

# The Particle Physics Landscape



What is Higgs telling us?  
What else is there?  
How do we find it?

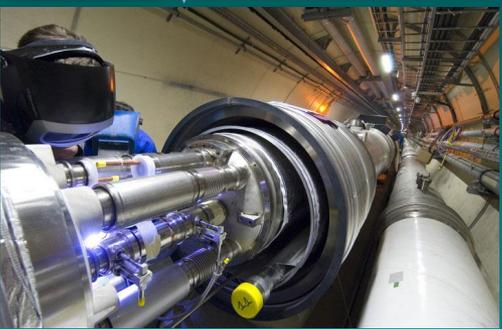
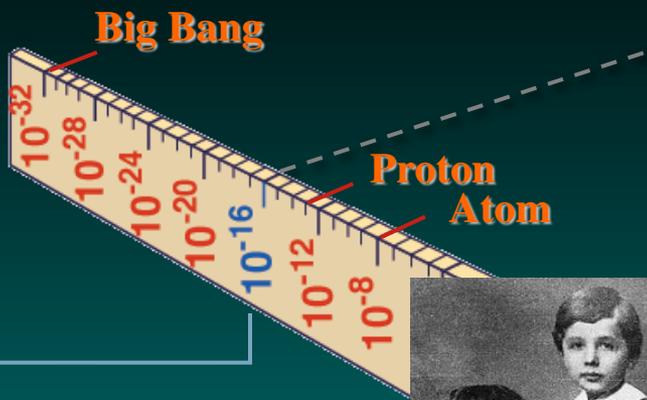
*John Ellis*

**KING'S**  
*College*  
**LONDON**

“Where do we come from?  
What are we?  
Where are we going?”



The aim of particle physics, CERN & the LHC:  
What is the Universe made of?

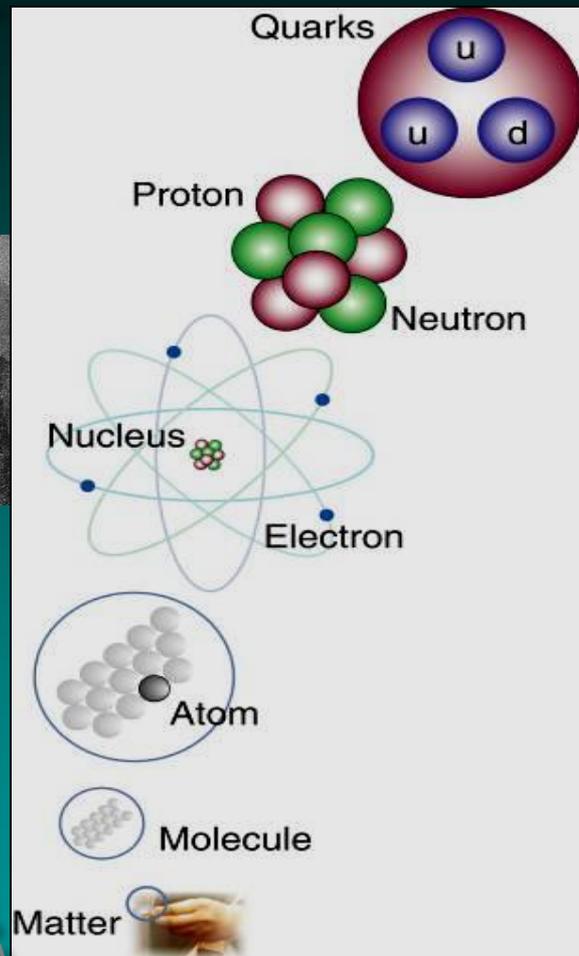


LHC

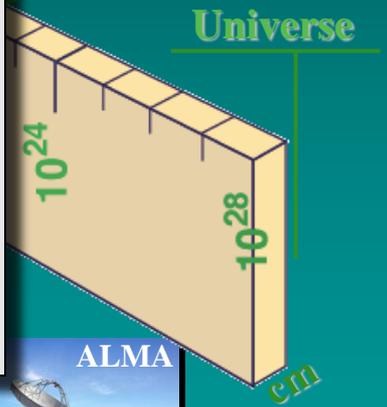
Super-Microscope



Study physics laws of first moments after Big Bang  
 increasing Symbiosis between Particle Physics,  
 Astrophysics and Cosmology



Radius of Galaxies

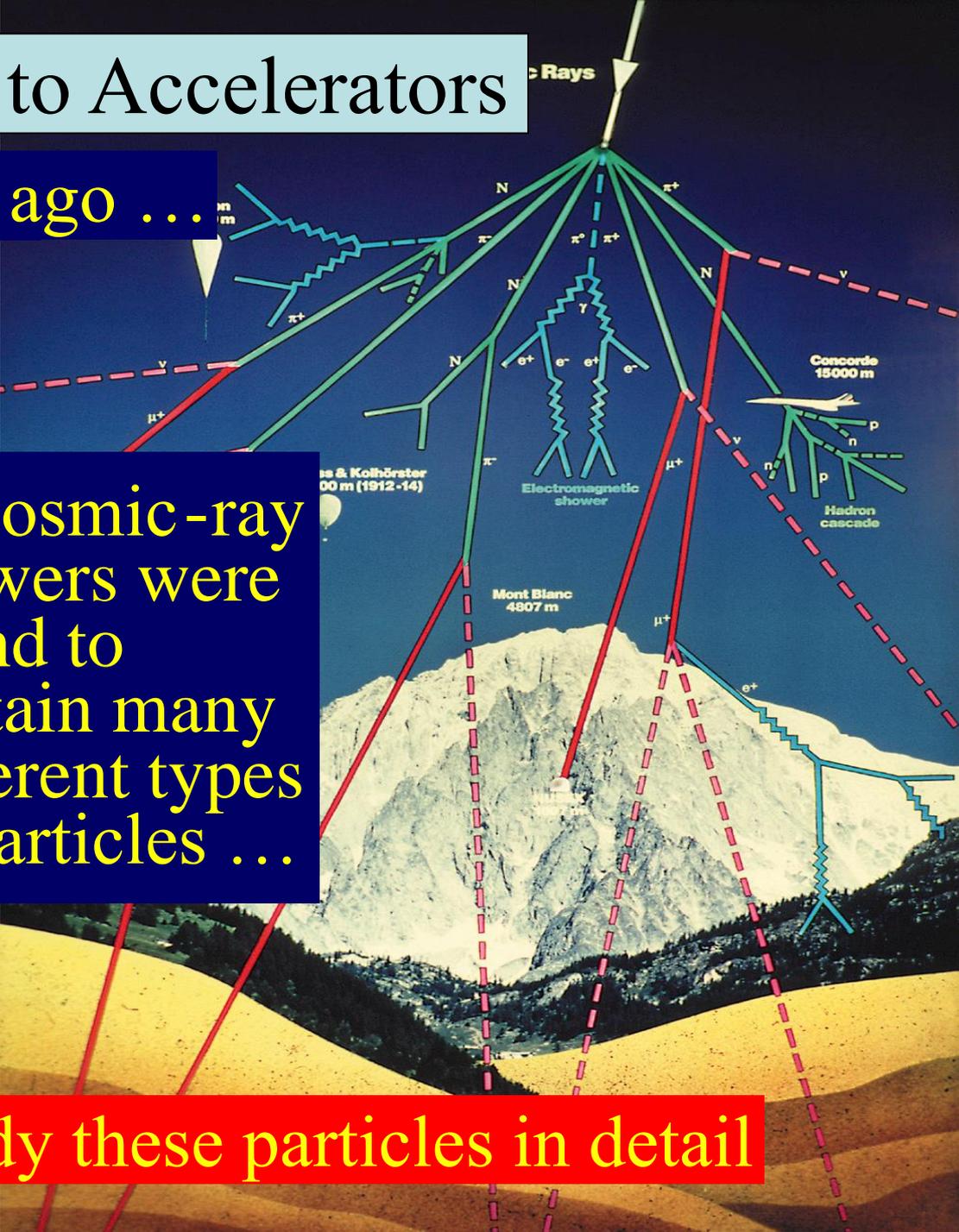
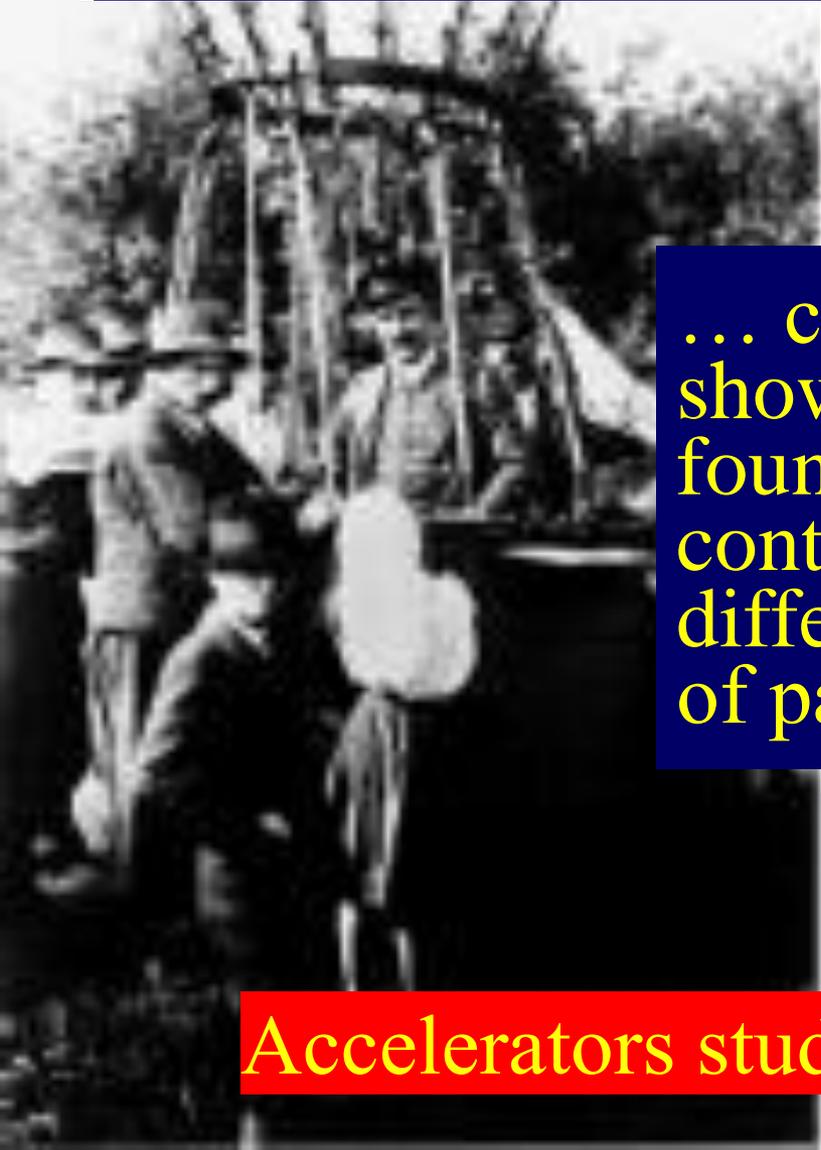


# From Cosmic Rays to Accelerators

Discovered a century ago ...

... cosmic-ray showers were found to contain many different types of particles ...

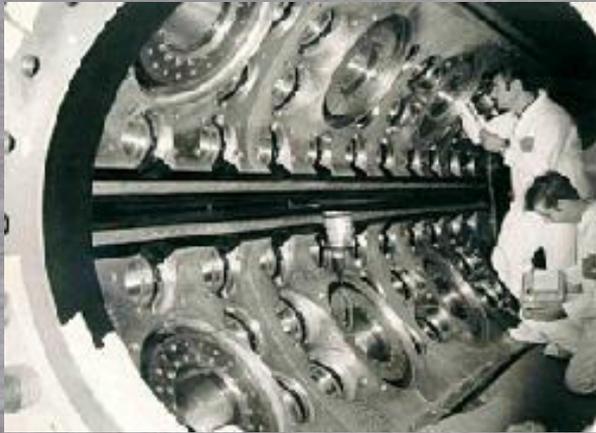
Accelerators study these particles in detail



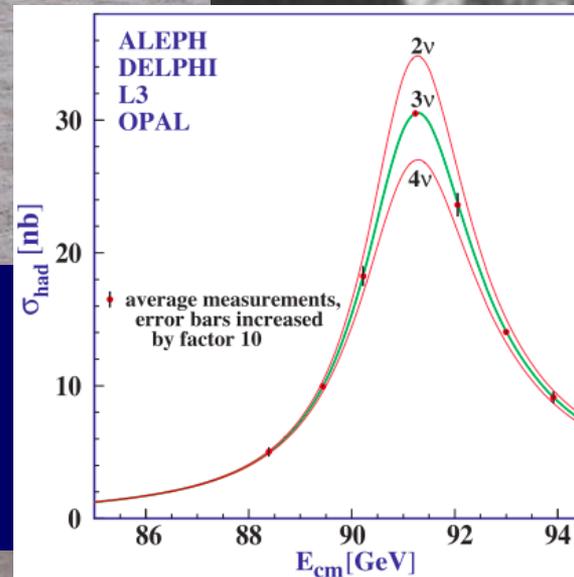
# The 'Standard Model' of Particle Physics

Proposed by Abdus Salam,  
Glashow and Weinberg

Tested by experiments  
at CERN



Perfect agreement between  
theory and experiments  
in all laboratories



# The 'Standard Model'

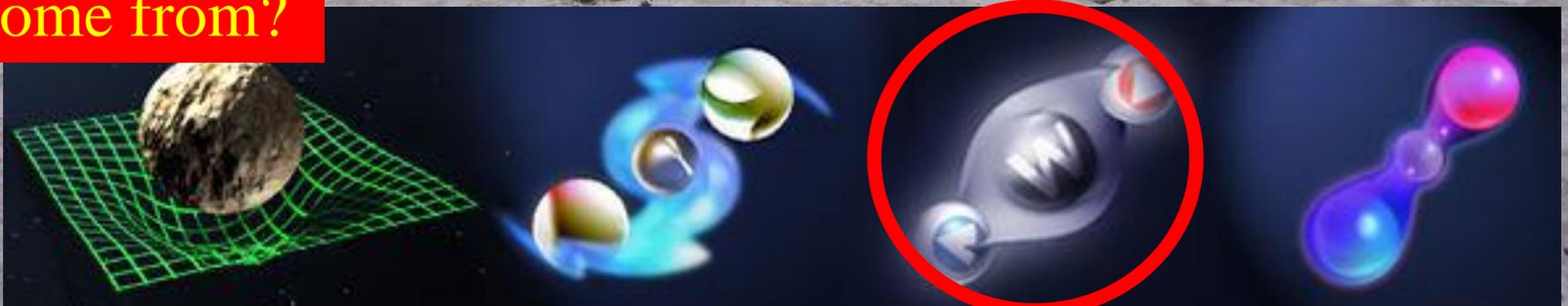
= Cosmic DNA

## The matter particles



Where does mass come from?

## The fundamental interactions



Gravitation

electromagnetism

weak nuclear force

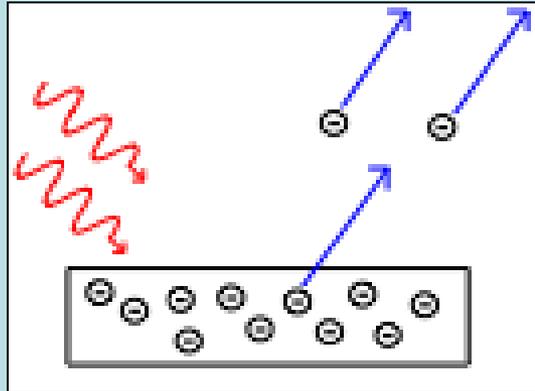
strong nuclear force

# Photon: the Particle of Light

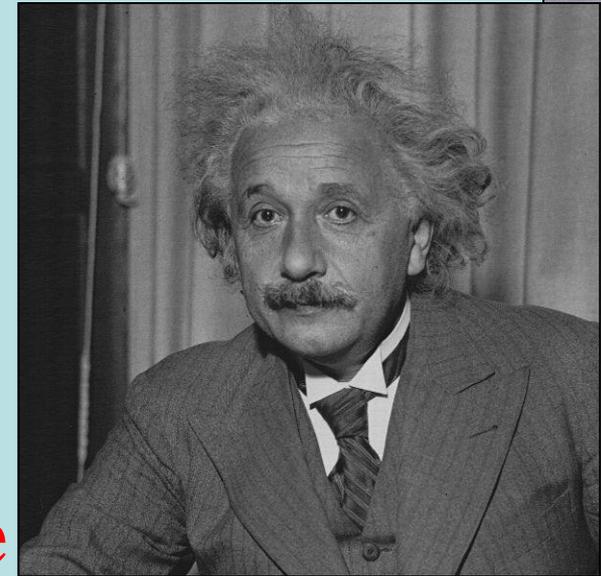
- Quantum hypothesis introduced by Planck:

$$E = hf$$

- Physical reality postulated by Einstein to explain photoelectric effect

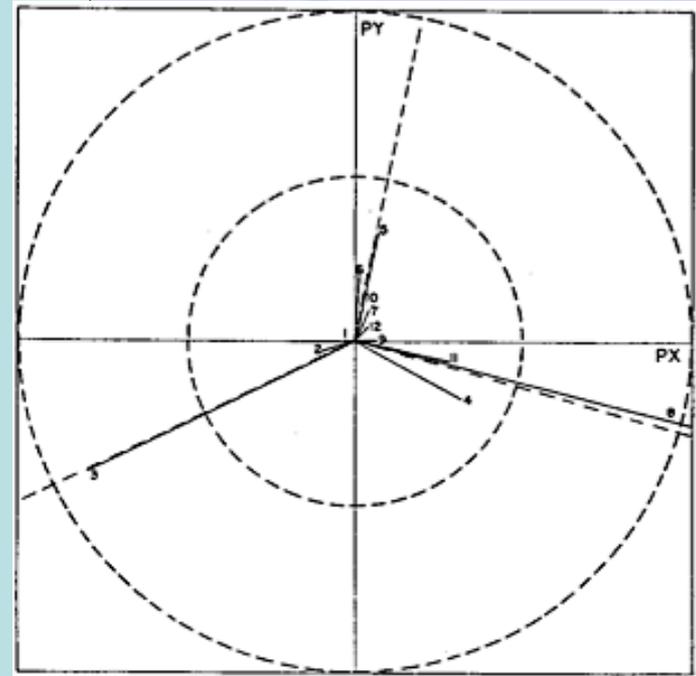


- **Motivation for his Nobel Prize**



# Strong Nuclear Forces

- Modelled after Maxwell's theory
- Carried by 'gluon' particles
- Massless like the photon
- Discovered in 1979
- Using method suggested by JE, Mary Gaillard, Graham Ross in 1976
- **Second force particle discovered**

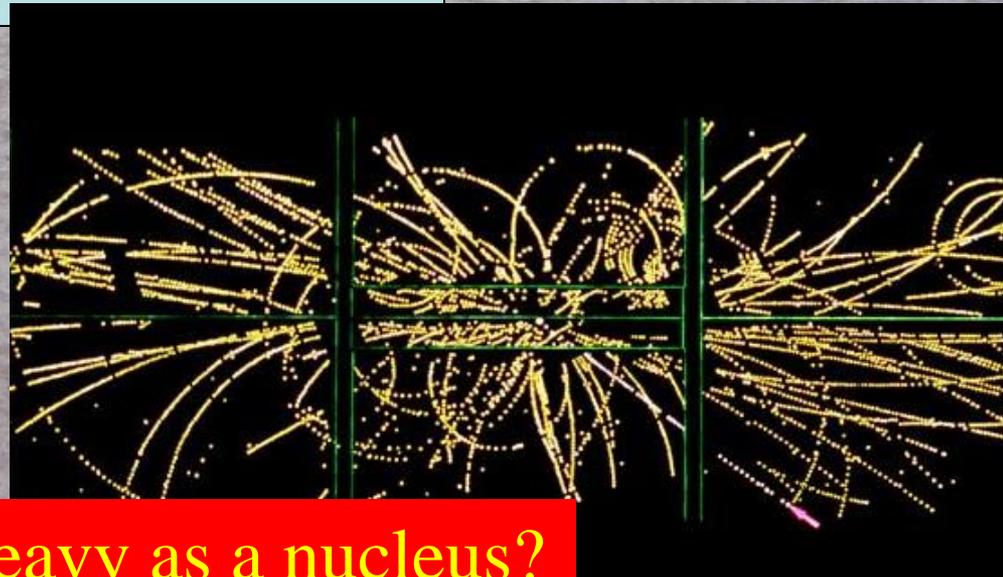
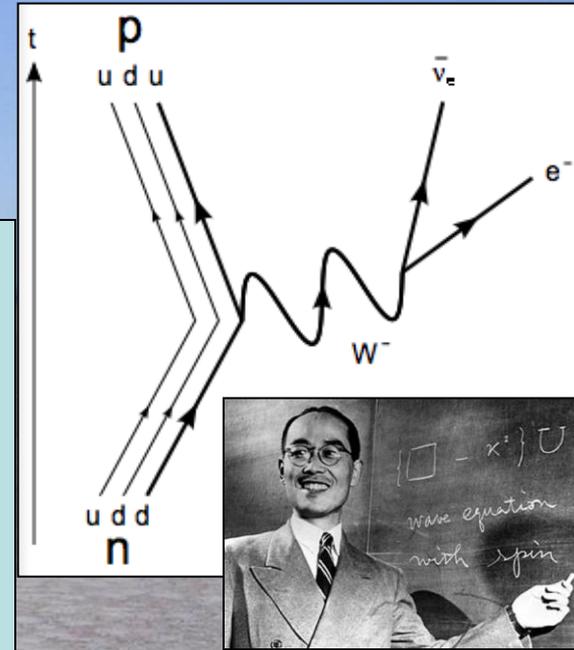


# Weak Interactions

Radioactivity due to weak interactions  
( $\beta$  decay)

**W boson - carrier of weak interaction**  
postulated by Yukawa

Discovered at CERN in  
1983 by Carlo Rubbia et al



**Why is it as heavy as a nucleus?**

# Gauguin's Questions in the Language of Particle Physics

- What is matter made of?
- Why do things weigh?
- What is the origin of matter?
- What is the dark matter that fills the Universe?
- How does the Universe evolve?
- Why is the Universe so big and old?
- What is the future of the Universe?



**Our job is to ask - and answer - these questions**

# Why do Things Weigh?

Newton:

Weight **proportional to** Mass

Einstein:

Energy **related to** Mass

Neither explained origin of Mass

Where do the masses  
come from?

Are masses due to Higgs boson?  
(the physicists' Holy Grail)



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# Think of a Snowfield



Skier moves fast:

Like particle without mass

e.g., photon = particle of light

Snowshoer sinks into snow,  
moves slower:



Like particle with mass

e.g., electron

Hiker sinks deep,

moves very slowly:

Particle with large mass



**The LHC looked for  
the snowflake:  
The Higgs Boson**

# A Phenomenological Profile of the Higgs Boson

- First attempt at systematic survey

## A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

John ELLIS, Mary K. GAILLARD \* and D.V. NANOPOULOS \*\*  
*CERN, Geneva*

Received 7 November 1975

A discussion is given of the production, decay and observability of the scalar Higgs boson  $H$  expected in gauge theories of the weak and electromagnetic interactions such as the Weinberg-Salam model. After reviewing previous experimental limits on the mass of

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3,4] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

# A Simulated Higgs Event @ LHC



To answer these questions:

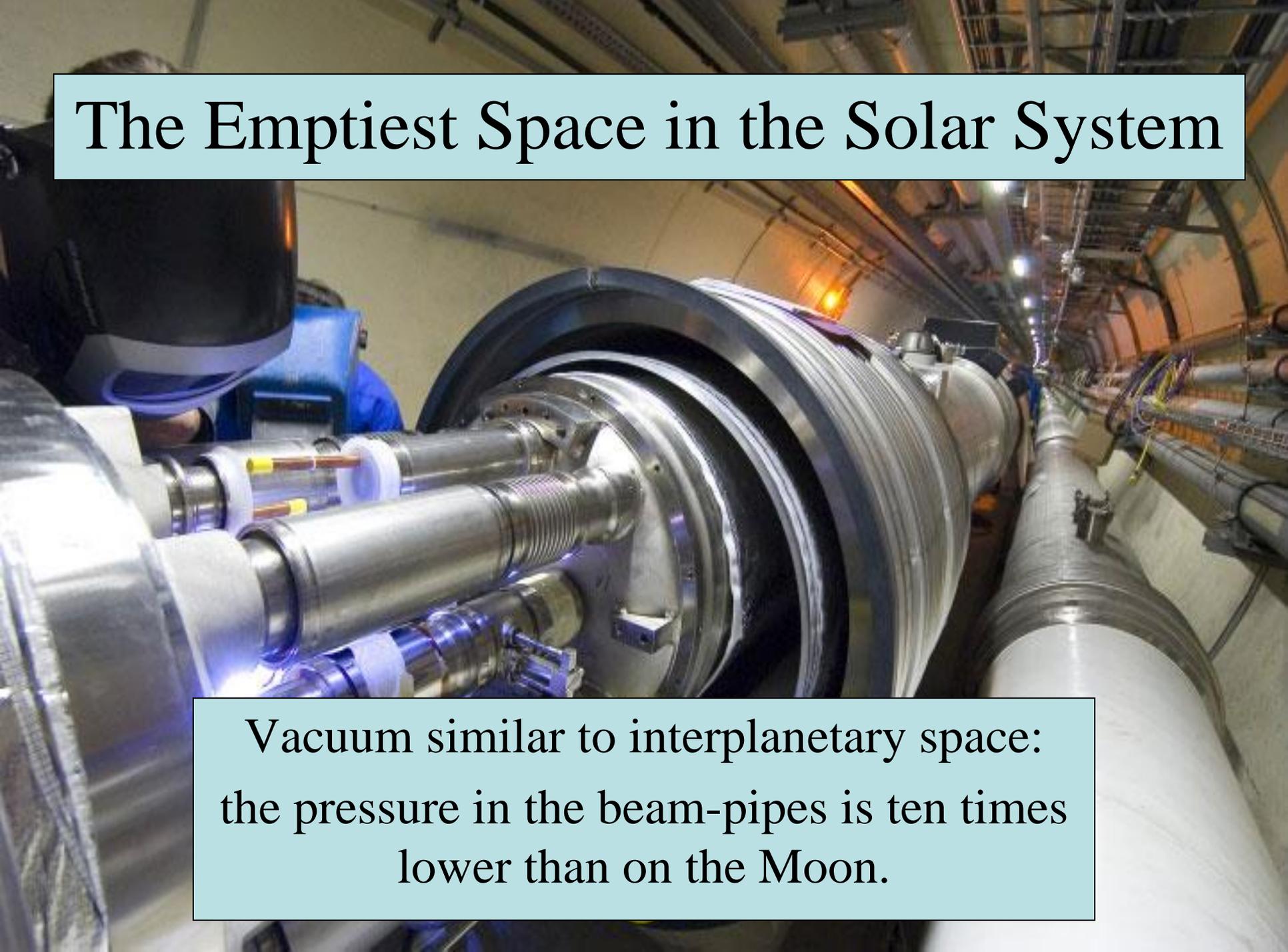
## The Large Hadron Collider (LHC)

Several thousand billion protons  
Each with the energy of a fly  
99.9999991% of light speed  
Orbit 27km ring 11 000 times/second  
A billion collisions a second

Primary targets:

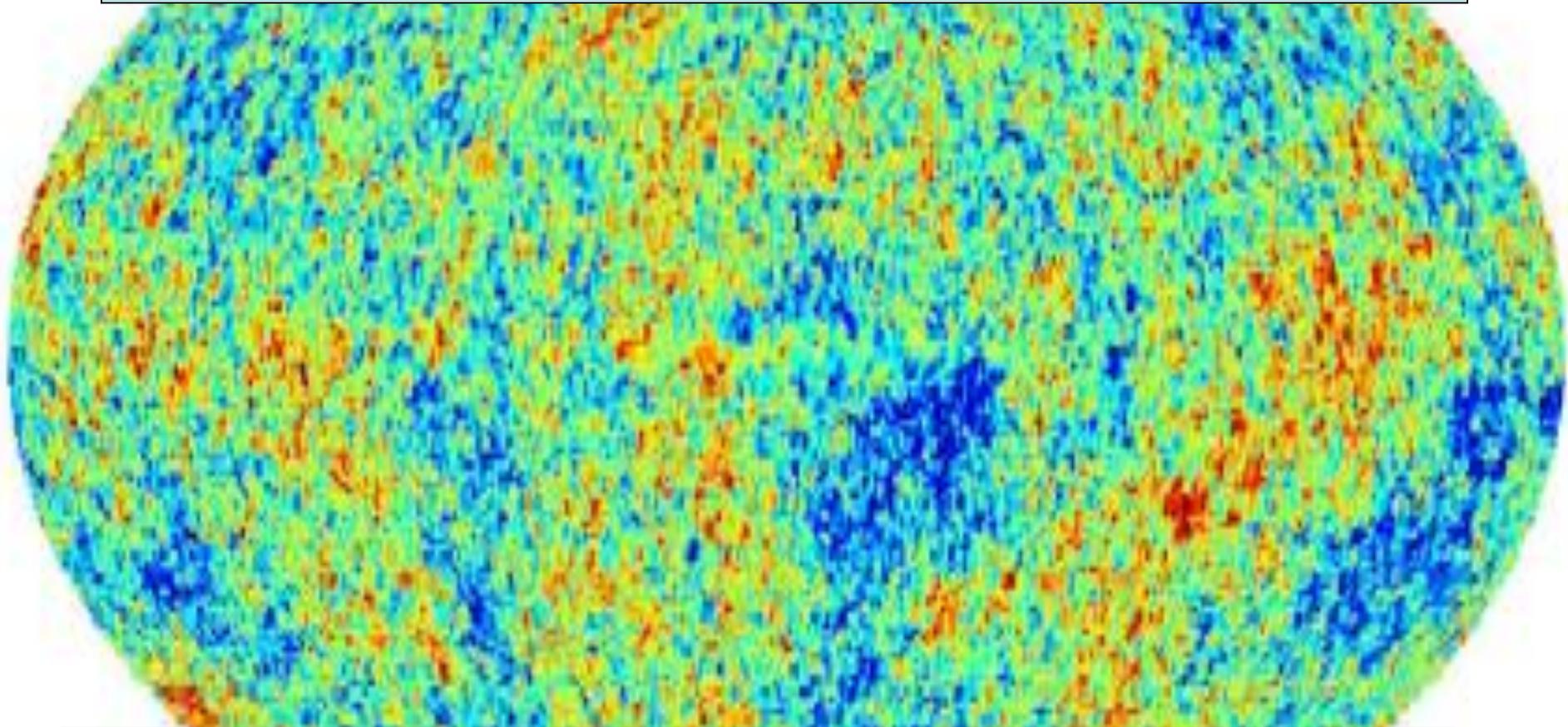
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

# The Emptiest Space in the Solar System

A photograph of a particle accelerator tunnel. The tunnel is long and cylindrical, with a series of large, silver, cylindrical components (beam pipes) running along its length. The components are connected by various pipes and machinery. The lighting is bright, with some orange and blue hues. The perspective is from the end of the tunnel, looking down its length.

Vacuum similar to interplanetary space:  
the pressure in the beam-pipes is ten times  
lower than on the Moon.

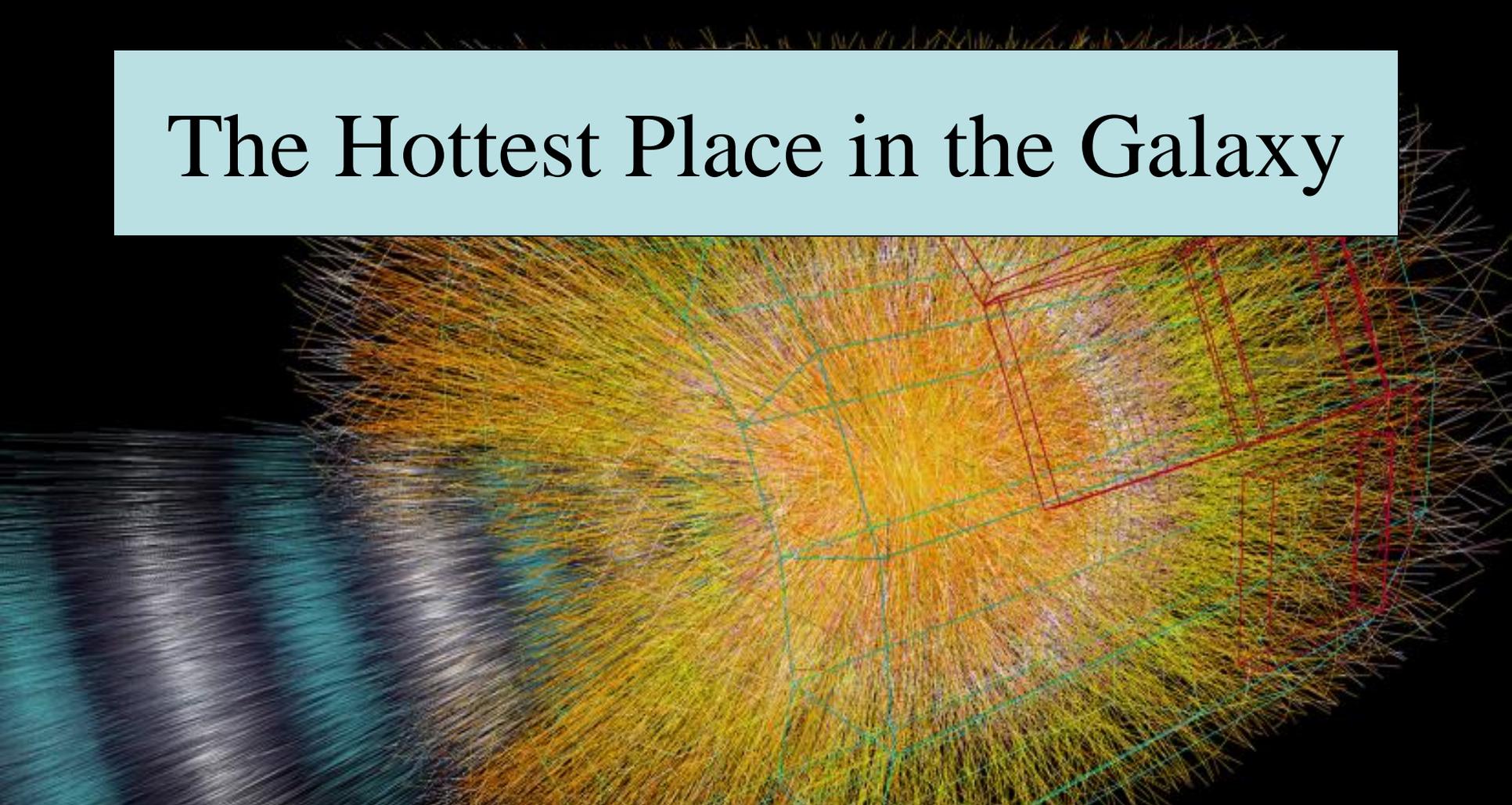
# Cooler than Outer Space



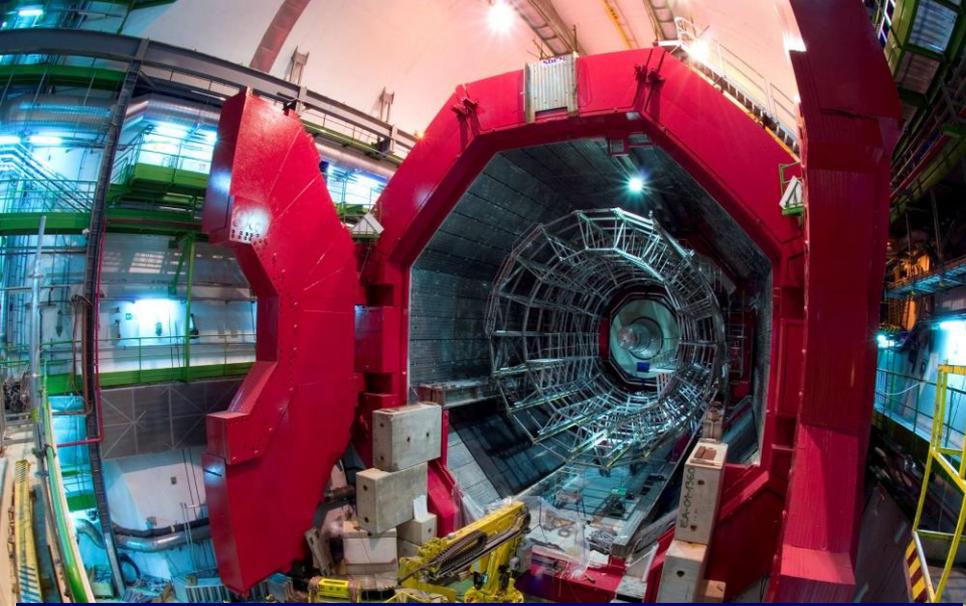
LHC 1.9 degrees above absolute zero = - 271 C

Outer space 2.7 degrees above zero = - 270 C

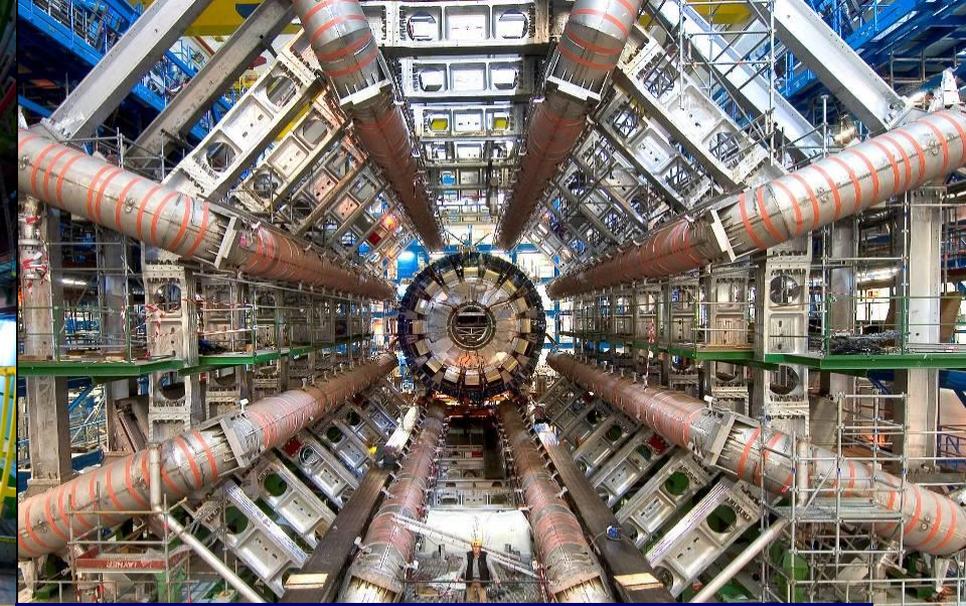
# The Hottest Place in the Galaxy



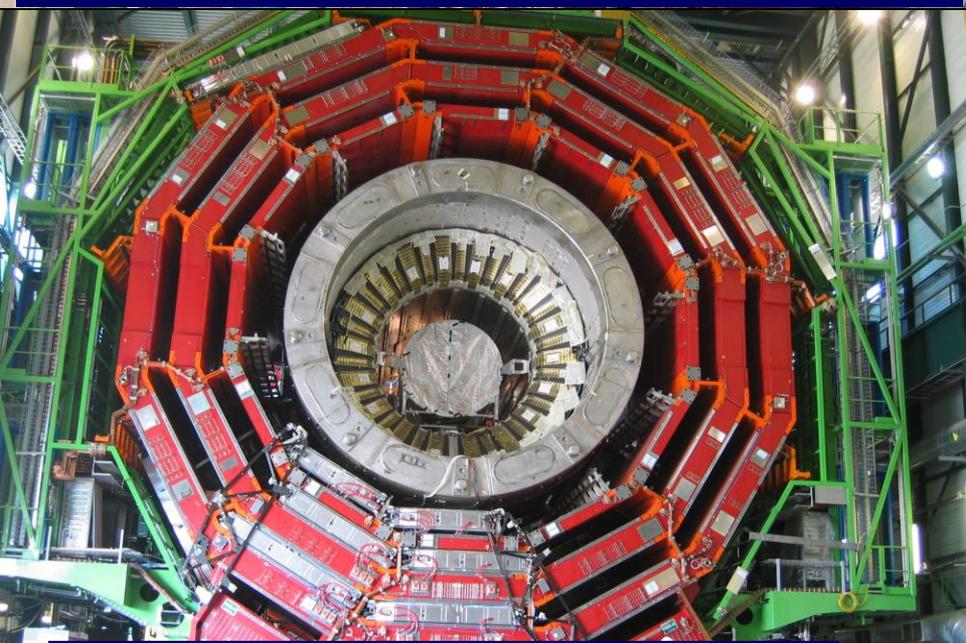
Particle collisions create  
(within a tiny volume)  
temperatures a billion times higher than in  
the heart of the Sun



**ALICE: Primordial cosmic plasma**



**ATLAS: Higgs and dark matter**



**CMS: Higgs and dark matter**

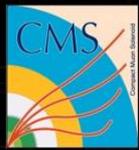


**LHCb: Matter-antimatter difference**

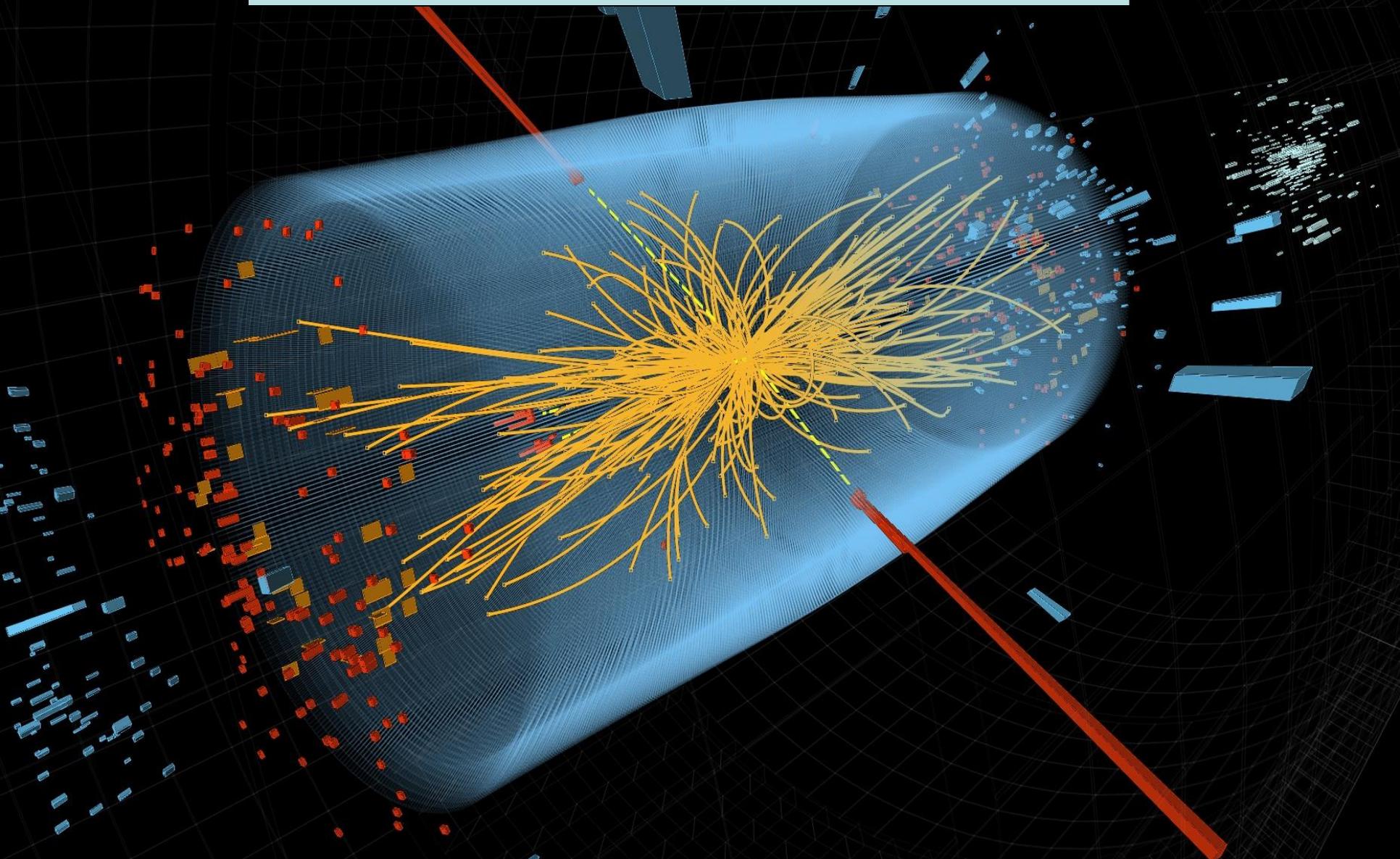
# The Discovery of the Higgs Boson



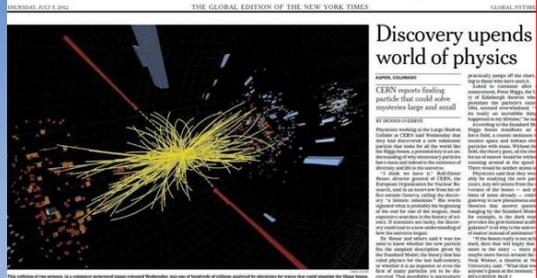
Mass Higgsteria



# Interesting Events



July 4<sup>th</sup> 2012
The discovery of a new particle



Discovery upends world of physics

CERN reports finding particle that could solve mysteries large and small



ヒッグス粒子検出 年内に結論
新素粒子検出 年内に結論
日米欧2チーム

Le Monde newspaper snippet with headline 'Science : la matière dévoilée' and 'Milhares de moradores de bairros sociais em risco de perderem RSI'.

Frankfurter Allgemeine newspaper snippet with headline 'Masse macht's' and 'Große Mehrheit im Bundestag'.

The Gazette newspaper snippet with headline 'falleda la partícula clave para a comprensión del universo'.

MK newspaper snippet with headline 'ПОСЛЕДНИЙ КИРПИЧ В СТЕНУ МИРОЗДАНИЯ' and 'САМОЛЕТЫ ПРИШЛОСЬ МЕНЯТЬ НА ПЕРЕГРABE'.

AD Algemeen Dagblad newspaper snippet with headline 'EINDELIJK BELIJK NA 48 JAAR' and 'Zieke Kaj en zijn moeder toch samen in de VS'.

Frankfurter Allgemeine newspaper snippet with headline 'Große Mehrheit im Bundestag'.

China Daily newspaper snippet with headline 'Big bang moment: Scientists may have found 'God particle''.

The Hindu newspaper snippet with headline 'Elusive particle found, looks like Higgs boson'.

Corriere della Sera newspaper snippet with headline 'La particella che può svelare i segreti dell'universo'.

Gazeta Wyborcza newspaper snippet with headline 'Czastke Higgsa fizycy najpierw wymyślił, potem szukali 40 lat BOSKA MASA'.

Bangladesh newspaper snippet with headline 'বিশ্বানের 'ঈশ্বর' দর্শন'.

The New York Times newspaper snippet with headline 'Physicists Find Elusive Particle Seen as Key to Universe'.

The Gazette newspaper snippet with headline 'falleda la partícula clave para a comprensión del universo'.

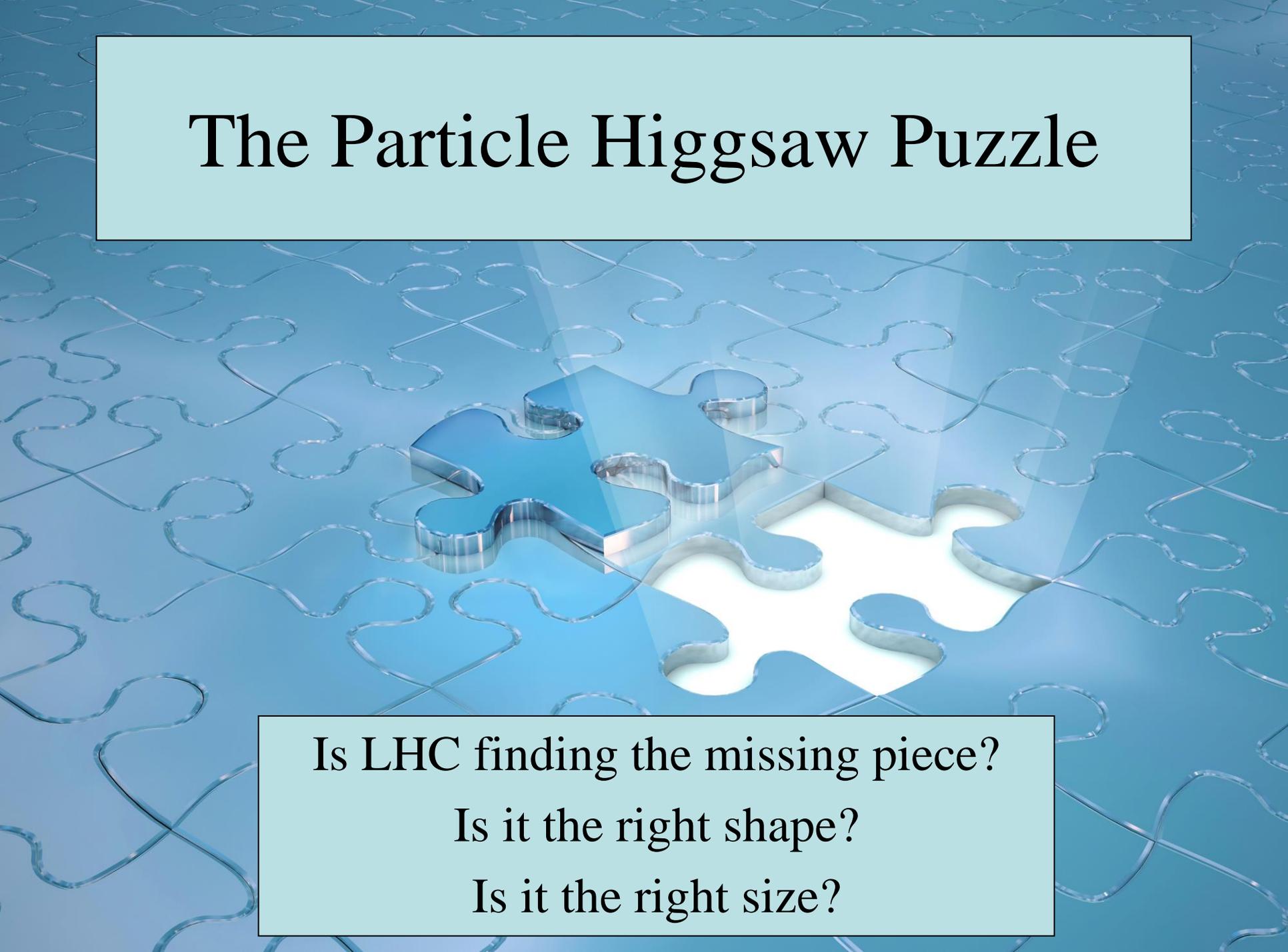
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# Higgsdependence Day!



# The Particle Higgsaw Puzzle



Is LHC finding the missing piece?

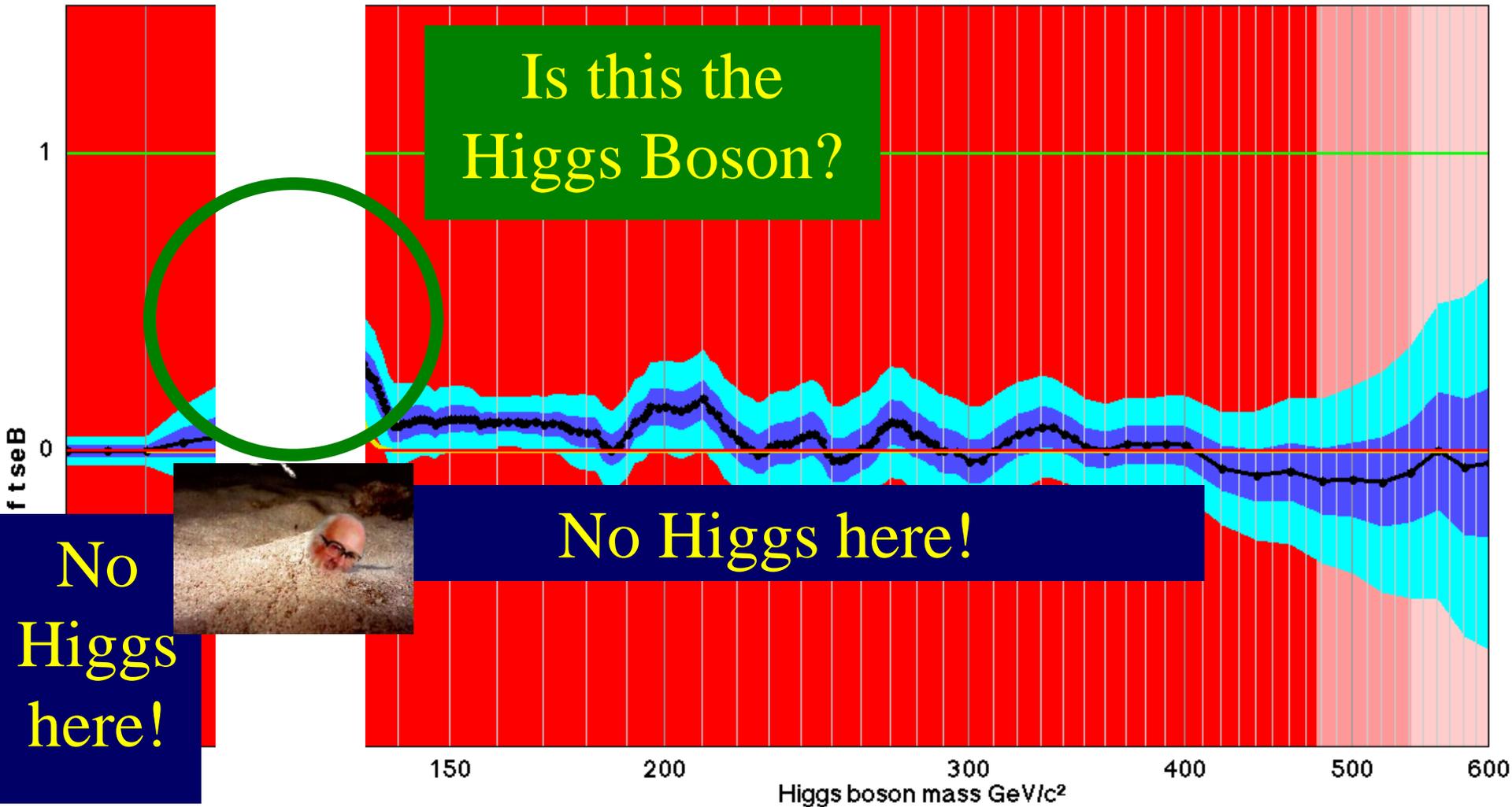
Is it the right shape?

Is it the right size?

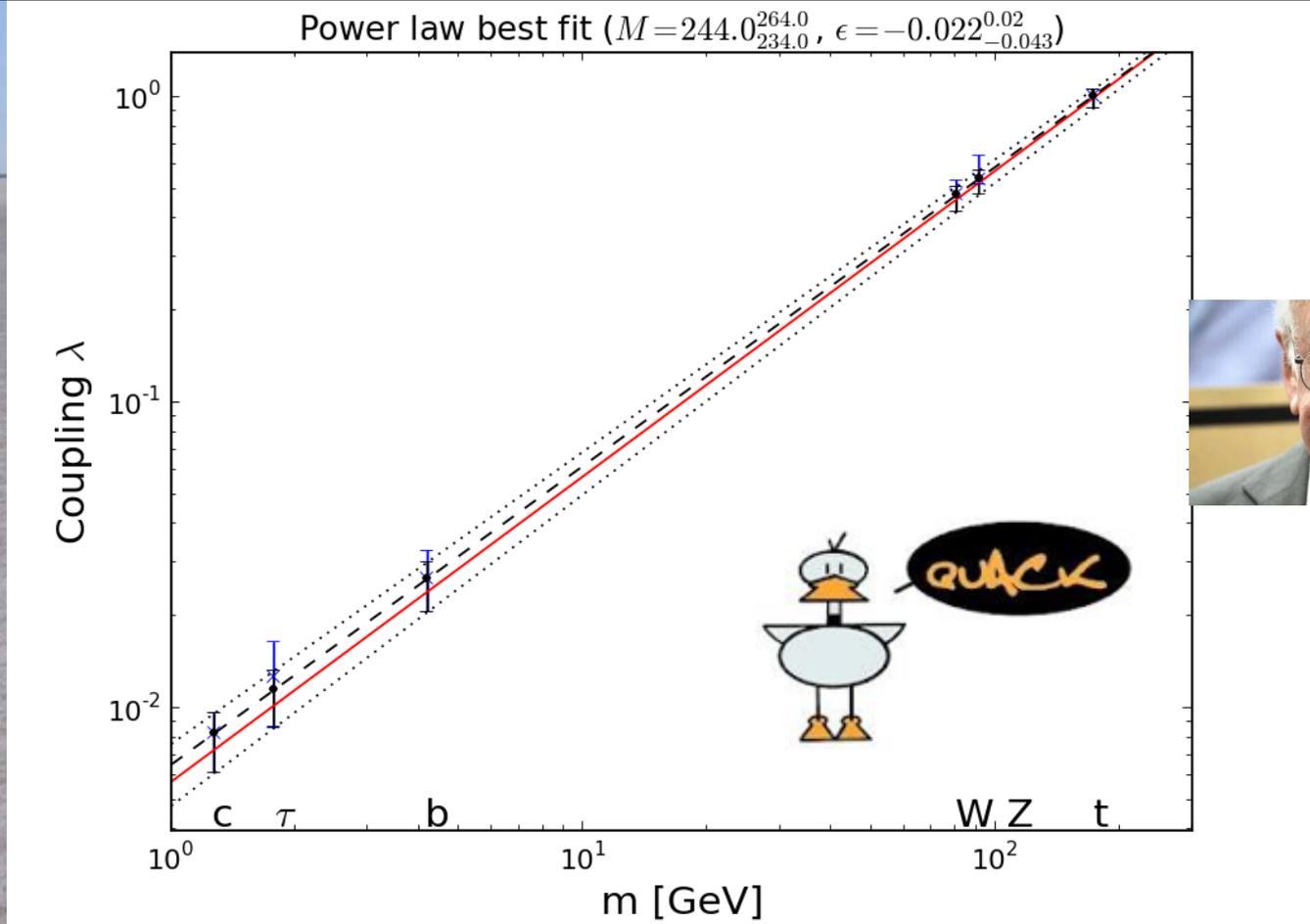
# Unofficial Combination of Higgs Data

1/fb - 10/fb

06/03/2013

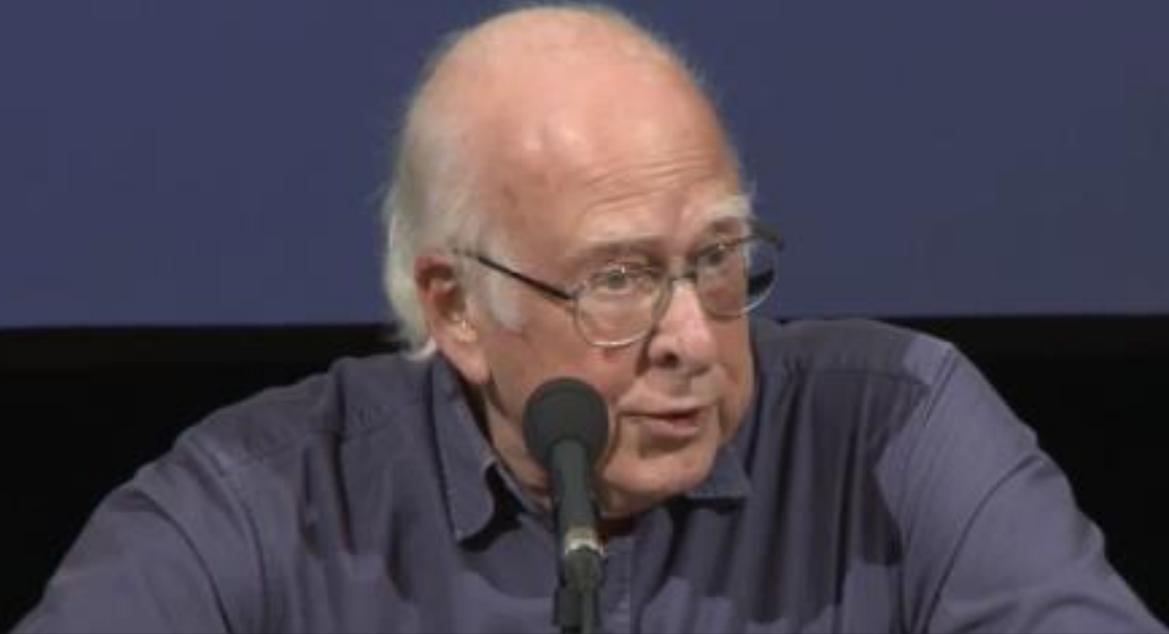


# It Walks and Quacks like a Higgs



So far, it looks like a (bog) Standard Model Higgs Boson

# Dixit Swedish Academy



*Today we believe that “Beyond any reasonable doubt, it is a Higgs boson.” [1]*

[http://www.nobelprize.org/nobel\\_prizes/physics/laureates/2013/advanced-physicsprize2013.pdf](http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/advanced-physicsprize2013.pdf)

[1] = JE & Tevong You, arXiv:1303.3879

# Without Higgs ...

... there would be no atoms

- massless electrons would escape at the speed of light

... there would be no heavy nuclei

... weak interactions would not be weak

- Life would be impossible: everything would be radioactive

**Its existence is a big deal!**



- « Empty » space is unstable
- Dark matter
- Origin of matter
- Masses of neutrinos
- Why is weak force so strong?
- Cosmological inflation
- Quantum gravity
- ...

*The Standard Model*

PIERCE BROSNAN in IAN FLEMING'S JAMES BOND 007™

# *The World Is Not Enough*

007™

ALBERT R. BROCCOLLI'S SON PRODUCTIONS PRESENTS PIERCE BROSNAN in IAN FLEMING'S JAMES BOND 007™

"THE WORLD IS NOT ENOUGH" SOPHIE MARCEAU ROBERT CARULÉ DENISE RICHARDS MIRIE COUDRYAN and JOHN DENCH  
REGINA LINDY HEARINGS with DAVID ARNOLD music by JIM CLARK JAMES NEWTON HOWARD and PETER JARANT  
produced by ANTHONY WATE with NEAL PURVIS & ROBERT WADE executive producer NEAL PURVIS & ROBERT WADE and BRUCE FENSTER  
written by MICHAEL E. WOLSON and BARBARA BROCCOLLI directed by MICHAEL APTED

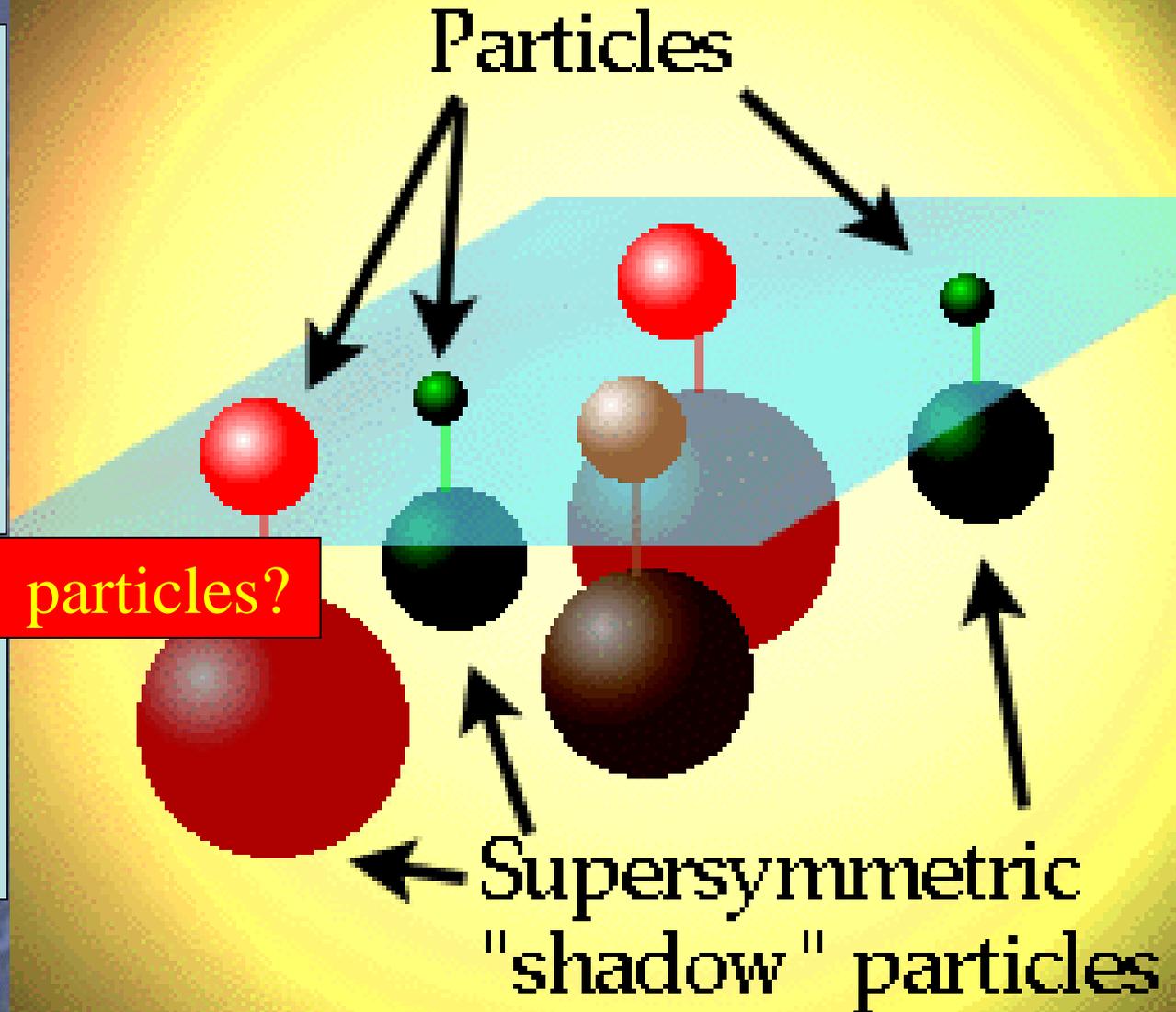
WARNER BROS. PICTURES PRESENTS A WARNER BROS. PICTURES PRODUCTION

# Dark Matter in the Universe

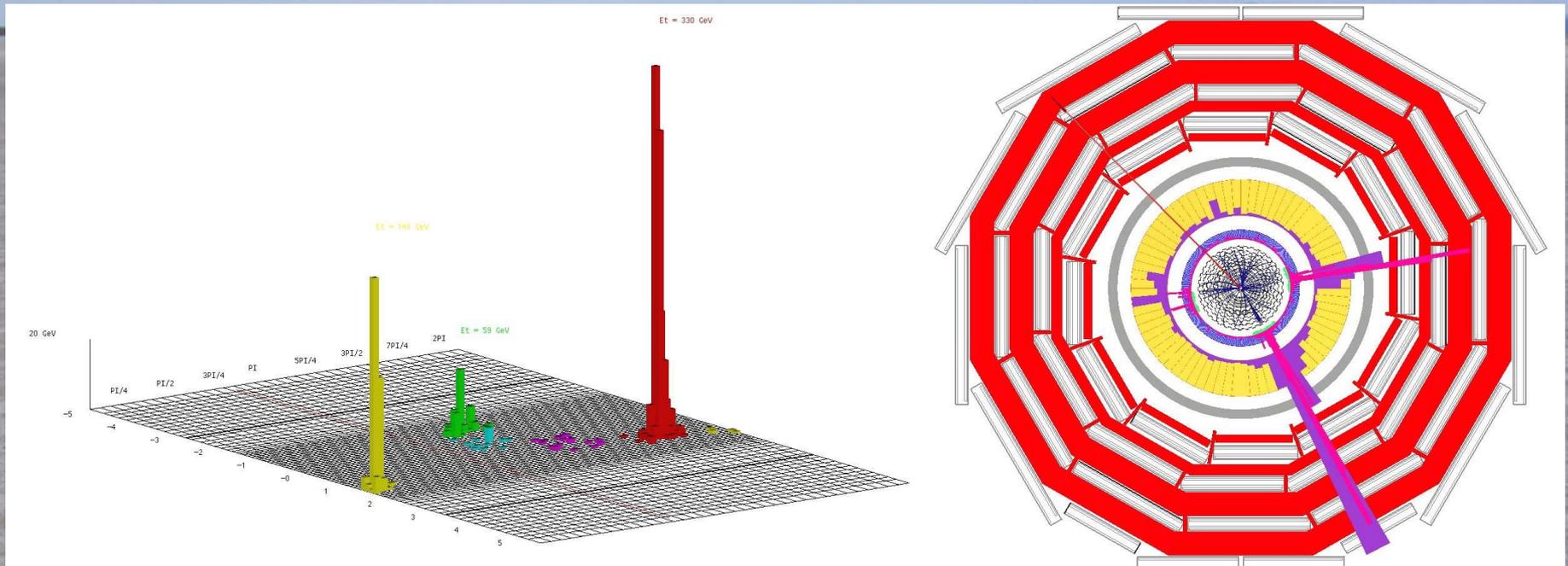
Astronomers say that most of the matter in the Universe is invisible Dark Matter

**'Supersymmetric' particles?**

We shall look for them with the LHC



# Classic Dark Matter Signature



Missing transverse energy  
carried away by dark matter particles

# General Interest in Antimatter Physics



Physicists cannot make enough for  
Star Trek or Dan Brown!

# How do Matter and Antimatter Differ?

Dirac predicted the existence of antimatter:  
same mass  
opposite internal properties:  
electric charge, ...

Discovered in cosmic rays  
Studied using accelerators  
Used in PET scanners

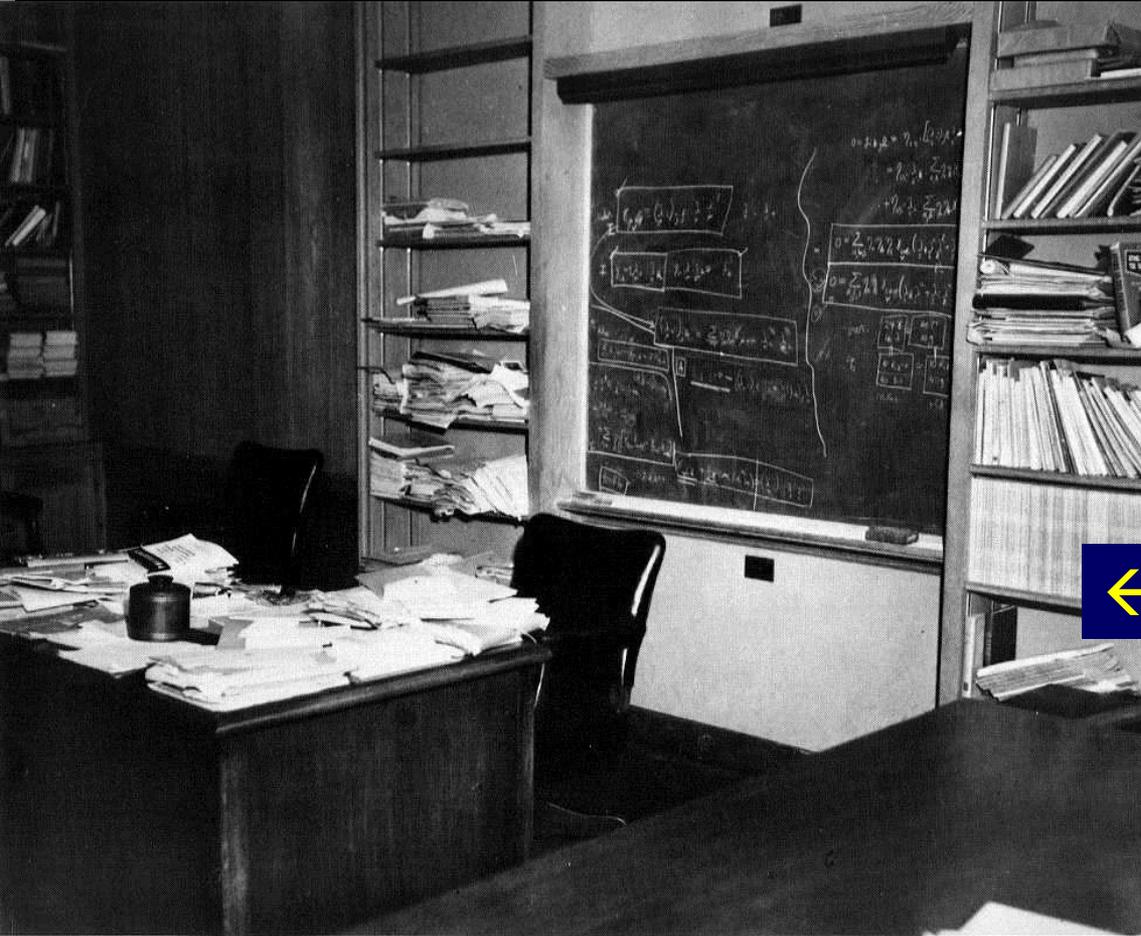


Matter and antimatter not quite equal and opposite: WHY?

Why does the Universe mainly contain matter, not antimatter?

Experiments at LHC and elsewhere looking for answers

# Unify the Fundamental Interactions: Einstein's Dream ...



← ... but he never succeeded



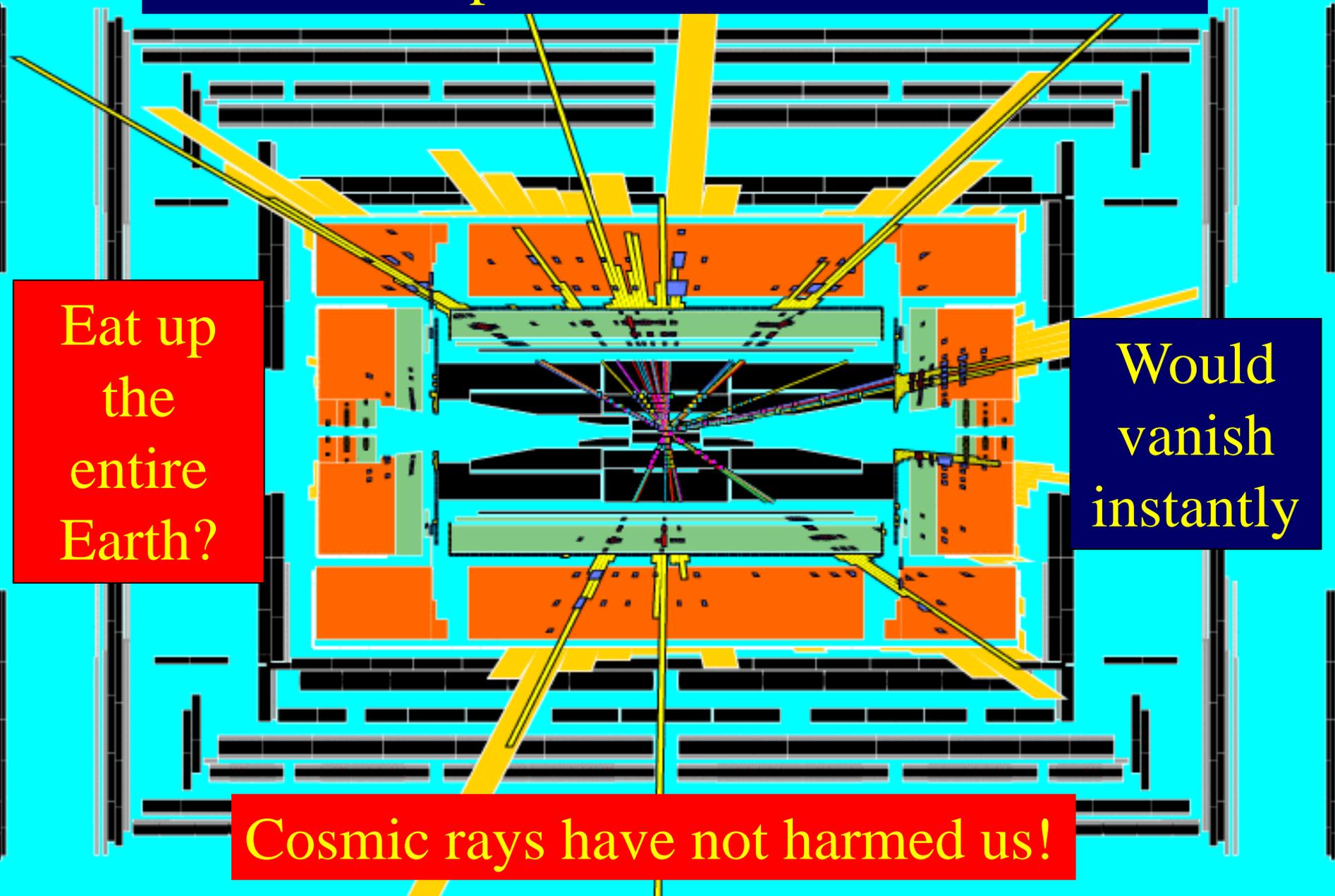
Unification via extra dimensions of space?

# Will LHC experiments create black holes?

Eat up  
the  
entire  
Earth?

Would  
vanish  
instantly

Cosmic rays have not harmed us!



# In the Inimitable words of the Daily Mail ...

The fate of the Universe depends on the masses of the Higgs boson and the top quark – not whether we find and measure them

## Finding the 'God' particle could destroy the universe, warns Stephen Hawking

- The Higgs boson 'God particle' could destroy the universe, Hawking says
- Space and time could suddenly collapse - and 'we would not see it coming'
- If scientists put too much energy in the Higgs boson the universe could end
- Disaster very unlikely as physicists do not have large enough collider

By OLLIE GILLMAN FOR MAILONLINE

PUBLISHED: 11:17, 7 September 2014 | UPDATED: 18:11, 7 September 2014



[View comments](#)

The elusive 'God particle' discovered by scientists in 2012 has the potential to destroy the universe, Professor Stephen Hawking has warned.

At very high energy levels, the Higgs boson could cause space and time suddenly collapse - and 'we wouldn't see it coming', the former Cambridge professor of mathematics says.

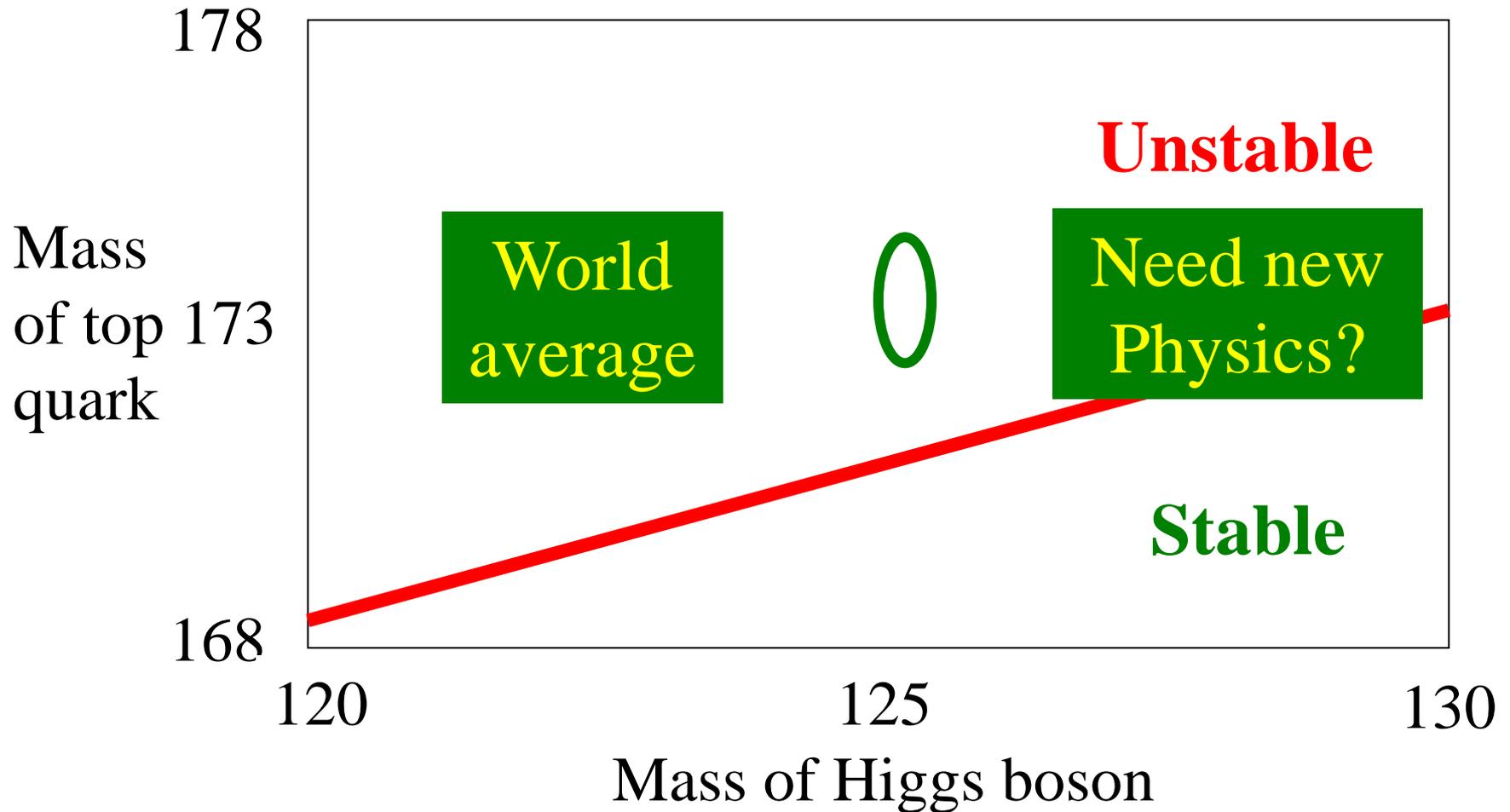
The God particle, which gives shape and size to everything that exists, could cause a 'catastrophic vacuum delay' if scientists were to put it under extreme stress.

**Scroll down for video**



# Is “Empty Space” Unstable?

- Depends on masses of Higgs boson and top quark



# Will the cosmic water spill?

Fairbairn & Hogan, arXiv:1403.6786

Fluctuate over barrier  
in the early Universe?

Infinite barrier  
if supersymmetry

We are here



HIGGS FIELD



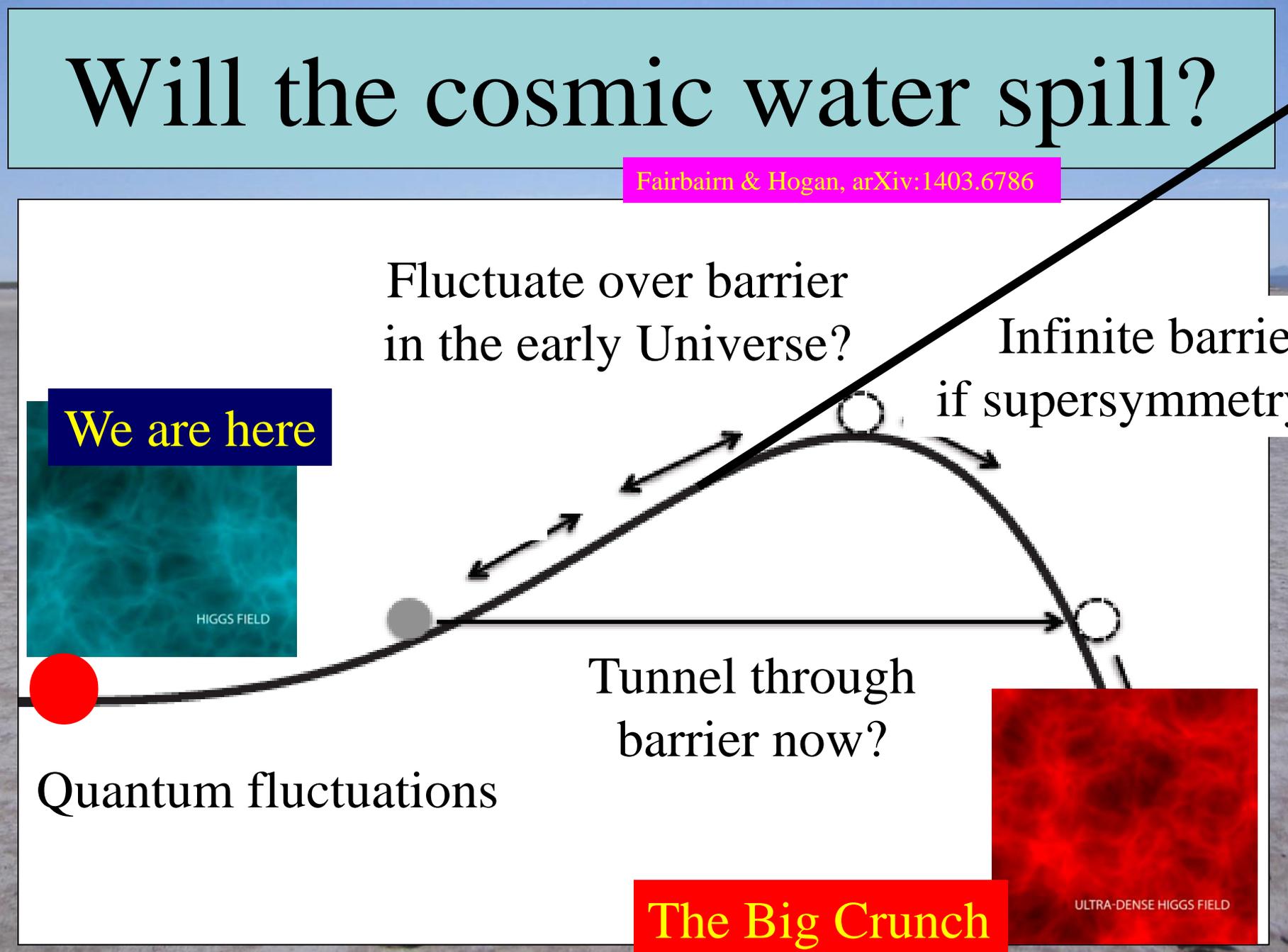
Quantum fluctuations

Tunnel through  
barrier now?

The Big Crunch



ULTRA-DENSE HIGGS FIELD



What else is there?

# Supersymmetry

New motivations  
From LHC Run 1

- **Stabilize electroweak vacuum**
- **Successful prediction for Higgs mass**
- **Successful predictions for couplings**
  - **Should be within few % of SM values**
- **Naturalness, GUTs, string, ..., dark matter**

The LHC is the world's most powerful microscope ...



... and also a telescope  
looking into the past,  
and perhaps the future