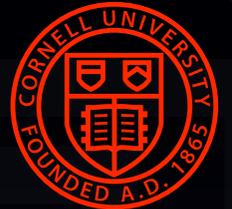


# The Physics of ANGELS & DEMONS

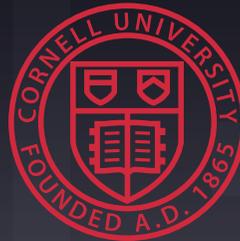


*Flip Tanedo & Don Teo*

PhD students in theoretical and experimental particle physics  
Cornell Laboratory for Elementary Particle Physics (LEPP)



Cornell



University

# The Story

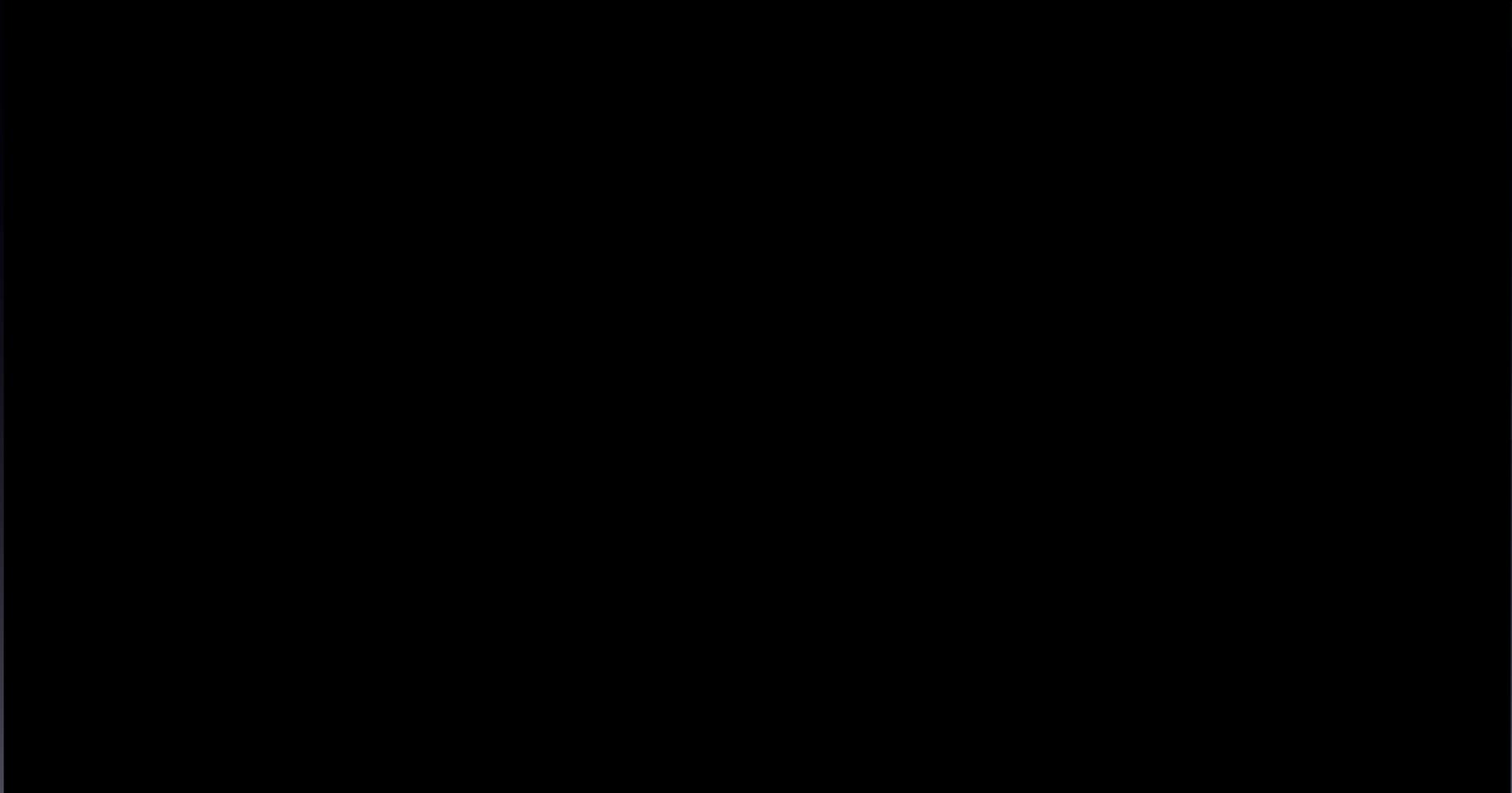


- The Illuminati? (Or is it?)
- **Antimatter** is stolen from the Large Hadron Collider
- ... and is used as a **weapon** to threaten the Vatican
- Robert Langdon and Vittoria Vetra (**CERN**) save the day

# The Story

- **HEP**: study the fundamental laws of nature
- **Standard Model**: quantum theory that has been remarkably successful...
- ... but there's still a lot we don't know.
- Exciting developments in **theoretical** and **experimental** work

# Trailer



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# Fact vs. Fiction



Prof. Csaba Csáki  
Theoretical Particle Physicist  
Cornell University



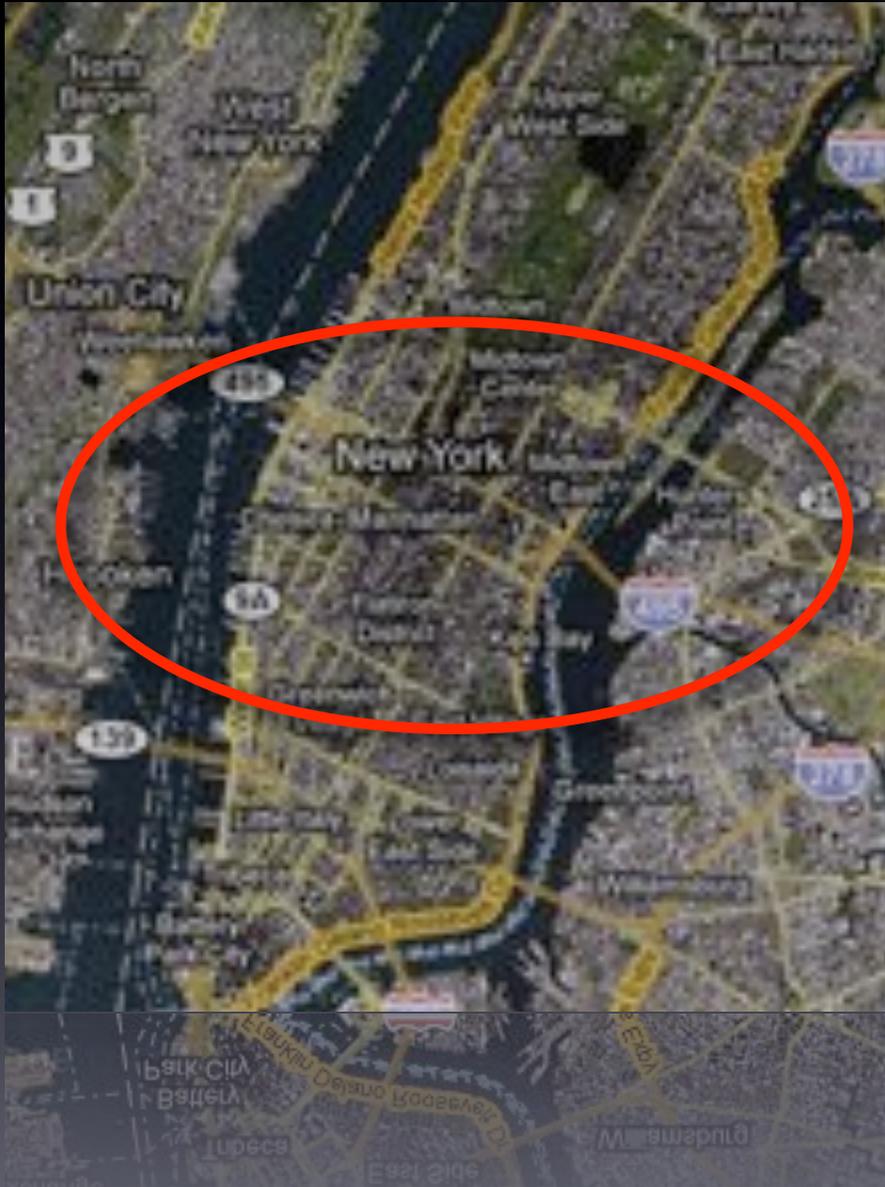
Prof. Robert Langdon  
“Symbologist”  
Harvard University

# Fact: CERN Exists



- European Organization for Nuclear Research  
*Conseil Européen pour la Recherche Nucléaire*
- Large Hadron Collider
- 25 km circumference
- Actually *five* experiments:  
ATLAS, CMS, LHCb, ALICE, TOTEM
- Founded in 1954: proto-EU
- 20 member states
- Mission: *fundamental science*

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# Fact: CERN Exists



- 9,000 scientists (1,000 from US universities/labs)
- World's most powerful accelerator

# Similar labs in the US



 Fermilab



  **LEPP**  
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

# What kind of science?

- **Physics**: probe fundamental interactions
- **Physics**: photon physics, lasers
- **Chemistry**: atomic-scale microscope
- **Medicine**: cancer therapy
- **Spin-offs**: microwaves, world-wide web

# Why colliders?

$$E = mc^2$$

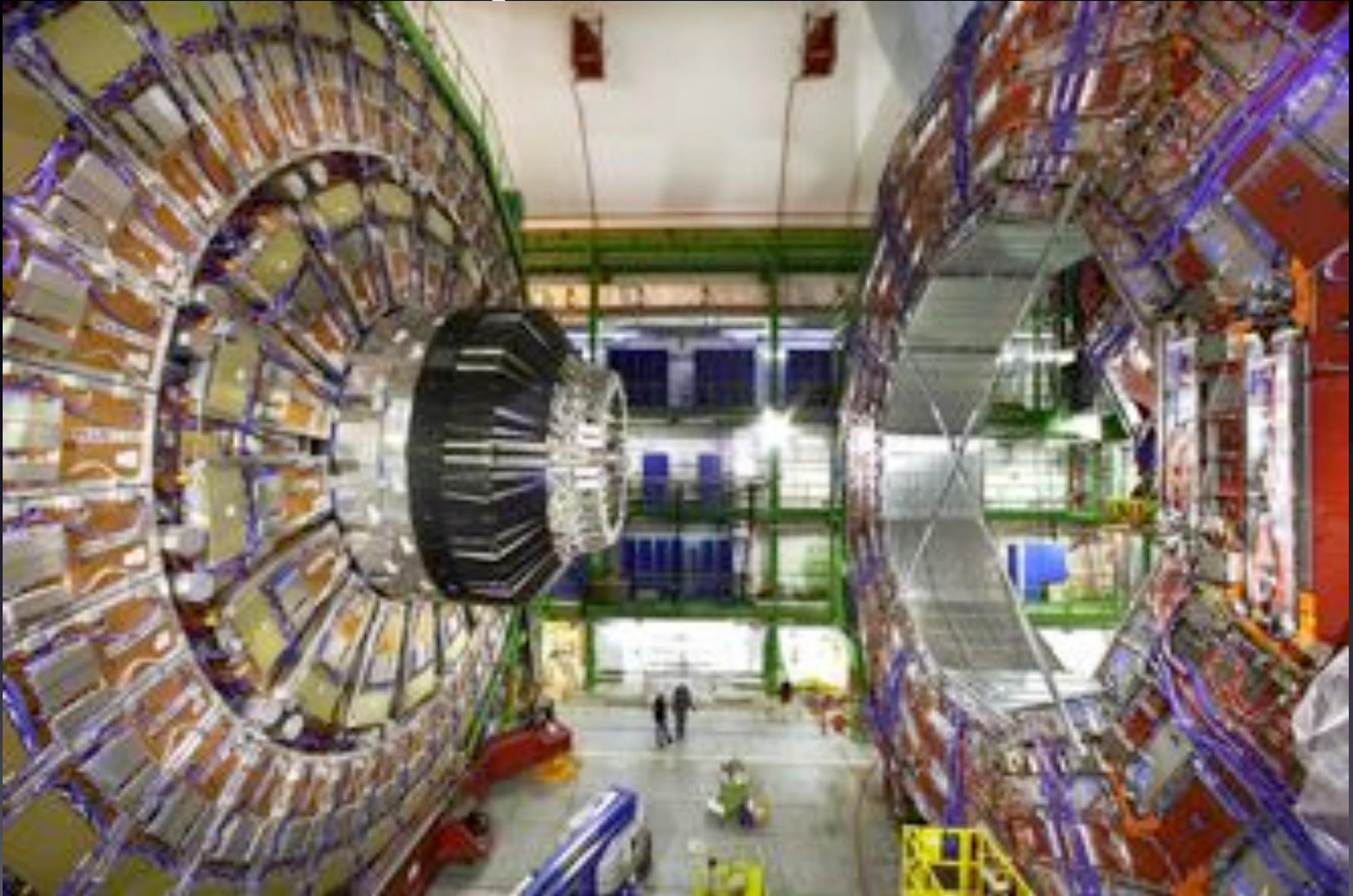
- The universe is made of light particles
- In order to make **massive** particles, need to convert lots of **energy** into **matter**.

# Why colliders?

$$E^2 = m^2 c^4 + p^2 c^2$$

- Mass is a kind of “potential energy”
- Turn **kinetic energy** into **potential energy**
- Speed of light is big... so a **lot** of kinetic energy is required to make a little mass

# Why colliders?



# Energies at the LHC

- Battleship cannons: 300 MJ
- LHC *beams* at full energy: 700 MJ
- LHC particle collision energy  $\sim 10^{-7}$  J  
(kinetic energy of a dozen mosquitoes)



# **Fiction:** 99% speed of light



... it's actually 99.999998% of the speed of light

# **Fiction:** lab coats



# Real physicists



**Theorist!** →



# Real Control Room



**Fermilab:** No windows, no lab coats, lots of post-it notes

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# Fact: Antimatter



plush particles from [particlezoo.net](http://particlezoo.net)

- “Opposite” of matter
- Annihilates with matter to produce energy

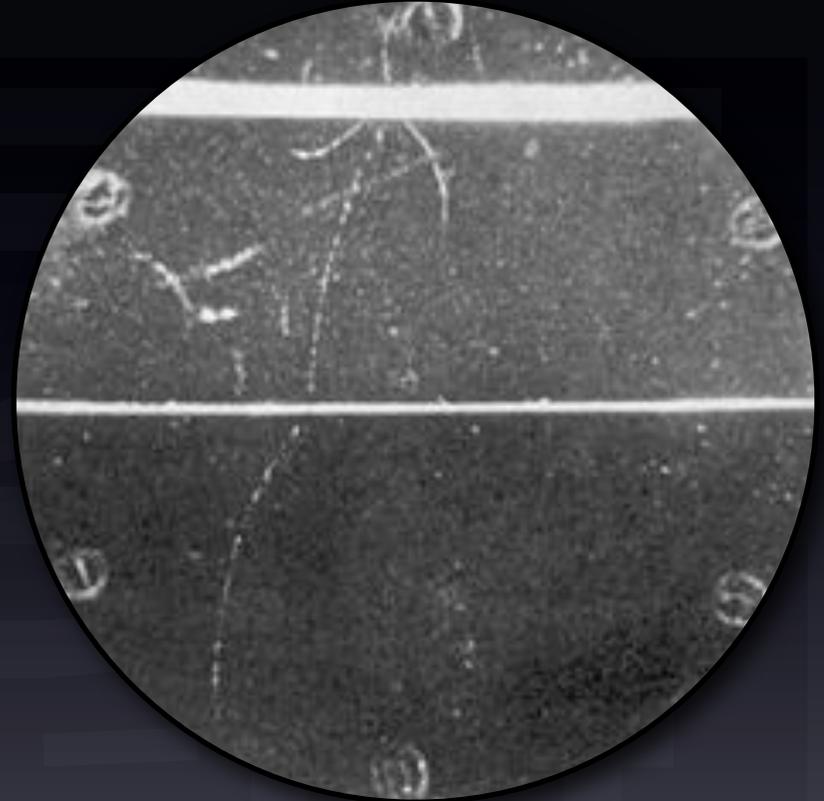
# What is antimatter?



- Charge-Parity conjugation
- **Right-handed, +charged** particle converted into a **left-handed, - charged** particle
- All fundamental particles have anti-partners
- Can even produce anti-*atoms* (1995 in CERN)... but can only store for a few sec.

# Since the 1930s...

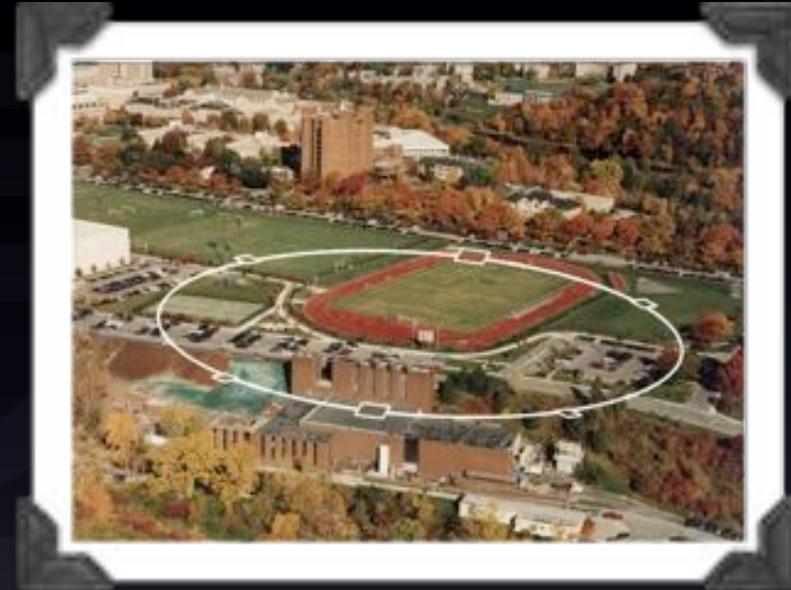
- **1933**: **Dirac** proposes positron
- **Anderson** discovers soon after
- Required for theoretical consistency of quantum theory
- Major role in chemistry
- Now used routinely in medicine (PET scans)



Physical Review 43, 1034 (1933)

# Producing antimatter

- **Cornell**: produce positrons,  $e^+$
- Collide  $e^+$  and  $e^-$  to produce **D mesons**
- 10 min to fill ring with  $e^+$
- **Tevatron**: 1.6 trillion antiprotons in 8 hours
- 1 million collisions makes only 20 antiprotons (low efficiency)



# Producing antimatter



**Nature** can produce antimatter, too.

# Producing antimatter

## Potassium-40 ( $^{40}\text{K}$ )

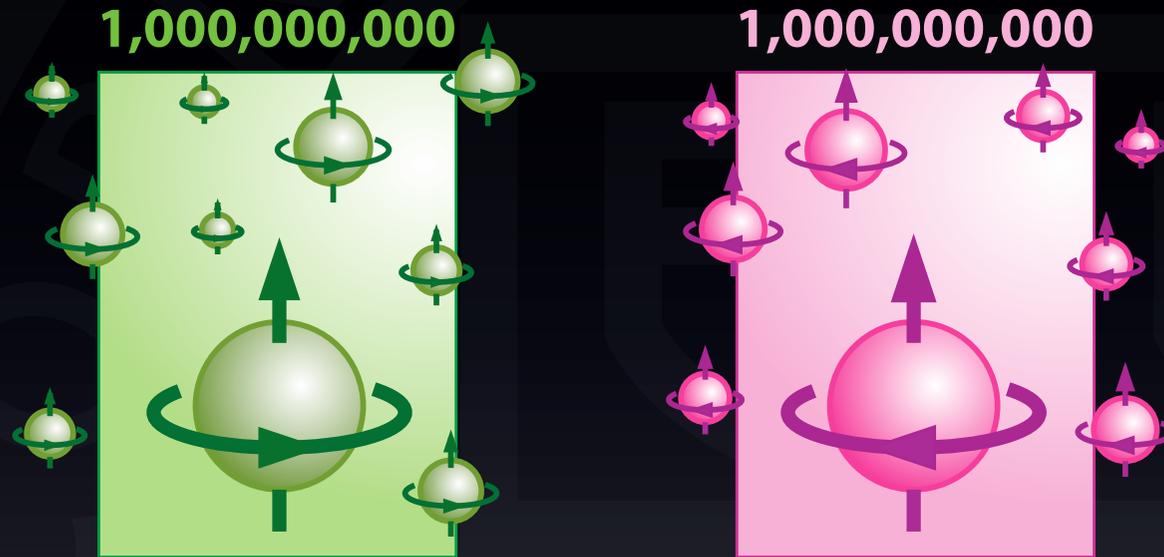
- 100 ppm of natural potassium
- $\tau \sim$  billion years
- $^{40}\text{K} \rightarrow ^{40}\text{Ca} + e^- + \bar{\nu}_e$  (89%)
- $^{40}\text{K} + e^- \rightarrow ^{40}\text{Ar} + \nu_e$  (11%)
- $^{40}\text{K} \rightarrow ^{40}\text{Ar} + e^+ + \nu_e$  ( $10^{-5}\%$ )

People contain  $^{40}\text{K}$ !  
You produce antimatter.



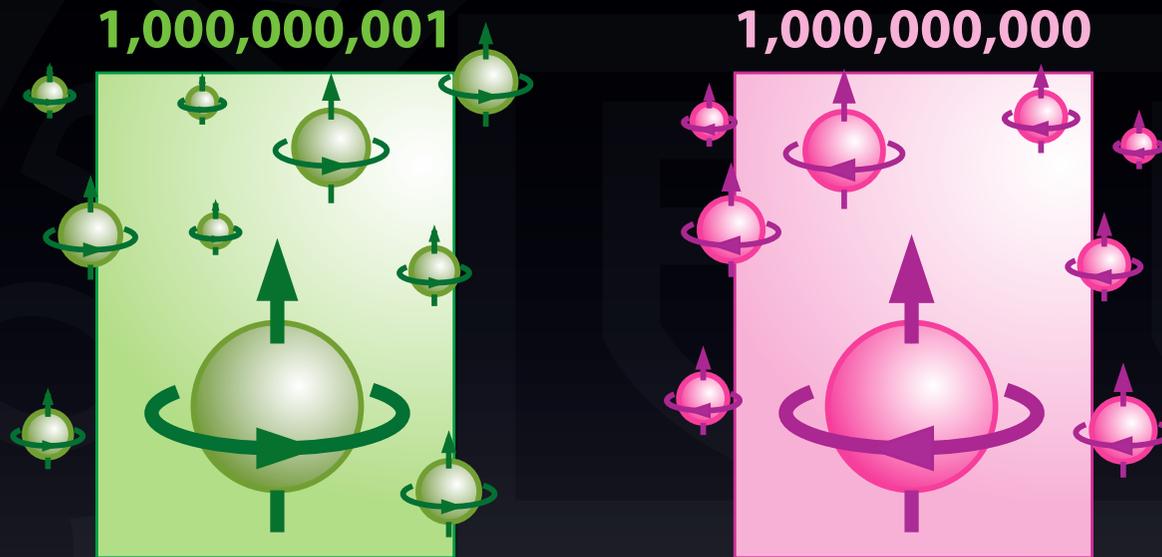
Contains  $e^+$   
every 75 min

# Early universe



Big bang produces equal amounts of matter and antimatter. Why do we only see matter?

# Early universe



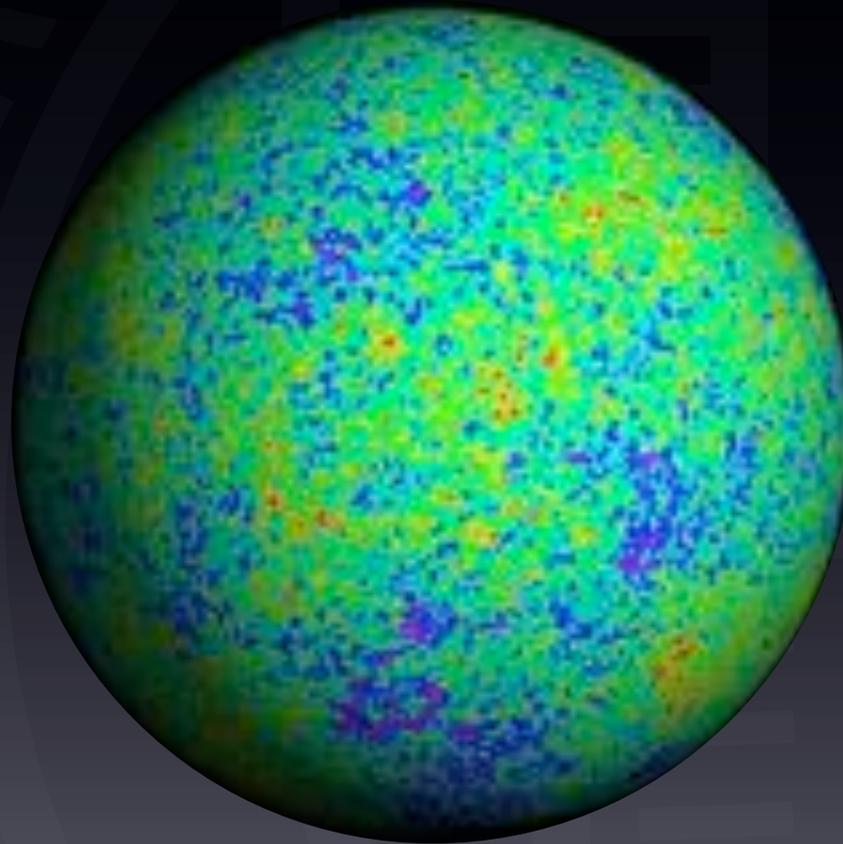
Assume there's some **small** asymmetry from **initial conditions** or **dynamics**.

# Early universe



- Matter-antimatter annihilation
- **CMB**: the remnants of a cosmic annihilation

# Cosmic Microwave Background



# What's the matter with antimatter?

- Why is the universe made of matter but not antimatter? (“**CP violation**”)
- If the universe started with equal amounts of matter and antimatter, how did it generate a **matter-antimatter asymmetry**?
- Can some particles be their own anti-particles? (maybe **neutrinos**?)

# **Fiction:** a gram of antimatter



Glowing?  
Um... that's  
**really** bad.

# **Fiction:** a gram of antimatter

- **Movie:**  $\frac{1}{4}$  g of antimatter  $\sim$  5 kT TNT  
(Hiroshima: 15 kT TNT)
- $\frac{1}{4}$  g  $\sim 10^{23}$  antiprotons
- 1.6 trillion  $P^+$  in 8 hrs  $\Rightarrow$  100 million years
- **Movie:** produced this in 3 seconds

# **Fiction:** a gram of antimatter



- No way to store anti-matter
- LHC is a proton collider...  
no antimatter stored

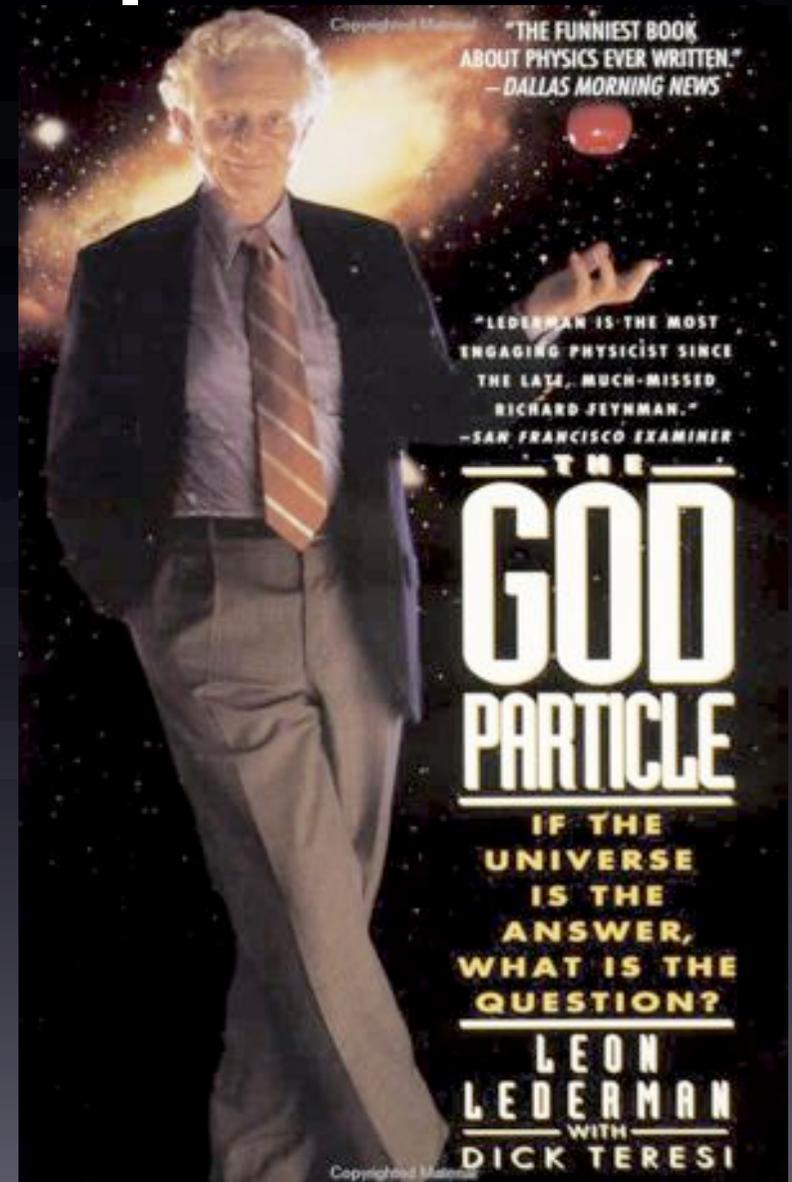
# Is it useful?



- **Sci-fi**: powers the starship *Enterprise*
- ... but not feasible in the near-term
- **Chemistry**:  $\beta$ -decay
- **Medicine**: basis of **PET** scans

# Fact: the 'God' particle

- Its real name is the **Higgs boson**
- Gives [most] other particles their mass  
**electroweak symmetry breaking**
- Exception: atomic nucleus; mass comes from **gluons**
- Not yet discovered... could it be that there is an alternative mechanism?

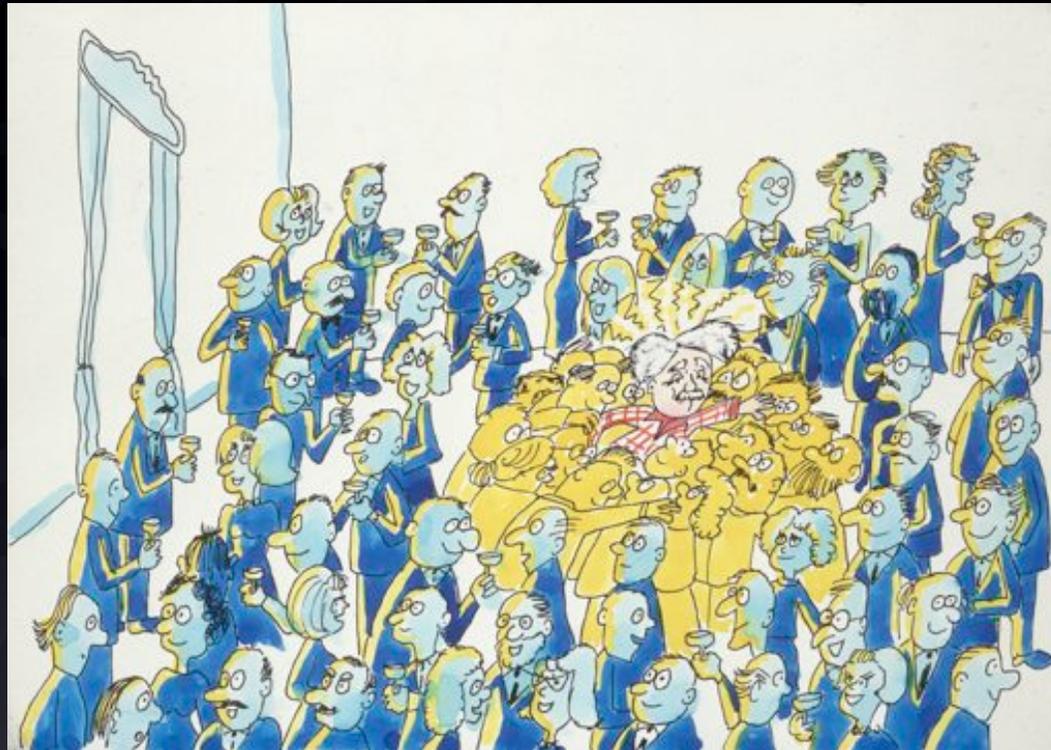


# The Higgs Boson



Suppose particles are like a famous scientist.

# The Higgs Boson



The particle is slowed down by a crowd of people (Higgs bosons) that want to chat

# The Higgs Boson



The Higgs gives itself mass: imagine a *rumor* that a famous scientist is coming soon.

# **Fiction:** bio-entanglement physics

- ✓ Biology
- ✓ Entanglement
- ✓ Biophysics
- ✓ Entanglement physics
- ✗ Bio-entanglement physics



# Real LHC Physics

- **Electroweak Symmetry Breaking**: what gives particles mass? **Higgs**, or something **exotic**?
- Are there new sources of **CP violation** (matter/antimatter asymmetry)?
- ‘Hot and dense’ physics (“heavy ion”)
- New physics scenarios... extra dimensions? Supersymmetry?

# Fiction: 'Illuminati'

- There is **no secret research** at CERN or in any of the US collider facilities
- All research is transparent
- Visitors welcome, **please do take pictures**
- No military research at HEP labs

# Micro Black Holes

Botanist sues to stop CERN hurling Earth into parallel universe

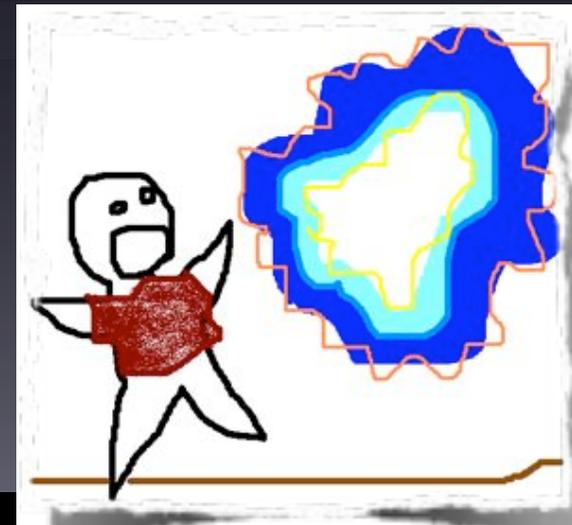
Hawaiian in lawsuit against particle billiards rig

By [Lewis Page](#) • [Get more from this author](#)

Posted in [Physics](#), 28th March 2008 14:11 GMT



“The Large Hadron Collider might make dragons that might eat us up.”  
-Prof. Nima Arkani-Hamed  
New York Times, 29 March 2008

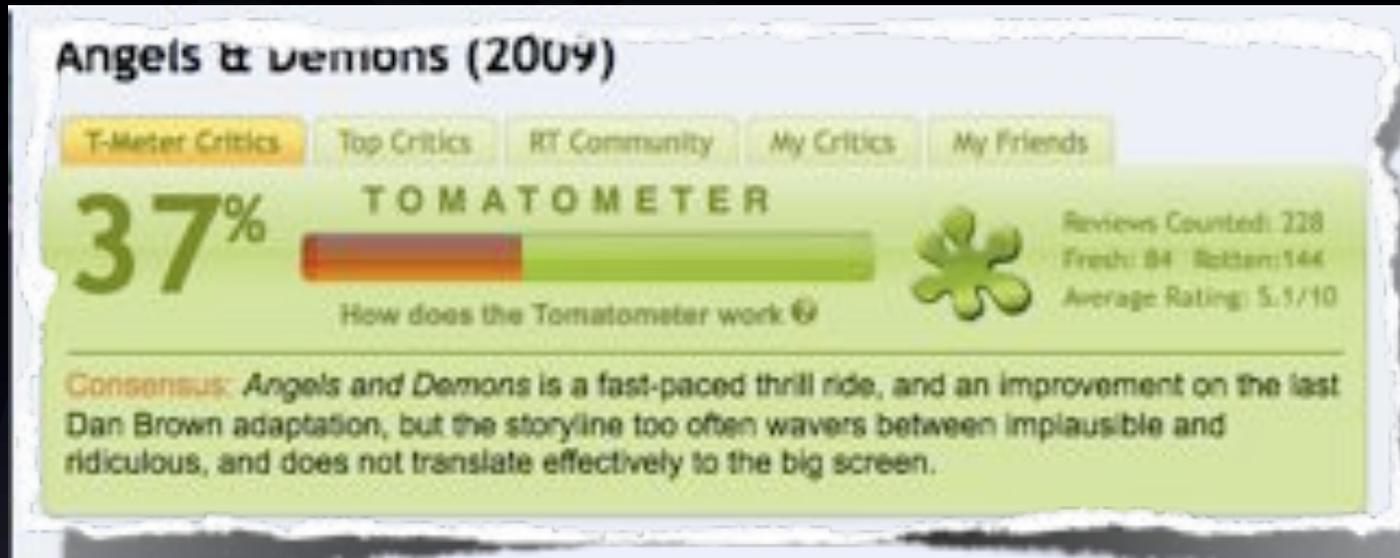


# Micro Black Holes

- LHC black holes? **Maybe**
- Planetary threat? Certainly **not\***
- High energy **cosmic rays** bombard the atmosphere with much higher energies than the LHC; Earth is still around
- Really cool physics, though...
  - ... suggestive of **extra dimensions**
  - ... such black holes would **evaporate** quickly

\*This is a problem in science communication.

# Summary



## Past CERN experiments...



1976 (Ting)



1984 (Rubbia, Van der Meer)



1992 (Charpak)

**LHC:** looking forward to the sequel!

# Further reading

- *The Newtonian Legacy*, Nick Evans.  
“Learn about the frontiers of particle physics within a fast-paced crime adventure.” [Available free online]
- *Insultingly Stupid Movie Physics*, Tom Rogers.  
Also see website. Movie with the worst physics? *The Core*.
- *The Physics of Star Trek*, Lawrence Krauss.  
This is the book that made FT want to be a physicist.
- *US LHC Blogs* ([blogs.uslhq.us](http://blogs.uslhq.us))  
*Quantum Diaries* ([quantumdiaries.org](http://quantumdiaries.org))  
Blogging about life as a particle physicist.