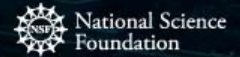


A large, dark, monochromatic statue of an angel and a demon. The angel on the left has a human-like face with curly hair and a halo, while the demon on the right has a more grotesque, horned face. They are both dressed in long, flowing robes. The background is a dark, atmospheric scene with a bright light source behind the figures.

ANGELS & DEMONS™
Lecture Night
THE SCIENCE REVEALED

Prof. Arán García-Bellido
Prof. Kevin McFarland
UNIVERSITY OF ROCHESTER
DEPARTMENT OF PHYSICS AND ASTRONOMY
30 APRIL 2009



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THE SCIENCE REVEALED

THE MOVIE TRAILER

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MOVIE SUMMARY

- Antimatter is stolen from CERN's Large Hadron Collider and hidden in Vatican City.
- Countdown to Vatican annihilation begins.
- Race through Rome to avert death and destruction.



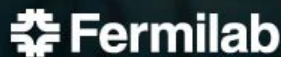
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THE SCIENCE: OUR TRAILER

truth



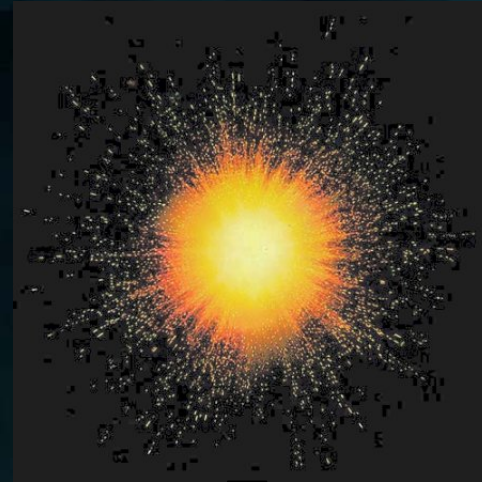
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SCIENCE SUMMARY

- Big Bang creates matter and anti-matter Universe
 - Excess of matter forms structures (atoms, solar systems, galaxies)
 - Much later, the miracle of human consciousness is used to analyze “Octomom”
- Inquiring minds want to know... why?



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THE MOVIE'S WEAPON OF TERRORISM

- CERN scientists have produced anti-matter
 - To demonstrate literal truth of Bible, that matter comes from light
 - As a form of energy
- Terrorists steal the anti-matter to use it as a bomb powerful enough to destroy the Vatican



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YES, VIRGINIA, THERE IS A CERN

Near Geneva, Switzerland



It is not top secret, and they do not own the prototype X-33 space plane used in the movie to fly Tom Hanks from Boston to Geneva in 1 hour

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HOLLYWOOD'S CERN

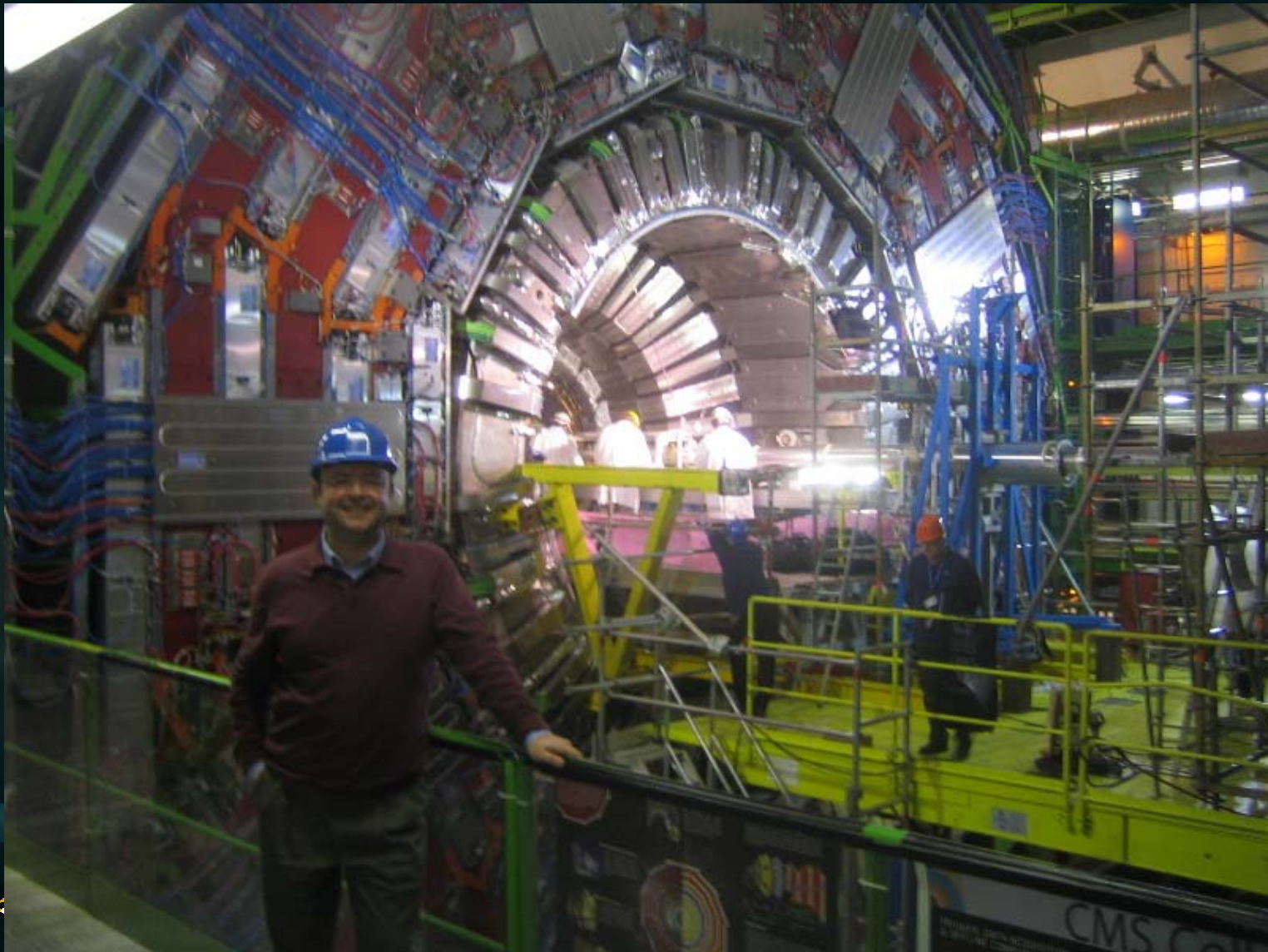
- It appears to have much better architecture and a much larger budget for such niceties than the real thing



- Not revealed if Hollywood CERN canteen also sells beer

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Retina scan is the only thing CERN copied from the book



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SCIENCE AT CERN

- CERN is home to the LHC, soon to be the most powerful particle accelerator, with a ring 16.8 miles in diameter in a tunnel 330 feet underneath Switzerland and France



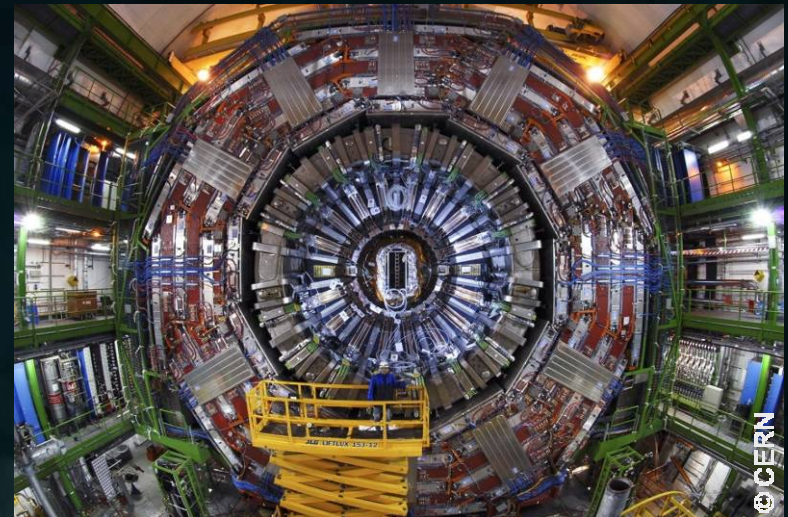
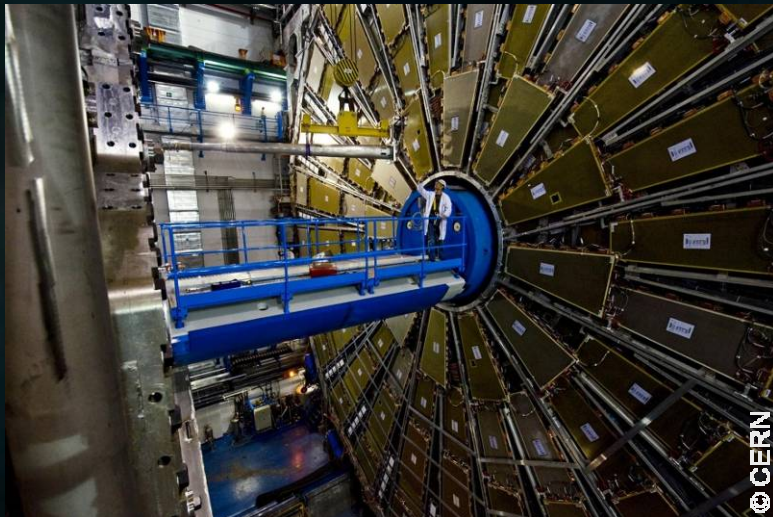
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WHAT THE LHC DOES

Will smash particles into
each other...

...to solve some of the
universe's biggest mysteries



HOW TO RELEASE ENERGY

- The goal of the terrorists in the movie is to make an explosion to destroy Vatican city
- Source of energy?
 - Kinetic is impractical
 - Chemical is “easy” but needs lots of material
 - Nuclear fuel is hard to obtain, but an energy winner

Object	Energy (calories/g)	Type
Bullet (300m/s)	0.01	Kinetic
Li-Ion Battery	0.1	Chemical
TNT	0.6	Chemical
Cookie	5	Chemical
Gasoline	10	Chemical
Hydrogen (fuel cell)	25	Chemical
Meteor (30km/s)	100	Kinetic
Uranium 235	20,000,000	Nuclear

UNLEASHING CHEMICAL ENERGY

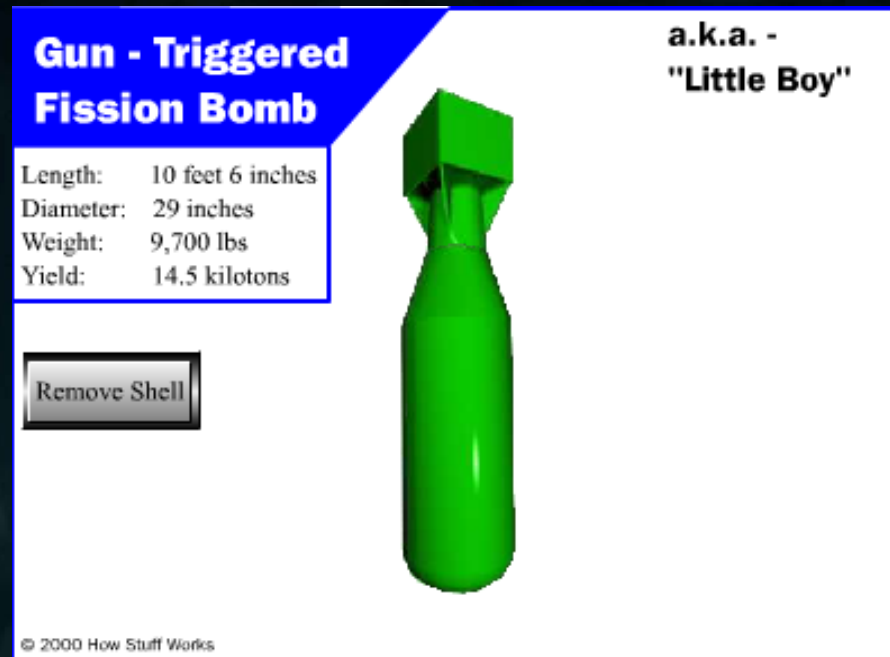
- A time-worn technique of the discerning terrorist
- The 5 kiloton (TNT) energy release in the book would require tons of material
- This is why you may not drive a truck to the door of St. Peter's Basilica



Alfred P. Murrah Federal Building
Oklahoma City, OK, April 19, 1995
Fertilizer-Fuel Truck Bomb

UNLEASHING NUCLEAR ENERGY

- If you can acquire 20kg of ^{235}U , it's not too difficult to build a crude fission bomb
 - Probably 1-2% efficiency and therefore 4-8 kTon explosion
 - The ^{235}U bomb dropped on Hiroshima, Japan, was 14 kTon
- This is why the world places a premium on making ^{235}U a difficult substance to obtain



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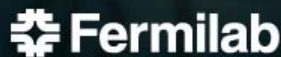
ANTIMATTER

IMAX DIGITAL BY PICTURES
ANGELS & DEMONS

Film Clip

The God Particle
(Hanks, Zurer, Skarsgard,
Favino, Pasquesi)

TRT 1:18



ANTIMATTER FOR TERRORISM?

- Anti-matter is real
- It's produced at the Large Hadron Collider and at other particle physics facilities around the world
- An anti-matter bomb is 100% efficient and releases about 2000 times the energy per gram of ^{235}U



- What is this anti-matter?

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WHAT IS MATTER?

Particles in various combinations

Quarks



up



charm



top



down



strange



bottom

Leptons



electron



muon



tau



electron
neutrino



muon
neutrino



tau
neutrino

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BUILDING A UNIVERSE



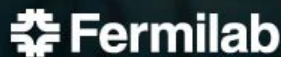
Multiply by billions and billions and billions and billions...

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BUILDING A UNIVERSE



NASA, ESA/JPL-Caltech/B. Mobasher (STScI/ESA)



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WHERE DOES ANTIMATTER FIT?

For every particle



up



electron



down



electron
neutrino

There is an antiparticle



anti-up



positron



anti-down



Anti-electron
neutrino

Particles and antiparticles have opposite **electric charge**

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CAN WE MAKE AND STORE ANTIMATTER?

We can, and do



In particle accelerators

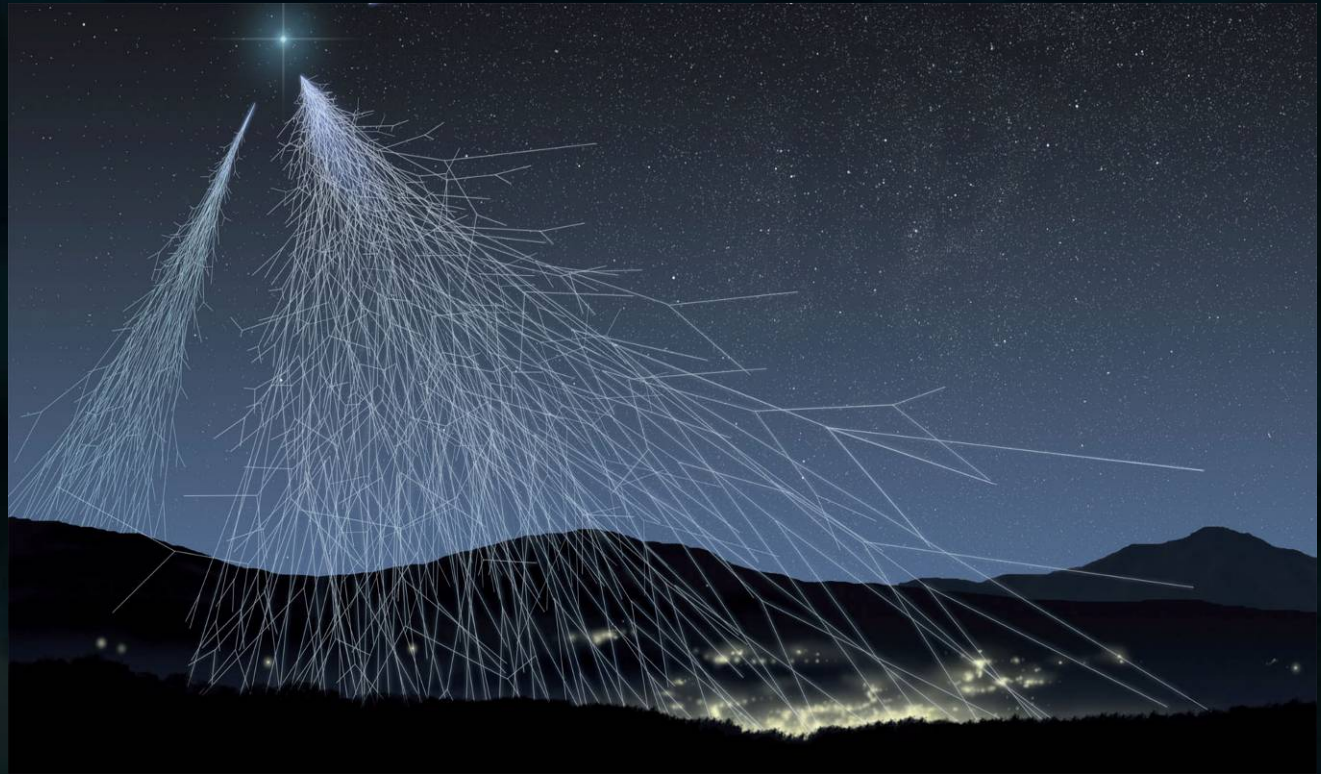
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CAN WE MAKE ANTIMATTER?

Nature can, too

High energy protons hit the upper atmosphere and produce cascades of particles and antiparticles



© L. Bret / Novapix / ASPERA



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MATTER VS. ANTIMATTER

Anti-Tom Hanks



Would look
very much
like

Tom Hanks

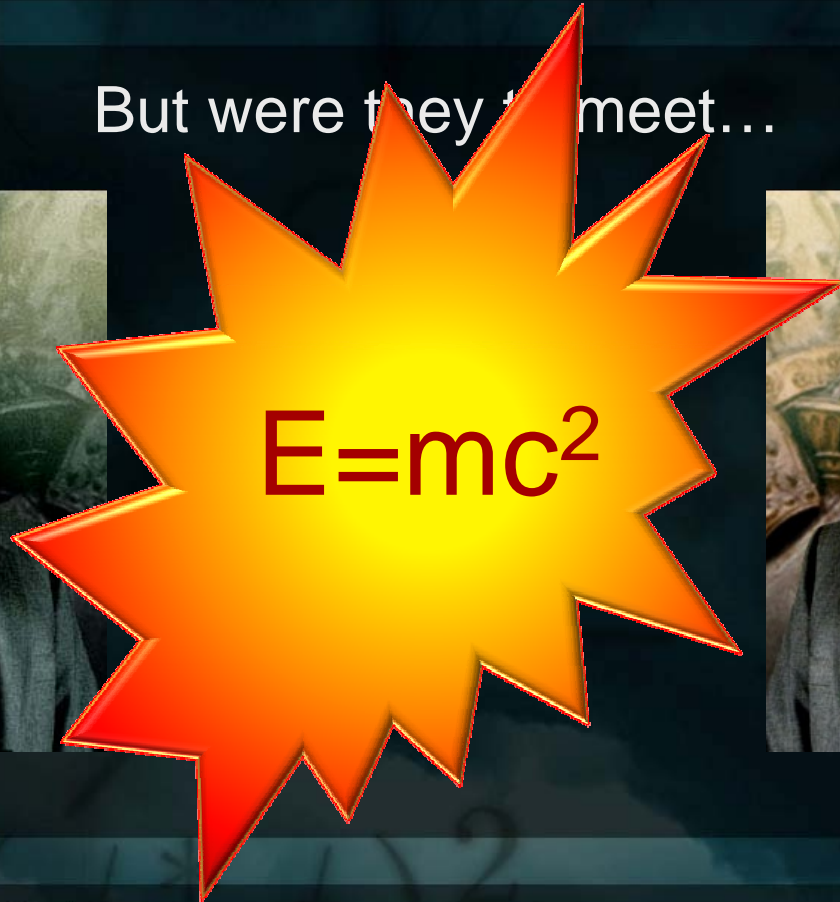


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MATTER VS. ANTIMATTER

But were they to meet...



THE MOVIE'S ANTIMATTER BOMB

- Rome is threatened by $\frac{1}{4}$ gram of antimatter
- Annihilation of $\frac{1}{4}$ g matter + $\frac{1}{4}$ g antimatter = 10 kilotons of TNT
 - More than enough to destroy the Vatican
 - Book and movie get it wrong, by the way, by a factor of two. (They forgot to include the energy from the annihilating matter!)



$\frac{1}{4}$ gram

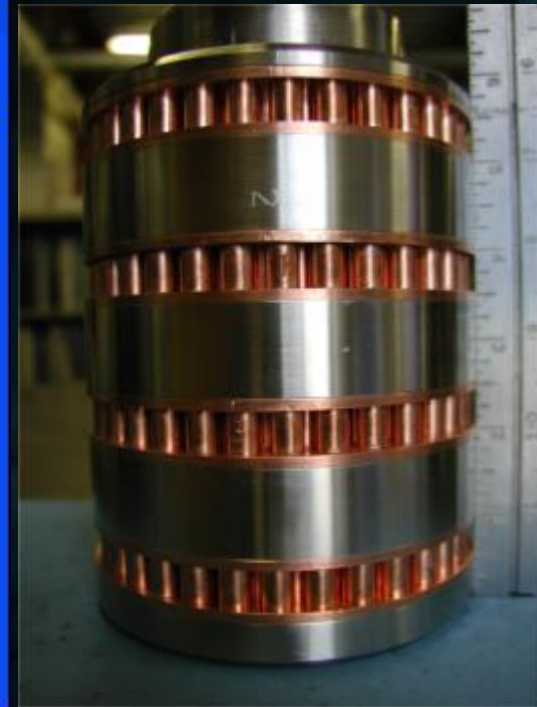
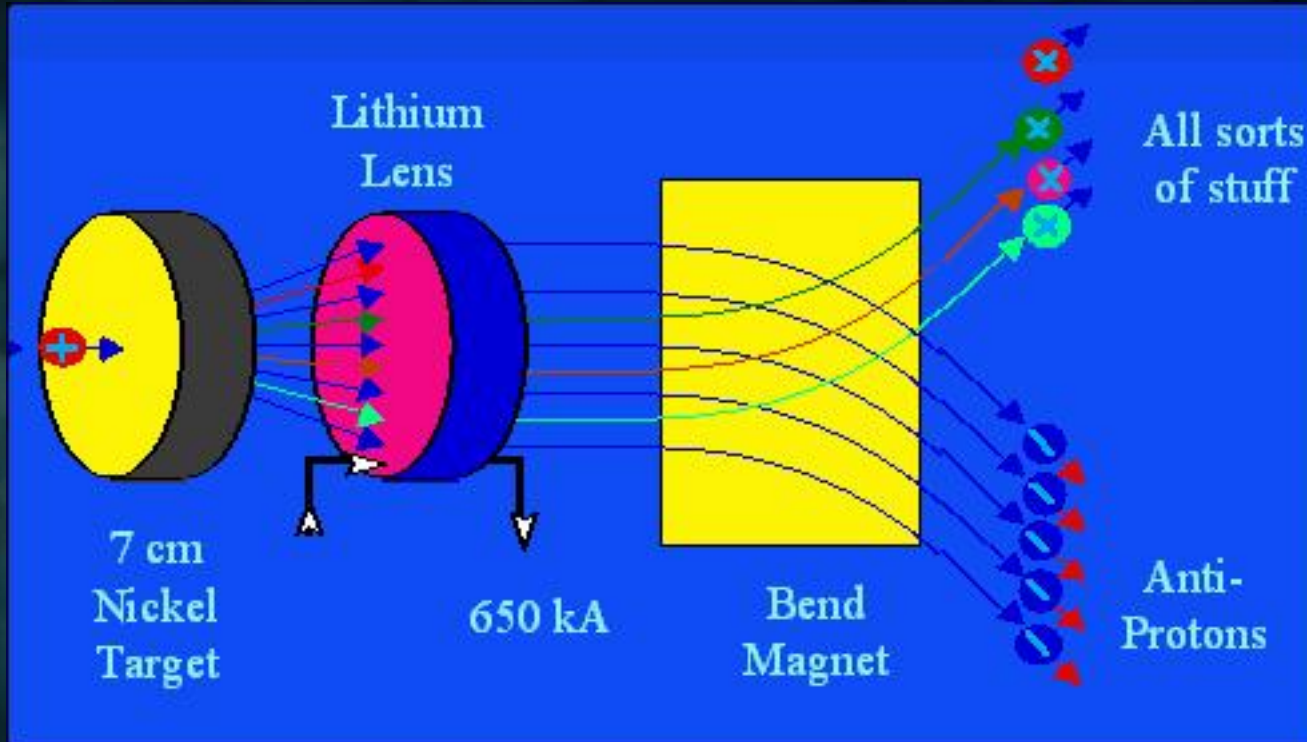
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Storage and acceleration



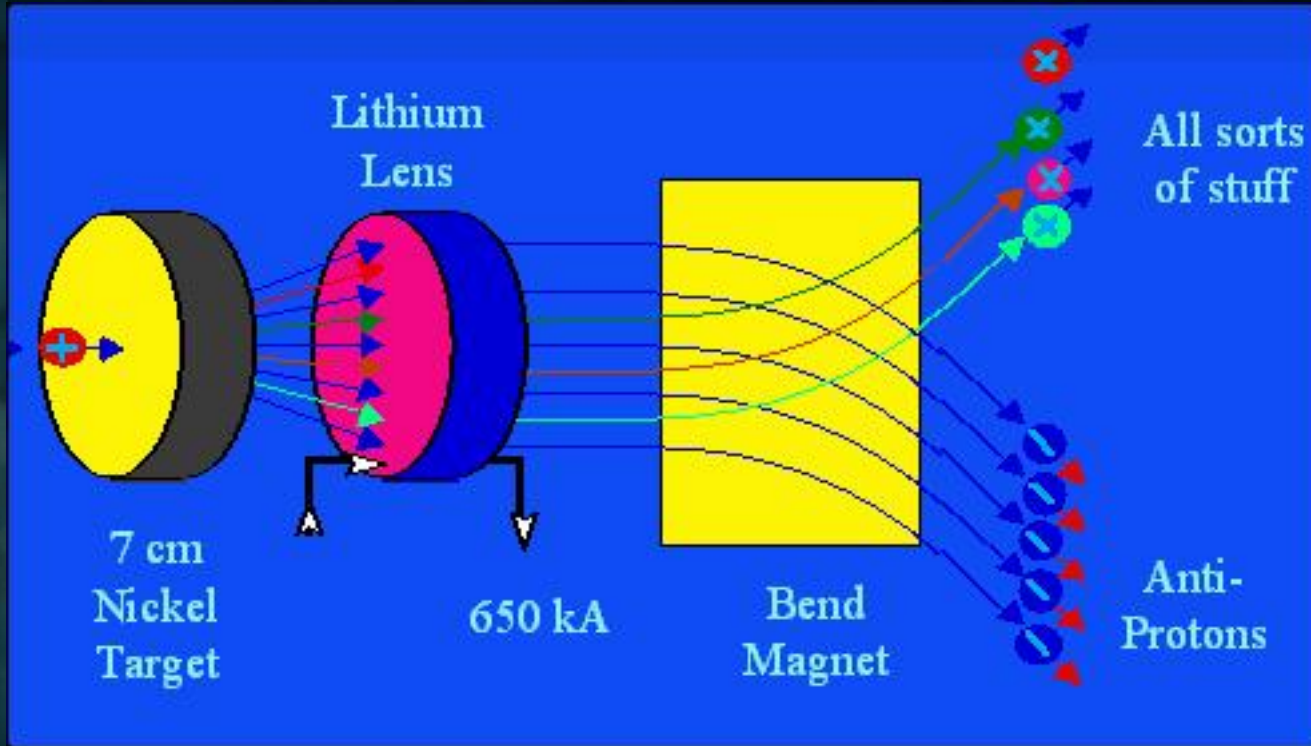
How do we create antiprotons?



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How do we create antiprotons?



For every million protons, we only produce 20 antiprotons

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HOW MUCH ANTI-MATTER?

- We make *very* little antimatter
- Fermilab creates 2 nanograms of antiprotons per year



- It would take 109 million years to make the $\frac{1}{4}$ gram

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WHAT ANTI-MATTER IS NOT...

- **A Source of Limitless Energy**
 - To make a single anti-proton currently requires billions of times more energy than is “stored” by separating anti-matter from matter
 - More energy goes in than is produced

- **Easy to Store**

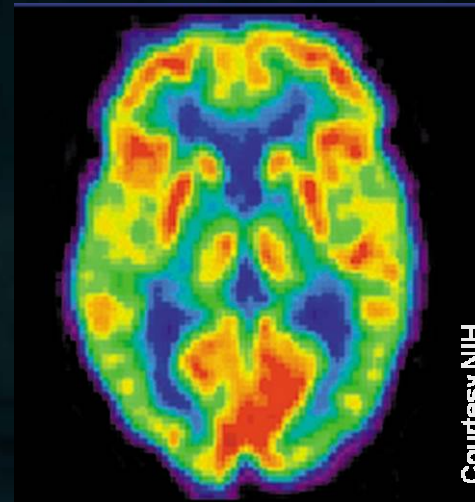


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ANTIMATTER CAN BE USED FOR

PET Scans



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ANTIMATTER CAN BE USED FOR

- Solving some of the biggest mysteries in science
 - Why do we live in a universe with an excess of matter over antimatter?
 - What gives particles mass that is released as energy when matter and antimatter meet? ($E=mc^2$)

THE MYSTERY OF ANTIMATTER

- We exist because there is almost no antimatter nearby
- More surprisingly, we don't see evidence of far away anti-matter!



NASA/STScI/G. Bacon



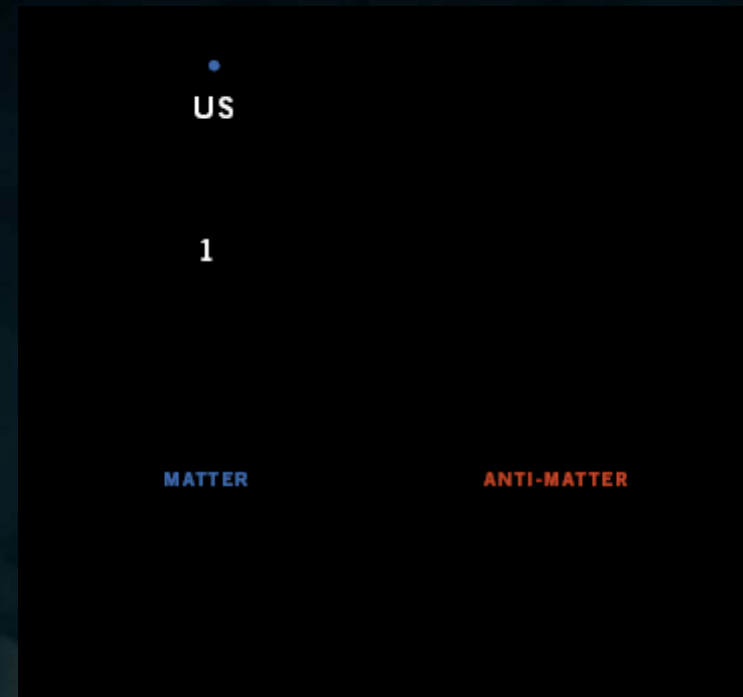
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THE BIG BANG

- 14 billion years ago, the Big Bang produced equal amounts of matter and antimatter
- Everything should have annihilated
- Instead...



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WHAT HAPPENED TO THE ANTIMATTER?

- After 40 years of research we know that some particles (quarks) behave differently from their antiparticles
 - But this difference is very slight – not enough to explain the lack of antimatter in the Universe today
- We are searching for another explanation in the tiniest building blocks of nature, fundamental particles and forces

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SOLVING THE MYSTERY

With neutrinos?

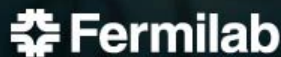
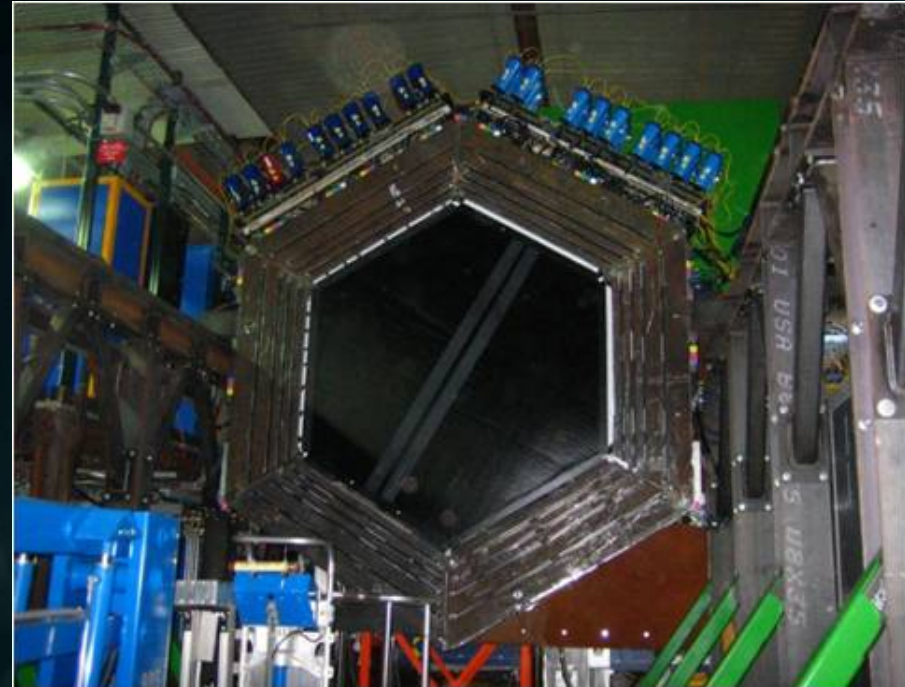
- When they travel over long distances, neutrinos and their antimatter counterparts may behave differently
- Experiments in US, Japan and Europe underway to look for this



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University of Rochester also involved in these experiments

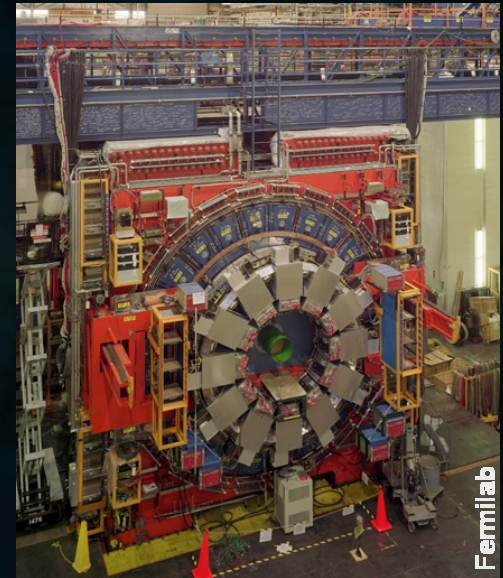
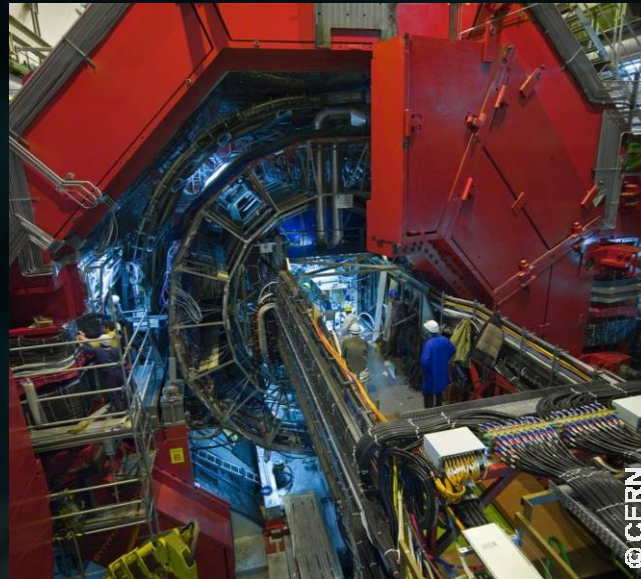


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SOLVING THE MYSTERY

Do completely new particles or forces
differentiate matter from anti-matter?



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WHY DO WE HAVE MASS?

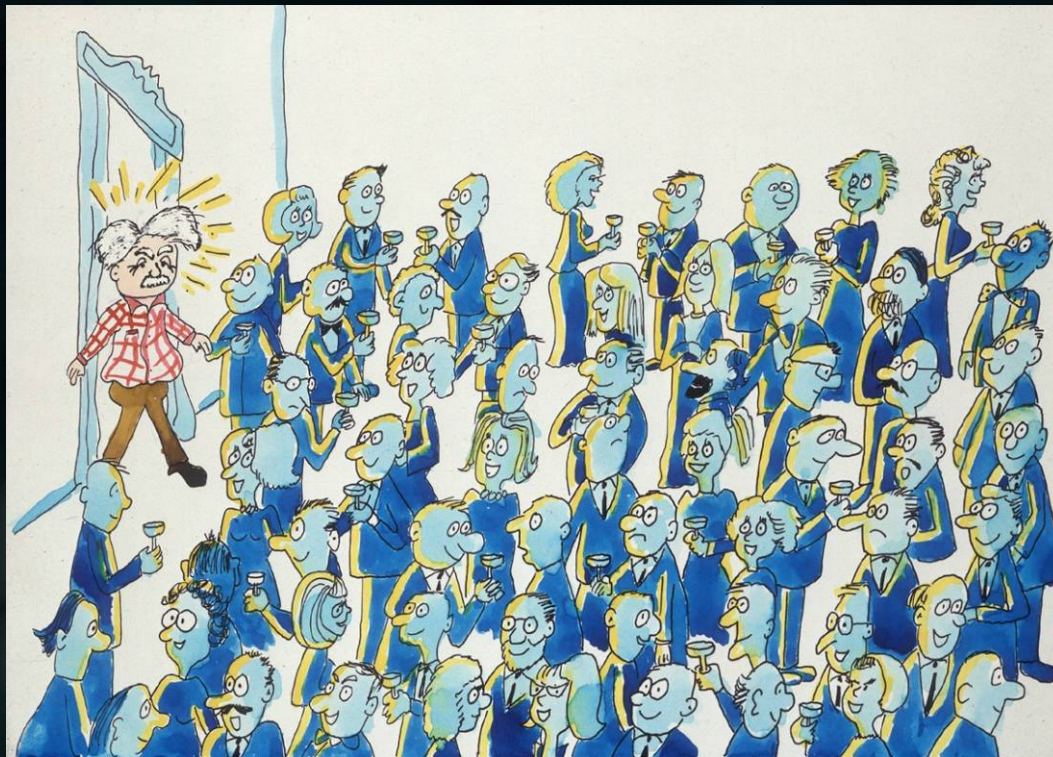
- Still a mystery
- One possibility: Higgs field
- Predicted in 1964
- Still unconfirmed

- Can prove it by finding the **Higgs Boson**
- God particle is BIG misnomer, introduced to sell books!

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WHAT'S A HIGGS BOSON?



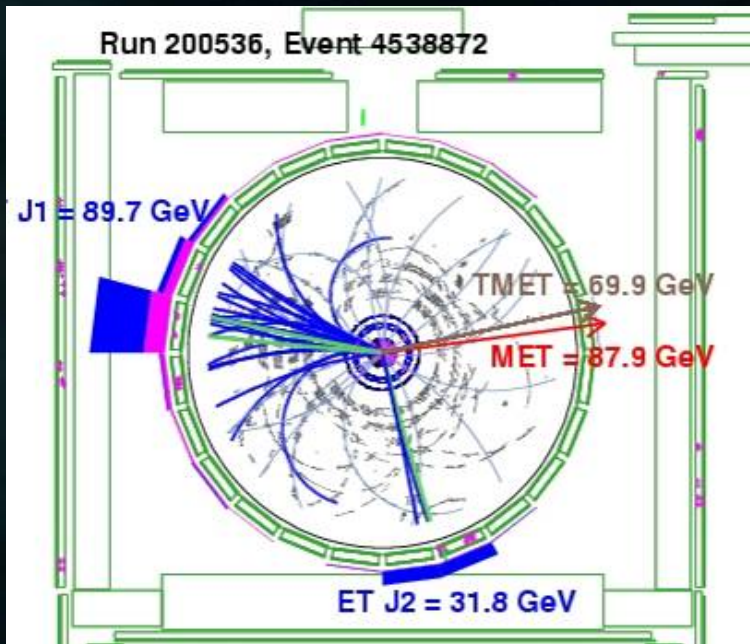
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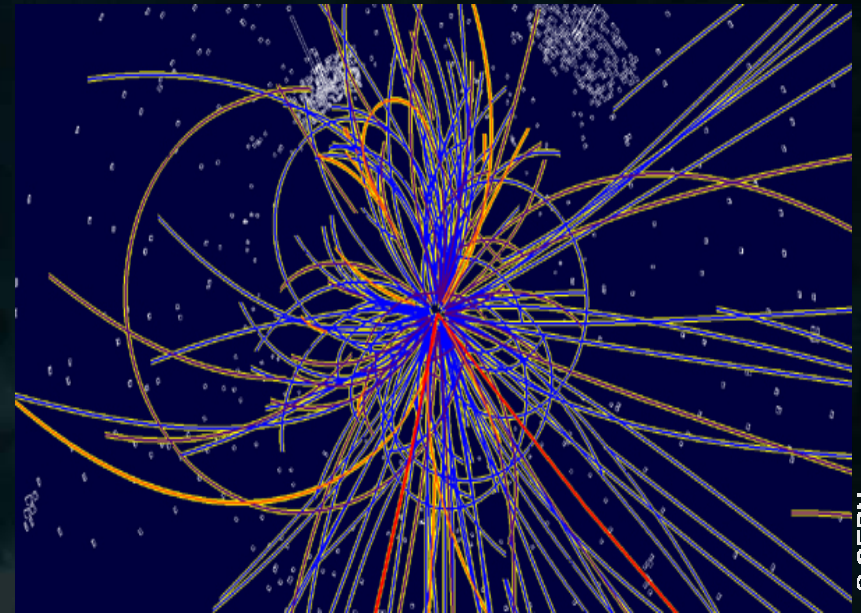
THE SEARCH IS ON

Tevatron



Fermilab

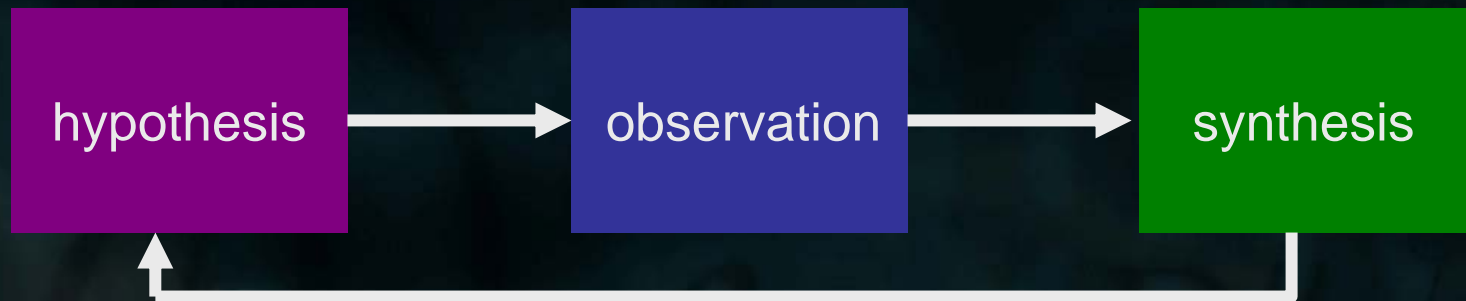
Large Hadron Collider



© CERN

Science and Religion

- Science wants to address creation of our Universe, just as religion does. Scientists follow the scientific method:



- Many scientists find justification for their faith in the results of their work.
- We believe there is no inherent conflict.

A large, dark, monochromatic statue of an angel and a demon. The angel is on the left, with its wings spread and head turned towards the demon. The demon is on the right, with its head covered in a hood and its body in a dark, flowing robe. The background is a dark, atmospheric landscape with a bright light source behind the angel's head.

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THANK YOU

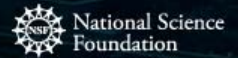
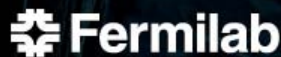
For more information

www.uslhc.us

www.fnal.gov

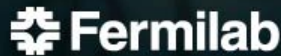
www.cern.ch

www.pas.rochester.edu



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BACKUP MATERIAL

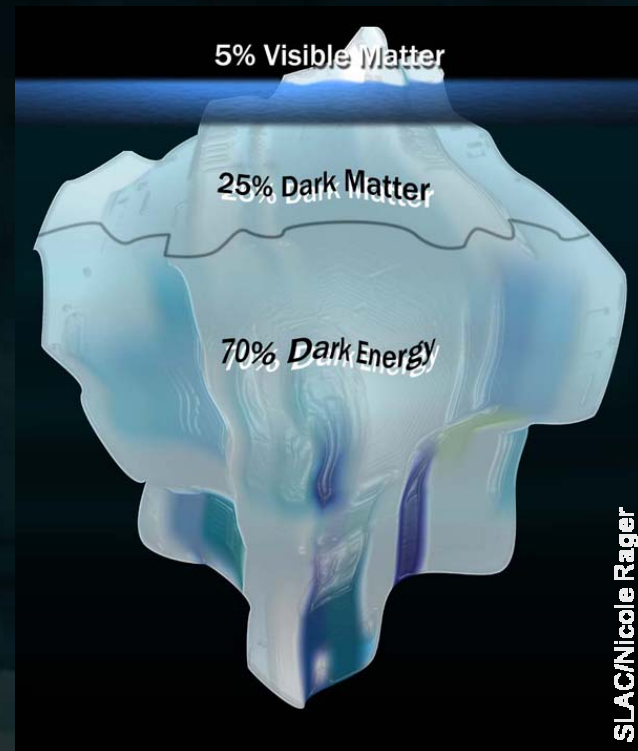


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WHAT'S OUT THERE?

- Astronomy tells us:
- The matter we know is 5% of the universe
- The rest is dark matter
- And dark energy



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DARK MATTER

- “Dark” because we can’t detect it
- Can tell it’s there from effects on galaxies
- Could be made of undiscovered particles



NASA/JES&C, Heymans (Univ. of Edinburgh), Gray (Univ. of Nottingham), Barden (Imperial College London), Wot (Oxford University), K. Weisheimer (Max-Planck Institute for Astronomy), the COMBO-17 collaboration

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SEARCHING FOR DARK MATTER

On earth



In space



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WE MIGHT EVEN MAKE DARK MATTER

At particle accelerators like the Large Hadron Collider

