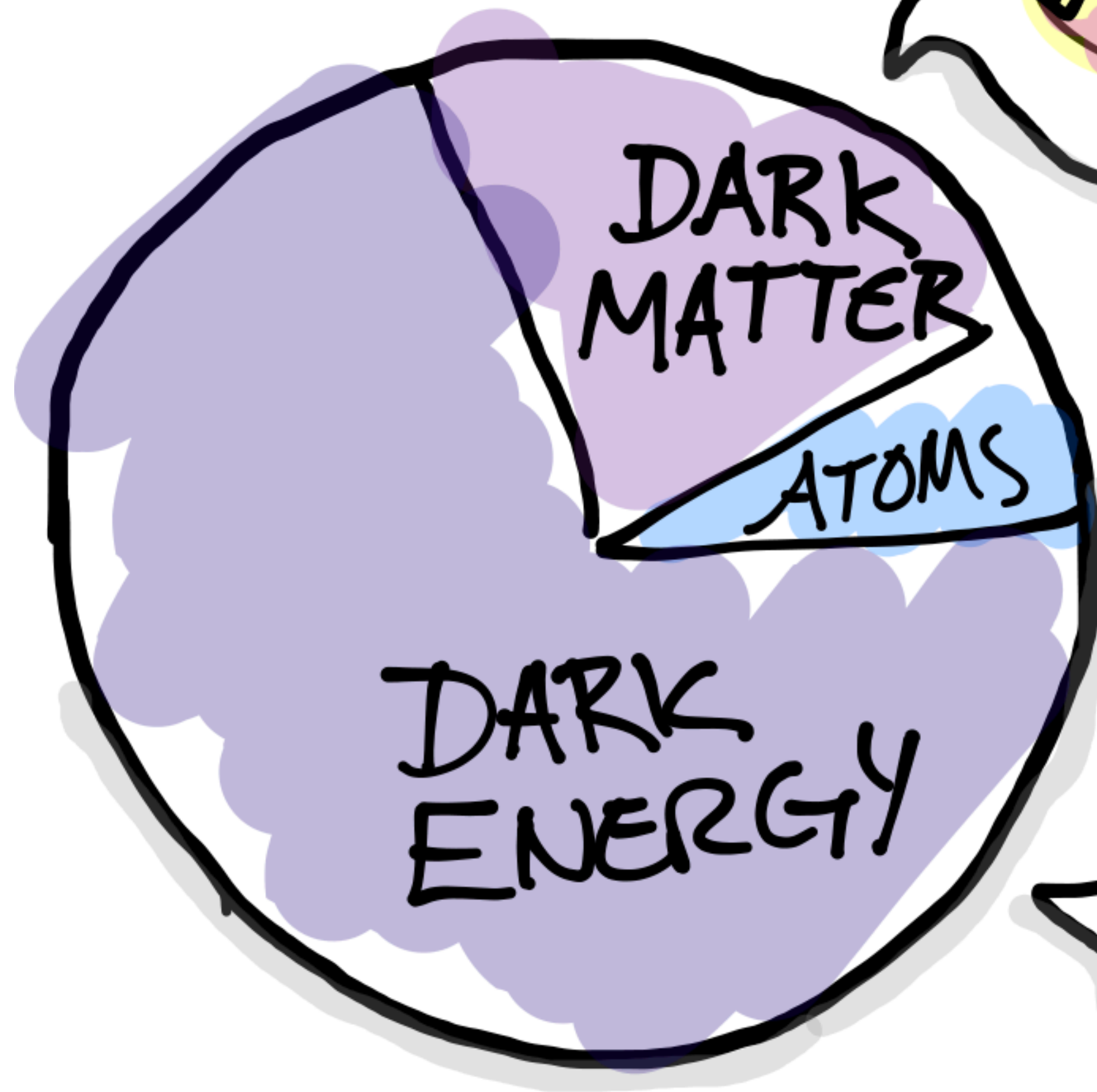
Z and W bosons, Z^0, W^\pm – 1983

Top quark, t – 1995

Tau neutrino, ν_τ – 2000

Higgs Boson, h – 2012

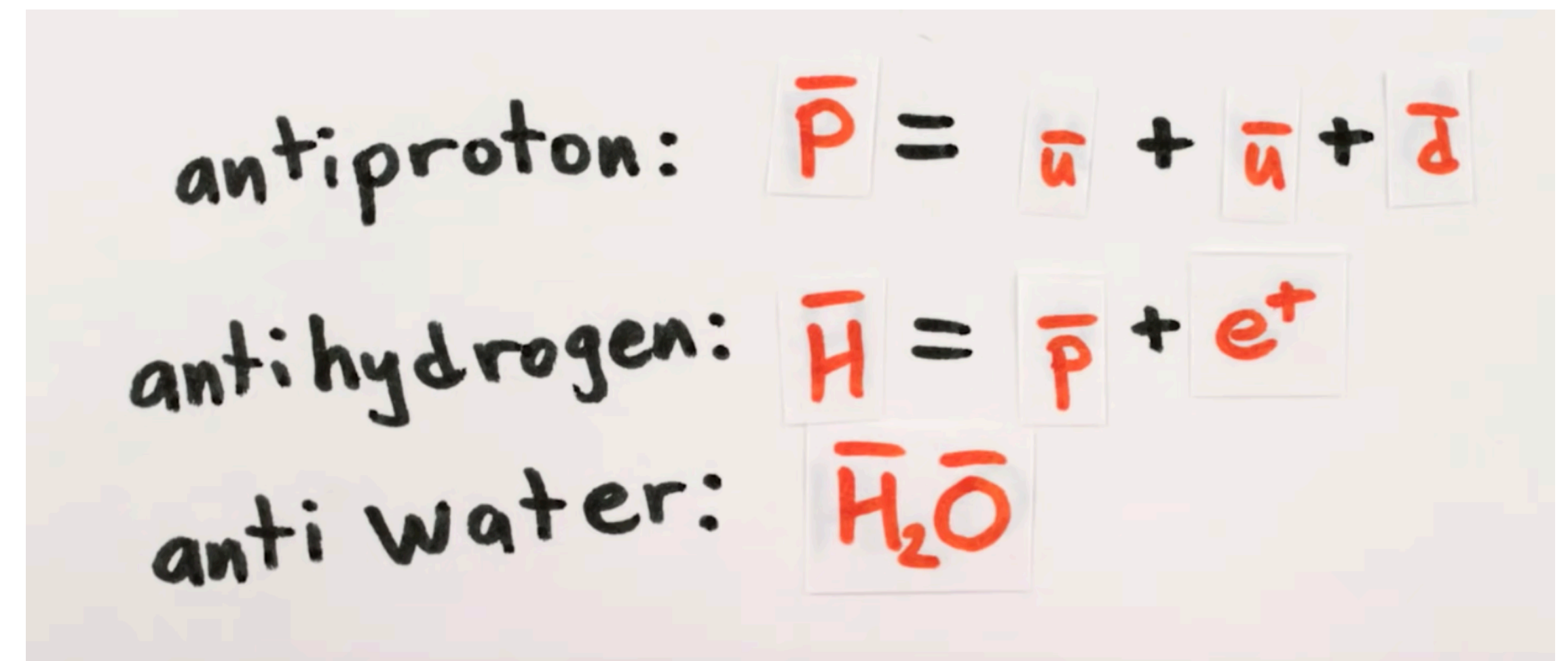
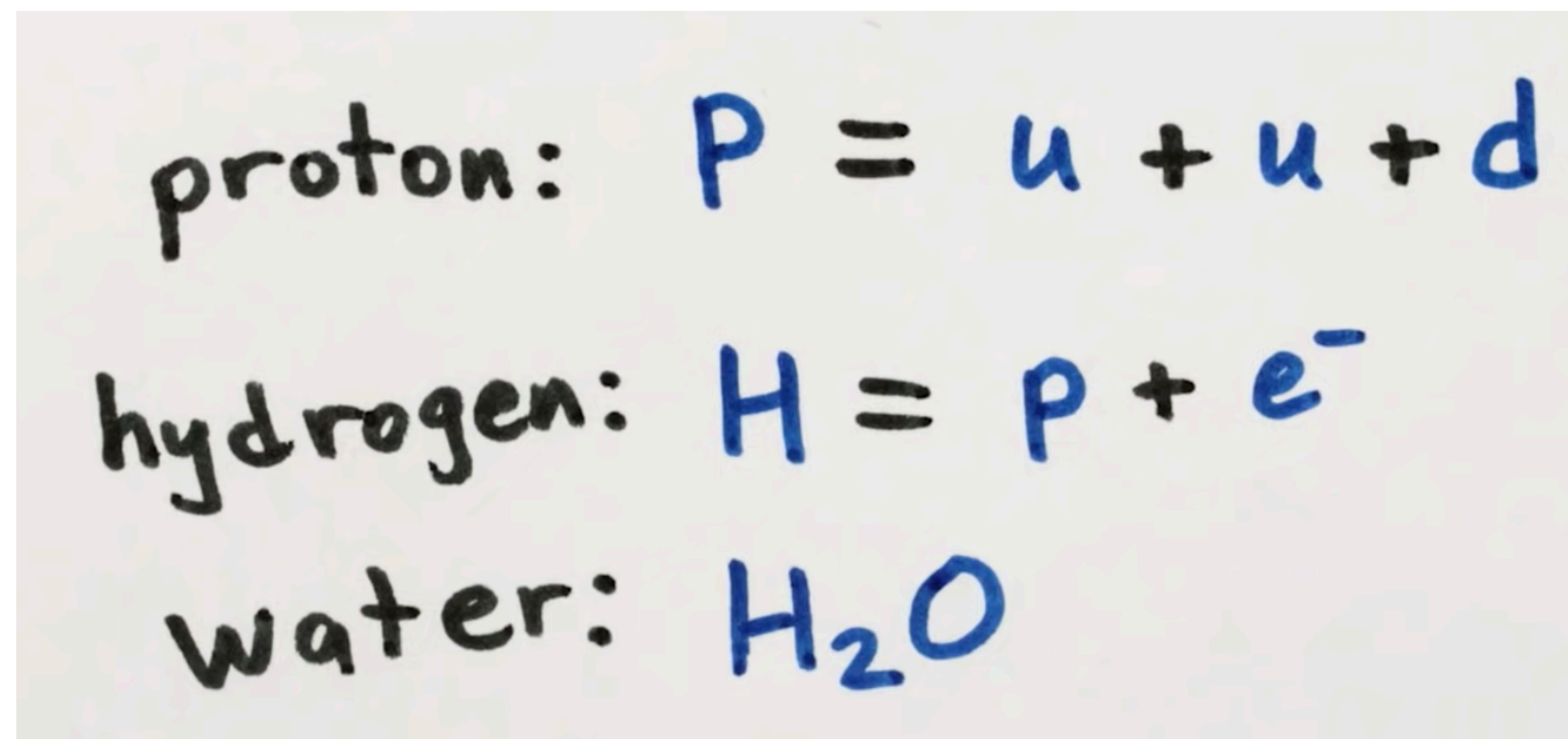
What are some open questions?



We know that **dark matter** exists because of astrophysical and cosmological measurements. We know that it interacts gravitationally. We would like to know what **dark matter**, is it heavy, is it light?

Also, we would like to understand **dark energy**: a term used to describe the mechanism responsible for the accelerated expansion of the universe. What is causing the universe's expansion to accelerate?

You may have heard of anti-matter too. Anti-matter is a type of matter that simply has opposite electrical charge.



But, antimatter is so rare that it costs \$62.5 trillion per gram to produce it! Why is there more matter than antimatter?

There are also other questions that may keep us up at night.

The list includes but is not limited to:

Are there other new forces/new particles?

Is one particle more special than the other: examples are the

Higgs boson, the muon particles, the neutrinos?

What else can we learn from astrophysics objects about
inflation/dark energy/dark matter?

What does Fermilab do now?

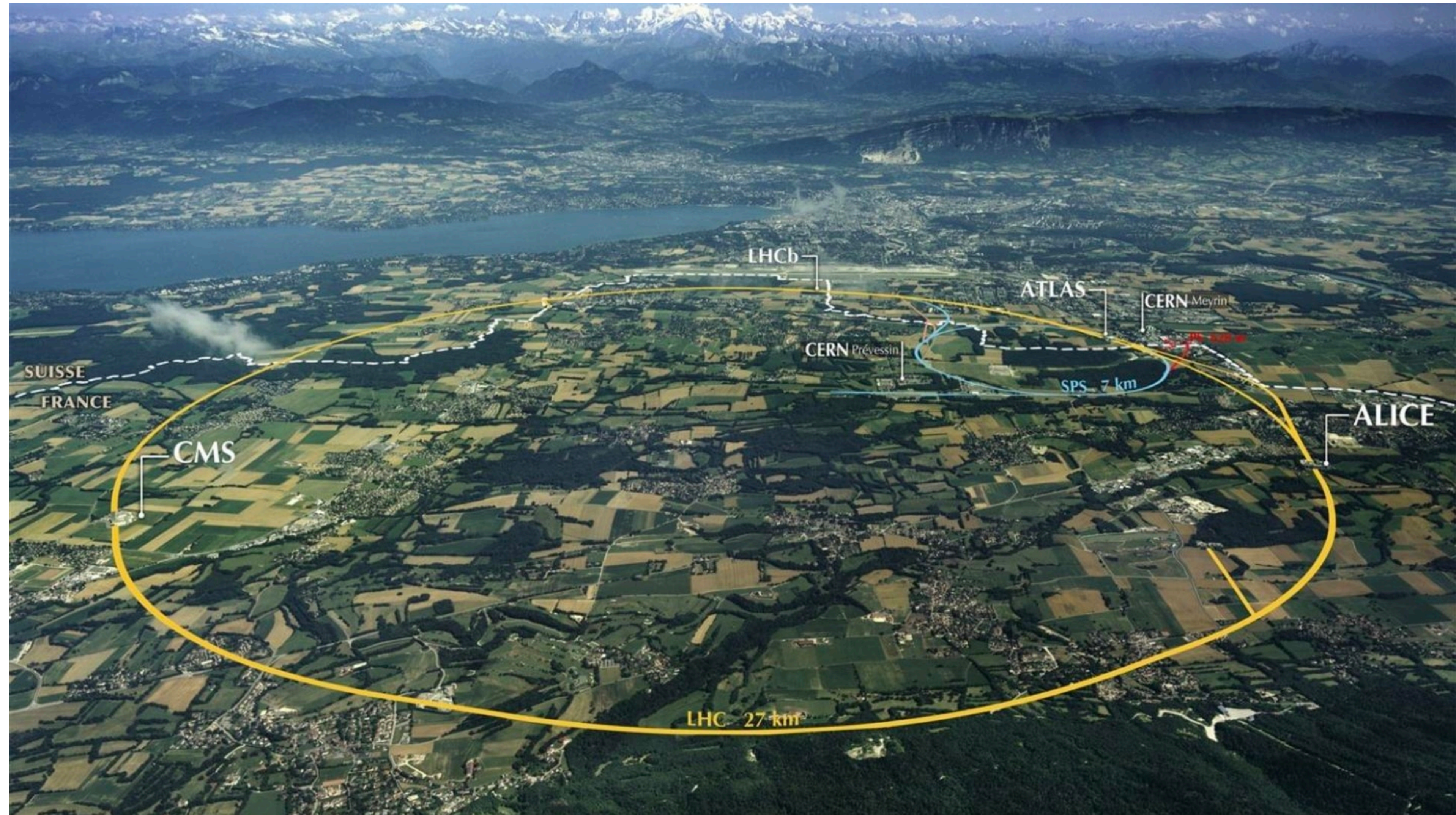
Use accelerators



Tevatron

Particle accelerators are machines that use electric and magnetic fields to bring particles to very high speeds, and collide particles to produce other particles.

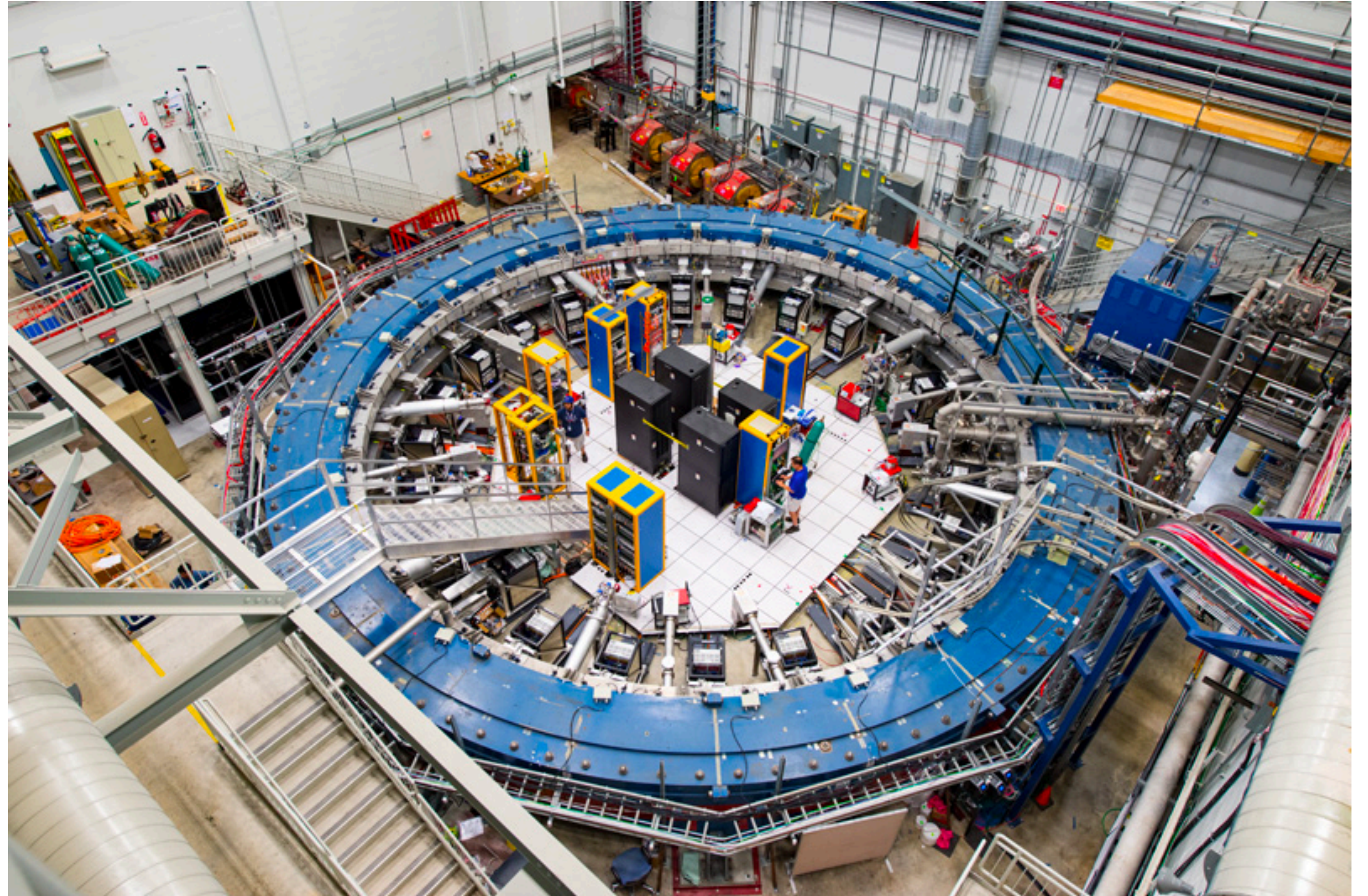
Study Proton collisions



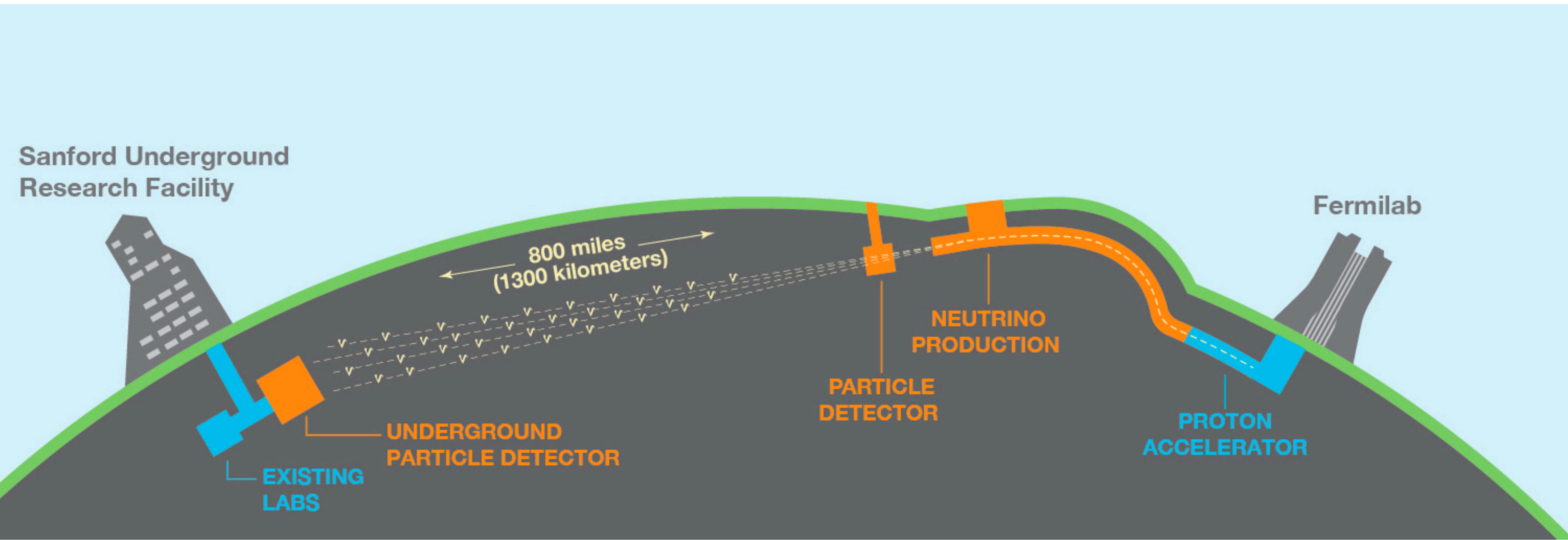
The Large
Hadron Collider

Study Muons and their properties

The $g-2$ / $\mu 2e$
experiments



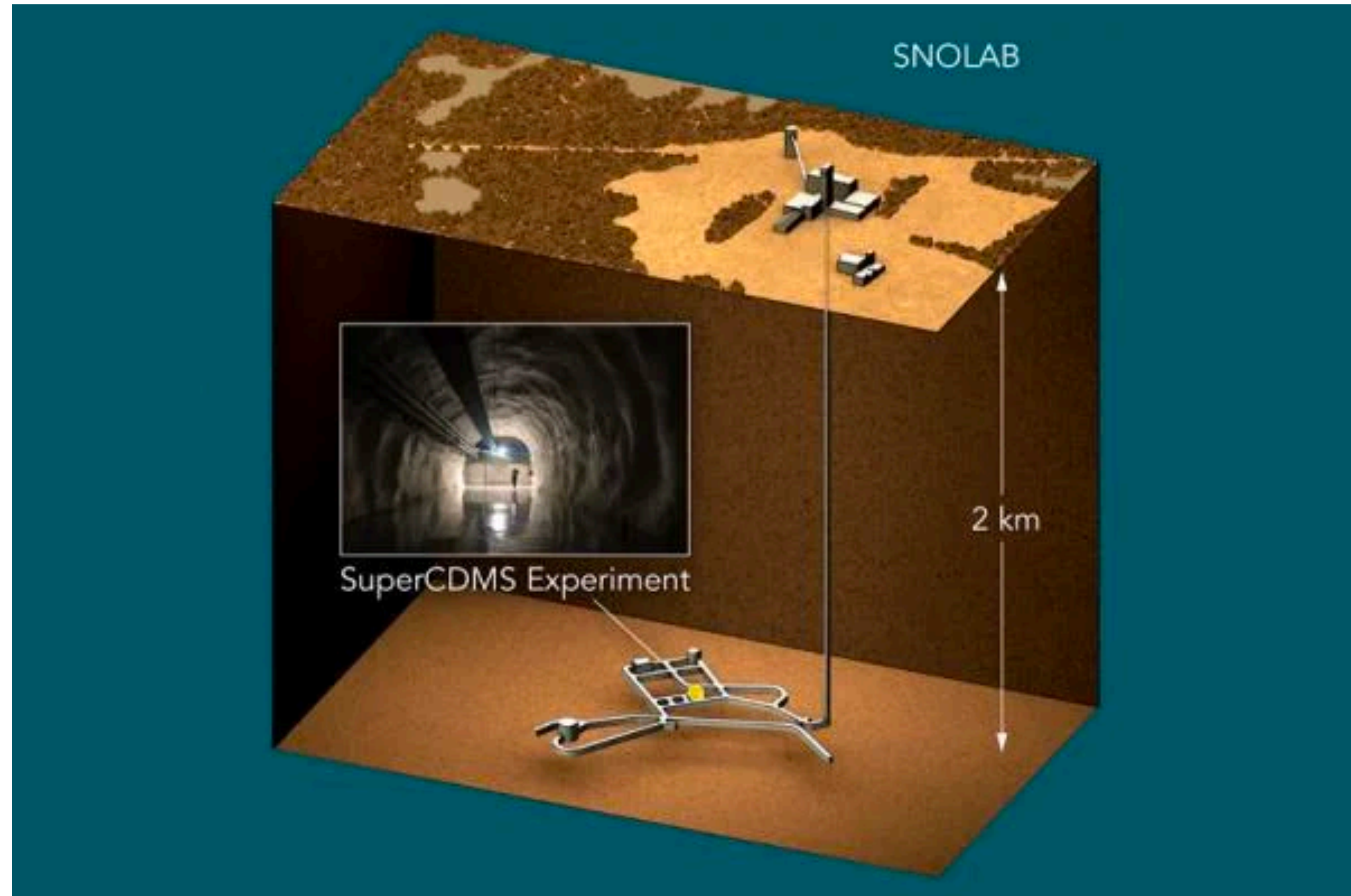
Study Neutrinos and send them through very long paths



The Nova, (MicroBoone + SBND), DUNE experiments

Search for dark matter

The SuperCDMS, Sensei,
Oscura, ADMX, LDMX
experiments

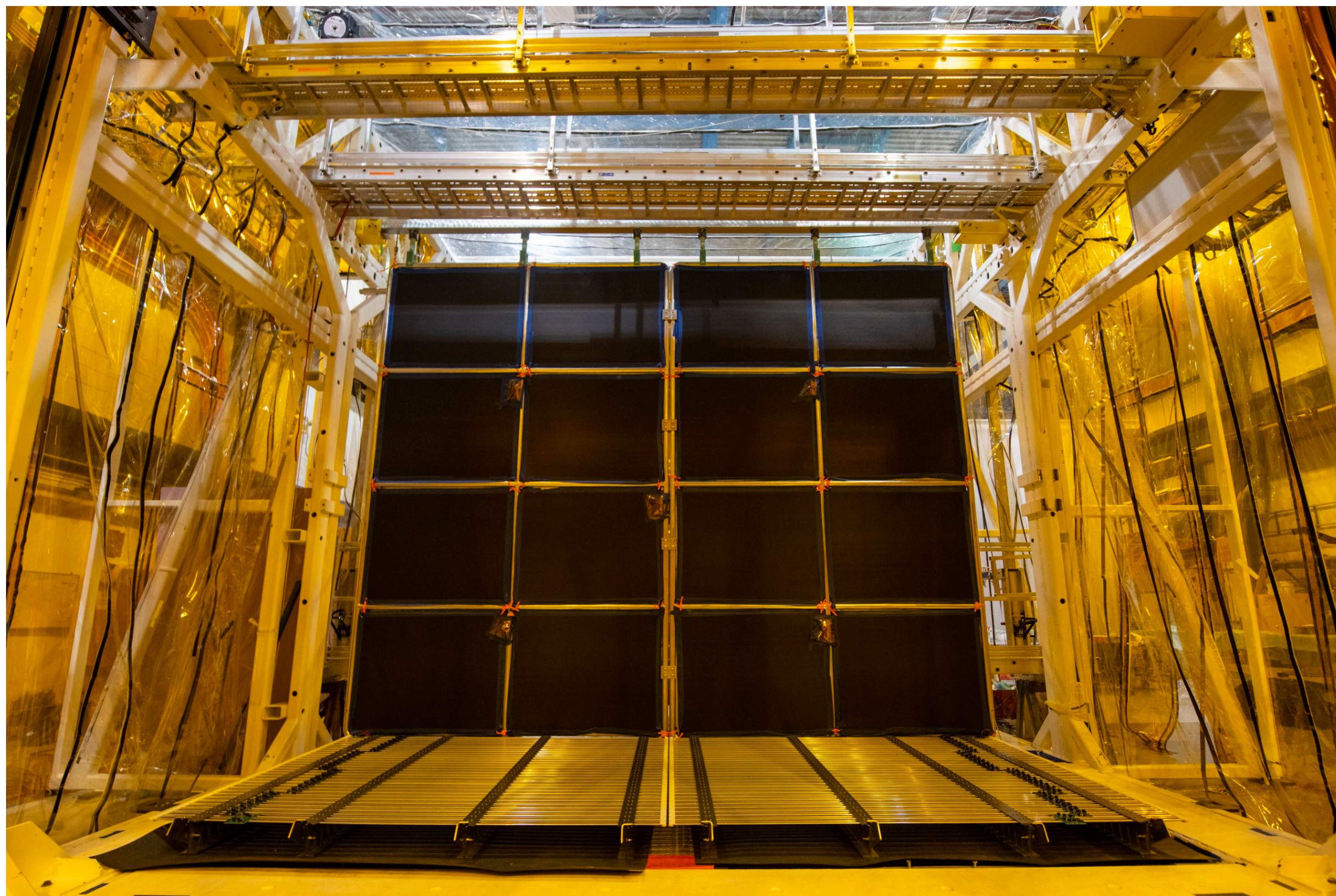


Explore astrophysical objects and perform cosmological measurements

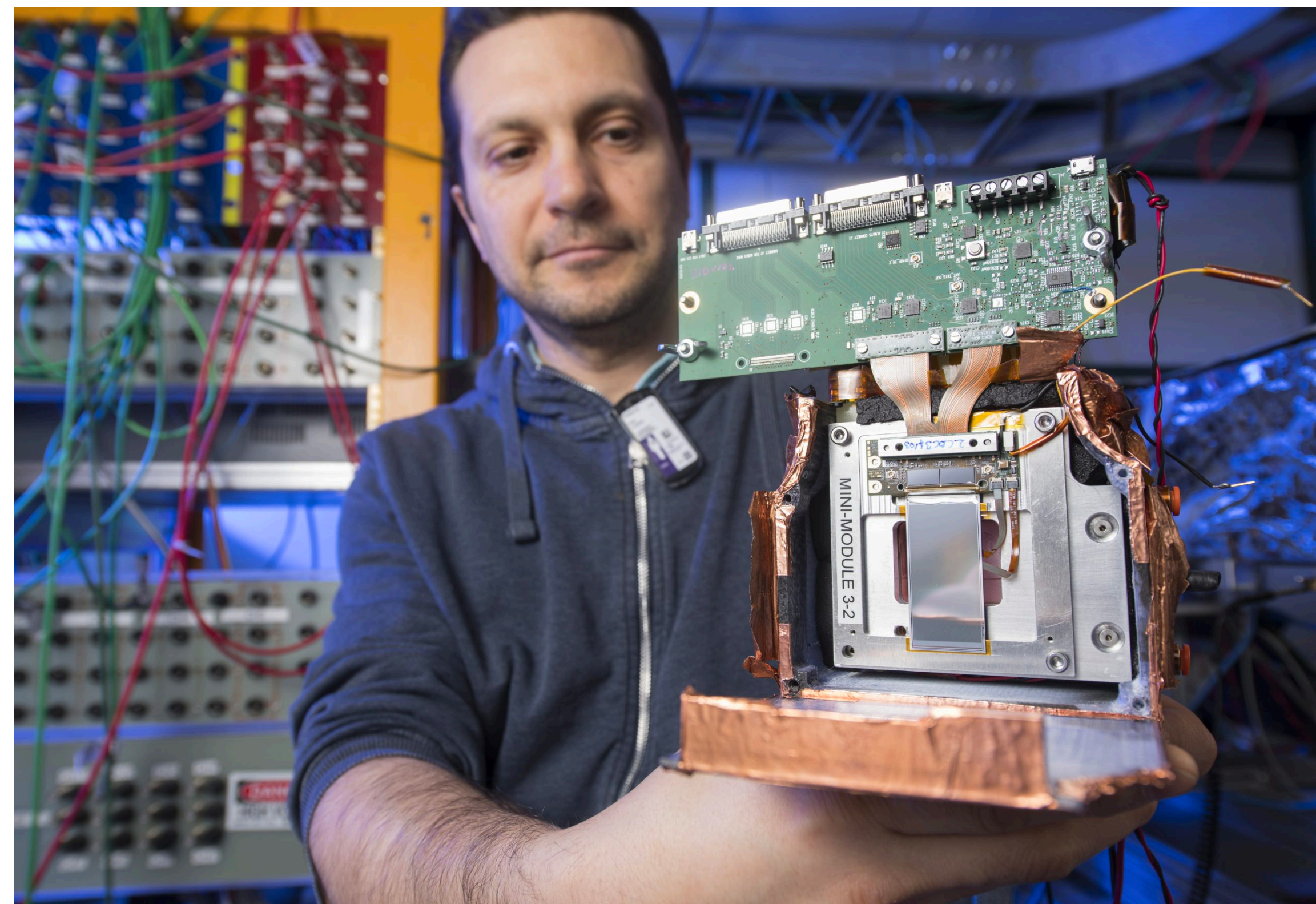
The DES, Rubin LSST,
CMB-S4



Build particle detectors

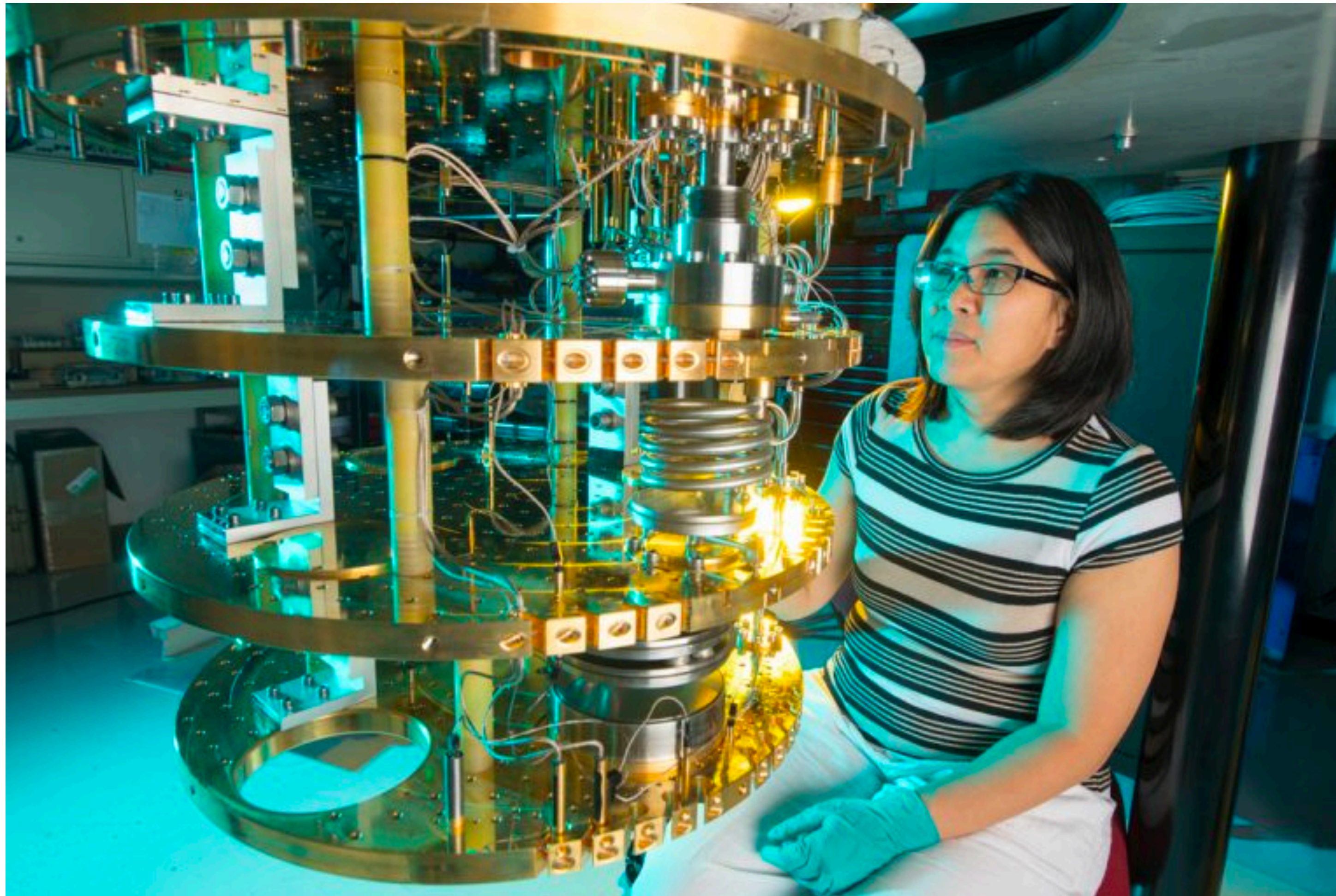


As big as a tank filled with
liquid argon.



As small as a silicon strip.

Use quantum computing for sensing, communication and electronics

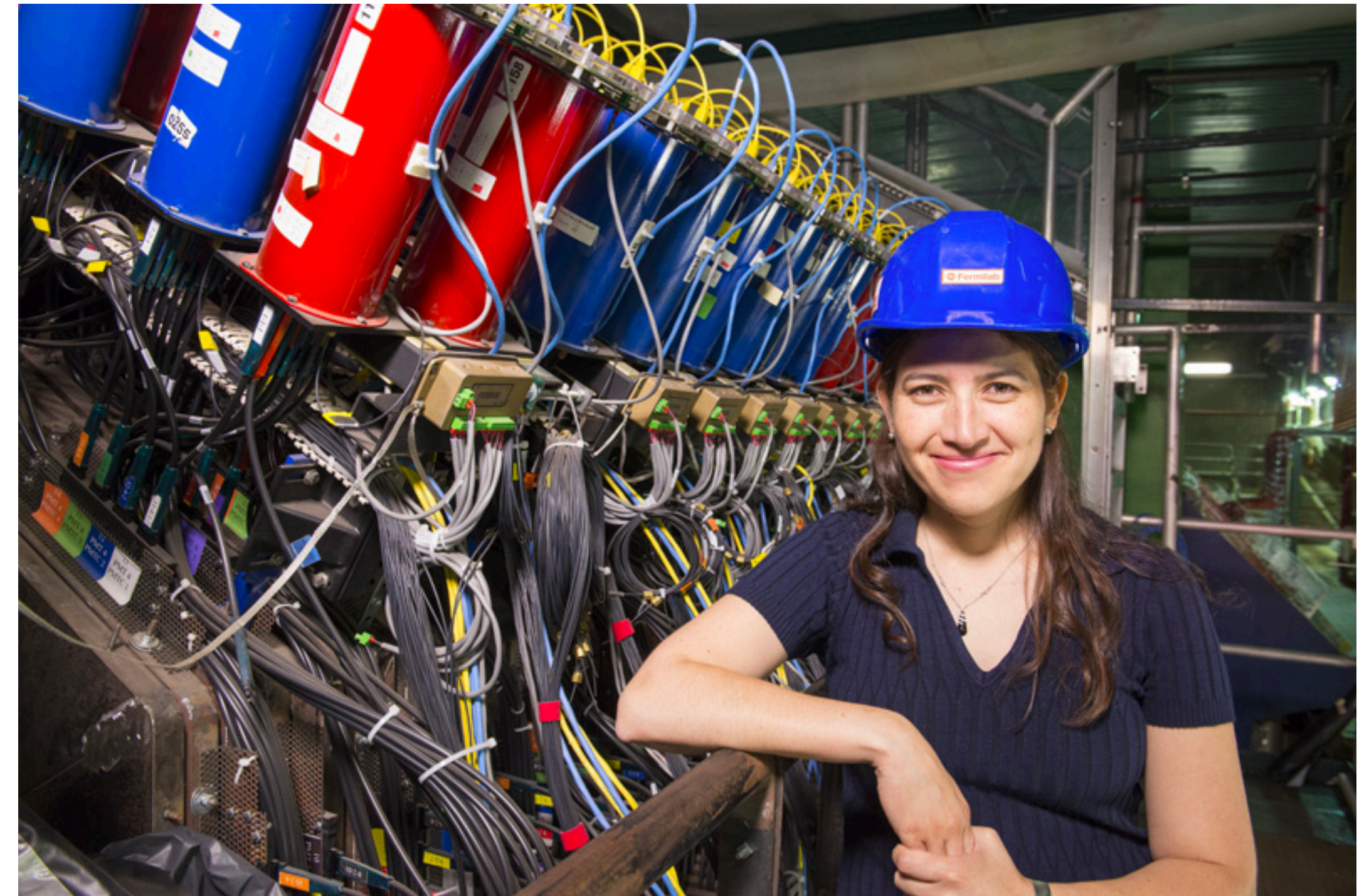


Dilution refrigerator for a
dark matter detector that
will detect qubits.

Scientists focus on developing theories developing particle detectors, and understanding the data from the particle detectors.



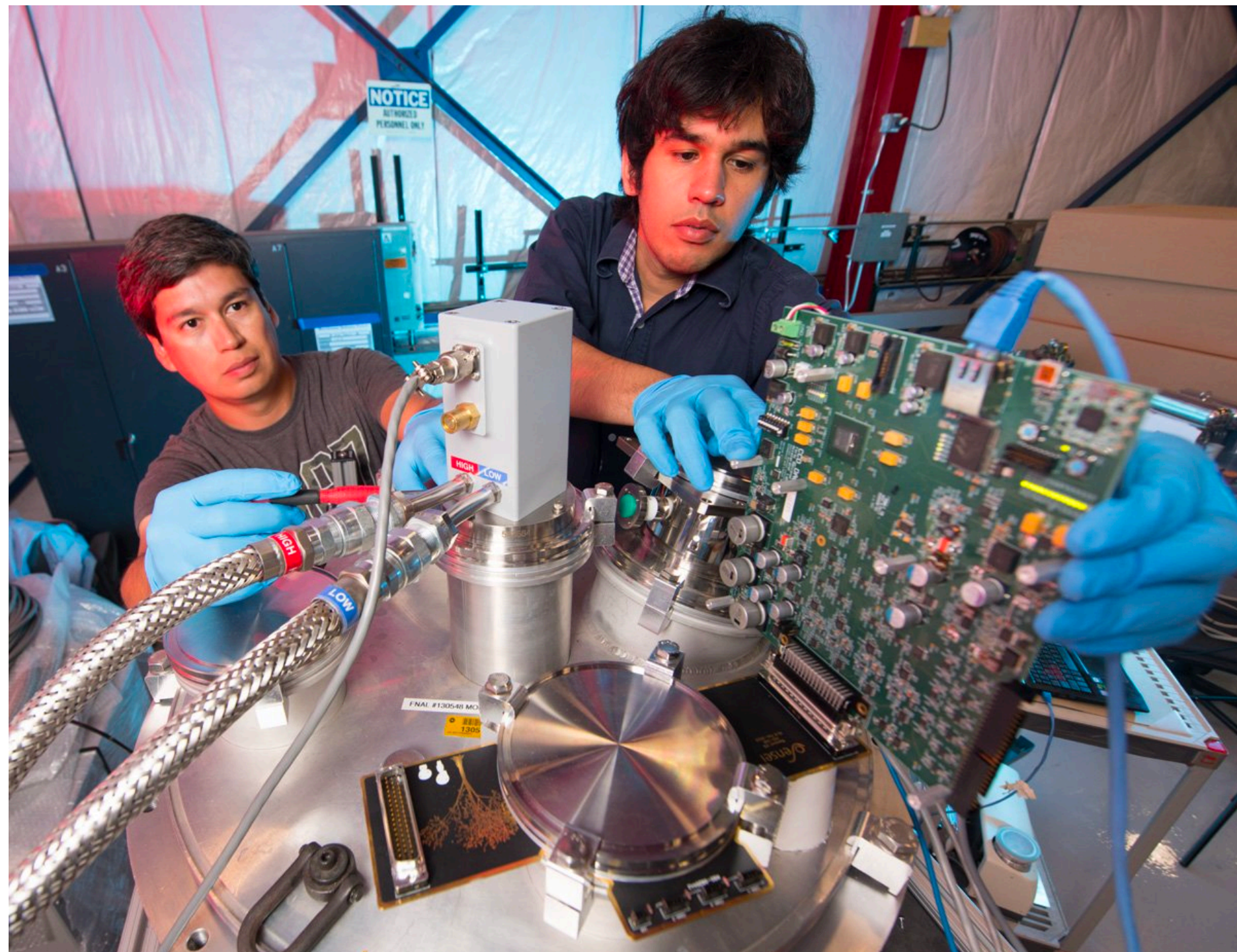
Scientist Monica Nunes from Brazil



Scientist Minerba Betancourt from Venezuela

Engineers (Electrical/Mechanical and others) can focus on making electronics that can readout detector data.

They can design and test electronics, design fluid, cooling, and mechanical systems that allow detectors/accelerators to work.



Engineers Claudio Chavez Blanco/Christian Torres
Hermosa from Paraguay

Computing Scientists develop software and manage modern computing systems to make sure that data can be stored and analyzed in an effective way.



But, what do particle/astrophysics/
computing scientists, electrical and
mechanical engineers/technicians
actually do?

