

Seeking the Structure of Matter

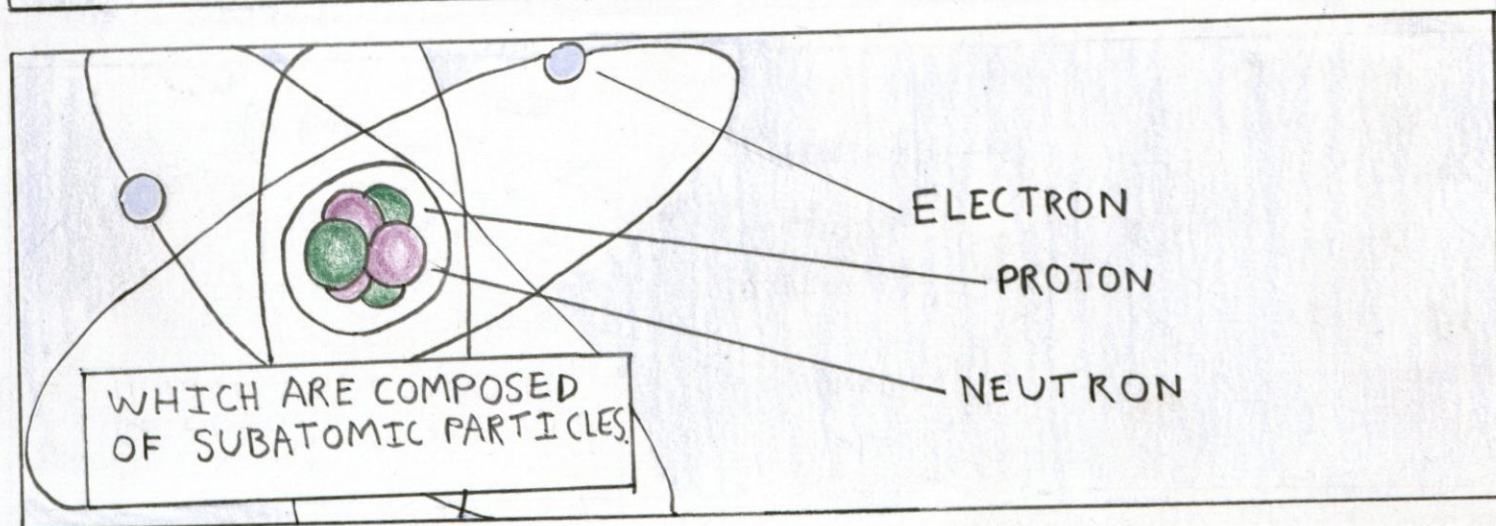
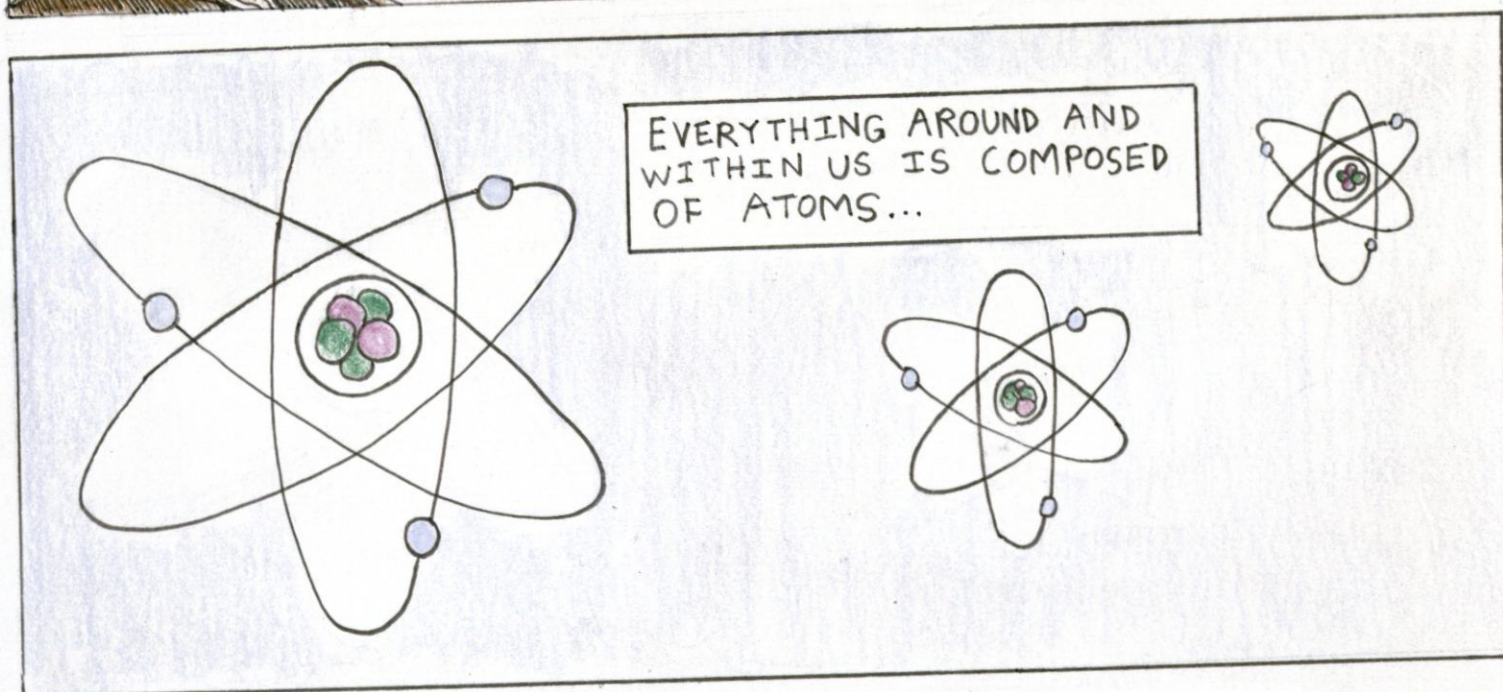
BY
ELLA GORDON
AND
DAVE SOPER

LEARN MORE ABOUT PARTICLE PHYSICS
AT HOME.CERN!

SPECIAL THANKS TO NATALIE
GARCIA FOR HELP WITH INKING!

RESOURCES:

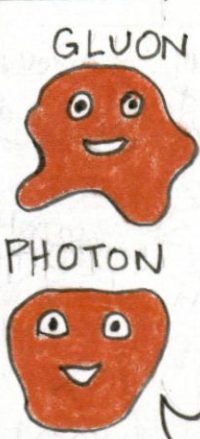
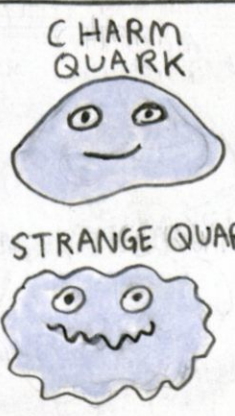
- HOME.CERN
- "PARTICLE FEVER" - A FILM
ABOUT CERN AND THE LARGE
HADRON COLLIDER
- "CERN HIGGS BOSON JULY
4TH 2012 PRESS CONFERENCE -
YOUTUBE VIDEO



THERE ARE MANY TYPES OF PARTICLES... BUT 17 OF THEM ARE KNOWN AS FUNDAMENTAL PARTICLES.

I BIND PROTONS AND NEUTRONS TOGETHER!

QUARKS
WE MAKE UP PROTONS AND NEUTRONS!

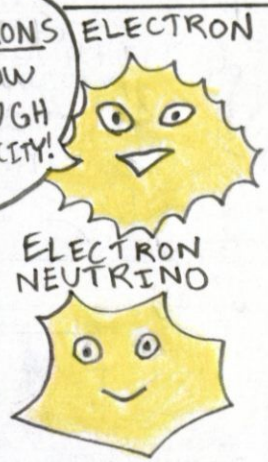


MORE ABOUT ME LATER...

PHOTON
I MAKE UPLIGHT!

AS FAR AS WE KNOW, THESE PARTICLES ARE THE SMALLEST THINGS IN THE UNIVERSE.

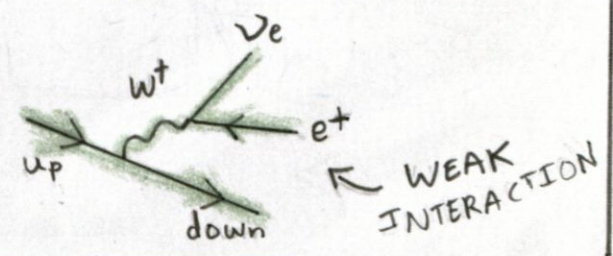
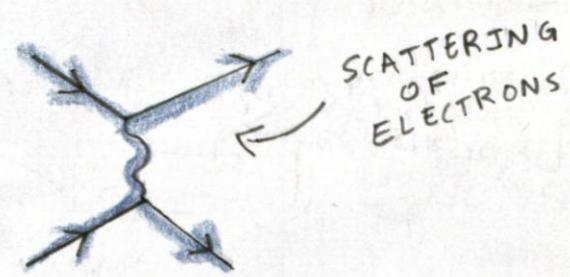
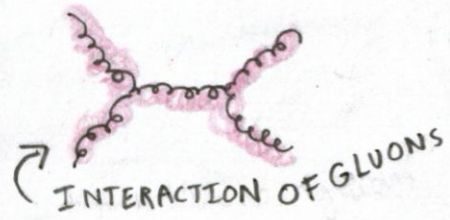
ELECTRONS
WE FLOW THROUGH ELECTRICITY!



W AND Z BOSONS
WE REGULATE PROCESSES IN THE SUN!

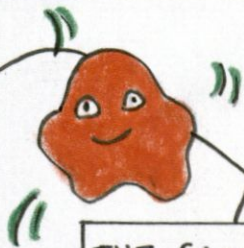
THEY EXIST WITHIN A QUANTUM THEORY DEVELOPED IN THE 1970S, CALLED THE STANDARD MODEL.

FEYNMAN DIAGRAMS
DEPICT INTERACTIONS BETWEEN PARTICLES!

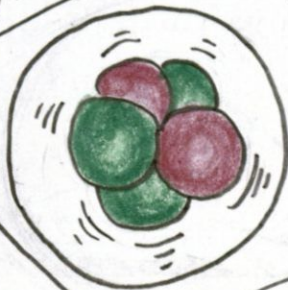


WE CAN THINK OF THE STANDARD MODEL AS A MAP THAT EXPLAINS THE FOUR FUNDAMENTAL FORCES, OR INTERACTIONS, BETWEEN PARTICLES.

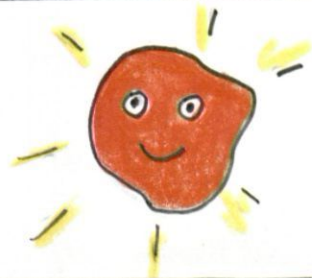
A DIFFERENT BOSON CORRESPONDS
TO EACH FUNDAMENTAL FORCE:



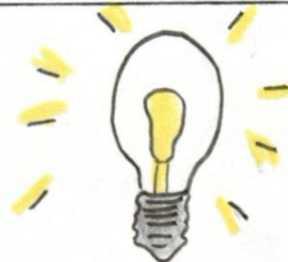
THE GLUON CARRIES A
STRONG FORCE.



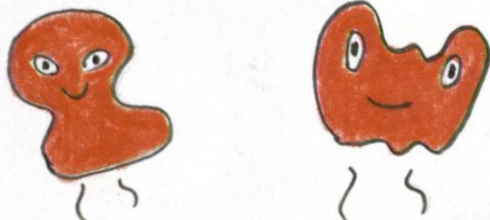
IT HOLDS THE NUCLEUS
OF AN ATOM TOGETHER.



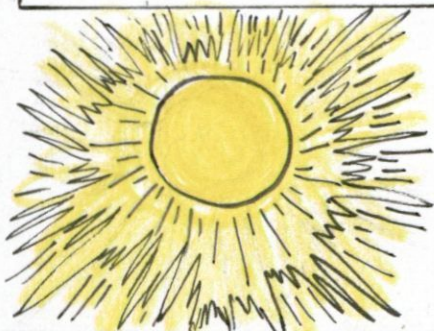
THE PHOTON CARRIES
AN ELECTROMAGNETIC FORCE.



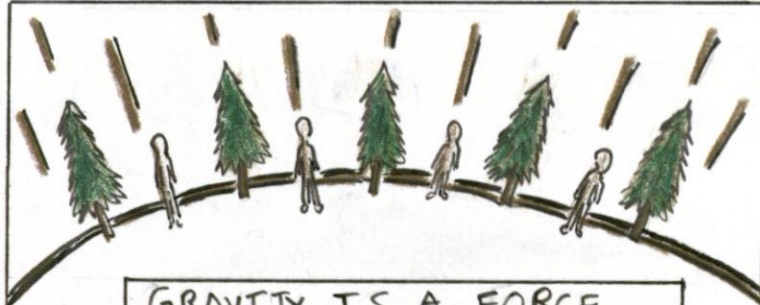
PHOTONS ARE THE UNITS
OF ALL LIGHT. THEY
MAKE IT POSSIBLE FOR
YOU TO READ THIS COMIC.



AND THE W AND Z
BOSONS CARRY A WEAK
FORCE.

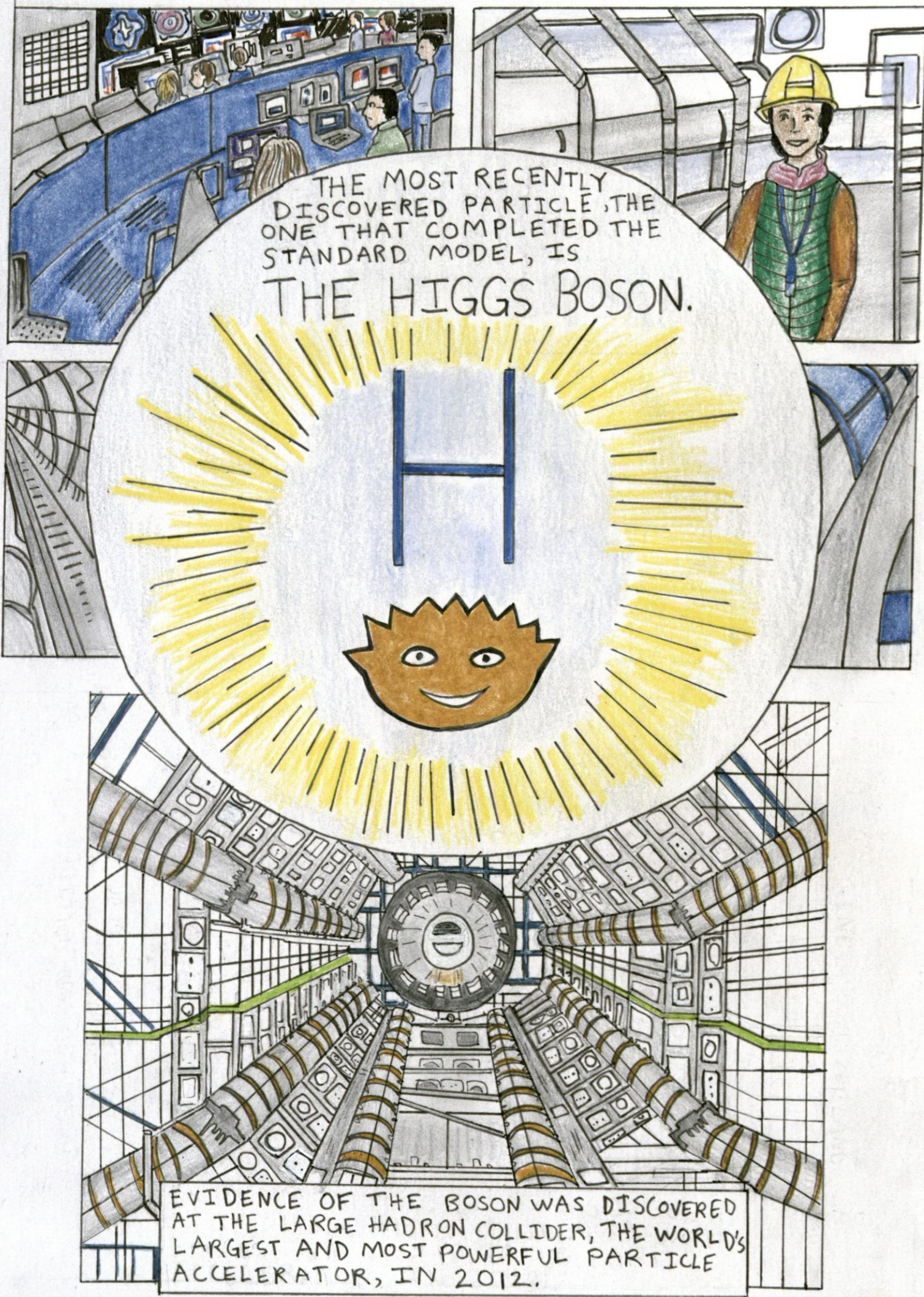


THEY REGULATE SOME
OF THE NUCLEAR
PROCESSES TAKING
PLACE IN THE SUN.



GRAVITY IS A FORCE
THAT PULLS EVERYTHING
TO THE EARTH, BUT IT
IS NOT INCLUDED IN
THE STANDARD MODEL.

THERE HASN'T BEEN A
QUANTUM THEORY
DEVELOPED FOR IT YET.



THE MOST RECENTLY
DISCOVERED PARTICLE, THE
ONE THAT COMPLETED THE
STANDARD MODEL, IS
THE HIGGS BOSON.

H

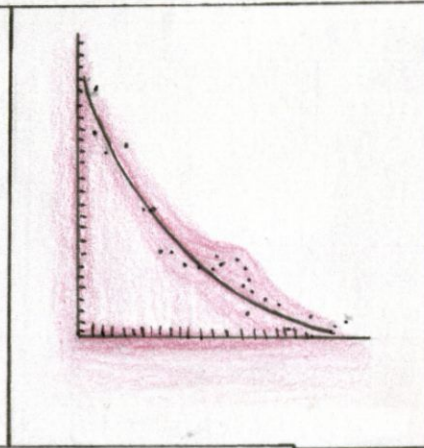
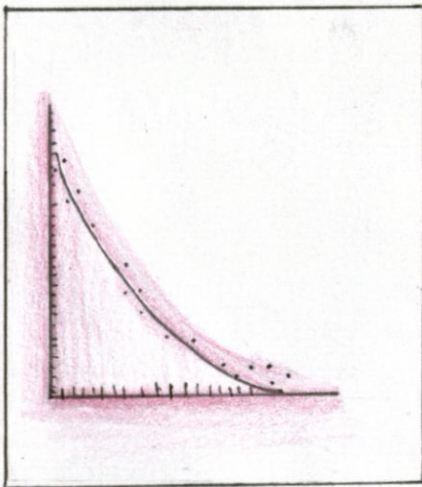


EVIDENCE OF THE BOSON WAS DISCOVERED
AT THE LARGE HADRON COLLIDER, THE WORLD'S
LARGEST AND MOST POWERFUL PARTICLE
ACCELERATOR, IN 2012.

IN ORDER TO FIND THE HIGGS BOSON,
EXPERIMENTS HAD TO BE CONDUCTED
AND RESULTS HAD TO BE COMPARED
WITH PREDICTIONS.



DATA WAS LOGGED WITH THE HELP
OF STATISTICAL GRAPHS.

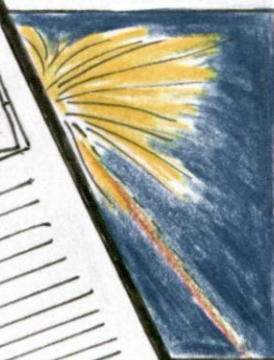


AND EACH MEASUREMENT CAME WITH EXPECTED ERROR.



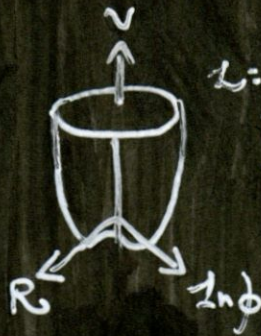
Herald Tribune

Scientists Prove
Existence of
'God Particle'

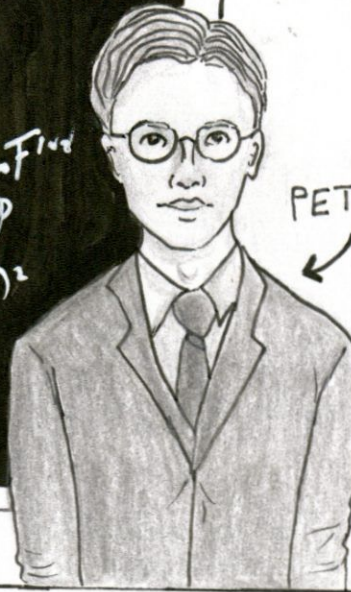


THE HIGGS DISCOVERY CAME MANY YEARS AFTER PREDICTION.

THE HIGGS BOSON WAS FIRST PREDICTED BY PETER HIGGS IN 1964.



$$\begin{aligned}
 \mathcal{L} &= (D_\mu \phi)^\dagger D_\mu \phi - V(\phi) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\
 D_\mu \phi &= \partial_\mu \phi - ie A_\mu \phi \\
 F_{\mu\nu} &= \partial_\mu A_\nu - \partial_\nu A_\mu \\
 V(\phi) &= \frac{1}{2} m^2 \phi^2 + \frac{\lambda}{4} (\phi^2)^2 \\
 \mathcal{L}(0, \beta) &> 0
 \end{aligned}$$



PETER HIGGS

HIGGS FIELD

PARTICLES MOVE THROUGH THE FIELD!



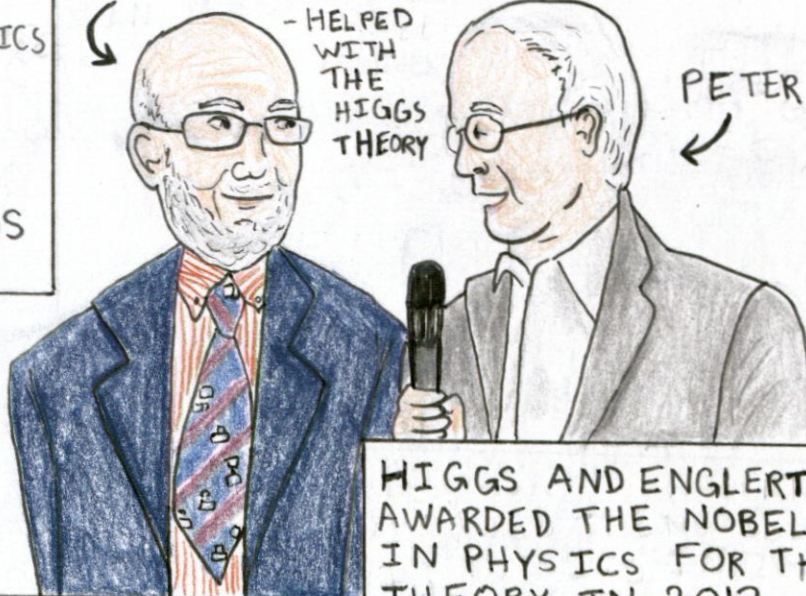
IT AND OTHER PARTICLES EXIST WITHIN A FIELD CALLED THE HIGGS FIELD, WHICH IS RESPONSIBLE FOR THE MASS OF ELEMENTARY PARTICLES.

NO PREVIOUS PARTICLE PHYSICS EXPERIMENT BEFORE 2012 WAS ABLE TO FIND A HIGGS BOSON.

FRANÇOIS ENGLERT

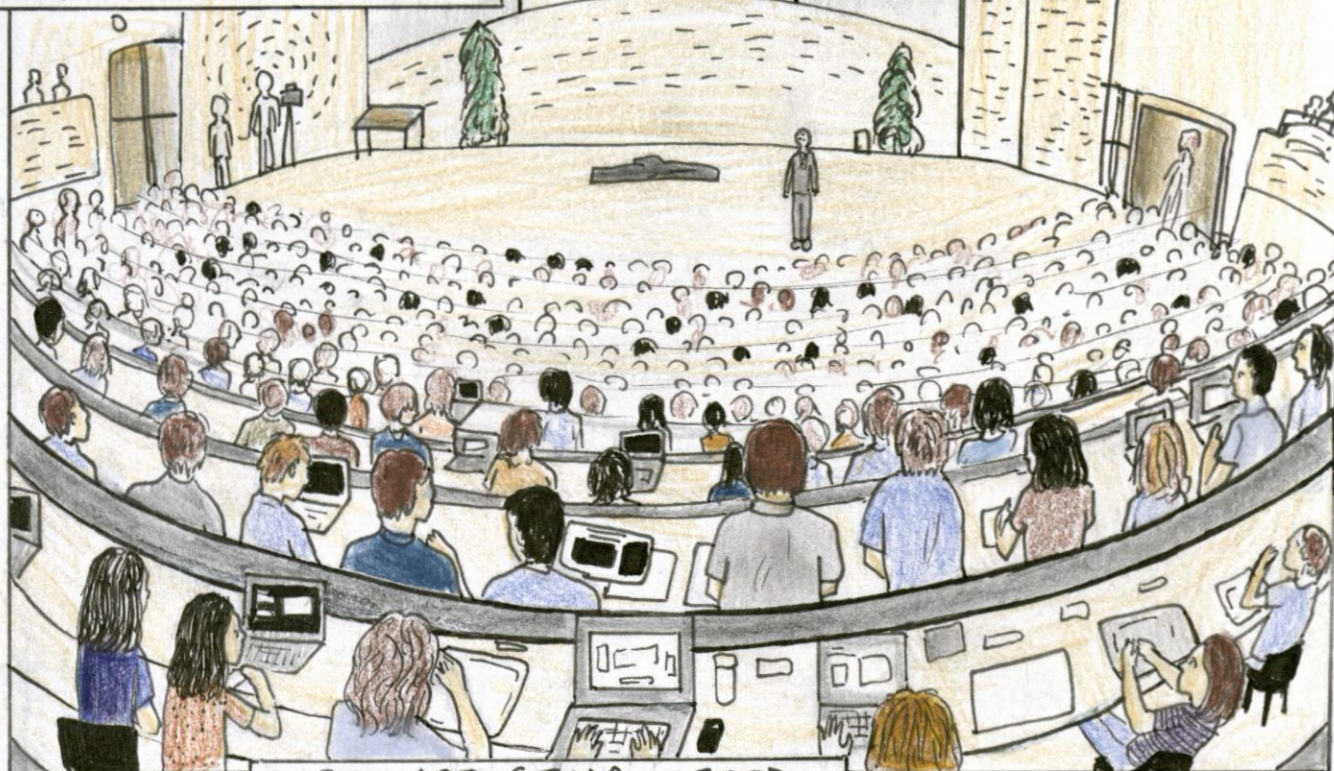
- HELPED WITH THE HIGGS THEORY

PETER HIGGS

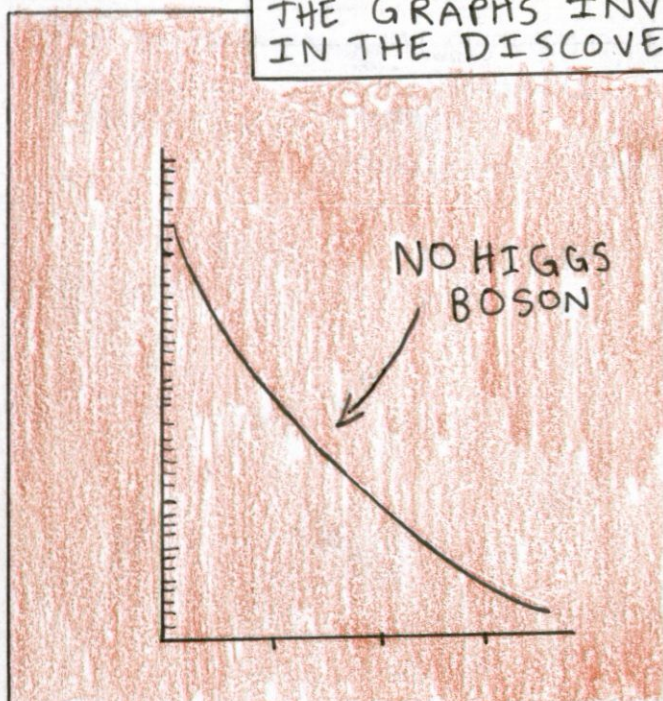


HIGGS AND ENGLERT WERE AWARDED THE NOBEL PRIZE IN PHYSICS FOR THE THEORY IN 2013.

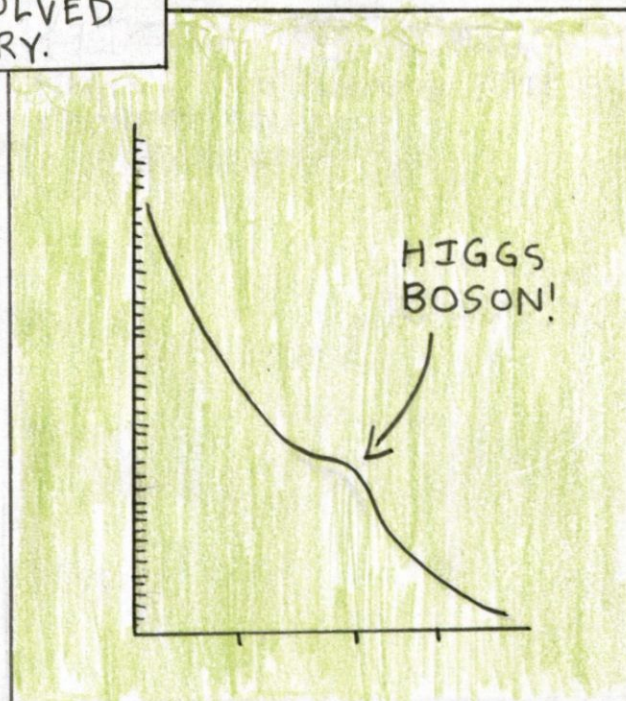
ON THE DAY THE HIGGS
BOSON'S EXISTENCE
WAS PUBLICLY ANNOUNCED,
A PRESENTATION OF
DATA WAS SHOWN AT
THE CERN AUDITORIUM
IN SWITZERLAND.



THESE ARE SIMPLIFIED
VERSIONS OF SOME OF
THE GRAPHS INVOLVED
IN THE DISCOVERY.



THIS GRAPH REPRESENTS
ONE POSSIBLE OUTCOME OF
THE EXPERIMENTS.



THIS GRAPH REPRESENTS
WHAT WAS FOUND.

THE HIGGS BOSON WAS AN EXCITING DISCOVERY BECAUSE IT COMPLETED THE STANDARD MODEL...

HIGGS

WHAT IS DARK MATTER MADE OF?

IS THERE SUPERSYMMETRY?

BUT THERE IS STILL MUCH TO BE LEARNED.

HOW DOES GRAVITY WORK AT THE QUANTUM LEVEL?

ARE THERE HIDDEN SECTORS OF THE STANDARD MODEL WITH OTHER IMPORTANT PARTICLES?

DO AXIONS EXIST? ARE THEY A COMPONENT OF DARK MATTER?

PHYSICISTS AT THE LARGE HADRON COLLIDER DETECTED A PARTICLE THAT CLOSELY CORRESPONDS TO THE PREDICTED HIGGS BOSON.

THEORY VS. WHAT WE HAVE



WE'RE SIMILAR, BUT ARE WE TWINS?



YOUR GUESS IS AS GOOD AS MINE!

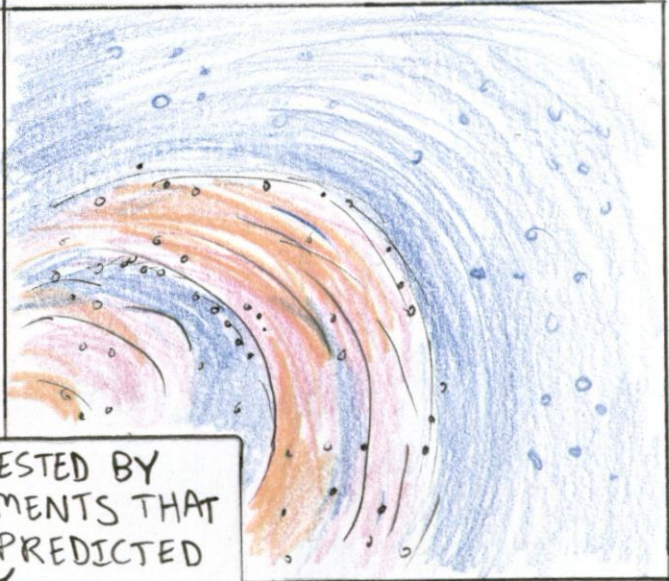
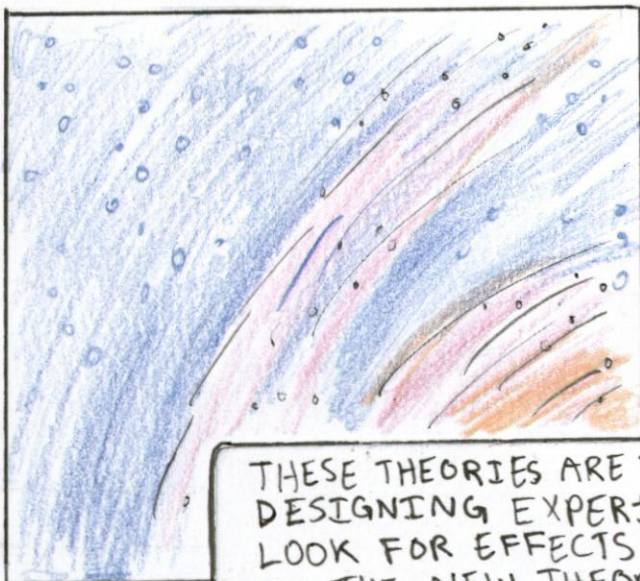
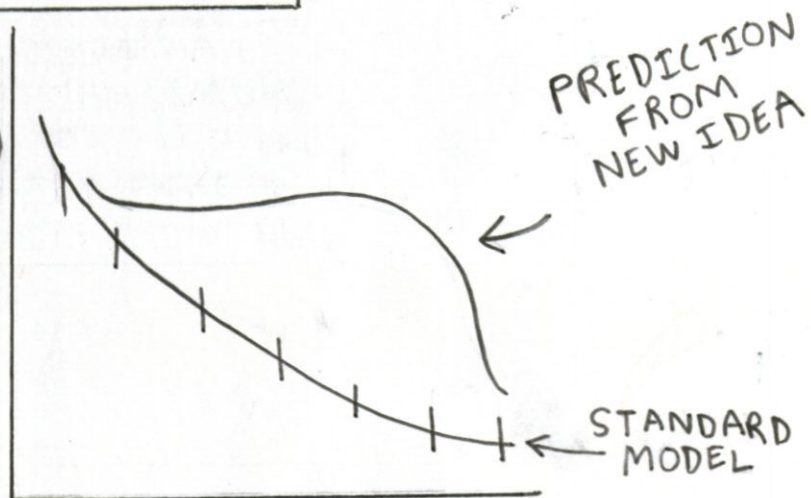
IT REMAINS TO BE SEEN HOW CLOSE THE CORRESPONDENCE IS.



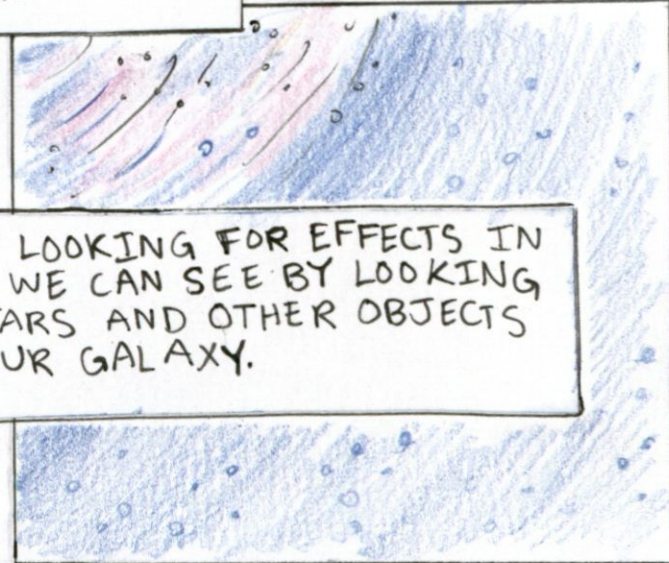
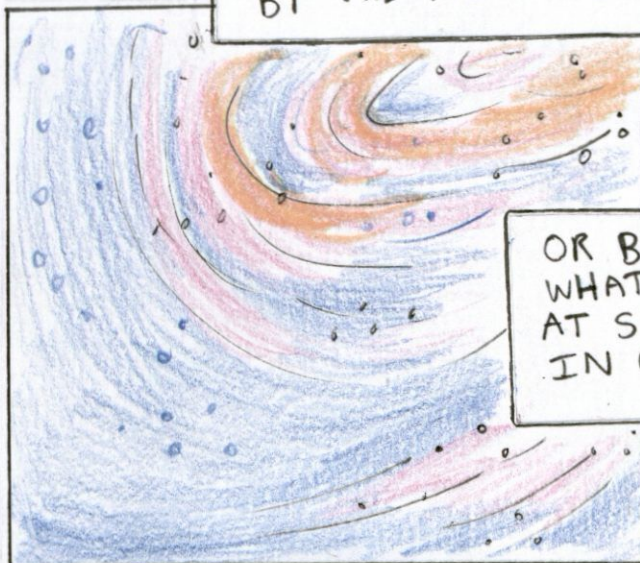
IT'S HARD TO FIGURE ME OUT.

AFTER ALL, I'M SO SMALL THAT NO ONE CAN SEE ME!

SOME PHYSICISTS HAVE BELIEFS THAT THE STANDARD MODEL IS NOT ALL THERE IS, AND THEY MAKE UP NEW THEORIES ABOUT DIFFERENT MODELS.



THESE THEORIES ARE TESTED BY DESIGNING EXPERIMENTS THAT LOOK FOR EFFECTS PREDICTED BY THE NEW THEORY,



OR BY LOOKING FOR EFFECTS IN WHAT WE CAN SEE BY LOOKING AT STARS AND OTHER OBJECTS IN OUR GALAXY.

A cartoon illustration of a person with long brown hair, wearing a yellow hard hat, a light blue long-sleeved shirt, and blue jeans. They are standing on a grey path that leads towards a large, blue, curved structure with a grid pattern, resembling a tunnel or a large pipe. The structure is illuminated by a bright yellow light source on the left. A speech bubble from the person contains the text: "PHYSICISTS ALL OVER THE WORLD CONTINUE TO DEVELOP THEORIES AND CONDUCT EXPERIMENTS." At the bottom of the image, there is a caption: "NO MATTER HOW MANY DISCOVERIES ARE".

PHYSICISTS ALL OVER THE WORLD CONTINUE TO DEVELOP THEORIES AND CONDUCT EXPERIMENTS.

NO MATTER HOW MANY DISCOVERIES ARE

DISCOVERIES ARE
MADE IN THE YEARS
TO COME...

$X(4,2)=6$
 $m_{\bar{4}4}$
 $i\bar{4}dD4p \rightarrow$
 $D_i = d_i - igA_i$
 MASS TERM INVARIANT
 INVARIANT WITH D_i
 $e(r)\bar{\chi}$
 COVARIANTS
 $L=1$

On shell cond.

$$p_1 + p_2 = p_3 + p_4$$

$$\sum_i p_i = \sum_2 p_2 = \sum_3 p_3 = 0$$

$$p_i^2 = m_i^2$$

field

$$h \rightarrow h$$

Ind

ERE WILL STILL BE QUESTIONS ABOUT THE PROCESSES OF THE UNIVERSE.

THERE WILL STILL BE
QUESTIONS ABOUT THE
PROCESSES OF THE UNIVERSE.