What IS the LHC and How Will We Use It?

Since the beginning of time, man has relied upon his SENSES to explore the world around him.

To “SEE” the world, we use our eyes.
What IS the LHC and How Will We Use It?

Since the beginning of time, man has relied upon his SENSES to explore the world around him.

To “SEE” the world, we use our eyes.
(sometimes with help from eyeglasses)
Since the beginning of time, man has relied upon his SENSES to explore the world around him.

To “SEE” the world, we use our eyes.

But our eyes are very limited in our ability to “SEE” the universe.
So, we have to extend our vision.
We use ground-based and satellite-based telescopes to observe the visible universe.
We use microscopes to look deep into tiny structures.
We use electromagnetic detectors to probe the “invisible”.
But, in order to “see” the world of subatomic particles, we need **GIGANTIC MACHINES** to accelerate particles to VERY high speeds, in order to “SMASH” them into each other with **EXTREMELY HIGH ENERGY!!!!!!**
It’s a bit like firing a bullet . . .

. . . into a pocket watch

And carefully observing the pieces flying out!!!!

NOT VERY ELEGANT, IS IT?
These machines are called **PARTICLE ACCELERATORS** or **COLLIDERS**.
An older television set is a type of “particle accelerator” since it has a CATHODE RAY TUBE. Electrons produced and accelerated.
An older television set is a type of “particle accelerator” since it has a CATHODE RAY TUBE. A cathode ray is a beam of electrons that collide with phosphors on the screen.
BUT, in order to give particles higher speeds (more kinetic energy), machines must be used!
VERY POWERFUL ELECTRIC FIELDS PRODUCE AND ACCELERATE THE PARTICLES,

AND VERY POWERFUL MAGNETIC FIELDS GUIDE THE PARTICLES.

WHERE THEY EITHER HIT A “TARGET”, OR COLLIDE WITH OTHER PARTICLES MOVING IN THE OPPOSITE DIRECTION.

AND THE “REMNANTS” OF THE COLLISION ARE OBSERVED BY VERY SENSITIVE DETECTORS.

FORCES MUST BE CONTINUOUSLY SUPPLIED TO KEEP THE PARTICLES ACCELERATING.

(Newton’s Second Law!)
Some accelerate particles in a straight line . . .

Like the STANFORD LINEAR PARTICLE ACCELERATOR (SLAC)
...And some accelerate particles in a CIRCULAR PATH ("synchrotron")

like

FERMILAB (outside of Chicago)
The most powerful accelerator in the United States.
BUT,
Just outside of Geneva, Switzerland, located on the France-Switzerland border, the MOST POWERFUL ACCELERATOR ever built has just been constructed!!!
At a facility called
CERN
THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
Founded in 1954 by 12 countries, CERN is a collaborative effort that brings together thousands of scientists, engineers, and technicians from 20 member countries as well as other contributing countries from around the world.
CERN is not just a single building, but a self-contained “city” covering several square miles of laboratories, research facilities, particle accelerators, detectors, massive assembly buildings, office buildings, a science “museum”, dormitories, even restaurants, its own police and fire stations, and hospital!
BUT, most of the action takes place deep underground. . .

in a maze of caverns and tunnels 100 meters below the surface,

extending from Switzerland into France.

IT IS HERE WHERE PARTICLES ARE PRODUCED, ACCELERATED, COLLIDED, AND DETECTED!!!

SO, WHAT IS THE L.H.C.??

LET'S BREAK IT DOWN . . .
THE L.H.C. STANDS FOR
THE LARGE HADRON COLLIDER

So, what does THAT mean???

Let’s break it down some more:
LARGE:

THIS IS DUE TO ITS LARGE SIZE!!!

THIS IS JUST ONE OF MANY SURFACE BUILDINGS, (HOUSING THE LHCb).
LARGE:
THIS IS DUE TO ITS LARGE SIZE!!

BUT MOST OF THE LHC LIES 100 METERS
BELLO THE GROUND, WHERE PARTICLES
ARE ACCELERATED IN OPPOSITE DIRECTIONS
IN A TUNNEL 27 KM (ALMOST 17 MILES) IN
CIRCUMFERENCE!!!
LARGE:

THIS IS DUE TO ITS LARGE SIZE!!!

HERE IS AN ARIAL VIEW OF THE OUTSKIRTS OF GENEVA, SWITZERLAND WITH FRANCE IN THE BACKGROUND.
LARGE:

THIS IS DUE TO ITS LARGE SIZE!!!

HERE IS A SHOT OF CERN SHOWING THE SIZE AND LOCATION OF THE LHC TUNNEL UNDERGROUND

LHC TUNNEL
(27km CIRCUMFERENCE, 100 m BELOW GROUND!)
ENGINEERS INSPECT A SMALL SECTION OF THE TUNNEL THAT HOUSES MORE THAN 1600 MAGNETS, MOST ABOUT HALF THE SIZE OF A BASKETBALL COURT, EACH WEIGHING OVER 30 TONS!
THE BEAMS OF PROTONS WILL BE STEERED BY THESE POWERFUL MAGNETS ALONGSIDE PIPES OF LIQUID HELIUM, COOLED TO -456 DEGREES F, MAKING IT ONE OF, IF NOT THE, COLDEST PLACES IN THE UNIVERSE!
AT FOUR LOCATIONS IN THE TUNNEL, THE BEAM PIPE IS BROKEN WHERE COLLISIONS MAY OCCUR, WITH A MASSIVE DETECTOR AT EACH LOCATION, LOOKING FOR SPECIFIC TYPES OF PARTICLES THAT MAY EMERGE FROM THE COLLISION. HERE THEY ARE:
LARGE:

“ALICE”
A Large Ion Collider Experiment
LARGE:

“ATLAS”
A Toroidal LHC ApparatuS
LARGE:

“LHCb”
The Large Hadron Collider Beauty Experiment
LARGE:

“CMS”
Compact Muon Solenoid
NOW, THAT’S SLARGE!!!
HADRONE: THESE ARE PARTICLES AFFECTED BY THE STRONG NUCLEAR FORCE

WHAT KIND OF PARTICLES ARE THESE, AND WHAT IS THE STRONG NUCLEAR FORCE?

LET'S DO A SIMPLE BREAKDOWN OF WHAT WE CALL "NORMAL MATTER":
HADRON:

If this cube is made of normal matter, then we can look at it as composed of molecules, held together by electrical forces.

Each molecule is composed of a number of atoms, also held together by electrical forces.

Each atom is composed of a positively-charged nucleus, consisting of protons and neutrons, surrounded by negatively-charged electrons, held in place by electrical forces.

Each nucleus is held together by the “Strong Nuclear Force” (much stronger than the electrical force that would repel protons, since they have the same positive charge).
HADRON:

PROTONS AND NEUTRONS ARE EACH MADE UP OF THREE PARTICLES CALLED “QUARKS”.

THERE ARE SIX TYPES OF QUARKS - PROTONS HAVE TWO “UP” QUARKS AND ONE “DOWN” QUARK, WHILE NEUTRONS HAVE TWO “DOWN” QUARKS AND ONE “UP” QUARK EACH.

(According to the STANDARD MODEL of particle physics.)
PROTONS AND NEUTRONS ARE EACH MADE UP OF THREE PARTICLES CALLED “QUARKS”.

THERE ARE SIX TYPES OF QUARKS - PROTONS HAVE TWO “UP” QUARKS AND ONE “DOWN” QUARK, WHILE NEUTRONS HAVE TWO “DOWN” QUARKS AND ONE “UP” QUARK EACH.

THE QUARKS ARE HELD TOGETHER BY FORCE-CARRYING PARTICLES CALLED “GLUONS”.

So, what type of particle would this be????
PROTONS AND NEUTRONS ARE EACH MADE UP OF THREE PARTICLES CALLED “QUARKS”.

THERE ARE SIX TYPES OF QUARKS - PROTONS HAVE TWO “UP” QUARKS AND ONE “DOWN” QUARK, WHILE NEUTRONS HAVE TWO “DOWN” QUARKS AND ONE “UP” QUARK EACH.

THE QUARKS ARE HELD TOGETHER BY FORCE-CARRYING PARTICLES CALLED “GLUONS”.

PARTICLES THAT CONSIST OF THREE QUARKS ARE CLASSIFIED AS “HADRONS”... SO
PROTONS AND NEUTRONS ARE ALSO KNOWN AS HADRONS*

*MORE SPECIFICALLY, THEY ARE CLASSIFIED AS “BARYONS.”

HADRONS THAT CONSIST OF EXACTLY TWO QUARKS (ONE QUARK AND ONE “ANTIQUARK”) ARE CLASSIFIED AS “MESONS.”

THE TITLE MIGHT ALSO BE INTERPRETED AS “LARGE HADRON. . .” (BARYONS), AS OPPOSED TO “SMALL HADRON” (MESONS)
Protons and neutrons are also known as hadrons.

But, only beams of protons will be used in the LHC, since they have a positive charge, and can be accelerated by an electromagnetic field.

(Neutrons have no charge, so they would not be affected.)
And now, a word about

THE

LARGE

HADRON
But, first, did you know that...
THE LHC IS NOT THE ONLY PARTICLE ACCELERATOR AT CERN

OTHER LINEAR AND CIRCULAR ACCELERATORS ALREADY CONSTRUCTED WILL BE USED TO INITIALLY ACCELERATE THE PROTONS BEFORE THEY ENTER THE LHC TUNNEL. HERE’S A DIAGRAM:
There are a series of accelerators at CERN, each with increasing energies. The LHC is the final link in this chain, accelerating protons to a record energy of 7 TeV!
(An eV stands for “electron-Volt” and is used to measure the energy of very small particles. A “TeV” is a terra electron-Volt, which is one thousand BILLION electron-Volts!!!)
1 TeV = 1,000,000,000,000 eV
STEP 1:

Hydrogen ions (hydrogen atoms stripped of their electrons, leaving just the protons) are injected into the PS Booster (PS) at an energy of 50 MeV (50 million eV) from “Linac 2” (linear accelerator).
STEP 2:

The booster accelerates them to 1.4 GeV (giga eV, 1.4 billion eV).
The beam is then fed into the Proton Synchrotron (PS), where it is accelerated to 25 GeV.
STEP 4:

Protons are then fed into the Super Proton Synchrotron (SPS), where they are accelerated to 450 GeV.
They are finally transferred to the LHC tunnel, where they are injected in “bunches” (2808) of billions of protons, some going clockwise, some going counterclockwise. It takes about four hours and twenty minutes to fill these two rings. The beams of protons are actually 40 microns in diameter. (About one-third the size of a human hair)!
After about 20 minutes, they reach the target energy of 7 TeV. When they collide, it's like a head-on collision between two cars going in opposite directions, they will have a combined energy of 14 TeV!!! Even with so many bunches of protons crossing paths, an average of 20 actual collisions may occur in one bunch. This is the most energetic (man-made) collision between particles ever produced!
STEP 5:

JUST HOW MUCH ENERGY IS 14 TeV??
STEP 5:

JUST HOW MUCH ENERGY IS 14 TeV??
MORE THAN A NUCLEAR BOMB?
STEP 5:

JUST HOW MUCH ENERGY IS 14 TeV??

ENOUGH TO DESTROY THE EARTH?
STEP 5:

JUST HOW MUCH ENERGY IS 14 TeV??

ENOUGH TO CREATE A MASSIVE BLACK HOLE???
STEP 5:

JUST HOW MUCH ENERGY IS 14 TeV??

NO!!!
STEP 5:

JUST HOW MUCH ENERGY IS 14 TeV??

ONE TeV IS ABOUT THE AMOUNT OF ENERGY GENERATED BY THE FLAPPING WINGS OF A MOSQUITO!!!!!!
STEP 5:

JUST HOW MUCH ENERGY IS 14 TeV??

ONE TeV IS ABOUT THE AMOUNT OF ENERGY GENERATED BY THE FLAPPING WINGS OF A MOSQUITO!!!!!!!

YOU PRODUCE MORE ENERGY WHEN YOU CLAP YOUR HANDS!
STEP 5:

THE KEY IS HOW THIS ENERGY IS CONCENTRATED!!
STEP 5:

THE ENERGY IS SQUEEZED INTO A SPACE THAT IS ONE MILLION MILLIONTH THE SIZE OF A MOSQUITO!

(1/1000000000000000)
STEP 5:

THE ENERGY IS SQUEEZED INTO A SPACE THAT IS ONE MILLION MILLIONTH THE SIZE OF A MOSQUITO!

\[ \frac{1}{1000000000000000} \]

You would NOT want to clap your hands if you were holding a needle pointed towards one hand!

THIS IS CONCENTRATED!
STEP 5:

BUT THIS AMOUNT OF CONCENTRATED ENERGY IS EQUIVALENT TO A 400 TON TRAIN TRAVELING OVER 100 MILES/HR!
STEP 6:

These protons will be traveling at 0.999999991 the speed of light, making more than 11,000 trips around the 27 km tunnel every second!

Collisions are allowed to take place in any or all of the four “experiment” detectors.
When a collision occurs, the detectors are designed to trace the paths of emerging particles if they are *charged*. In this way, they can be identified by the ion trail they leave behind.

If they are *not* charged, the particles will be “stopped” by specialized targets, where their energy can be absorbed and measured. These are called
When a collision occurs, the detectors are designed to trace the paths of emerging particles if they are charged. In this way, they can be identified by the ion trail they leave behind.

If they are not charged, the particles will be “stopped” by specialized targets, where their energy can be absorbed and measured. These are called “CALORIMETERS.”
HERE IS WHAT THIS PROCESS LOOKS LIKE:
Large Hadron Collider

ATLAS Detector

http://www.youtube.com/watch?v=AHT9RTICqiQ
So, what are we looking for in these collisions?
What do we hope to learn from all this???
AND HOW WILL IT ADVANCE SCIENCE AND TECHNOLOGY?????
HIGH ENERGY PARTICLE PHYSICISTS LOOK FOR THE ANSWERS TO THE FOLLOWING QUESTIONS:
WHAT IS THE UNIVERSE MADE OF?
HOW DOES IT WORK?
WHY?
ARE THERE **FUNDAMENTAL BUILDING BLOCKS**?

IF SO, WHAT ARE THEY?

ARE QUARKS MADE UP OF EVEN SMALLER PARTICLES?

ACCORDING TO THE STANDARD MODEL, ALL “NORMAL MATTER” IS MADE UP OF QUARKS AND “LEPTONS”
ARE THERE *FUNDAMENTAL* BUILDING BLOCKS?

IF SO, WHAT ARE THEY?

The STANDARD MODEL does *not* explain why some particles are more massive than others, and why some particles are even massless!
ARE THERE **FUNDAMENTAL** BUILDING BLOCKS?

IF SO, WHAT ARE THEY?

IT DOES NOT OFFER AN EXPLANATION AS TO EVEN WHY PARTICLES HAVE MASS AT ALL!!

**WHAT EXACTLY IS MASS?**
ARE THERE FUNDAMENTAL BUILDING BLOCKS?

IF SO, WHAT ARE THEY?

HOW DO THEY INTERACT?

One theory that physicists are pursuing is that particles acquire mass from interacting with force-carrying particles known as **HIGGS BOSONS**, (bosons are force-carrying particles) named after the British physicist Peter Higgs in the 1960’s.
ARE THERE **FUNDAMENTAL BUILDING BLOCKS**?

IF SO, WHAT ARE THEY?

HOW DO THEY INTERACT?

One theory that physicists are pursuing is that particles acquire mass from interacting with force-carrying particles known as **HIGGS BOSONS**, (bosons are force-carrying particles) named after the British physicist Peter Higgs in the 1960's.
ARE THERE *FUNDAMENTAL BUILDING BLOCKS*?

IF SO, WHAT ARE THEY?

HOW DO THEY INTERACT?

One theory that physicists are pursuing is that particles acquire mass from interacting with force-carrying particles known as *HIGGS BOSONS*, (bosons are force-carrying particles) named after the British physicist Peter Higgs in the 1960’s.

HERE’S A VERY SIMPLIFIED EXAMPLE OF HOW THE THEORY WORKS:
ACCORDING TO EINSTEIN’S

THEORY OF

SPECIAL RELATIVITY,

ANY PARTICLE THAT HAS MASS
CANNOT TRAVEL FASTER
THAN THE SPEED OF LIGHT (“c”)
(186,000 MILES/SECOND, OR
670,000,000 MILES/HOUR).

WHAT A GREAT IDEA!
ACCORDING TO EINSTEIN’S
THEORY OF SPECIAL RELATIVITY,

ANY PARTICLE THAT HAS MASS
CANNOT TRAVEL FASTER THAN THE SPEED OF LIGHT (“c”)
(186,000 MILES/SECOND, OR 670,000,000 MILES/HOUR).

..and my teachers said I would never amount to anything!
ACCORDING TO EINSTEIN’S THEORY OF SPECIAL RELATIVITY,

ANY PARTICLE THAT HAS MASS CANNOT TRAVEL FASTER THAN THE SPEED OF LIGHT ("c") (186,000 MILES/SECOND, OR 670,000,000 MILES/HOUR).

EVERYTHING MUST FOLLOW THE SPEED LIMIT!

NOT GALAXIES.
According to Einstein's theory of special relativity, any particle that has mass cannot travel faster than the speed of light ("c") (186,000 miles/second, or 670,000,000 miles/hour).

You will never make them go fast enough!

Not rockets.
According to Einstein’s theory of special relativity, any particle that has mass cannot travel faster than the speed of light ("c"). (186,000 miles/second, or 670,000,000 miles/hour). Faster than a speeding bullet...? Ha!!!!!!
According to Einstein’s Theory of Special Relativity, any particle that has mass cannot travel faster than the speed of light ("c") (186,000 miles/second, or 670,000,000 miles/hour). But, they can come close if they have enough energy!
ACCORDING TO EINSTEIN’S THEORY OF SPECIAL RELATIVITY,

ANY PARTICLE THAT HAS MASS CANNOT TRAVEL FASTER THAN THE SPEED OF LIGHT (“c”) (186,000 MILES/SECOND, OR 670,000,000 MILES/HOUR).

PARTICLES THAT ARE MASSLESS (PHOTONS OF LIGHT, RADIO, UV, X-RAY, GAMMA, ETC.) CAN TRAVEL AT THE SPEED OF LIGHT (IN A VACUUM).
So, Higgs theorized a field of particles permeating all of space (a “HIGGS FIELD”), and that ALL particles actually travel at the speed of light, but some interact with these Higgs Particles, or (BOSONS), giving them MASS, the amount of mass they have depending on how much they interact.

Massless particles do NOT interact at all with the Higgs Particles, which explains why they can travel at the speed of light.
According to Einstein's theory of special relativity, any particle that has mass cannot travel faster than the speed of light (c) (186,000 miles/second, or 670,000,000 miles/hour).

So, Higgs theorized a field of particles permeating all of space (a "Higgs field"), and that all particles actually travel at the speed of light, but some interact with these Higgs particles, or (bosons), giving them mass, the amount of mass they have depending on how much they interact.

Massless particles do not interact at all with the Higgs particles, which explains why they can travel at the speed of light.

Here's an example:

Thanks All!!!
LET’S SAY THAT THIS IS A HIGGS BOSON

NOW, LET’S MAKE A HIGGS FIELD:
THIS IS A SAMPLE OF A HIGGS FIELD:

IMAGINE THESE GUYS FILLING ALL OF SPACE!!!
THERE GOES A PHOTON:
THERE GOES A PHOTON:
THERE GOES A PHOTON . . .

PARTICLES NOT AFFECTED BY THE HIGGS FIELD DO NOT HAVE MASS!!!
HERE COMES AN ELECTRON: . . .
HERE COMES AN ELECTRON: . . .
HERE COMES AN ELECTRON: . . .
HERE COMES AN ELECTRON: . . .

THAT WAS PRETTY EASY!

ME TOO!!

I SLOWED HIM DOWN!
THERE GOES AN ELECTRON: . . .

PARTICLES THAT INTERACT SLIGHTLY WITH THE HIGGS FIELD HAVE A SMALL MASS.
(This is why they travel slower than light.)
HERE COMES A TOP QUARK . . .

HERE I COME!
HERE COMES A TOP QUARK . . .

I SLOWED HIM DOWN!
HERE COMES A TOP QUARK . . .
HERE COMES A TOP QUARK . . .

ME TOO!!
HERE COMES A TOP QUARK . . .

I GOT HIM!
HERE COMES A TOP QUARK . . .

<table>
<thead>
<tr>
<th>![Image of Top Quark Pattern]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAKE THAT!</td>
</tr>
</tbody>
</table>
HERE COMES A TOP QUARK . . .

PARTICLES THAT INTERACT MORE WITH THE HIGGS FIELD HAVE A LARGER MASS.
(This is why they travel even slower than light.)
THE LHC SHOULD PRODUCE COLLISIONS WITH ENOUGH ENERGY TO DETECT THE ELUSIVE HIGGS BOSON!

OK, YOU FOUND ME!
This would explain how and why particles have mass!

Photons (light, radio, infrared, etc.)
(no mass)
Travel at “c” in a vacuum.

Electrons
(negatively charged particles known as “leptons”)
Travel < “c” in a vacuum.

Protons
(positively charged hadrons)
Travel << “c” in a vacuum.
IT MAY ALSO LEAD TO TELL US SOMETHING ABOUT

GRAVITY

The WEAKEST FORCE in the UNIVERSE!!!
WHY is GRAVITY so WEAK?

COMPARED TO THE OTHER THREE FUNDAMENTAL FORCES
(electromagnetic, weak nuclear, strong nuclear)
DOESN’T GRAVITY KEEP US ON EARTH??

THIS IS ONE WAY TO LOOK AT IT.
DOESN’T GRAVITY KEEP US ON EARTH??

THIS IS ANOTHER WAY.

MAYBE GRAVITY IS STRONGER THAN WE THINK!

NOT REALLY!!!

(except in black holes, or at quantum distances)
DOESN’T GRAVITY KEEP US ON EARTH??

THIS IS ANOTHER WAY.

I’m ATLAS!

MAYBE GRAVITY IS STRONGER THAN WE THINK!

NOT REALLY!!!

THIS LEADS US TO
THE SEARCH FOR EXTRA DIMENSIONS AT THE LHC

(extra what?)
WE ARE ALL FAMILIAR WITH 3-DIMENSIONAL OBJECTS.

THESE ARE OBJECTS IN OUR “NORMAL” WORLD THAT HAVE LENGTH (x), WIDTH (y), AND HEIGHT (z).
WE ARE ALL FAMILIAR WITH 3-DIMENSIONAL OBJECTS.

THESE ARE OBJECTS IN OUR “NORMAL” WORLD THAT HAVE LENGTH (x), HEIGHT (y), and HEIGHT (z).

ALBERT EINSTEIN POPULARIZED A “FOURTH” DIMENSION: TIME (t).
So, we actually live in a FOUR-DIMENSIONAL WORLD of SPACETIME.

\[ (x, y, z, t) \]

x, y, and z are called "SPATIAL" dimensions, while t is called a "TEMPORAL" dimension (for time).
So, we actually live in a FOUR-DIMENSIONAL WORLD of

**SPACETIME**

(x, y, z, t)

x, y, and z are called “SPATIAL” dimensions, t is called a “TEMPORAL” (for time) DIMENSION.

WHAT OTHER POSSIBLE DIMENSIONS COULD THERE BE IF WE CAN’T “SEE” THEM?

“Imagination is more important than knowledge!”

[Diagram showing 4 dimensions: x, y, z, t]
SCIENTISTS BELIEVE THAT THERE MAY BE MORE DIMENSIONS THAT WE CANNOT SEE!!!

IMAGINE A “FLAT” ANT CRAWLING ALONG A ROLL OF PAPER
Scientists believe that there may be more dimensions that we cannot see!!!

Imagine a “flat” ant crawling along a roll of paper. It can distinguish left from right, and top from bottom; but it is restricted to the plane of the paper, so it would not be able to distinguish “up” from “down”. It would be impossible for the ant to have any sense of it at all!
JUST LIKE THAT ANT, IT IS POSSIBLE THAT MORE THAN THREE SPATIAL DIMENSIONS COULD EXIST. . .

BUT, SINCE WE ARE RESTRICTED TO THREE DIMENSIONS, OUR BRAINS ARE NOT “HARD-WIRED” TO COMPREHEND IT.
JUST LIKE THAT ANT, IT IS POSSIBLE THAT MORE THAN THREE SPATIAL DIMENSIONS COULD EXIST. . .

BUT, SINCE WE ARE RESTRICTED TO THREE DIMENSIONS, OUR BRAINS ARE NOT “HARD-WIRED” TO COMPREHEND IT.

ONE POSSIBLE EXPLANATION IS THAT THESE “EXTRA DIMENSIONS” ARE VERY SMALL, AND CURL UP ON EACH OTHER. . .
THESE EXTRA DIMENSIONAL “CYLINDERS” WOULD HAVE
A VERY TINY RADIUS, BUT COULD STRETCH INFINITELY
IN ITS LENGTH.

IF THIS IS TRUE, THEN ITS RESTRICTED RADIUS MIGHT ALSO
RESTRICT THE AMOUNT OF INFORMATION (IN THE FORM OF
RADIATION) IT COULD CARRY.

IN FACT, OUR UNIVERSE MAY BE CONFINED TO A “BRANE”
(SHORT FOR “MEMBRANE”) FLOATING IN A SPACE OF
3, 4, 5, . . ., DIMENSIONS!!
THIS WOULD GREATLY CHANGE OUR CURRENT VIEW OF THE “UNIVERSE” AND OPEN UP THE POSSIBILITY OF A “MANYFOLD UNIVERSE”, OR EVEN A “MEGAVERSE”!
OUR UNIVERSE WOULD BE ON ONE OF THESE “FOLDS”, AND THREE FUNDAMENTAL FORCES (ELECTROMAGNETIC, WEAK AND STRONG NUCLEAR) WOULD BE RESTRICTED,

AS WOULD PARTICLES OF “NORMAL MATTER”.

BUT WHAT IF. . .
THE FORCE OF GRAVITY IS "SHARED" WITH OTHER DIMENSIONS?

HOW WOULD THIS BE POSSIBLE?
ACCORDING TO THE STANDARD MODEL OF PARTICLE PHYSICS, THE PARTICLE THAT “CARRIES” THE GRAVITATIONAL FORCE IS CALLED THE GRAVITON.
WHAT IF GRAVITONS ARE ABLE TO “JUMP” FROM ONE DIMENSION (OR UNIVERSE) TO ANOTHER, *UNLIKE* OTHER FORCE-CARRYING PARTICLES?

A THEORY CALLED “STRING THEORY” PREDICTS THAT THIS *COULD* HAPPEN!
BUT, THERE'S ONE PROBLEM. . .
SINCE GRAVITY IS SO WEAK,
THE GRAVITON WOULD BE
VERY, VERY WEAK,
AND VIRTUALLY UNDETECTABLE
WITH OUR CURRENT TECHNOLOGY

IF THE STRENGTH OF GRAVITY IS = 1;

THE RELATIVE STRENGTH OF THE WEAK NUCLEAR FORCE IS
10,000,000,000,000,000,000,000,000

THE RELATIVE STRENGTH OF THE ELECTROMAGNETIC FORCE IS
100,000,000,000,000,000,000,000,000,000,000,000,000,000

THE RELATIVE STRENGTH OF THE STRONG NUCLEAR FORCE IS
100,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000

THE QUESTION OF THE RELATIVE WEAKNESS
OF GRAVITY COMPARED TO THE OTHER
FUNDAMENTAL FORCES IS KNOWN AS
"THE HIERARCHY PROBLEM."
THE LHC WILL BE SO

(REMEMBER, 14 TeV!)

THAT THE COLLISIONS IT PRODUCES
WHEN PROTONS COLLIDE MAY REVEAL
PARTICLES THAT MAY HAVE ONCE BEEN
PRODUCED IN THE “BIG BANG”
AND HAVE NOT BE SEEN SINCE.
GRAVITONS FROM THESE COLLISIONS MAY “JUMP” OFF INTO ANOTHER DIMENSION, PERHAPS EVEN ANOTHER UNIVERSE!!
GRAVITONS FROM THESE COLLISIONS MAY “JUMP” OFF INTO ANOTHER DIMENSION, PERHAPS EVEN ANOTHER UNIVERSE!!

EVEN THOUGH THEY CANNOT BE DIRECTLY OBSERVED,

THE LOSS OF MASS (ENERGY*) \textbf{CAN} BE IDENTIFIED AND MEASURED

*Einstein said they were equivalent.
THIS WOULD MEAN THAT OUR THEORIES ABOUT THE GRAVITON AND GRAVITY *MIGHT BE CORRECT*, OR AT LEAST ON THE RIGHT TRACK.

GRAVITY IS SO WEAK IN OUR UNIVERSE, BECAUSE IT IS CAPABLE OF JUMPING DIMENSIONS (AND PERHAPS OTHER UNIVERSES), UNLIKE THE OTHER THREE FORCES OF NATURE!!

IT MAY BE *JUST AS STRONG* AS ELECTROMAGNETISM AND THE STRONG AND WEAK NUCLEAR FORCES,
THIS WOULD MEAN THAT OUR THEORIES ABOUT THE GRAVITON AND GRAVITY *MIGHT* BE CORRECT, OR AT LEAST ON THE RIGHT TRACK.

GRAVITY IS SO WEAK IN OUR UNIVERSE, BECAUSE IT IS CAPABLE OF JUMPING DIMENSIONS (AND PERHAPS OTHER UNIVERSES), UNLIKE THE OTHER THREE FORCES OF NATURE!!

BUT...
IT WOULD BE LIKE AN ICEBERG

WE ONLY SEE THE TIP, BUT MOST OF IT IS HIDDEN UNDERWATER!
IT WOULD BE LIKE AN
ICEBERG

GRAVITY IN OUR
UNIVERSE

GRAVITY IN
OTHER UNIVERSES

BUT, WHAT'S EVEN MORE AMAZING...
USING GRAVITONS, WE MIGHT ACTUALLY BE ABLE TO. . .

ESTABLISH COMMUNICATION WITH OTHER DIMENSIONS OR UNIVERSES!
UNLOCK THE MYSTERY OF DARK MATTER!!!
WHAT IS **DARK MATTER**???

THE SIMPLE ANSWER IS . . .

WE DON’T KNOW!
WHAT IS DARK MATTER???

THE SIMPLE ANSWER IS . . . WE DON'T KNOW!

BUT, WHAT WE DO KNOW IS
STARS THAT WE OBSERVE IN DISTANT GALAXIES ARE NOT FOLLOWING LAWS OF NEWTONIAN PHYSICS.

THE LAWS OF NEWTON AND KEPLER REQUIRE THESE STARS TO BE REVOLVING MORE SLOWLY THAN THESE.
STARS REVOLVING AROUND THE GALACTIC NUCLEI ARE GOING **MUCH TOO FAST**!
ARE GOING MUCH TOO FAST!

HOW DO WE KNOW THIS?
BY OBSERVING AND MEASURING THE "DOPPLER SHIFT" OF STARS IN THE GALAXY.
STARS MOVING TOWARD US ARE "BLUE SHIFTED"

STARS MOVING AWAY FROM US ARE "RED SHIFTED"

ARE GOING MUCH TOO FAST!
ARE GOING MUCH TOO FAST!

AS ARE...
ENTIRE CLUSTERS OF GALAXIES!!

Dark matter here?

TOO FAST

...and here?

...and here?

(Virgo Cluster of Galaxies)
ENTIRE *CLUSTERS* OF GALAXIES!!

(Too fast)

(Dark matter?)

(Coma Cluster of Galaxies)
DARK MATTER?

“NORMAL” MATTER

DISTANCE: APPROX. 5.6 BILLION LIGHT YEARS

DARK MATTER?
THIS FACT IMPLIES THAT
THERE MUST BE A **SUBSTANTIAL AMOUNT
OF MATTER** CAUSING THIS THAT WE CANNOT
“SEE”!

HENCE,

**DARK MATTER!**
ASTROPHYSICISTS CAN ESTIMATE THE AMOUNT OF DARK MATTER IN (OUR) UNIVERSE, BASED ON EXTENSIVE OBSERVATIONS FROM GROUND-BASED AND SATELLITE-BASED OBSERVATORIES OF GALAXIES AND CLUSTERS OF GALAXIES.
ASTROPHYSICISTS CAN ESTIMATE THE AMOUNT OF DARK MATTER IN OUR UNIVERSE, BASED ON EXTENSIVE OBSERVATIONS FROM GROUND-BASED AND SATELLITE-BASED OBSERVATORIES OF GALAXIES AND CLUSTERS OF GALAXIES.
WE HAVE KNOWN THAT OUR UNIVERSE IS EXPANDING THANKS TO THE OBSERVATIONS OF EDWIN HUBBLE IN THE EARLY 20TH CENTURY.
WE HAVE KNOWN THAT OUR UNIVERSE IS EXPANDING THANKS TO THE OBSERVATIONS OF EDWIN HUBBLE IN THE EARLY 20TH CENTURY.

BUT, IS ITS RATE OF EXPANSION:

A) SPEEDING UP?
B) SLOWING DOWN?
C) REMAINING CONSTANT?

THE ANSWER TO THIS QUESTION MAY DECIDE THE FATE OF OUR UNIVERSE!
A) SPEEDING UP!!!
SHOULDN’T THE PRESENCE OF ALL THIS MATTER AND DARK MATTER CAUSE EXPANSION TO SLOW DOWN, OR AT LEAST REMAIN CONSTANT??????

SOMETHING ELSE IS GOING ON HERE!!
SHOULDN’T THE PRESENCE OF ALL THIS MATTER AND DARK MATTER CAUSE EXPANSION TO SLOW DOWN, OR AT LEAST REMAIN CONSTANT??????

SCIENTISTS BELIEVE THAT SOME “MYSTERIOUS” FORM OF ENERGY IN OUR UNIVERSE MUST BE DOING THIS!!!!

THIS ENERGY IS GIVEN THE NAME. . .
Actually, Albert Einstein, in his THEORY OF GENERAL RELATIVITY, inserted a term in his equation to account for such an occurrence - he called it the
Actually, Albert Einstein, in his THEORY OF GENERAL RELATIVITY, inserted a term in his equation to account for such an occurrence - he called it the **cosmological constant**.

\[ G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \]
EINSTEIN AND THE “COSMOLOGICAL CONSTANT”

AFTER HUBBLE’S DISCOVERY, HE THOUGHT HE WAS WRONG IN MODIFYING HIS EQUATION, CALLING THE ADDITIONAL TERM “... THE GREATEST MISTAKE OF MY LIFE.”

What was I thinking???
AFTER HUBBLE’S DISCOVERY, HE THOUGHT HE WAS WRONG IN MODIFYING HIS EQUATION, CALLING THE ADDITIONAL TERM “. . . THE GREATEST MISTAKE OF MY LIFE.”

BUT OUR OBSERVATIONS TODAY OF ACCELERATING EXPANSION MAY BE DUE TO THE PRESENCE OF DARK ENERGY (DESCRIBED BY THIS TERM)!

Well, maybe, . . . on second thought,
AFTER HUBBLE’S DISCOVERY,
HE THOUGHT HE WAS WRONG
IN MODIFYING HIS EQUATION,
CALLING THE ADDITIONAL TERM
“...THE GREATEST MISTAKE OF
MY LIFE.”

BUT OUR OBSERVATIONS
TODAY OF ACCELERATING
EXPANSION MAY BE DUE TO
THE PRESENCE OF DARK
ENERGY (DESCRIBED BY
THIS TERM)!

EINSTEIN WAS ACTUALLY CORRECT!
IN FACT, BASED ON OUR CURRENT MEASUREMENTS OF THE BEHAVIOR OF GALACTIC CLUSTERS, AND THE ACCELERATING EXPANSION OF THE UNIVERSE,

THE BREAKDOWN OF ALL THE “STUFF” IN OUR UNIVERSE GOES SOMETHING LIKE THIS:
IN FACT, BASED ON OUR CURRENT MEASUREMENTS OF THE BEHAVIOR OF GALACTIC CLUSTERS, AND THE ACCELERATING EXPANSION OF THE UNIVERSE,

THE BREAKDOWN OF ALL THE "STUFF" IN OUR UNIVERSE GOES SOMETHING LIKE THIS:

BREAKDOWN OF ALL "MATTER" IN THE UNIVERSE SHORTLY AFTER THE BIG BANG.

THIS REPRESENTS EVERYTHING WE CAN “SEE” OR DIRECTLY DETECT TODAY!!!

THIS ACCOUNTS FOR OUR ENTIRE "OBSERVABLE" UNIVERSE!!

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THIS ACCOUNTS FOR OUR ENTIRE “OBSERVABLE” UNIVERSE!!

THIS REALLY DOESN’T MAKE SENSE!!!
THE LHC MAY HELP US UNDERSTAND WHY
As we have seen, the LHC may help us find the answer to the following questions:

- What happened during the first instants after the “Big Bang”?
- Were the Fundamental Forces (gravity, EM, strong and weak nuclear) equally strong at that time?
- Can we detect the graviton?
- Are the observable predictions of String Theory accurate?
- Is the Higgs Mechanism a valid hypothesis in determining what mass actually is, and why particles differ in mass?
- Do extra dimensions actually exist, and can we detect them?
IN ADDITION TO THESE QUESTIONS, THE LHC MAY ALSO HELP US SOLVE THE FOLLOWING MYSTERIES:
WHAT IS THE NATURE OF DARK MATTER AND DARK ENERGY???

WHY DOES EVERYTHING WE SEE IN THE UNIVERSE ACCOUNT FOR ONLY 4.6% OF ALL THAT IS OUT THERE?

WHY DOES OUR UNIVERSE HAVE SUCH AN IMBALANCE OF MATTER OVER “ANTIMATTER”?

DO AN INFINITE NUMBER OF “PARALLEL UNIVERSES” EXIST ALL AROUND US?

WILL WE EVER FIND THE KEY TO QUANTUM GRAVITY AND A “THEORY OF EVERYTHING”? 
WHAT IS THE FUTURE OF OUR UNIVERSE?
THE LHC IS **MORE THAN JUST THE LARGEST AND MOST POWERFUL PARTICLE ACCELERATOR EVER BUILT BY MAN,**
IT IS A TESTIMONY TO THE HUMAN SPIRIT, THE STRENGTH OF COOPERATION AND INGENUITY,
...AND TO MAN’S INSATIABLE CURIOSITY
TO BETTER UNDERSTAND THE WORLD AROUND HIM AND HIS PLACE IN IT.
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"The most beautiful thing we can experience is the mysterious. It is the source of all true art and science."

Albert Einstein
REFERENCES AND SOURCES

This presentation could not have been made without the following sources:

The CERN Publication Office, including the ATLAS, CMS, LHCb AND ALICE sites
  Maximillien Brice, Mona Schweizer
The Keynote Presenters at the Teachers’ Conference at the Kavli Institute for Theoretical Physics at UCSB (Director Dr. David Gross):
  Ayana Holloway Arce
  Raman Sundrum
  Kevin McFarland
  James Wells
NASA - The CHANDRA PROJECT and The HUBBLE SPACE TELESCOPE
The Einstein Archives
SLAC
FERMILAB
The American Institute of Physics
The American Physical Society
The American Association of Physics Teachers

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Albert Einstein
Nick Nicastro has been teaching physics for the past thirty six years in Central Massachusetts.

During the summer of 2001, he worked at CERN, helping to develop curriculum in the field of high energy particle physics with physics teachers from 21 countries. He also had the opportunity to work with the scientists and engineers on the CMS Detector.

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