The beauty of particle physics

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Taos
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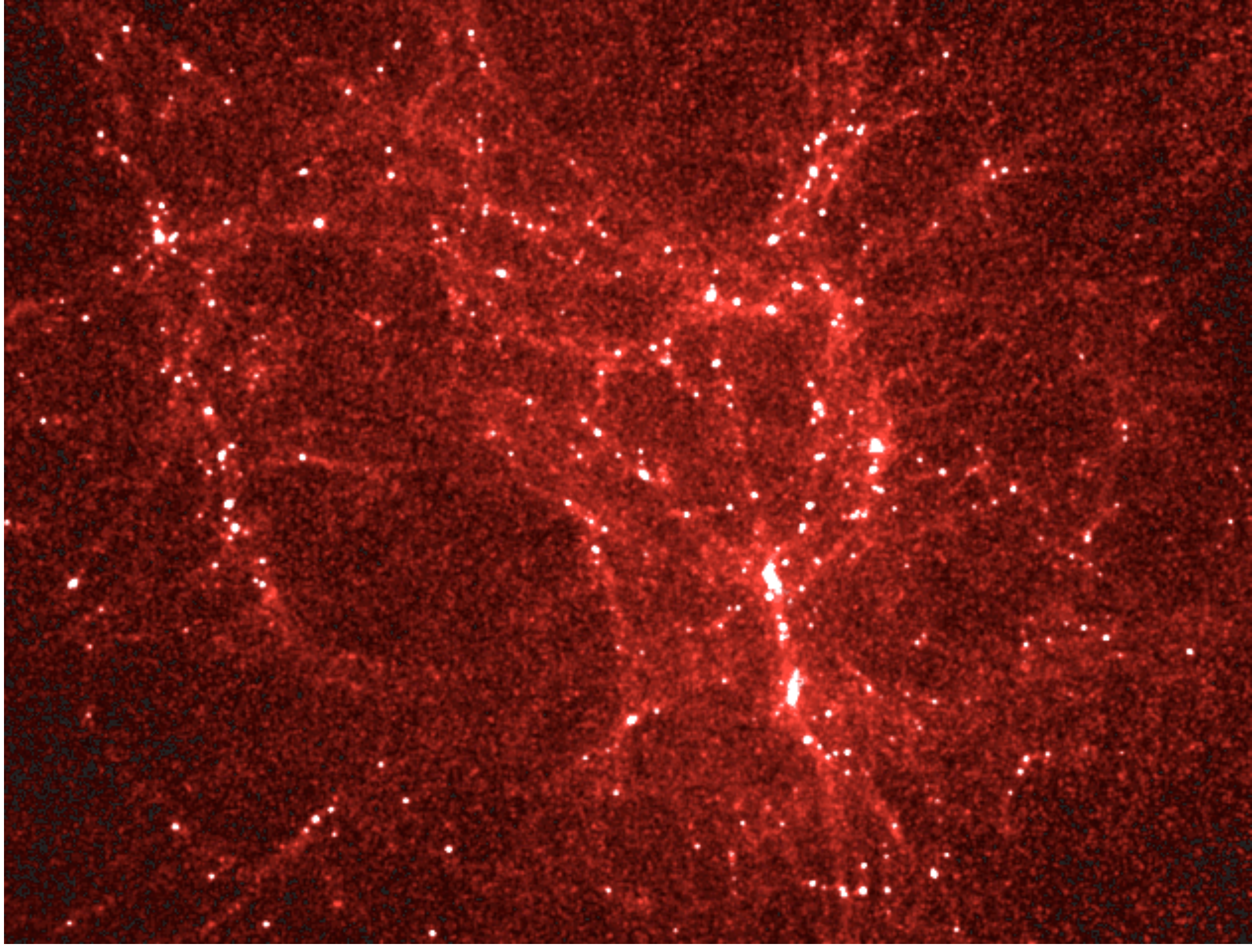
Let’s talk about
Elementary Particle Physics,
also called
High Energy Physics.



This is the study of the very smallest building-blocks of nature.

Why study it?

This is a way to learn what the universe was like just *seconds* after it was born, billions of years before life existed to see it directly.

To understand why, we need to talk about:

1. *Anti-matter*
2. $E = mc^2$
3. *The Big Bang*

1. Anti-matter and $E = mc^2$

Examples of some elementary particles:

electron (symbol e^-)
proton (symbol p^+)

Everything we see around us is made of these.

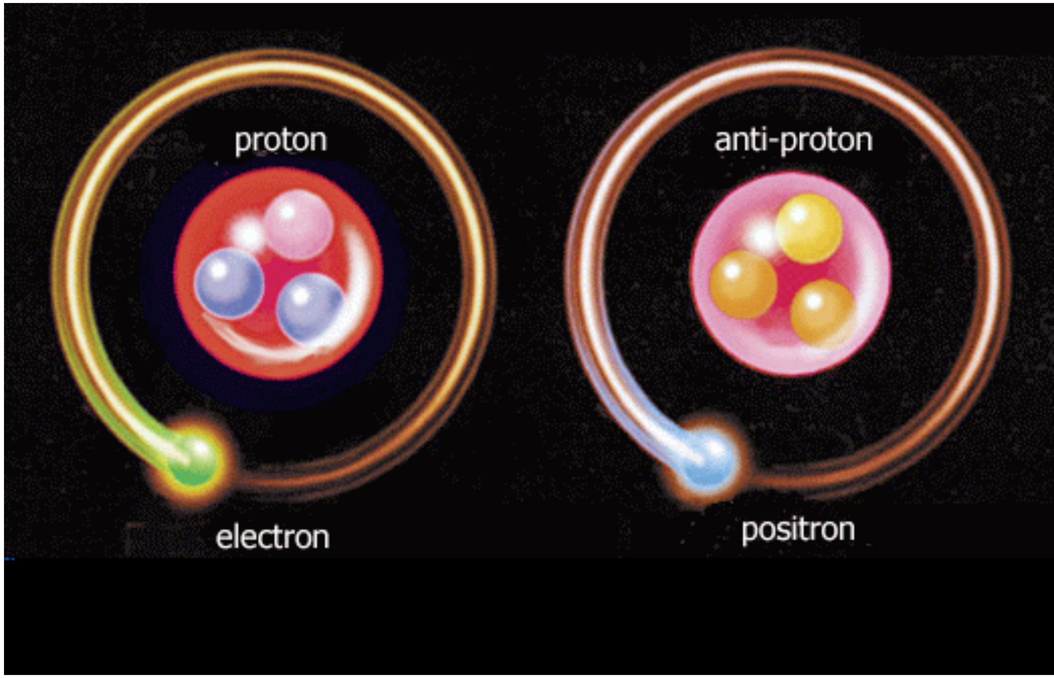
There are other kinds too.

It is a law of physics that for every kind of particle that exists, a matching kind exists with the same mass and most other properties, but with opposite electric charge.

The matching kind is called the ***anti-particle.***

Examples:

<u>particle</u>	<u>anti-particle</u>
e^-	e^+
p^+	p^-
"matter"	"anti-matter"



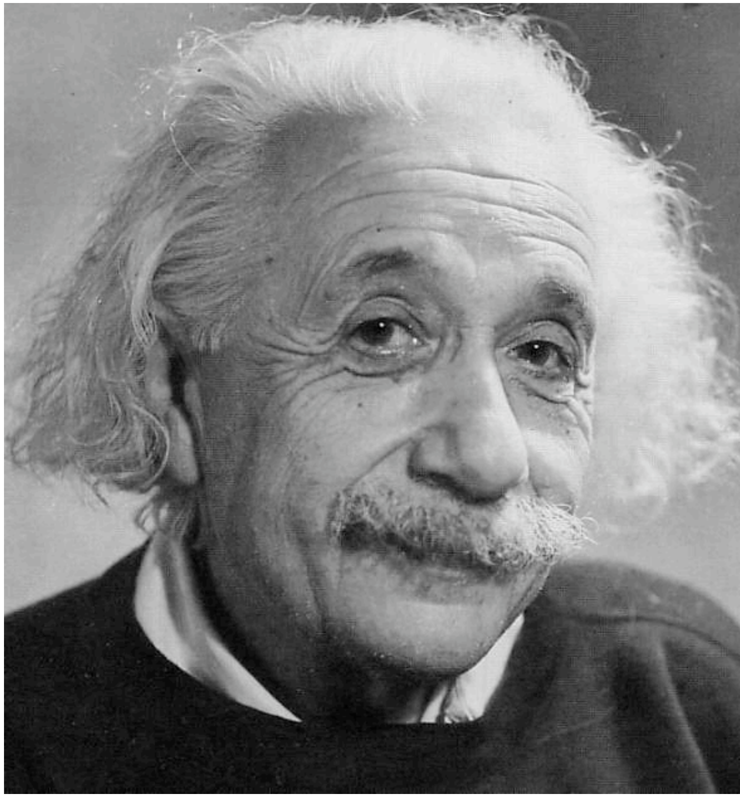
Four facts about anti-matter:

Fact 1: It behaves just like matter.
It responds to the force of gravity.
An e^+ and p^- can join to make an "anti-atom."

Fact 2: **If a particle meets an anti-particle of its own kind, they annihilate (disappear) and produce energy in their place.**

The energy produced is NOT a big explosion!

When a particle and anti-particle meet and annihilate, the amount of energy they produce in their place is

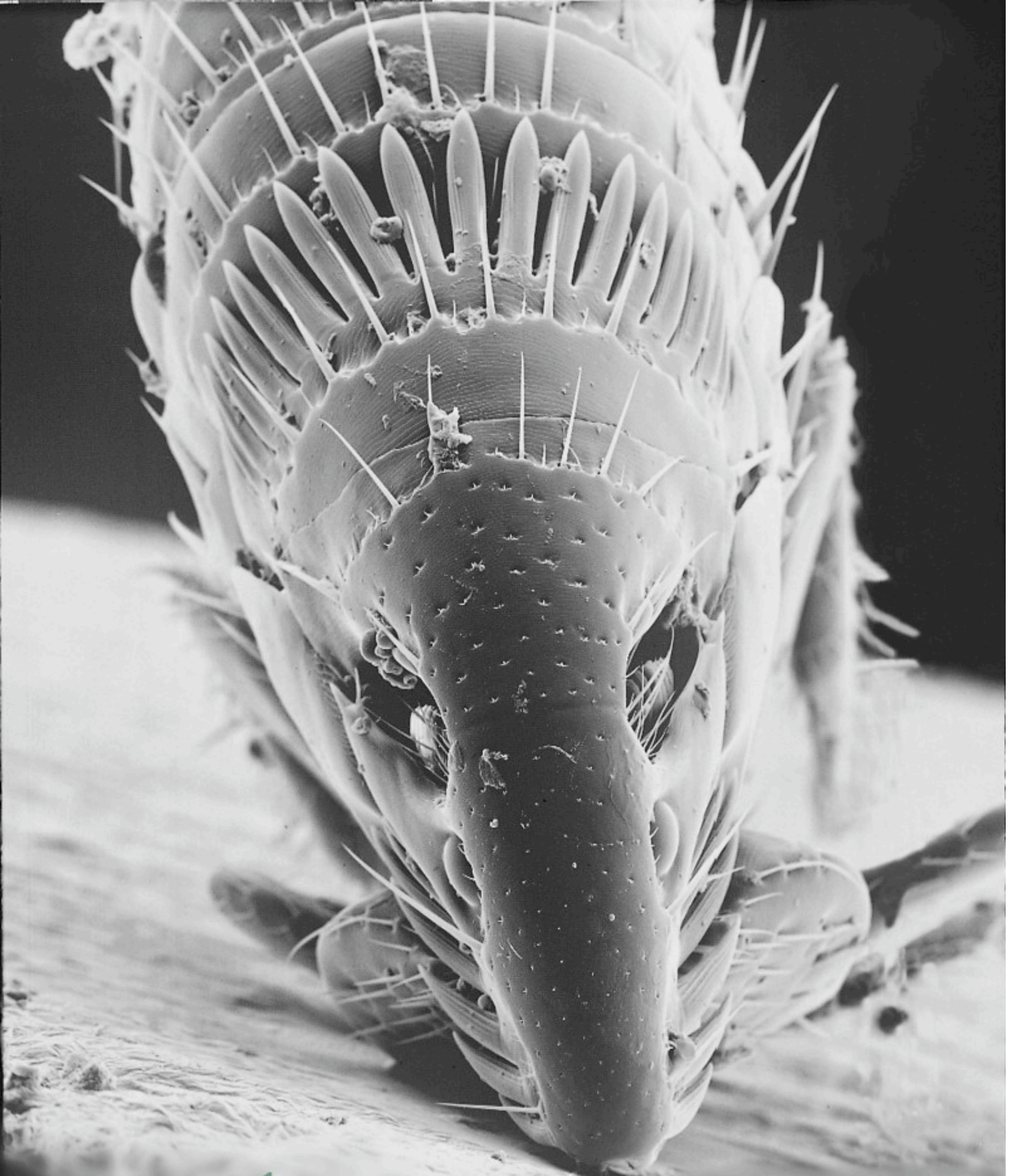


$$E = mc^2$$

The c^2 is just a number, the speed of light, squared.

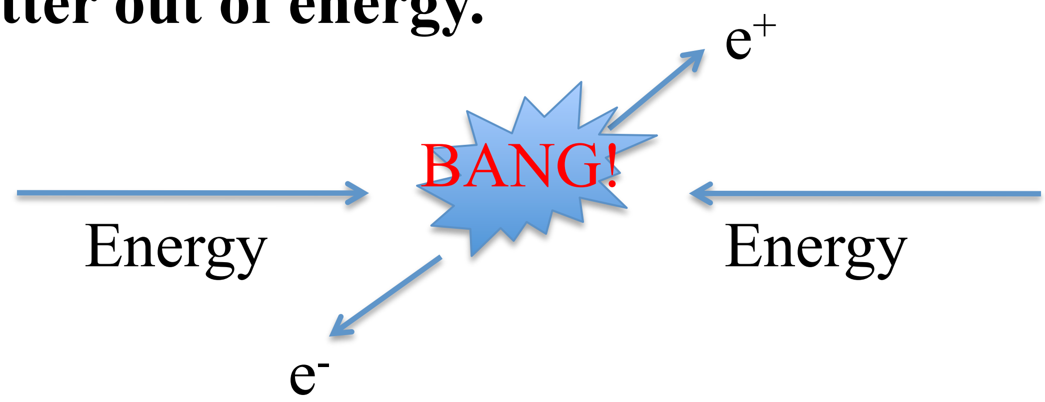
$c^2 = 90000000000000000$ m^2/s^2.

The m is the masses of the particle + antiparticle (really small! About 1/1000000000000000000000000000 of a gram each.)



If an electron meets an anti-electron, the “explosion” has as much energy as a flea doing a push-up.

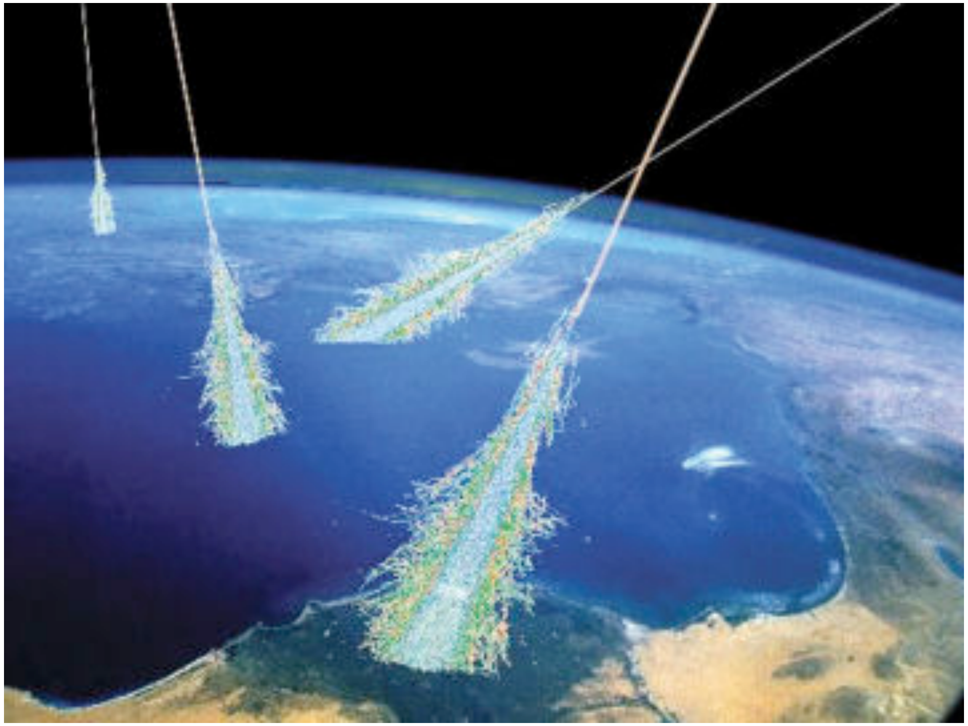
Fact 3: If you get energy packed into a tiny space, you can create matter out of energy.



This is using $E = mc^2$ “in reverse”: put in energy, get out mass.

Fact 4: Anti-matter really exists

- It is created in nature all the time. It is a normal product of radioactive decay and of collisions between cosmic rays and our atmosphere.



- Also we can create as much as we want in a lab by packing a lot of energy into a small space and letting it turn into particle-antiparticle pairs.

Now (2): The Big Bang

When astronomers observe other galaxies, they notice that almost all of them are moving away. They deduce:

There must have been a time (about 14 billion years ago) when everything was crushed together at a point...then it exploded.

Facts about the Big Bang and Expanding Universe:

(i) Look at the universe from the "outside." It looks like a gas: The galaxies are like molecules separated by large distances, barely affecting each other.

Think how gases respond to pressure...

Think of an air-filled balloon:
If you compress it, its volume decreases.

Higher pressure leads to lower volume.

But the more pressure a gas feels, the more energy it has. (Your car tires get warmer when you add air).

Higher pressure means higher energy.

Combine those facts, for a gas or for the universe:

High pressure means low volume, and high pressure means higher energy. **So low volume means high energy.**

Now remember what ***density*** means: The amount of stuff per volume.

So *when the universe was younger,* and had a smaller volume, *the density of energy* in it was *higher.*

Another way to look at it:

As the universe expands ➔ its volume increases ➔ so pressure decreases ➔ The average energy per volume ("energy density") decreases.

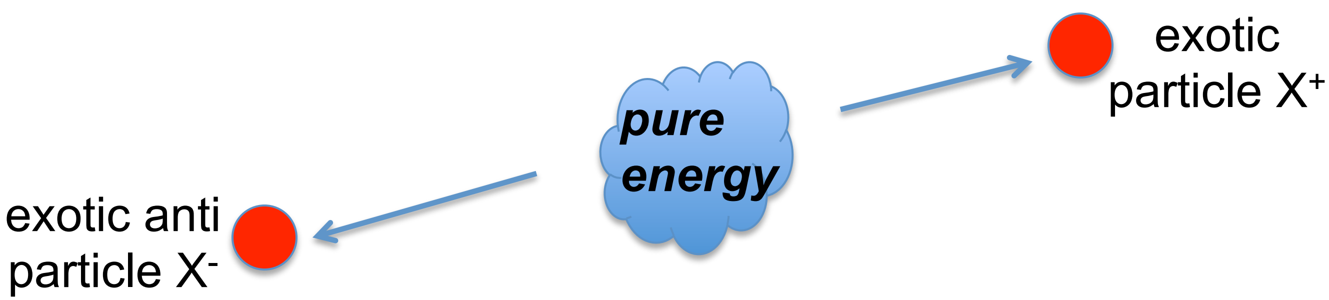
Now suppose we could **"run the movie backward" to picture the universe when it was younger.**

Younger universe ➔ smaller volume ➔ higher pressure ➔ higher energy density. All the energy was packed into a smaller space.

(ii) Put this together with $E = mc^2$:

The younger universe had its energy packed into a smaller volume.

$E = mc^2$ means large mass "m" particle/antiparticle pairs could be created back then, spontaneously, from that dense energy.



Today in the expanded universe the energy density is too low to create high mass exotic particles. We just have plain old electrons, protons, etc.

But in the early universe, probably lots of exotic unusual forms of matter existed because they were easier for nature to form.

Where have they all gone?

(iii) Particles "decay"

There are many kinds of particles besides protons, electrons, and neutrons---about 500!

But most of them spontaneously disintegrate just a fraction of a second after they're created.

Disintegration is called "decay," but it's not like rot.

So we don't expect to find any of the unusual early universe particles still around.

But **we can re-create the conditions of the early universe** right in the laboratory. Those conditions may include exotic particles.

We can replicate the way the universe was 1 billionth of a second after the Big Bang.

How we do this:

1. Build a machine that can ***concentrate a lot of energy in a small space***. This replicates the way the universe was when it was young, when its energy density was high.

2. Watch what kinds of particle/antiparticle pairs form naturally in this machine.

It turns out that there is ***NOT an unlimited variety. Nature seems to have a limited set of ingredients in its cookbook.***

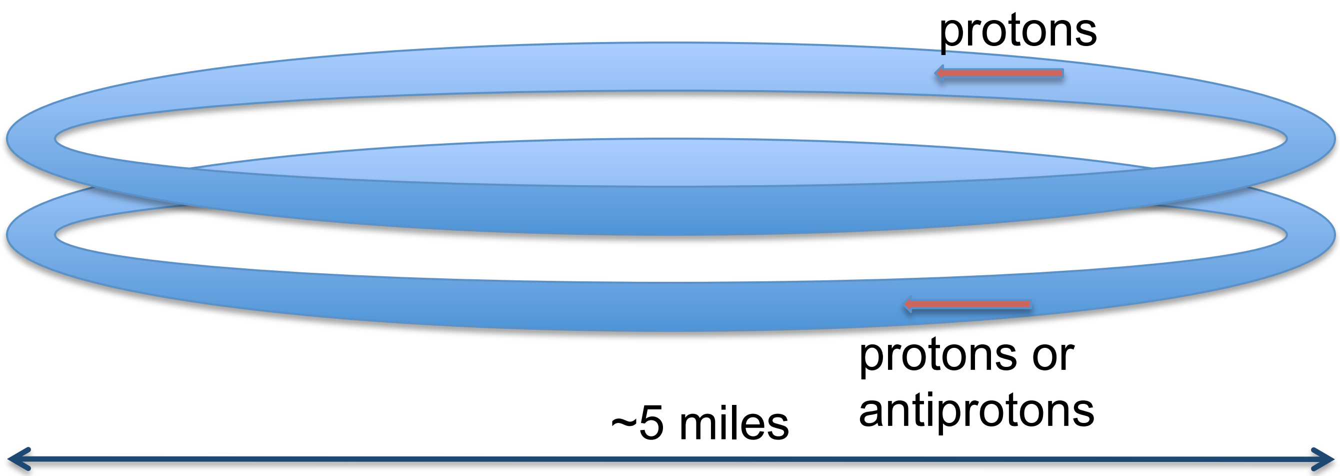
Even when we give Nature "all the energy it might want" to create anything at all, it "forbids" certain things to exist and "permits" others.

Seeing what Nature DOES and DOES NOT do when it has all the energy it needs tells us what rules Nature follows.

This is how we find the laws of nature.

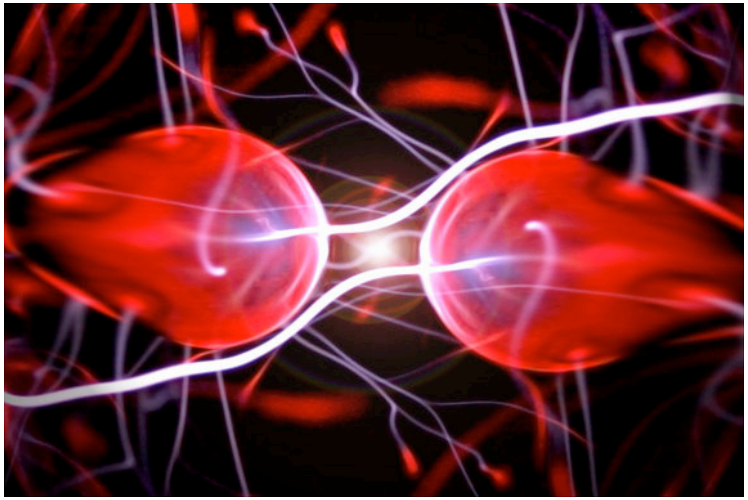
How do these "energy concentrator" machines work?

Take 2 hollow circular pipes with diameter about 5 miles. Place one next to the other.



Put particles in both rings, and make them circulate in opposite directions at speeds of almost ***1 billion miles per hour.*** Divert the beams so that they **collide head-on** at a few points.

Every particle is carrying **a lot of energy because of its high speed**. This "speed-energy" is called kinetic energy. At the moment of collision, **all that energy is concentrated in a space just the size of the 2 particles**.



How small is that space where the energy is concentrated? Take a cubic meter and divide it into 1,000,000,000,000,000,000,000,000,-000,000,000,000,000,000,000 equal parts. Take just one of these parts.

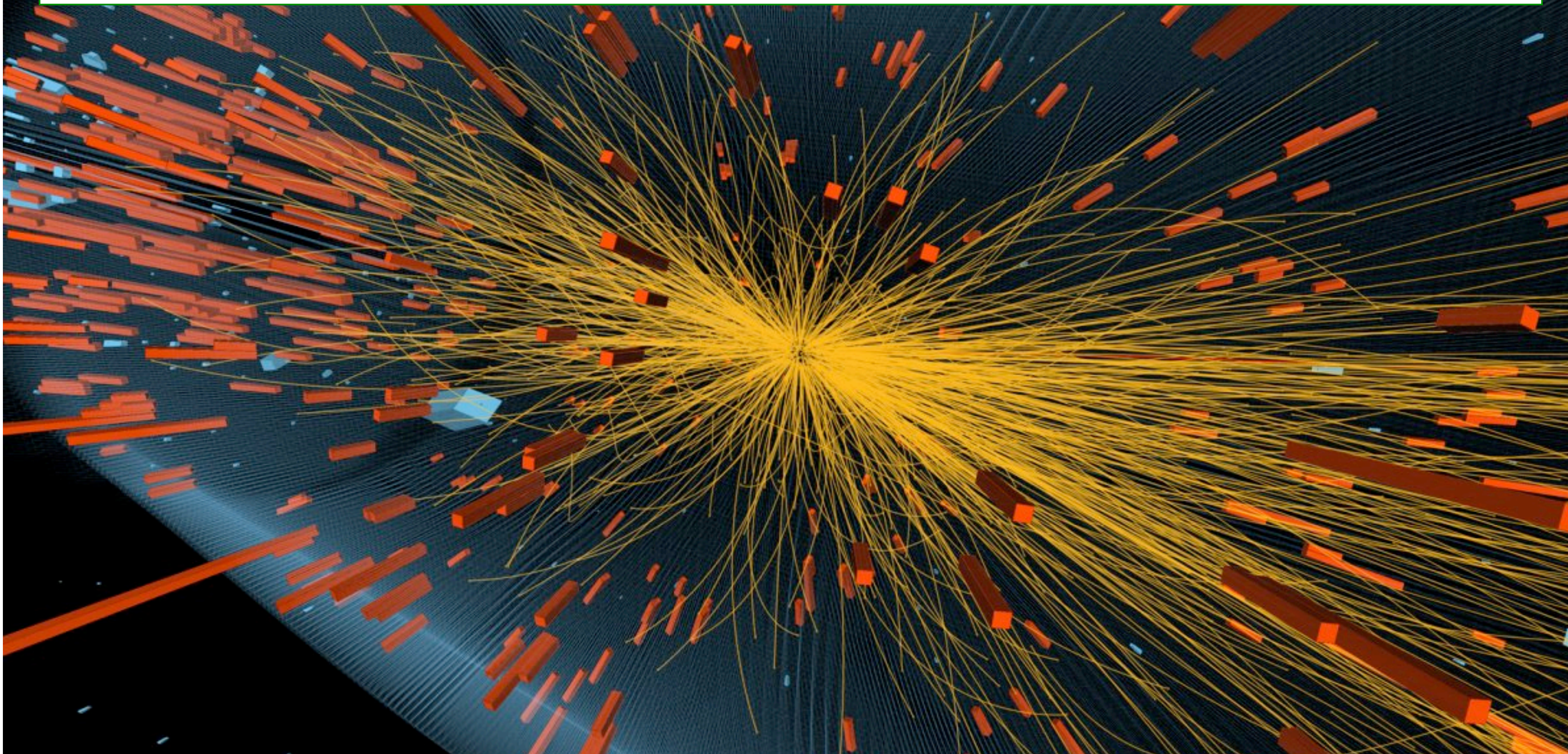
(If one of the things colliding is the antiparticle, then add to all of the kinetic energy the energy from the annihilation of the masses, too.)

An example machine: The Large Hadron Collider in Geneva, Switzerland.

How big is this?? Here's an airport runway!

When all the energy of the colliding particles is liberated, there's enough energy to make new, different, even more massive particles through $E = mc^2$.

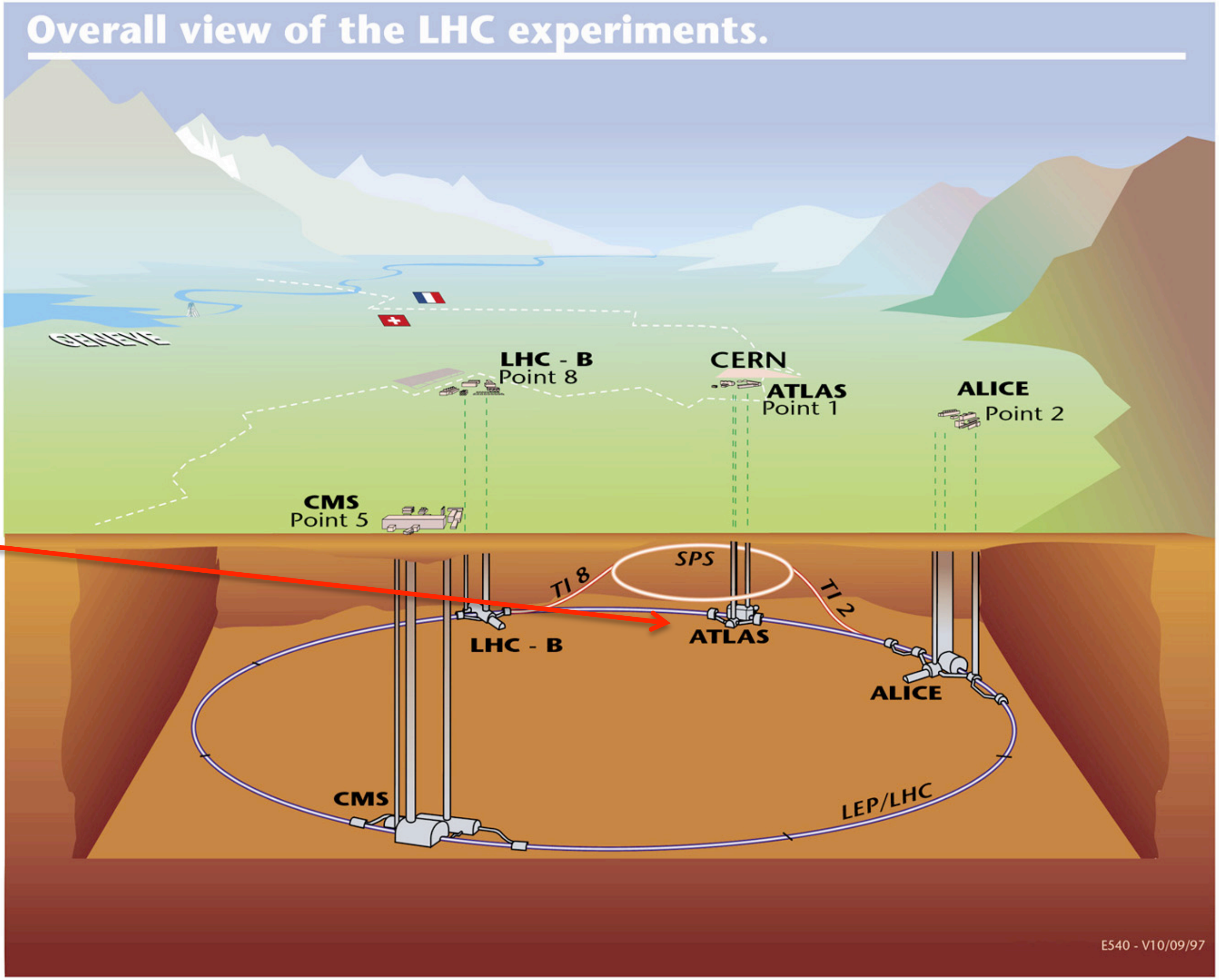
So much energy is available, that when it converts into particles ($E=mc^2$), tens of thousands of particles can be produced. They move away from the collision point at high speeds:



We want to know what they all are. Some of them are Z bosons like the ones you will be finding in the data this afternoon. Some of them could be things never seen before.

To record all the details, we need specialized cameras, called particle detectors. Like the collider itself, the particle detectors are enormous.

The detectors are located deep underground to keep out cosmic rays, which could overwhelm the collider data.

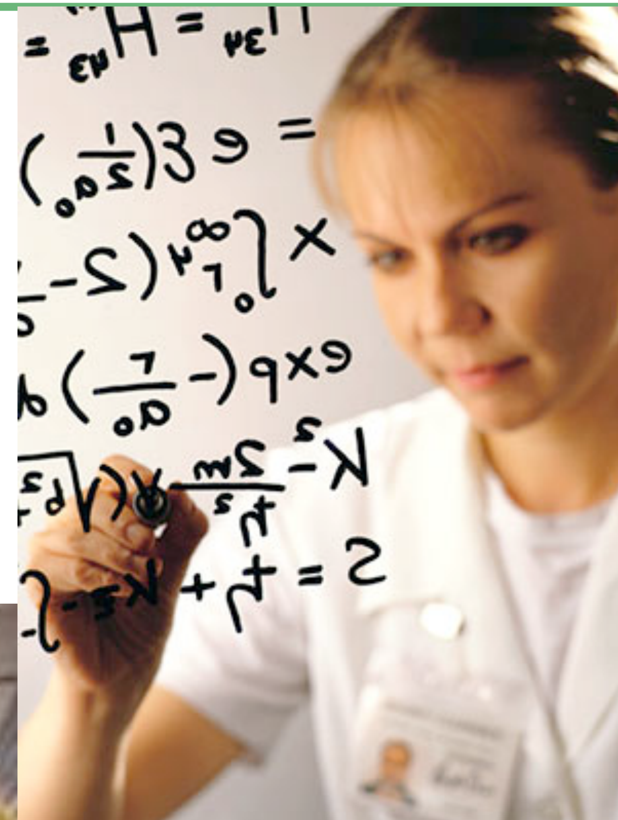


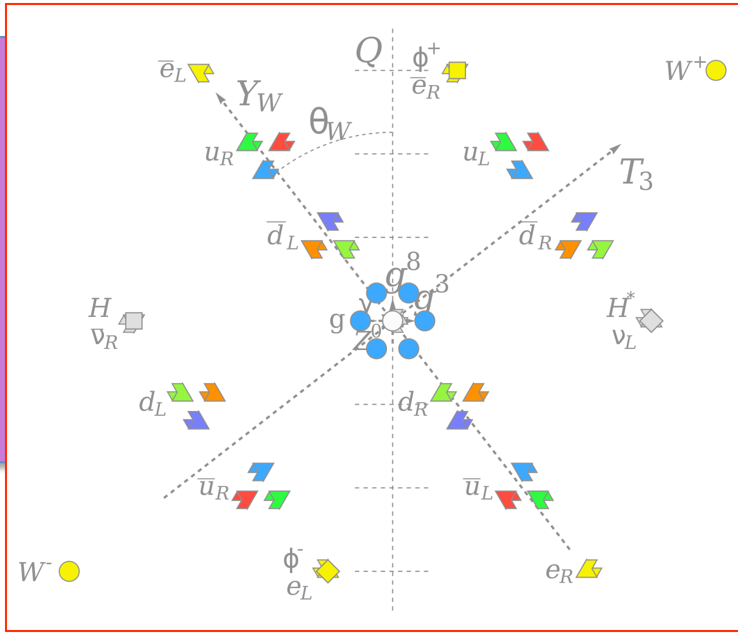
UNM works on this one along with 3000 scientists from 34 other countries.

Parts of this detector was built with help from UNM students:

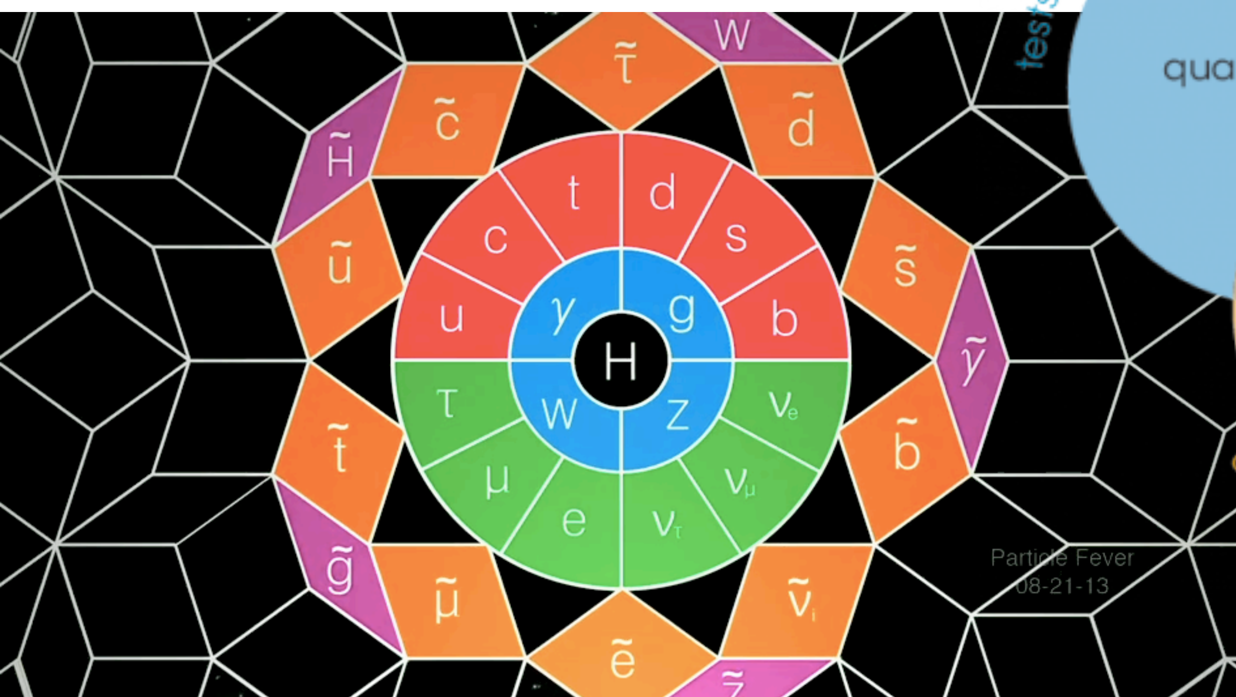
The ATLAS Pixel Detector

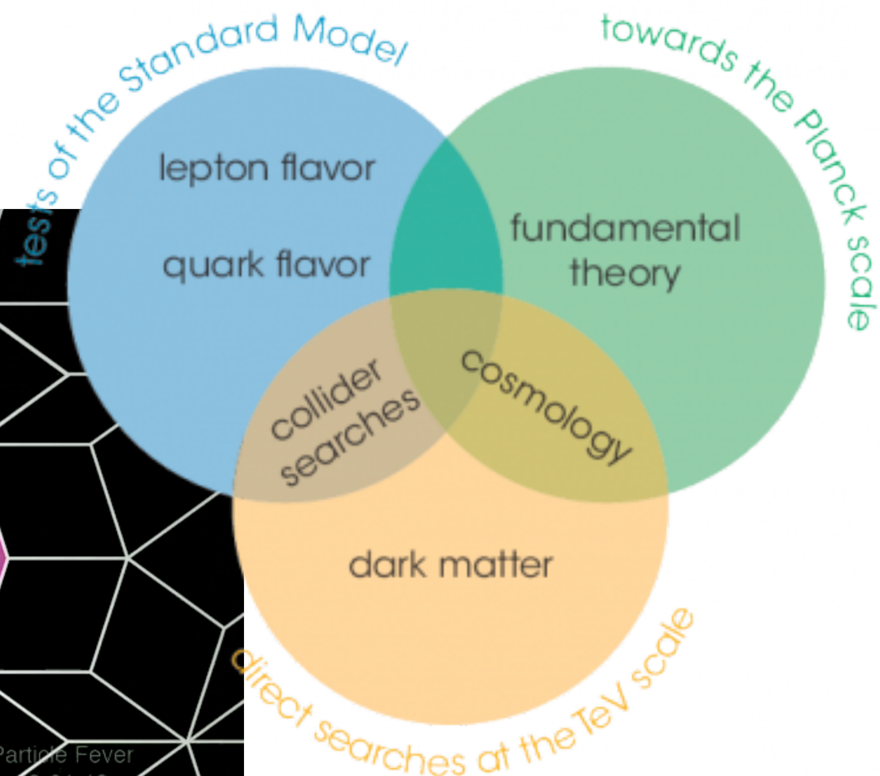
People who study particle physics...What kinds of training to they get, and what jobs do they like to do?





Many people study physics because the properties of the particles have mysterious and beautiful symmetries – like art.





And sometimes they discover amazing things....like the Higgs boson.

The future of science is bright. Consider studying particle physics.