$E = mc^2$
Opening Windows on the World

Young-Kee Kim
The University of Chicago

Aspen Physics Lecture
August 17, 2005

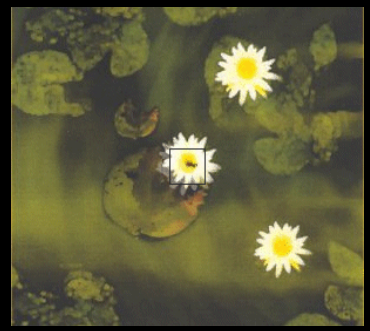

What is the world made of?
What holds the world together?
Where did we come from?

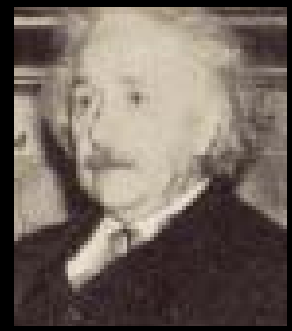
We need large tools to see small things!

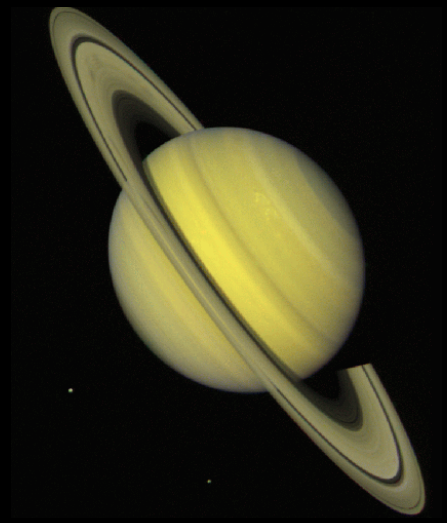
Accelerators are Tools.

What is the world made of?



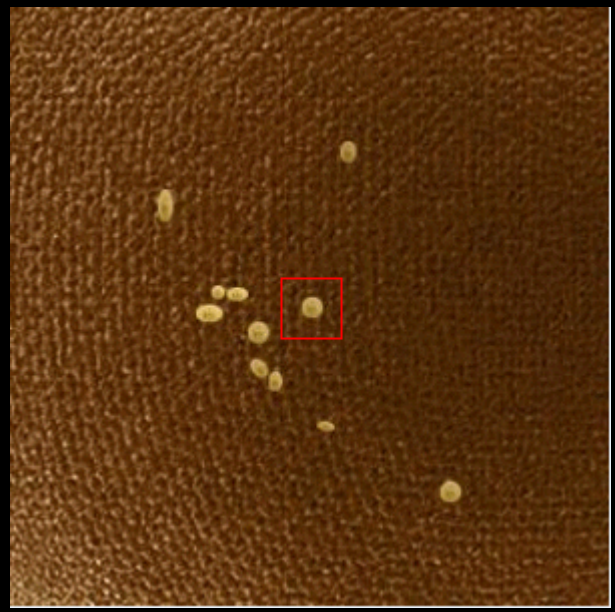


my cat Nah-Bee



100 mm

Seeing it at 100 times smaller scale

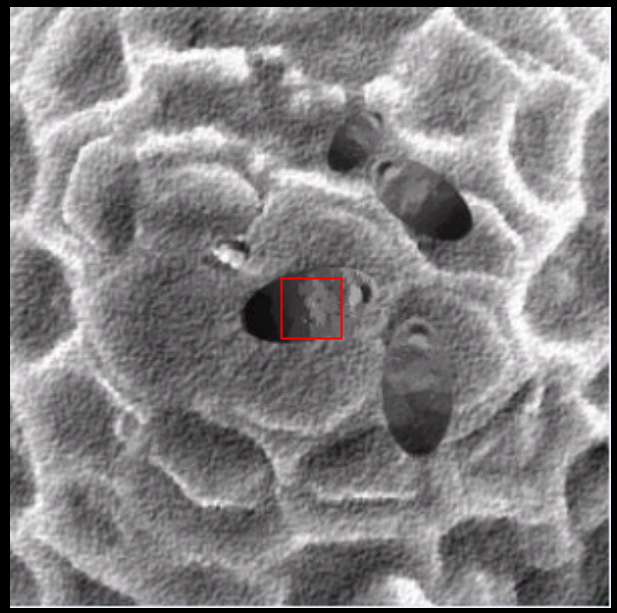


pollen

1 mm

Another 100 times smaller

Optical Microscope
using beam of light



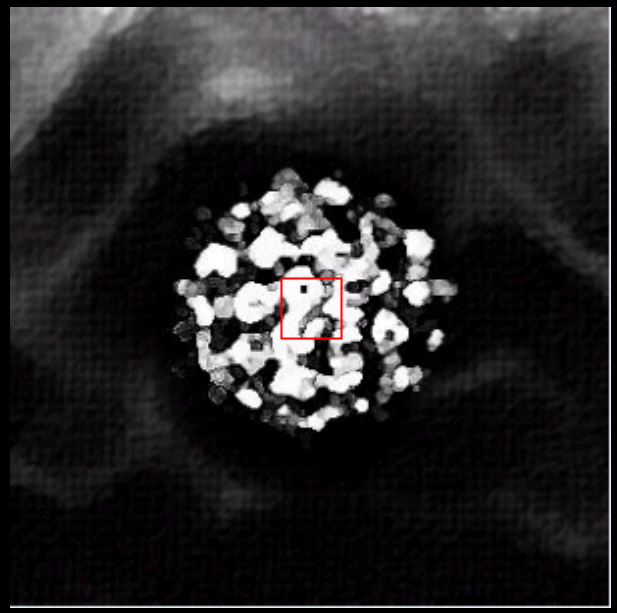
bacteria

0.01 mm

Another 100 times smaller

Electron Microscope using beam of particles (small accelerator)

Needed to change technology.



virus

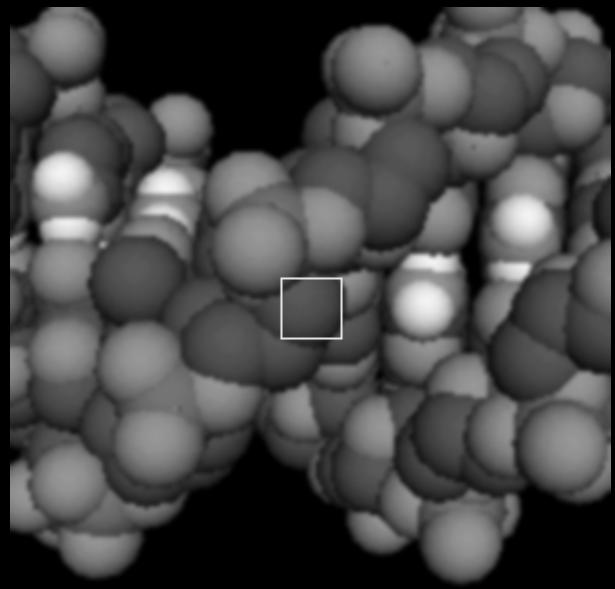
0.0001 mm

Another 100 times smaller

X Ray machine

using beam of x-rays

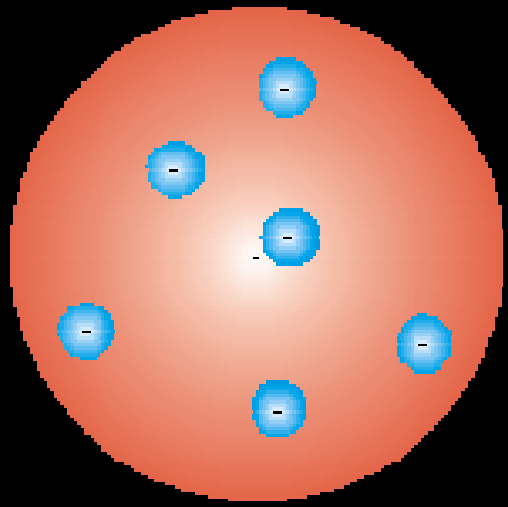
Needed to change technology again.



Atoms in DNA

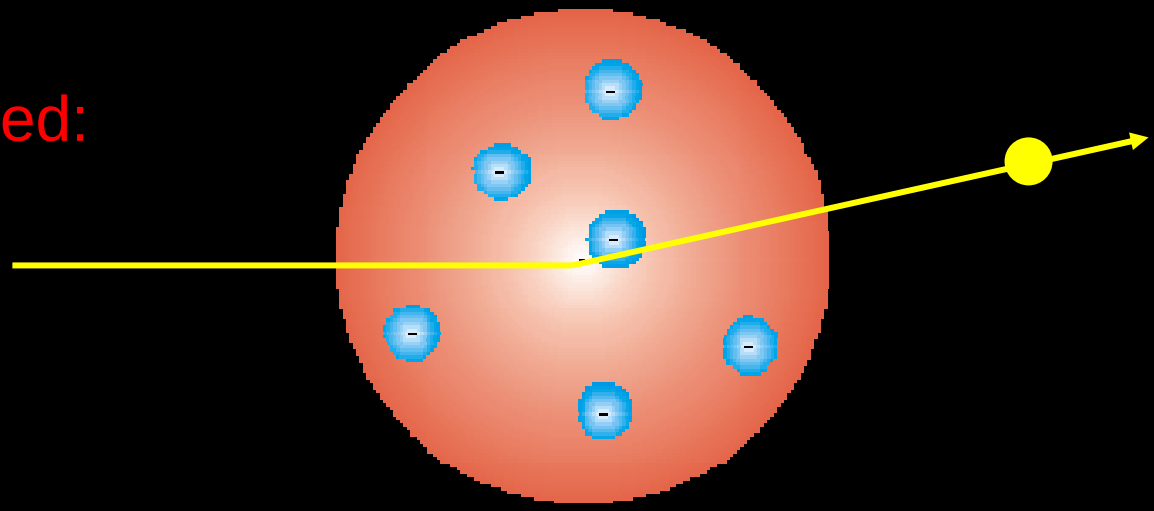
0.000001 mm

What are atoms made of? 1905 model



Rutherford's Experiment in 1909

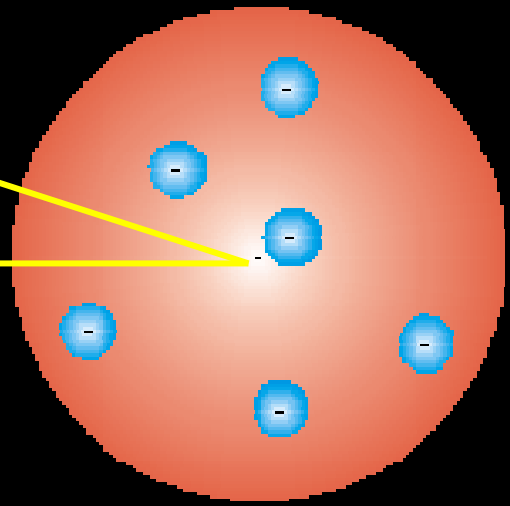
He expected:



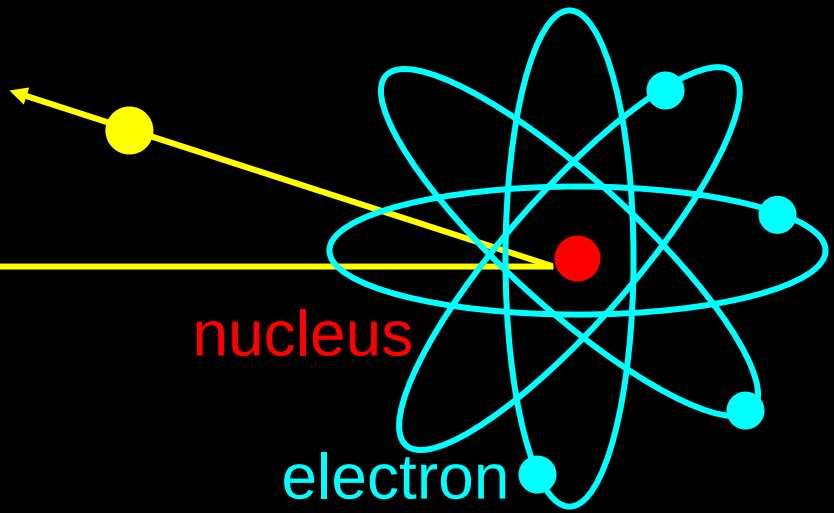
Rutherford's Experiment in 1909

He found:

particle



Led to <u>new</u> model of atom



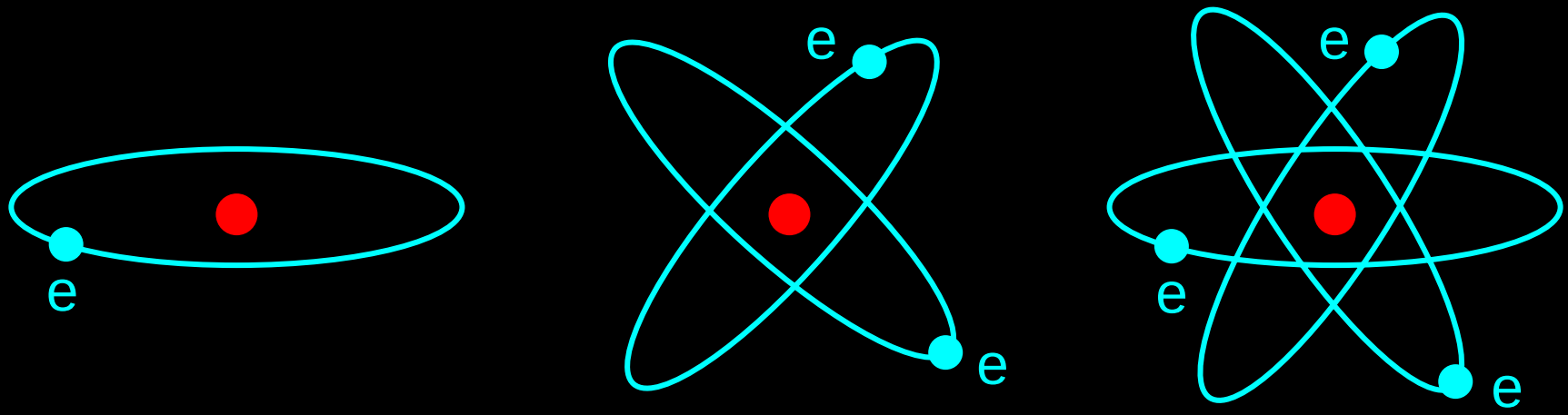
size:

$$\frac{\text{Nucleus}}{\text{Atom}} = \frac{\text{Fly}}{\text{Cathedral}}$$

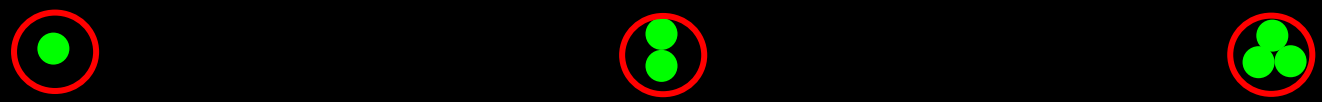
'like a fly in a cathedral'

Once glimpsed the fly in the cathedral,
ached to know more, to catch it, examine it, dissect it!

What is nucleus made of?



a single fundamental particle? - many of them!



made of a smaller thing or smaller things?

different nuclei = different quantities of ‘same’ small things

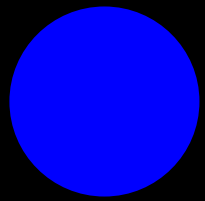
Needed to change technology once again.

Ernest Lawrence
(1901 - 1958)

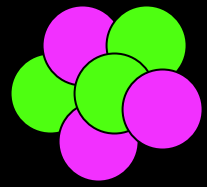
Tevatron at Fermilab, Chicago
million times more energy

Accelerators are Powerful Microscopes.

because they make higher energy particle beam
that allows us to see smaller things.

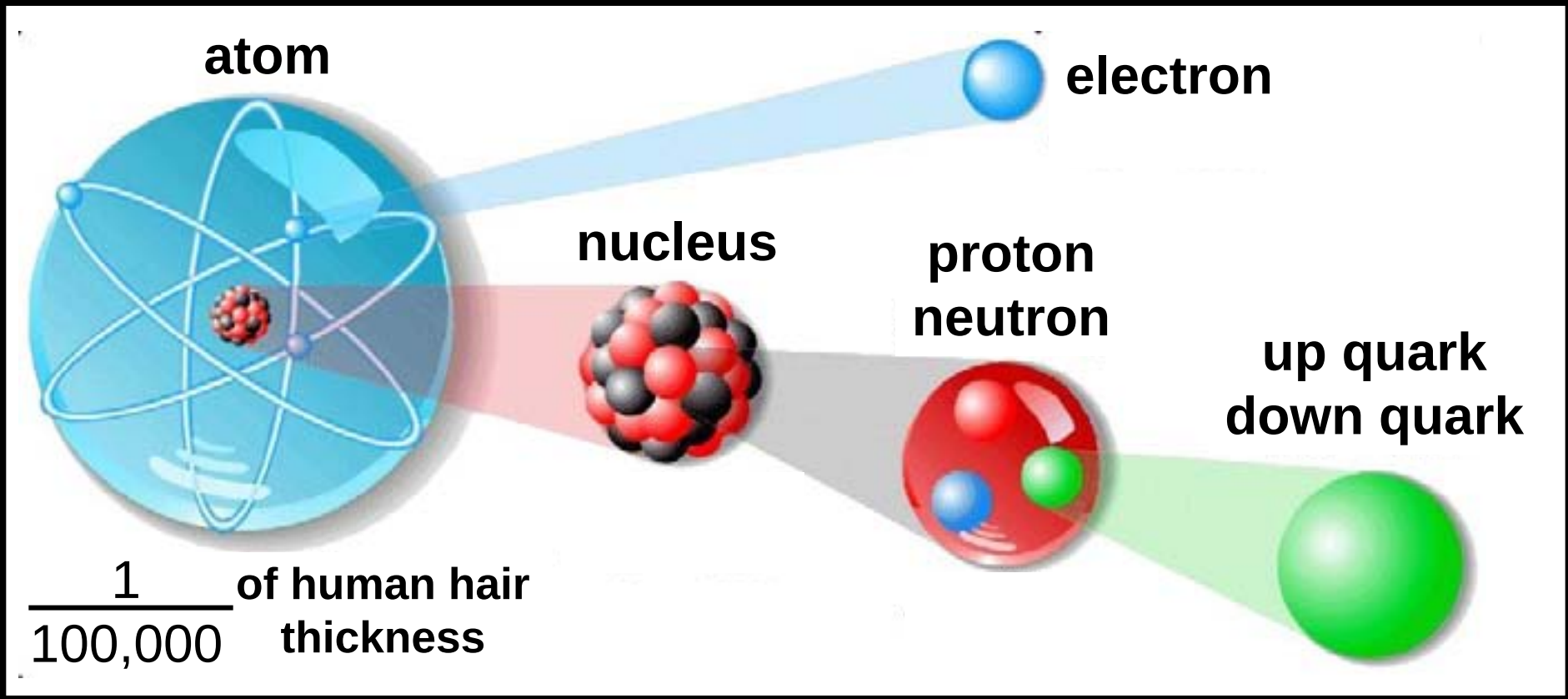


seen by
low energy beam
(poorer resolution)



seen by
high energy beam
(better resolution)

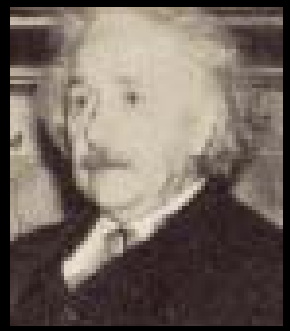
~90 years ago ~60 years ago ~40 years ago Present

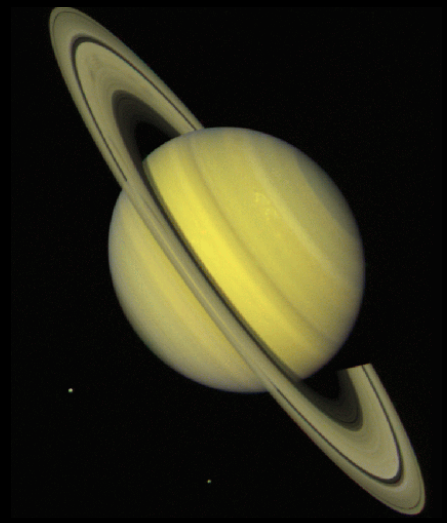


Everything is made of electrons, up quarks and down quarks.
Who would have thought it was so simple?







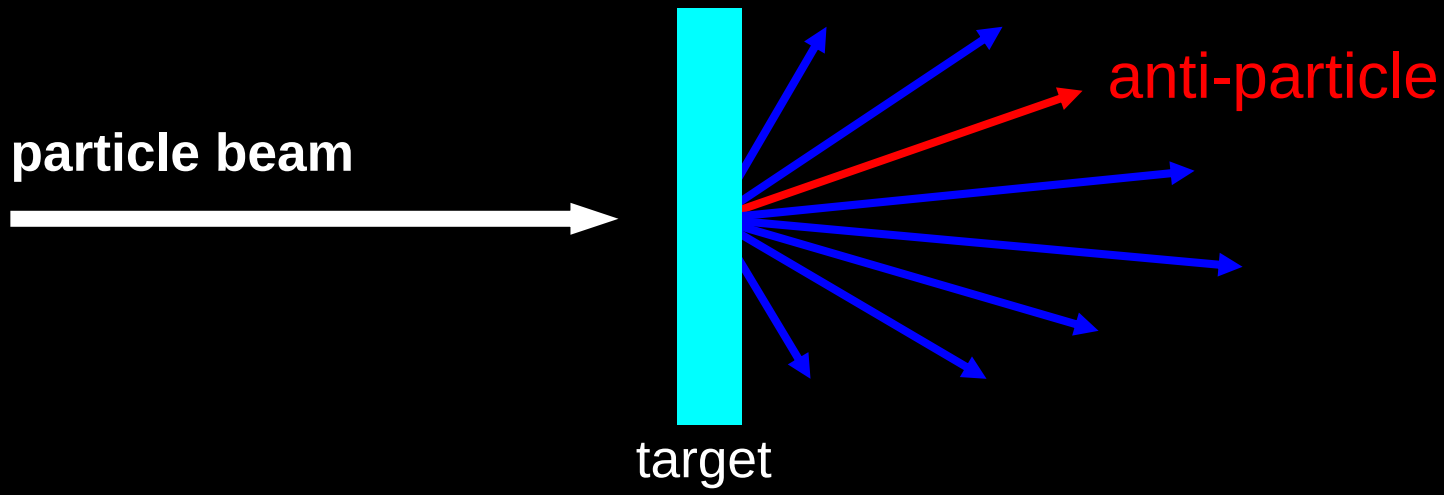




Are electrons, up and down quarks the smallest things?

Are they made of even smaller things?

Accelerators are also Time Machines

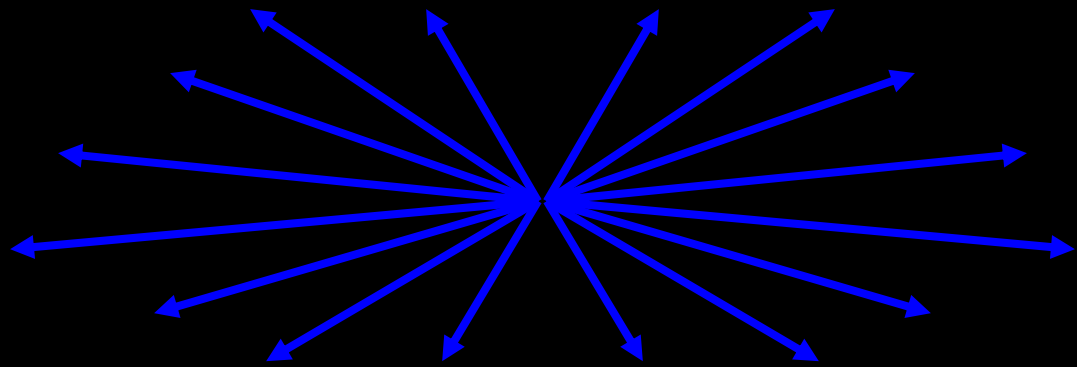
because they make particles last seen
in the earliest moments of the universe.



Every “particle” has “anti-particle” partner.
Same mass but opposite charge.
(Positron, anti-particle of electron, is used in PET Scan.)

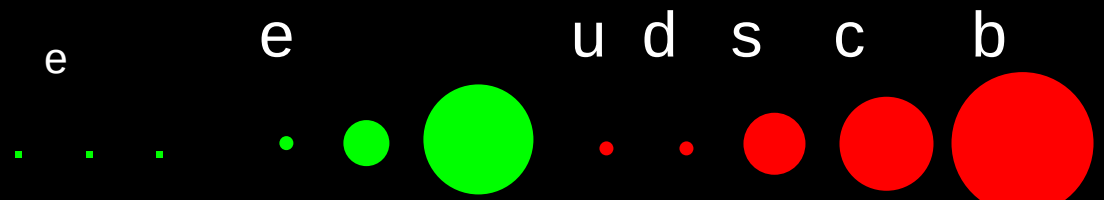
Accelerators are also Time Machines

because they make particles last seen
in the earliest moments of the universe.



The smallest things in the world.

Everything there is! *??*



top quark

photons
gluons

W

Z

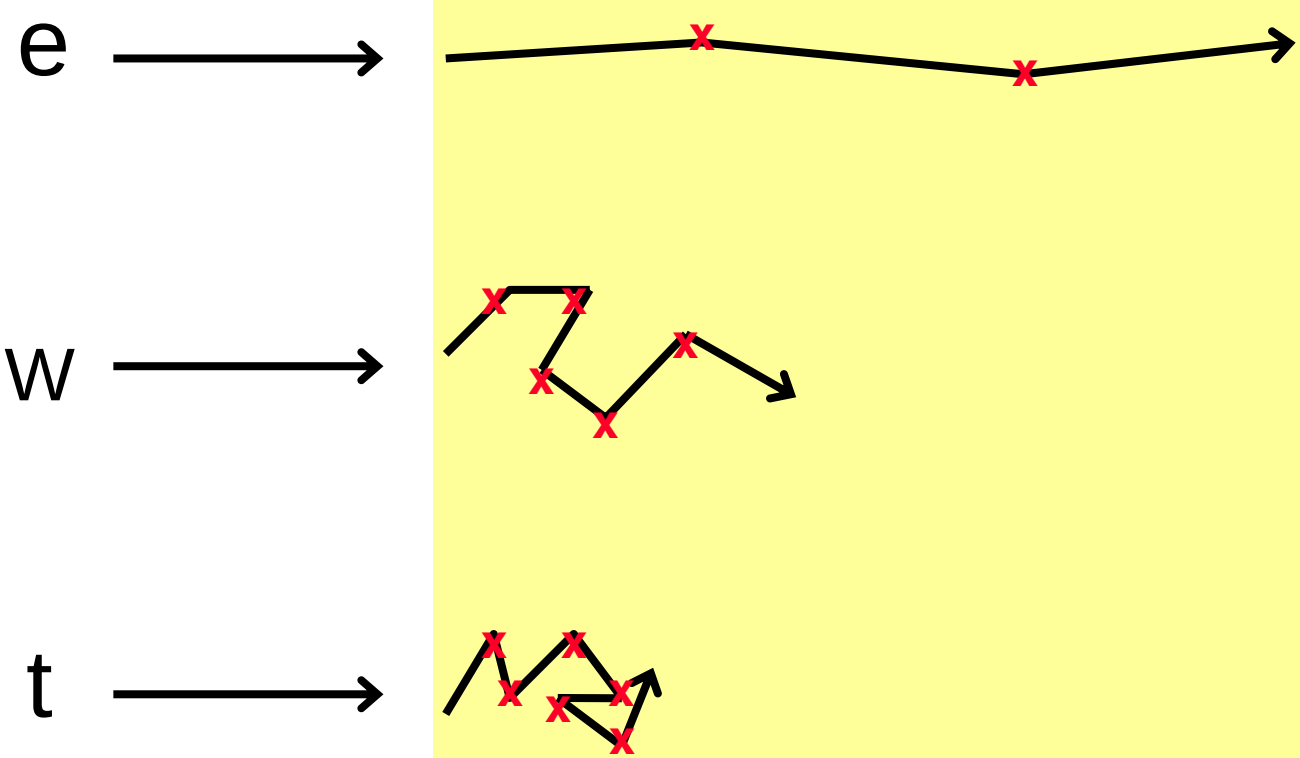
Mass proportional to area shown but all sizes still < 10^{-19} m

“Why are there so many?”

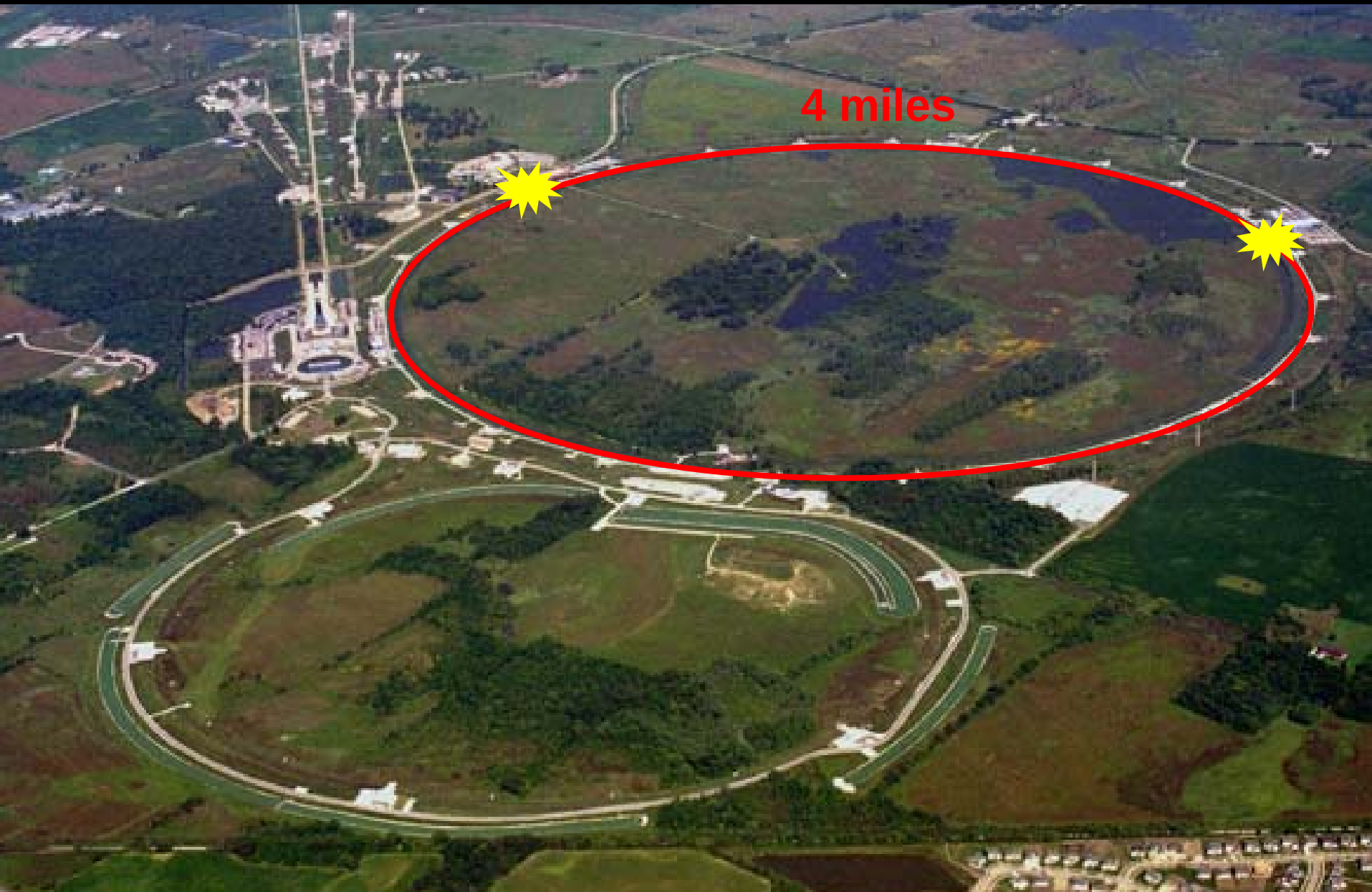
“Where does mass come from?”

There might be something (new particle?!) in the universe that gives mass to particles

Higgs Particles

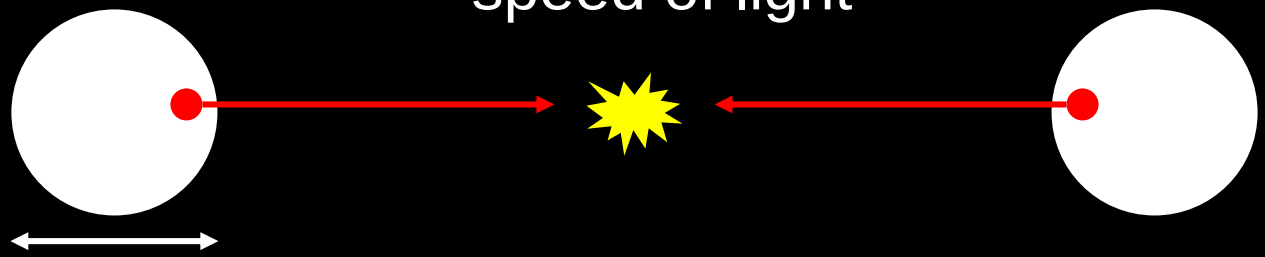


World's Most Powerful Accelerator: Fermilab's "Tevatron"



Challenges:

trillions of particles in beams
~ speed of light

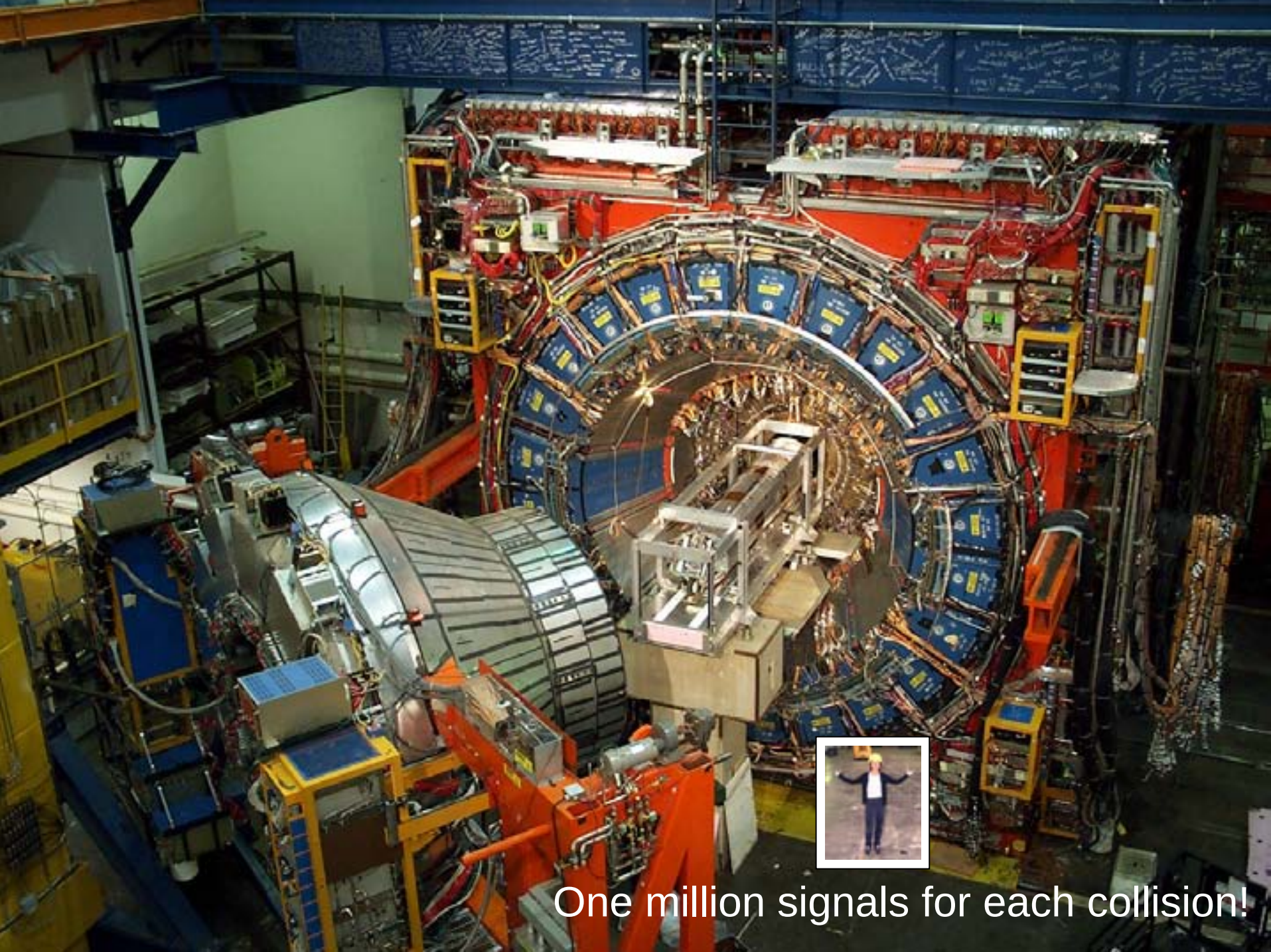


thickness of human hair

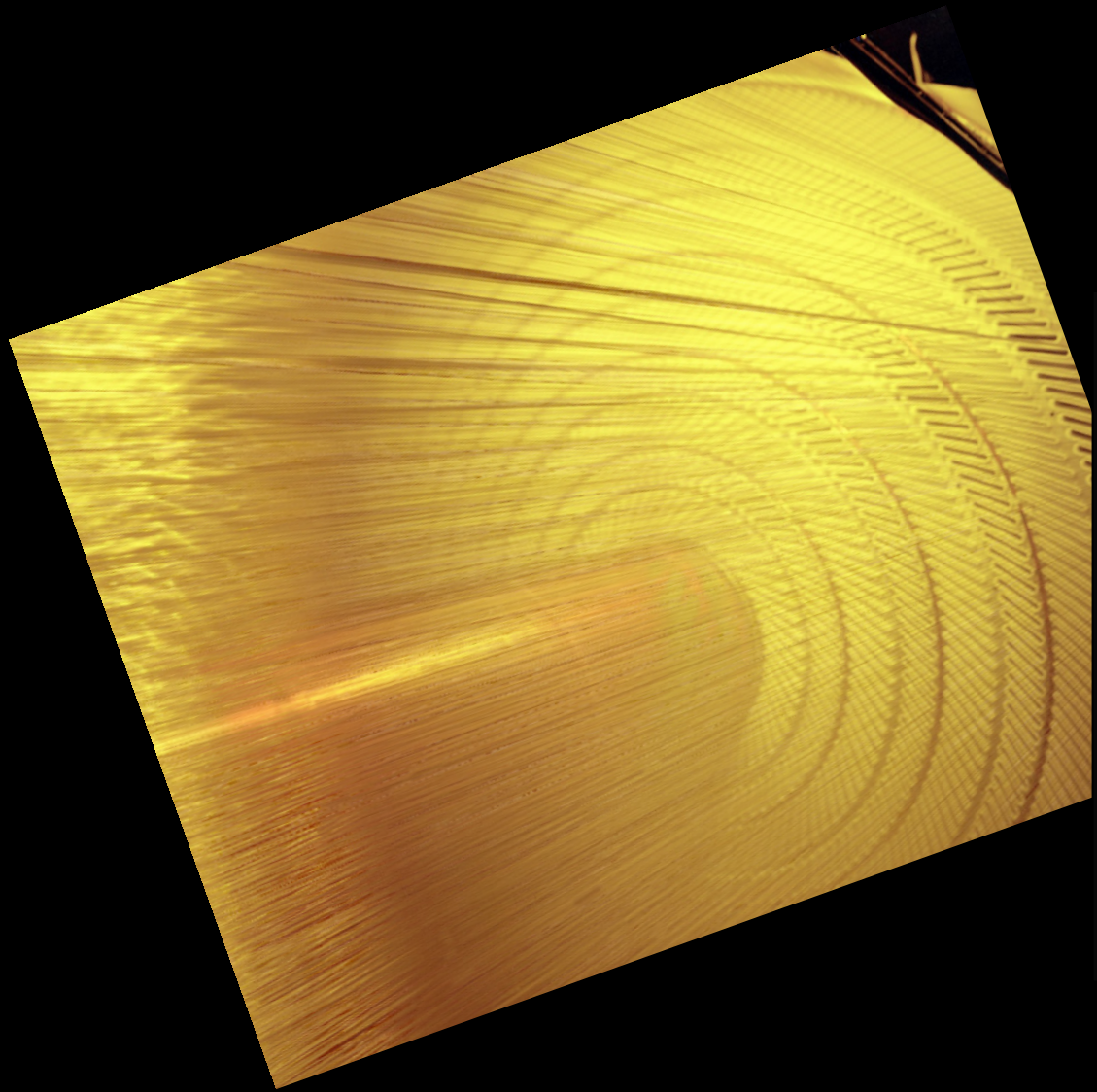
2 million collisions per second

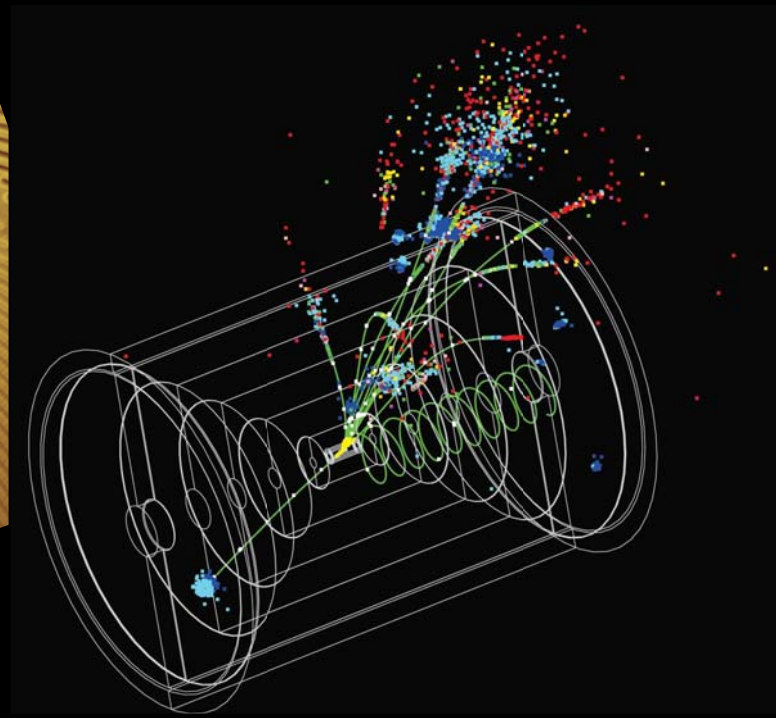
one out of one million

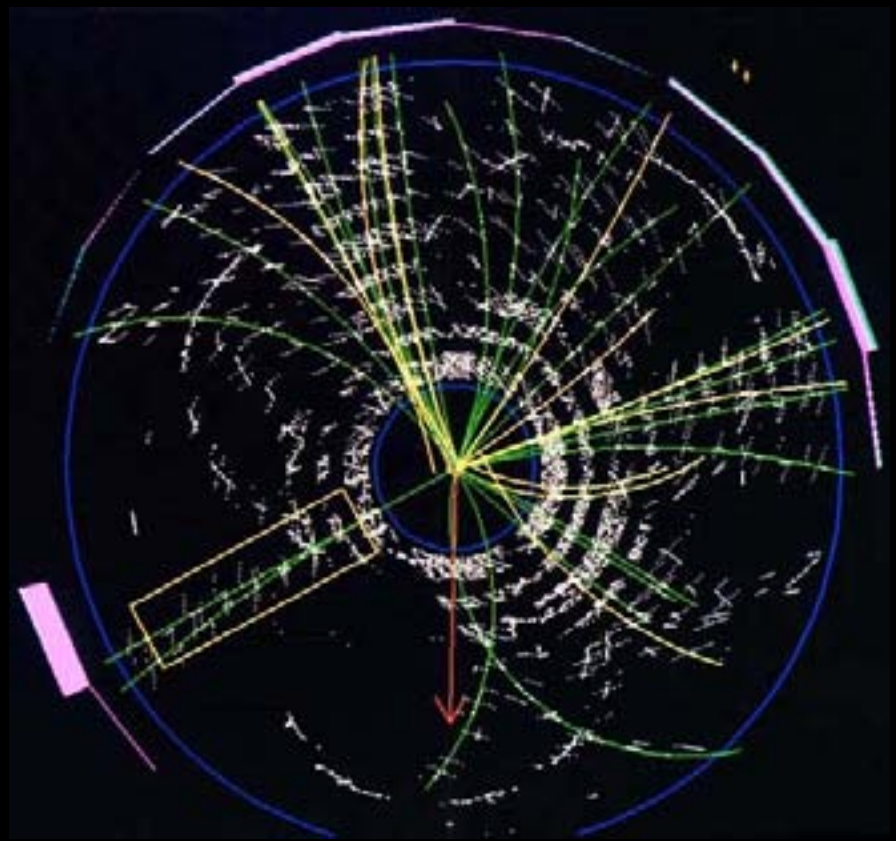
one out of ten billion

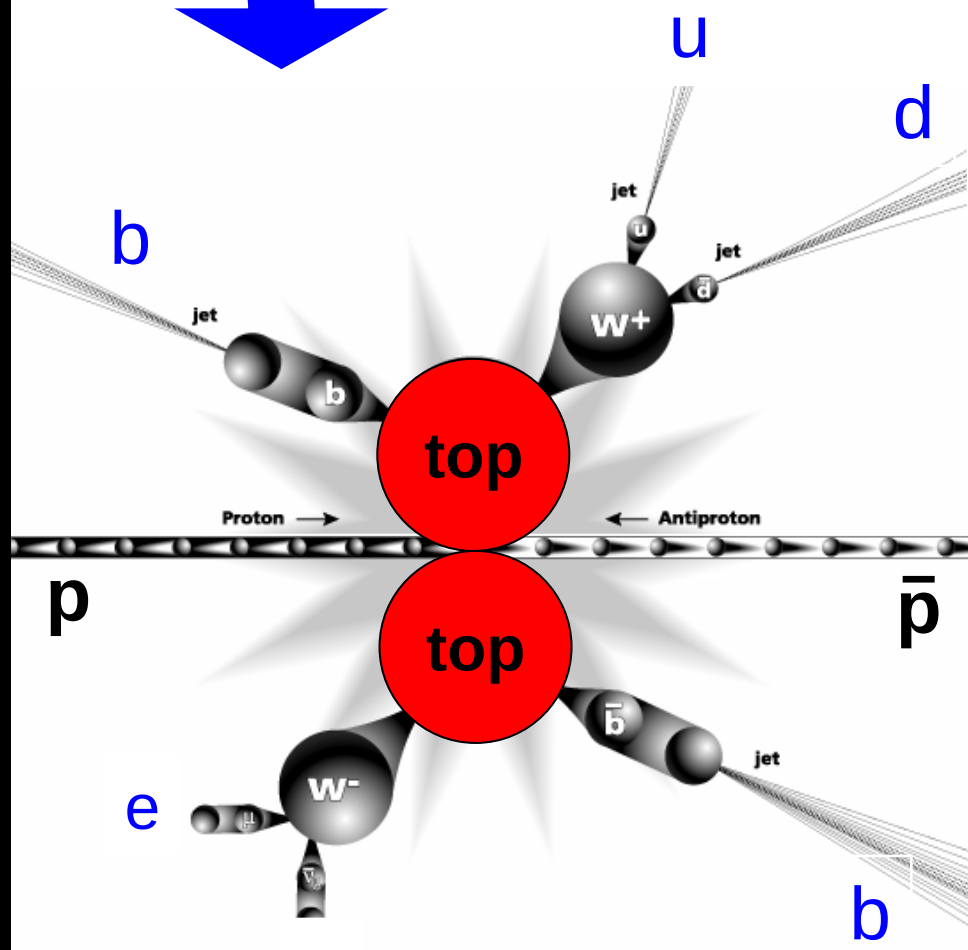

One million signals for each collision!

One detector with 30,000 high-voltage wires
thickness of human hair



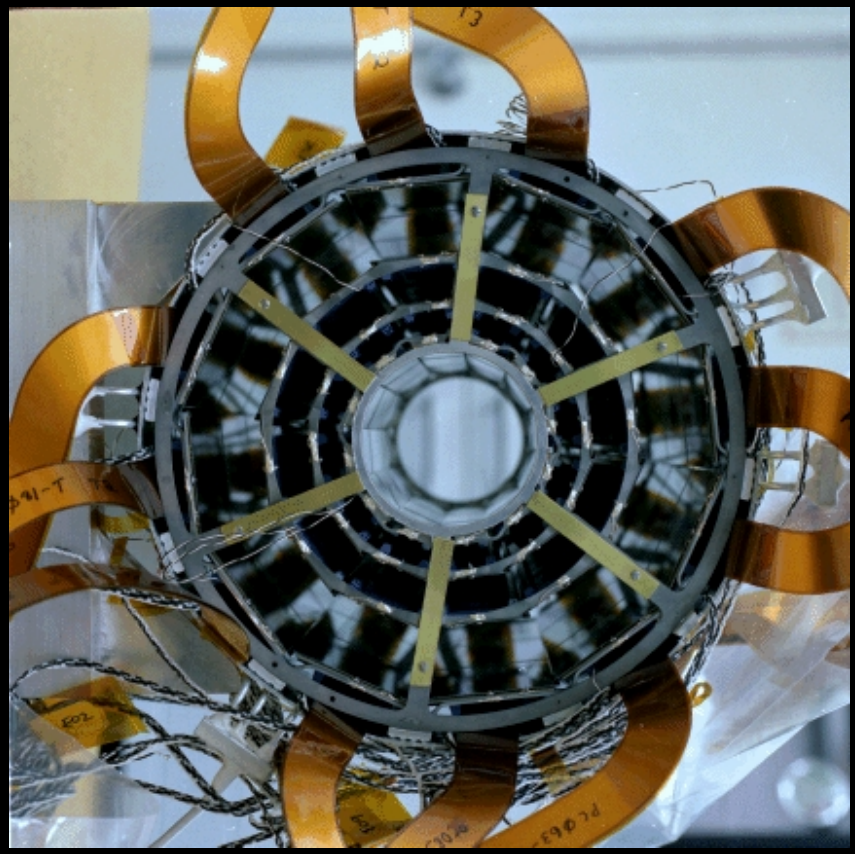




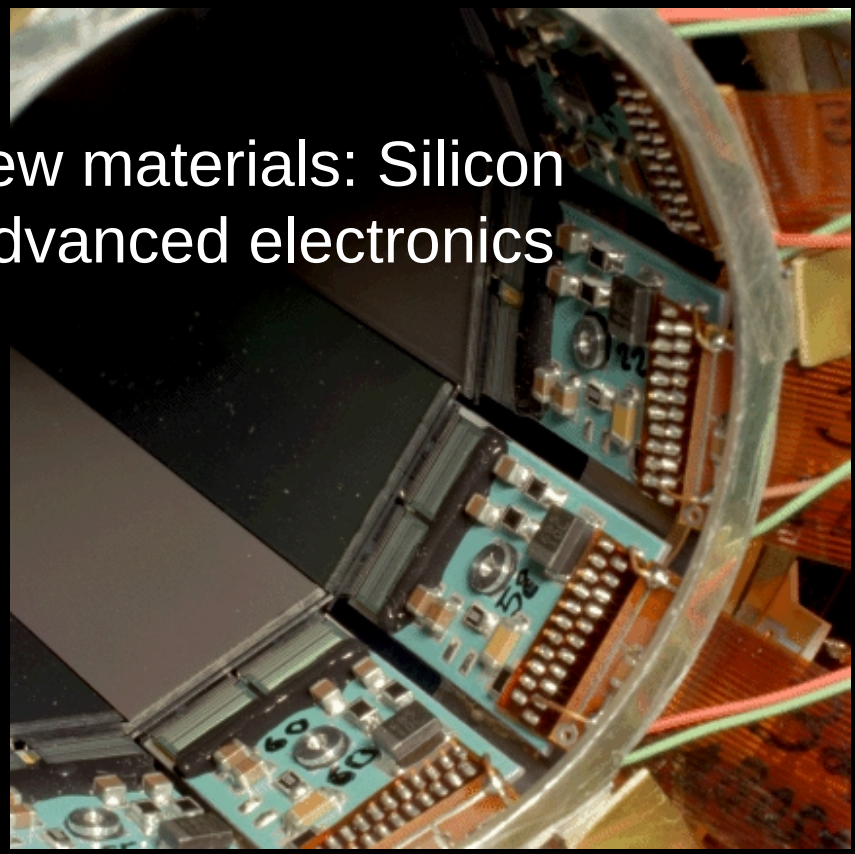

u
d
b
jet
jet
jet
W+
top
Proton
Antiproton
p
p̄
top
W-
e
jet
b

What does it take to make a discovery?

New Silicon Detector used for Discovery of Top Quark

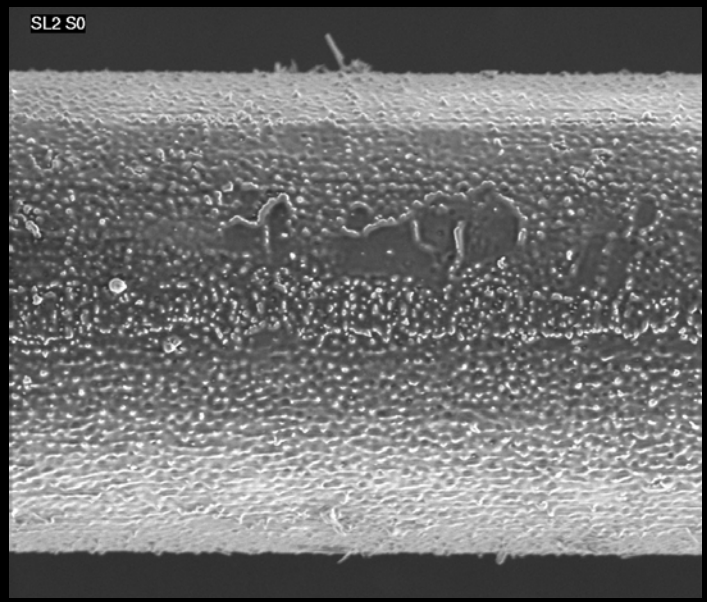


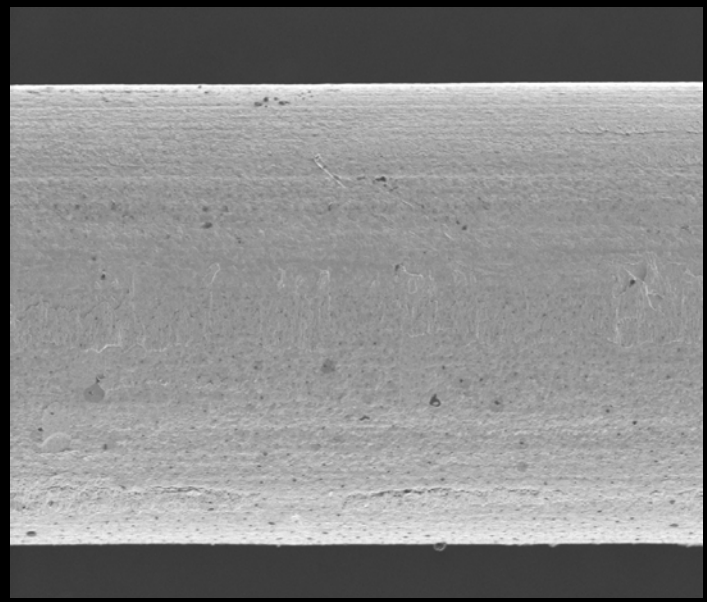
New materials: Silicon
Advanced electronics



For any discovery, we have to keep pushing technology,
not just in the directions we've already gone,
but with imagination to create innovative tools.

Challenging environment requires
broad knowledge in
physics, material science, and chemistry.





Human hair

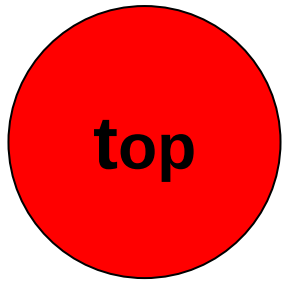
Discovery is Exciting!!

TOP QUARK DISCOVERY in 1994 - 1995

Adding something to the core of human knowledge is profoundly satisfying.

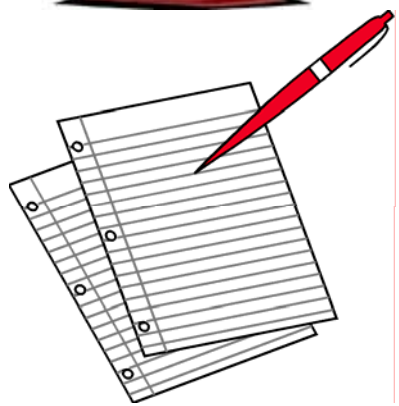
Remember Higgs Particle?

Made W and top:



Measured their masses accurately.

Estimated mass of Higgs particle.



Now go and FIND it!

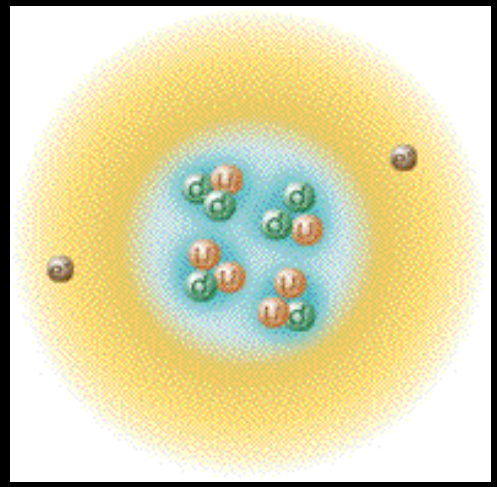
Particles Tell Stories!

Particles are messengers
telling a profound story
about nature and laws of nature in microscopic world.

The role of physicists is to listen the story
and
translate it into the language of human knowledge.

What story will the Higgs tell us?!
We can't wait to find out.

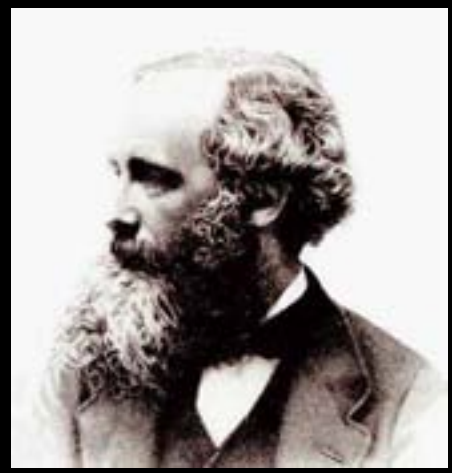
What forces hold the world together?



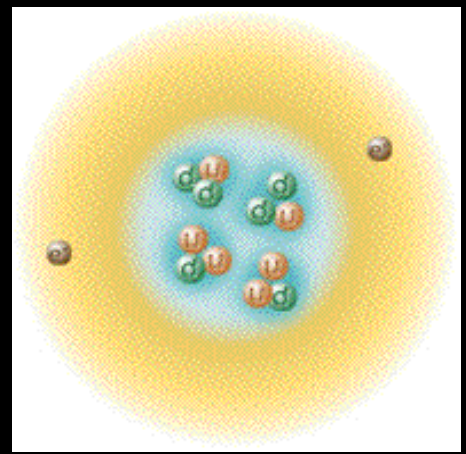
Gravitational Force

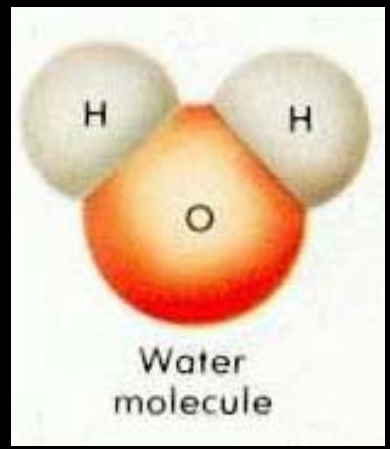
Issac Newton
(1642 - 1727)

Electromagnetic Force



James Clerk Maxwell
(1831 - 1879)

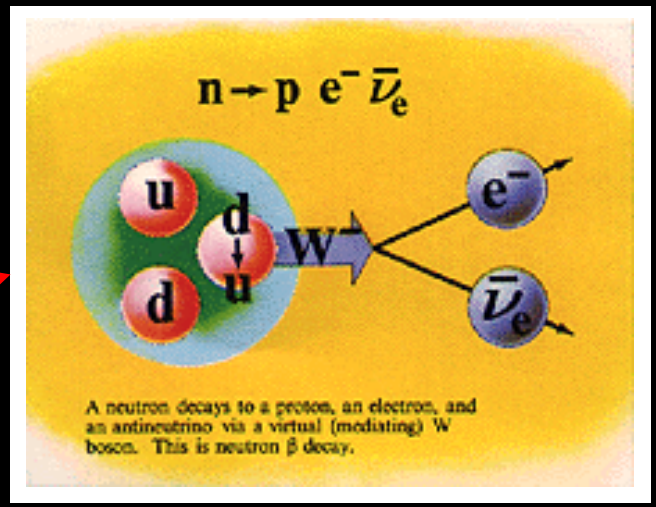


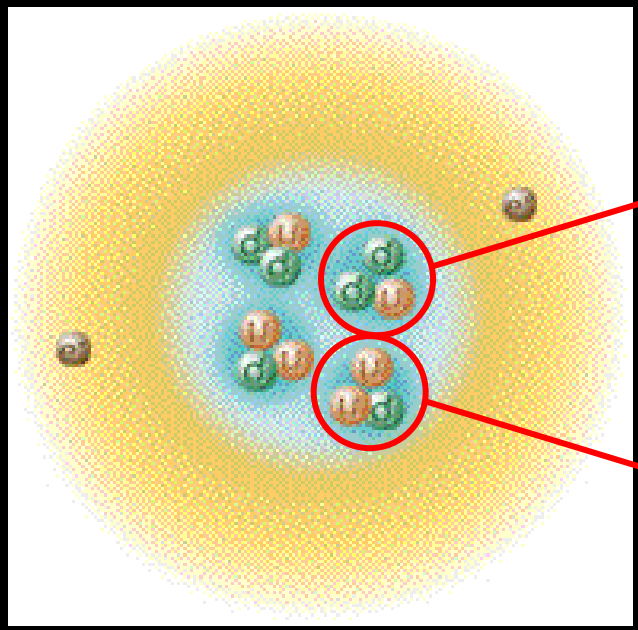


Weak Force

Enrico Fermi
(1901 - 1954)

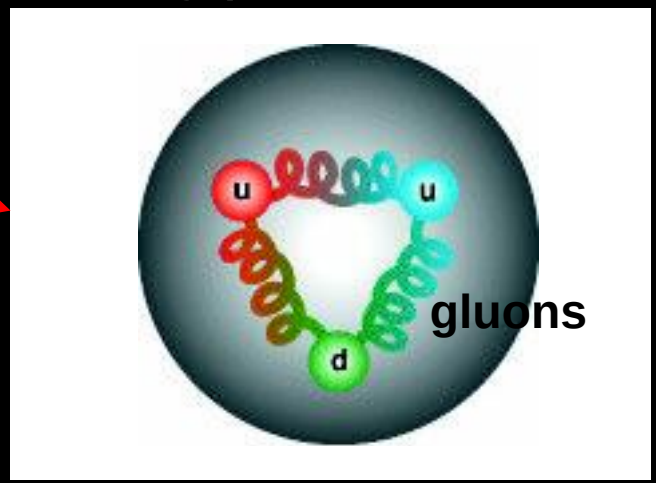
radioactive decays





neutron decay

holding proton, nucleus



Strong Force

Physicists (even including Einstein) think that with very high energy beams

forces start to behave the same

as if there is just one force, not several forces.

“Do all the forces become one?”

How did we get here?
Where are we going?

Understanding our Universe!

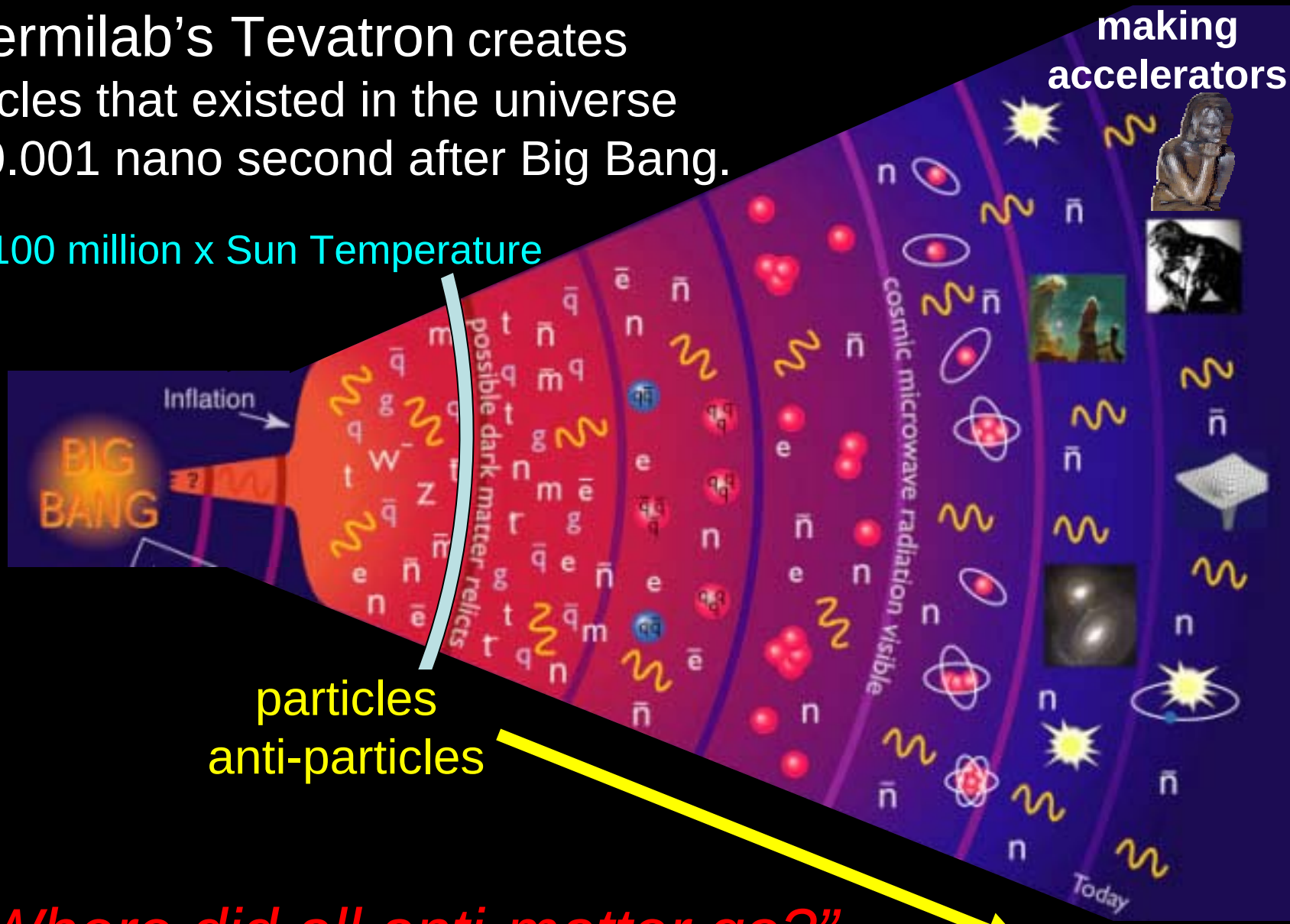
From Annie Hall by Woody Alan

Hey Alvi,
not only is the universe expanding, it is

accelerating!!

Where does energy come from?
Dark Energy
(Annie Hall 2?)

Fermilab's Tevatron creates
particles that existed in the universe
only ~0.001 nano second after Big Bang.



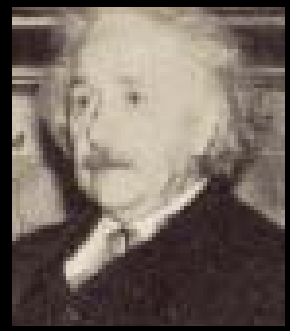
"Where did all anti-matter go?"

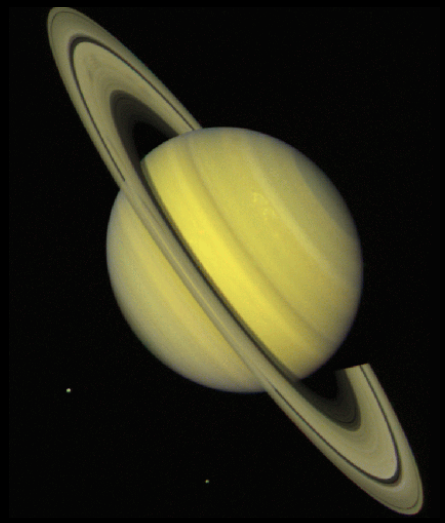
~~Everything~~ is made of electrons, up quarks and down quarks.

Everything that we can see



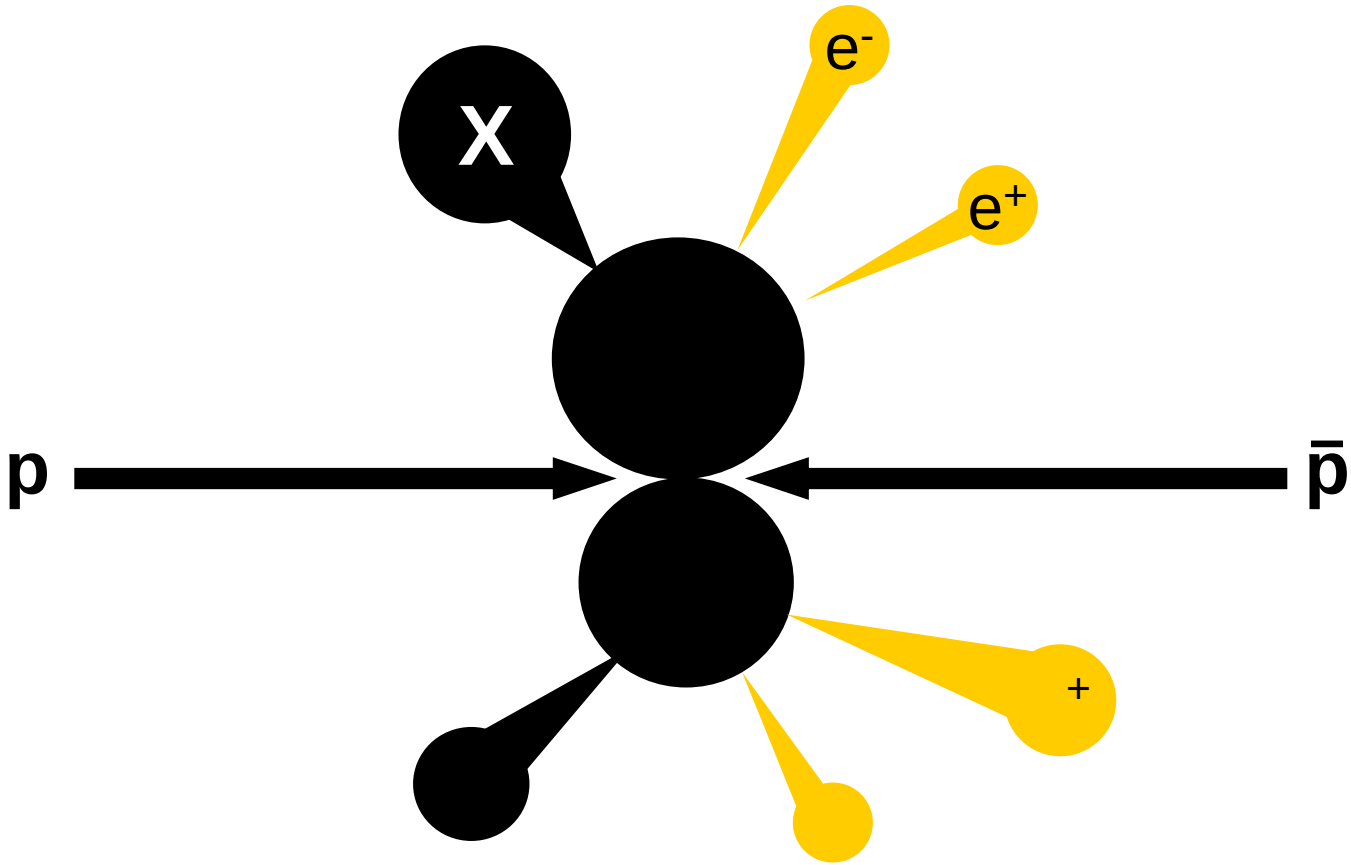





Need much more (x4) mass than what we see - Dark Matter *What is it?*

Searching for Dark Matter at Tevatron



Answers themselves lead to more questions:

Are quarks and electrons the smallest things?
Do all forces become one?
Where does mass come from?
Why are there so many smallest things?
What is Dark Energy?
Where did all anti-matter go?
Dark Matter - what is it?

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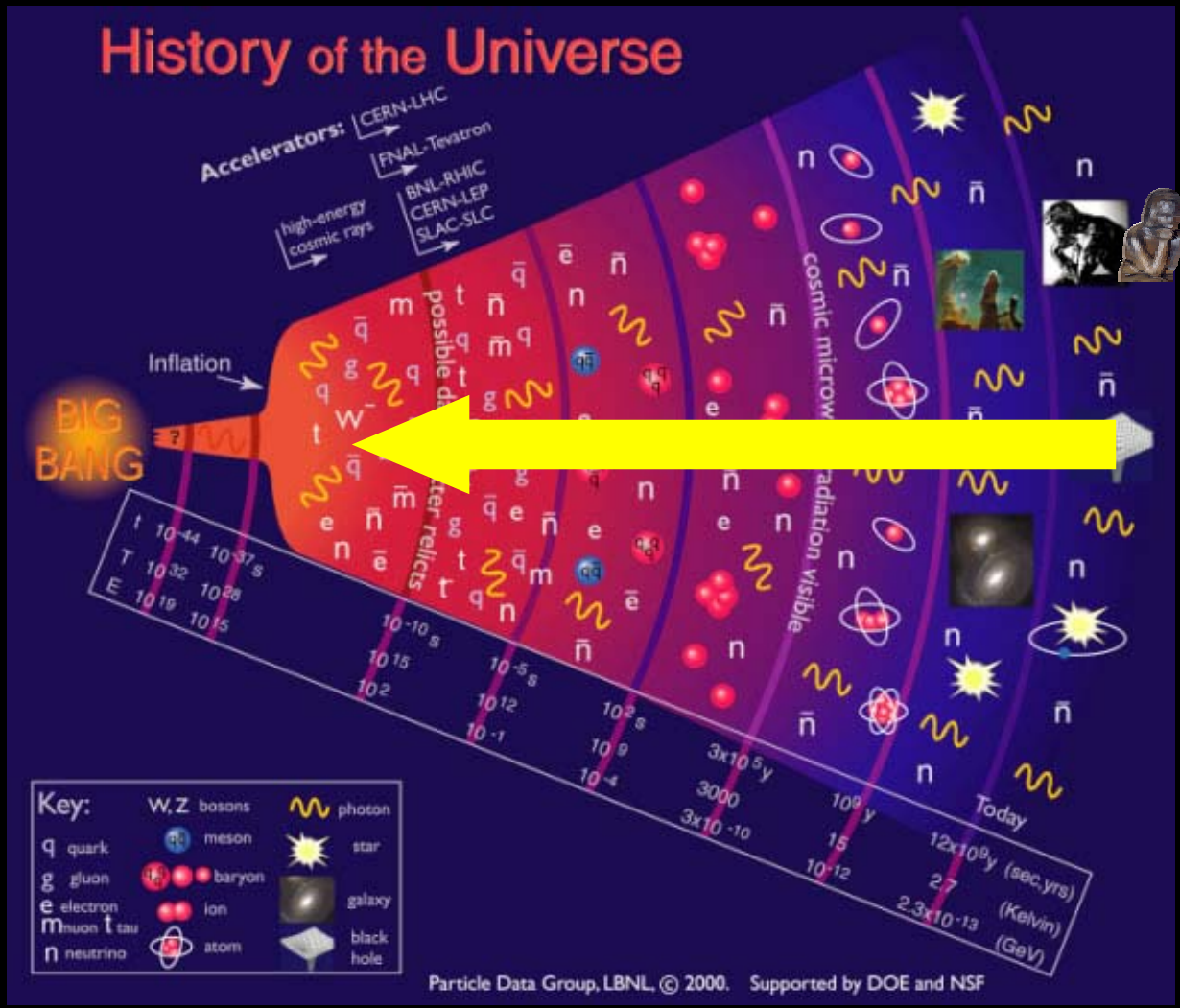
.

more powerful accelerators to answer



When the Tevatron was providing very first collisions, physicists were planning the next energy frontier accelerator.

Tevatron will be winding down by end of this decade after glorious history and further observations yet to come.

Large Hadron Collider will begin exploration where Tevatron leaves off.

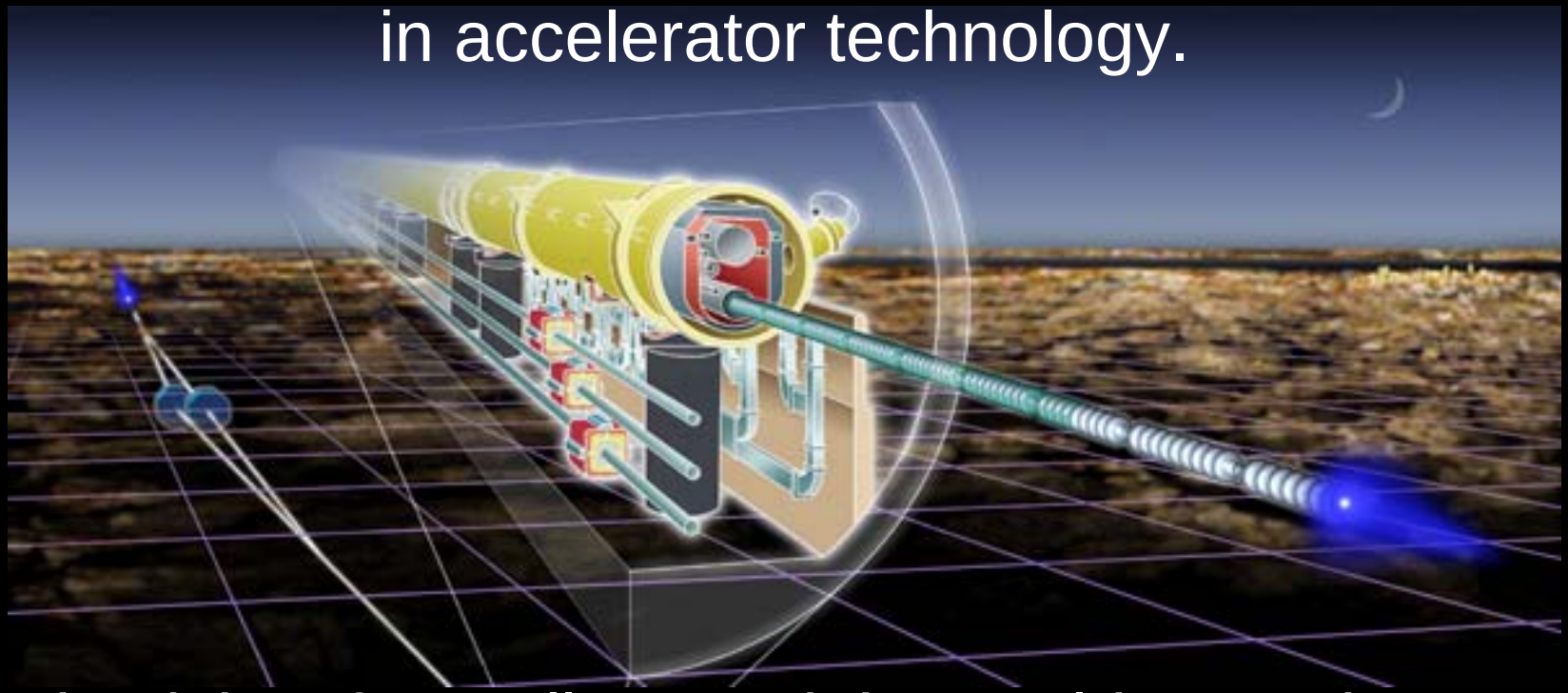
LHC will open a new window!

The LHC is about to begin….

Once again, physicists are preparing the next energy frontier accelerator.

January 2005 Workshop in KEK, Japan

The International Linear Collider (ILC) is chosen.
The ILC will use an enormous step forward
in accelerator technology.



Physicists from all around the world came here at Snowmass to figure out how to build the ILC.

The ILC will open another new window beyond the LHC.

Small things are Powerful and Beautiful!

They provide the building blocks
for everything in the Universe.

Every one of them tells a story.
With their stories, we discover new laws of nature.

That is the goal of particle physics.

Particle physics requires the support of the public,
people like you.

We have been well supported and we thank you.
Thank Depart. of Energy, National Science Foundation

We wish to continue this journey.
That's why all physicists are meeting at Snowmass now,
planning for the future, the International Linear Collider.

Do we as a nation have the resolve
to continue this journey for knowledge?


We Can Do It!
WAR PRODUCTION CO-ORDINATING COMMITTEE