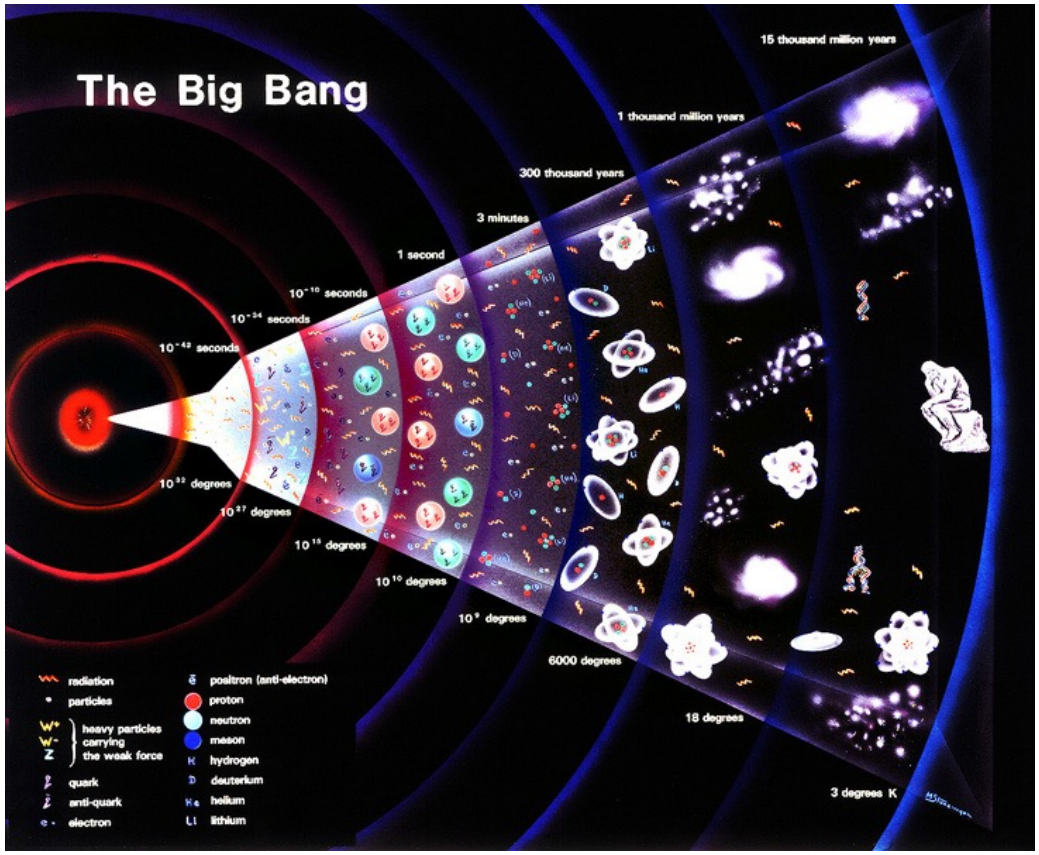
Research in Particle Physics

Ashutosh Kotwal
Duke University



National Center for Performing Arts, Mumbai
June 10, 2025

Why particle physics?

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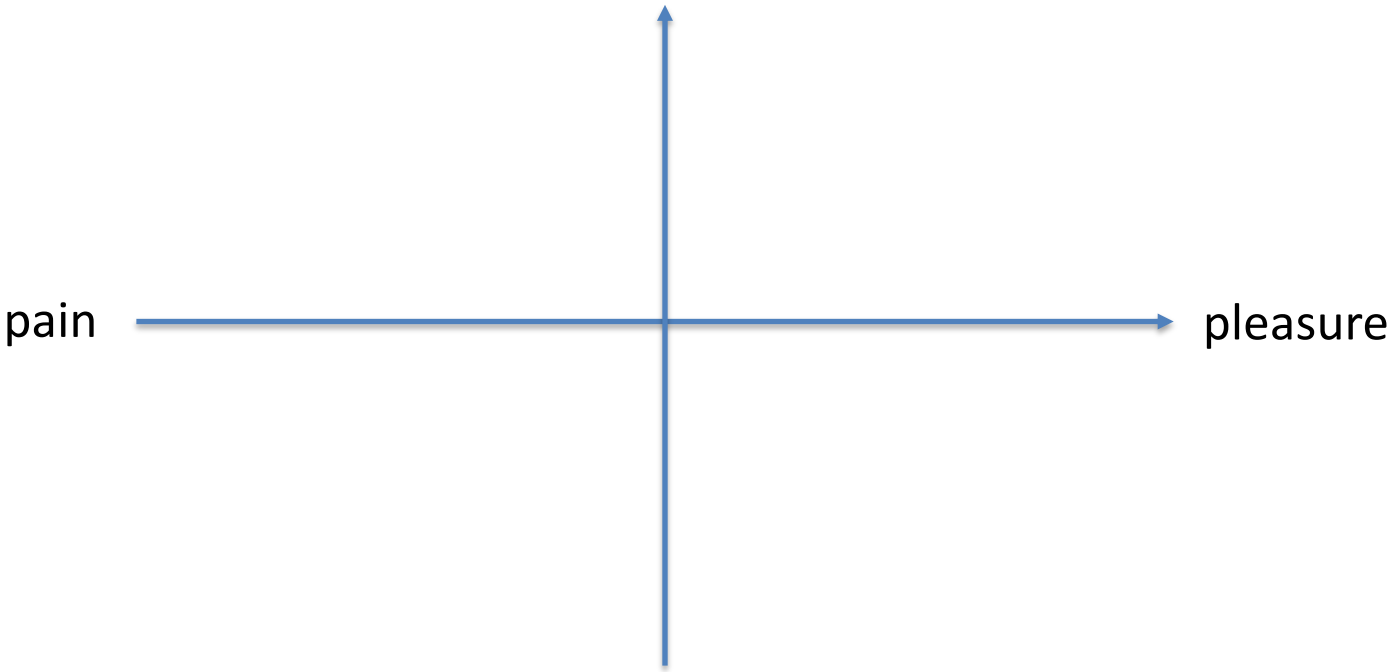
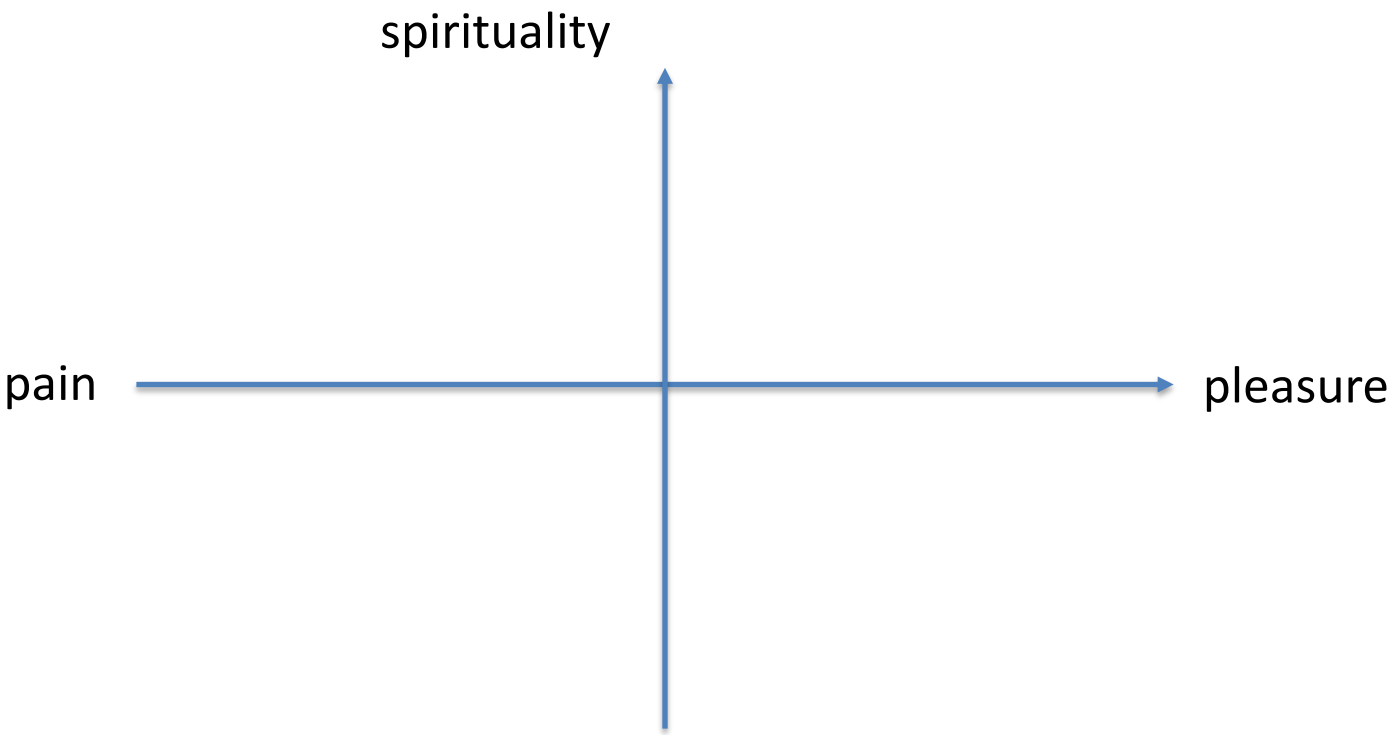


Why particle physics?



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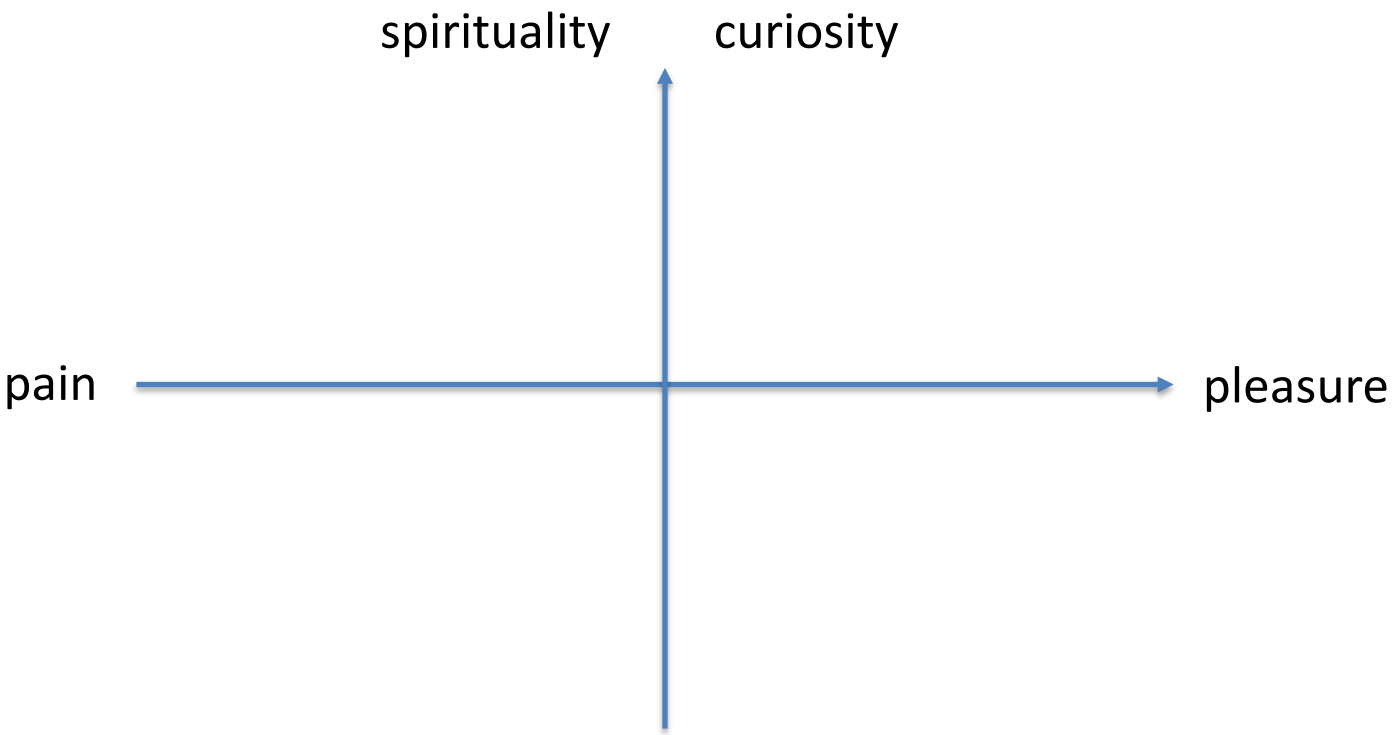

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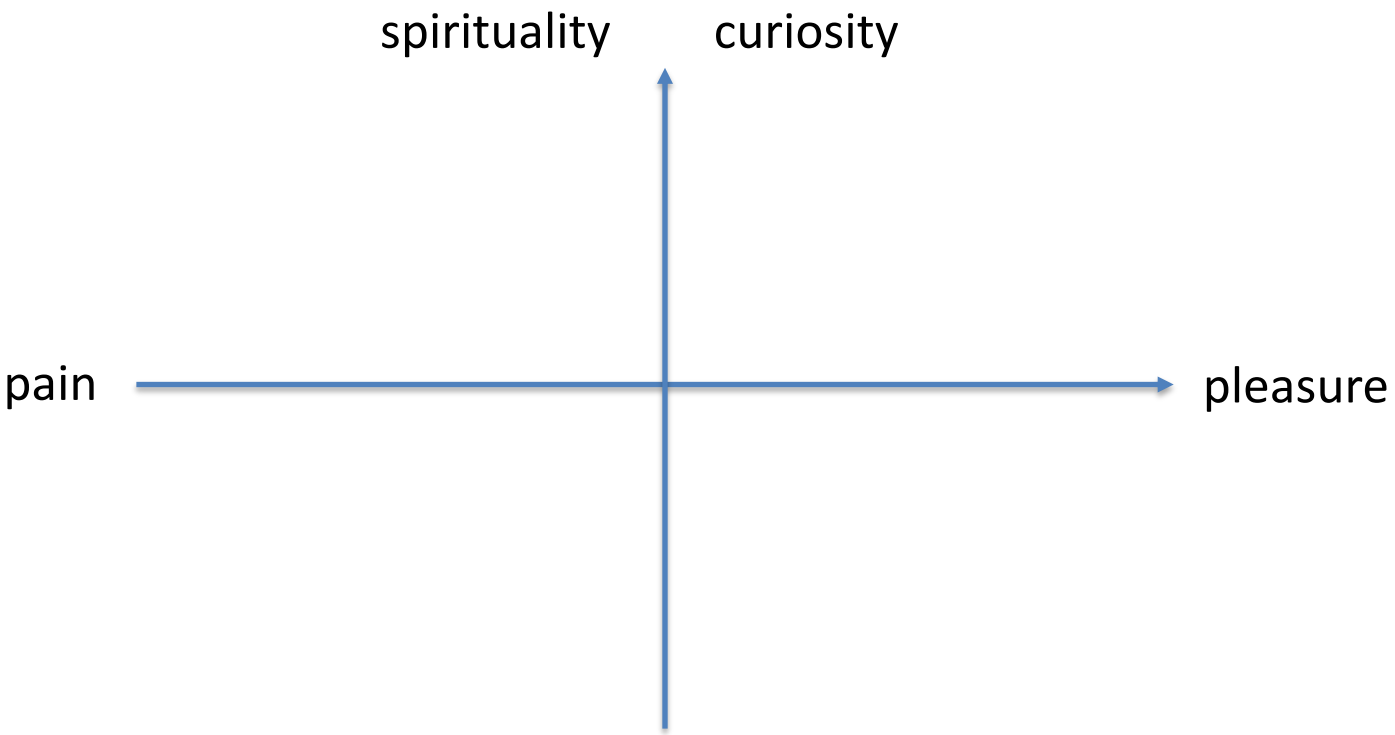
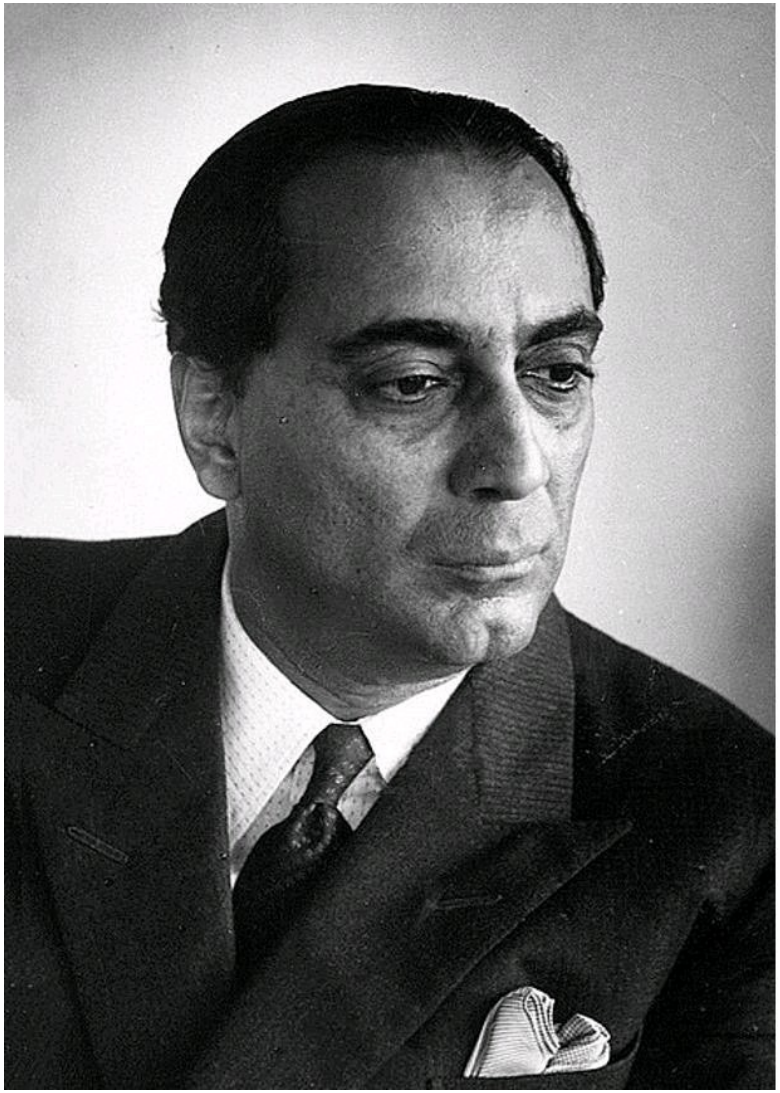


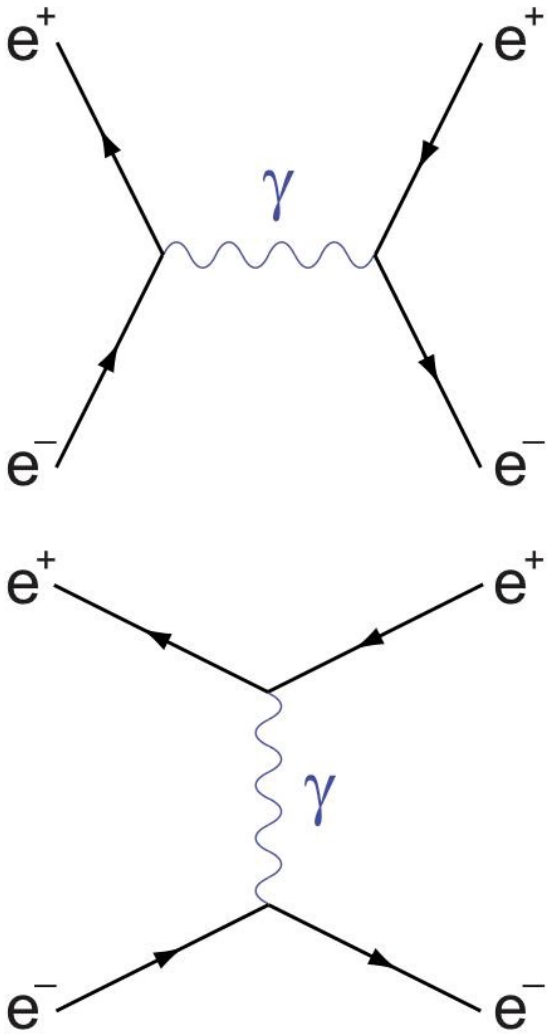
Particle physics is curiosity-driven research … discovery science

After a century of particle physics, where have we arrived?

- Following the brilliant insights of Paul Dirac and others, we can understand
  - Why there is matter and antimatter
  - Why matter occupies volume
  - How matter interacts via forces
  - The properties of forces
  - The Higgs field that explains fundamental particle masses

Homi Bhabha
electron-positron (anti-electron) scattering





The Higgs boson and Dark Matter are both intimately connected with properties of empty space…

(or what we thought was “empty space”)

…Making these phenomena unlike any other we have observed in the past

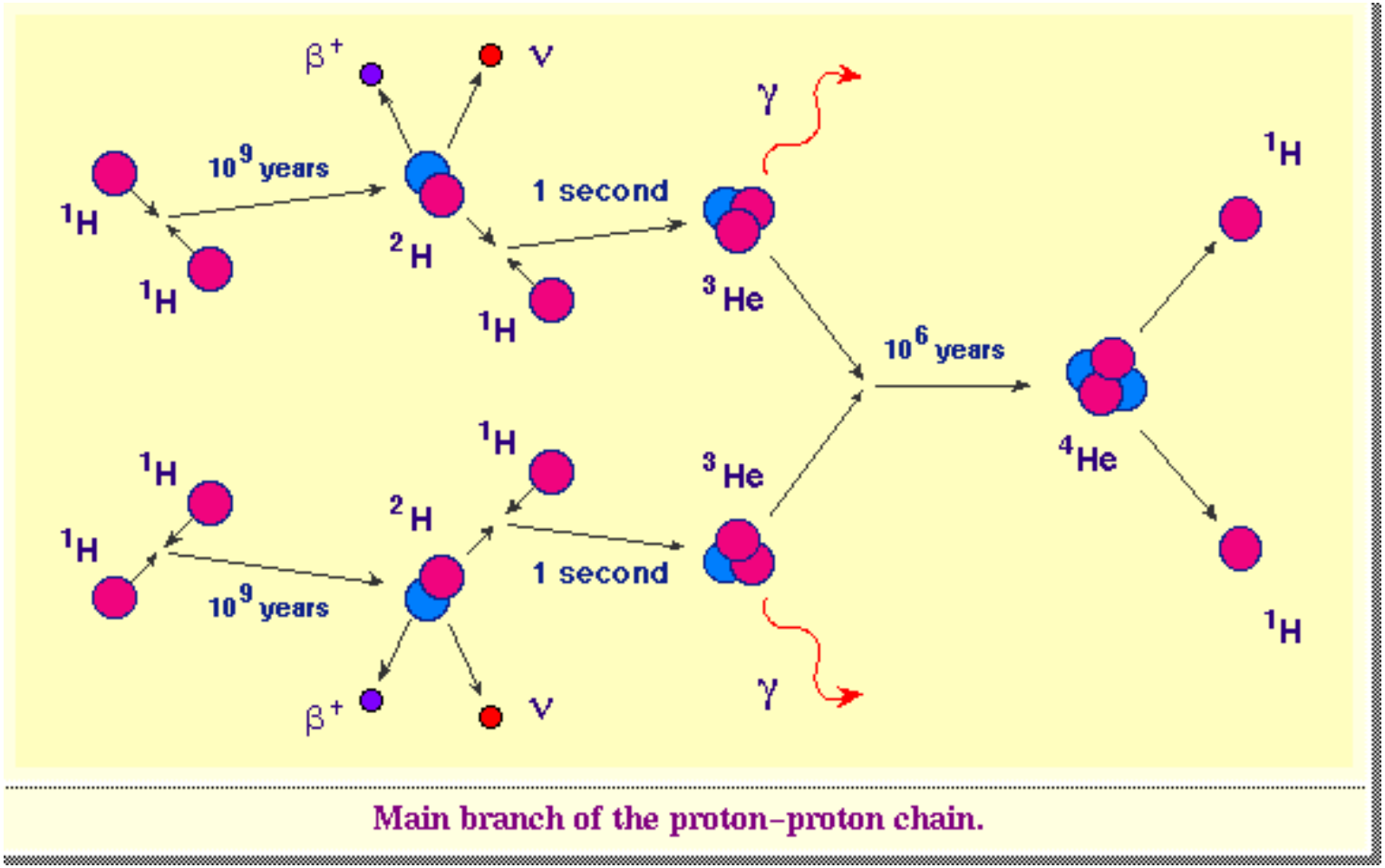
New Mysteries to Solve…

- Higgs is a completely new kind of ‘stuff’ in Nature
  - It is not matter and it is not a force
  - How and why does it exist?
  - Is it made up of something else?

- What is Dark Matter? We have no clue !!
  - Is it some mysterious particles made in the Big Bang?

- Why is there more matter than antimatter in the Universe?
  - Should have been created in equally in the Big Bang

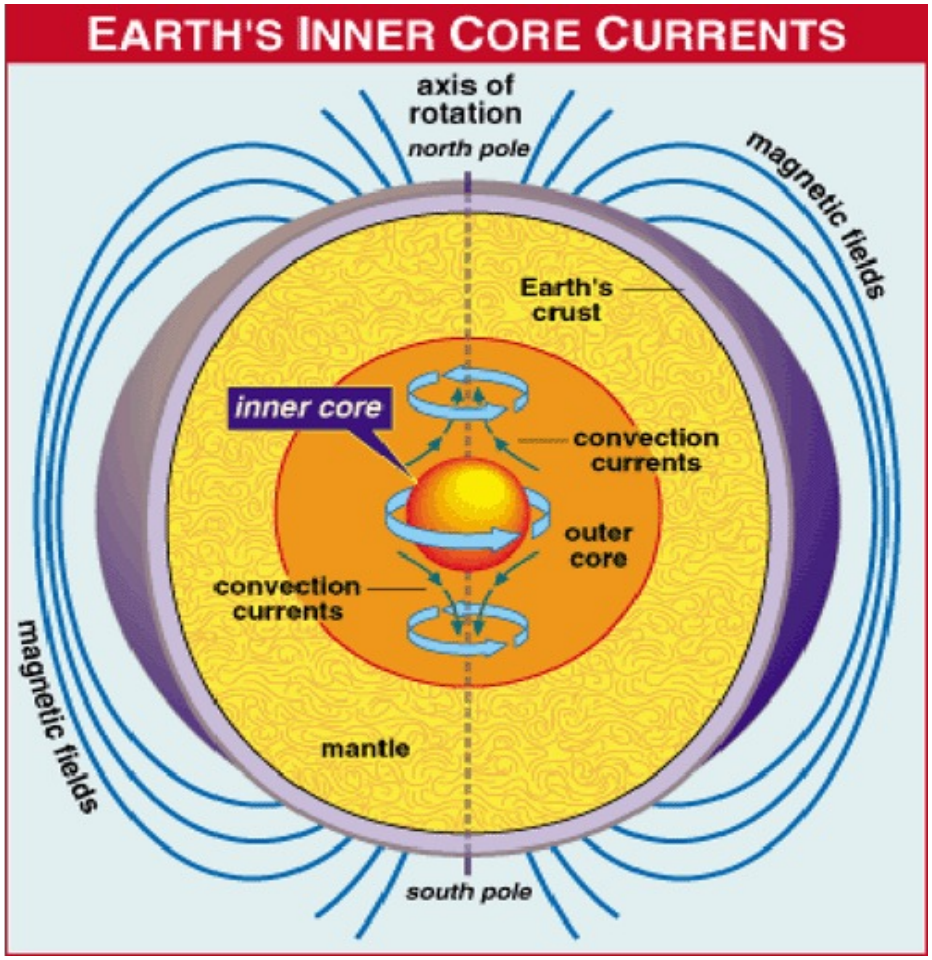
W boson drives Nuclear Fusion in Sun's Core

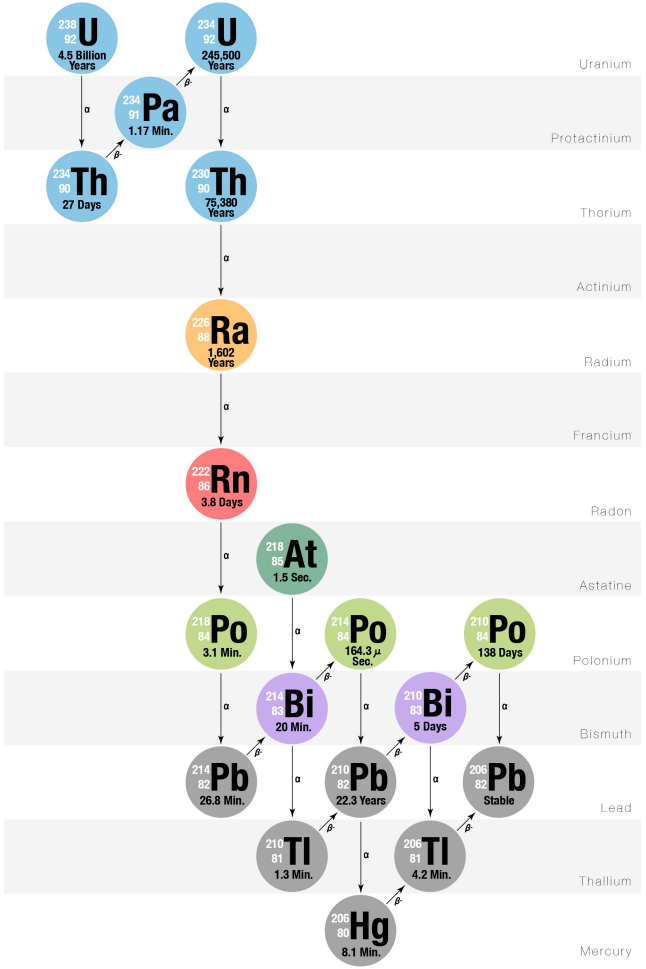


Main branch of the proton–proton chain.

Crucial role of W boson in hydrogen -> helium fusion in Sun's core

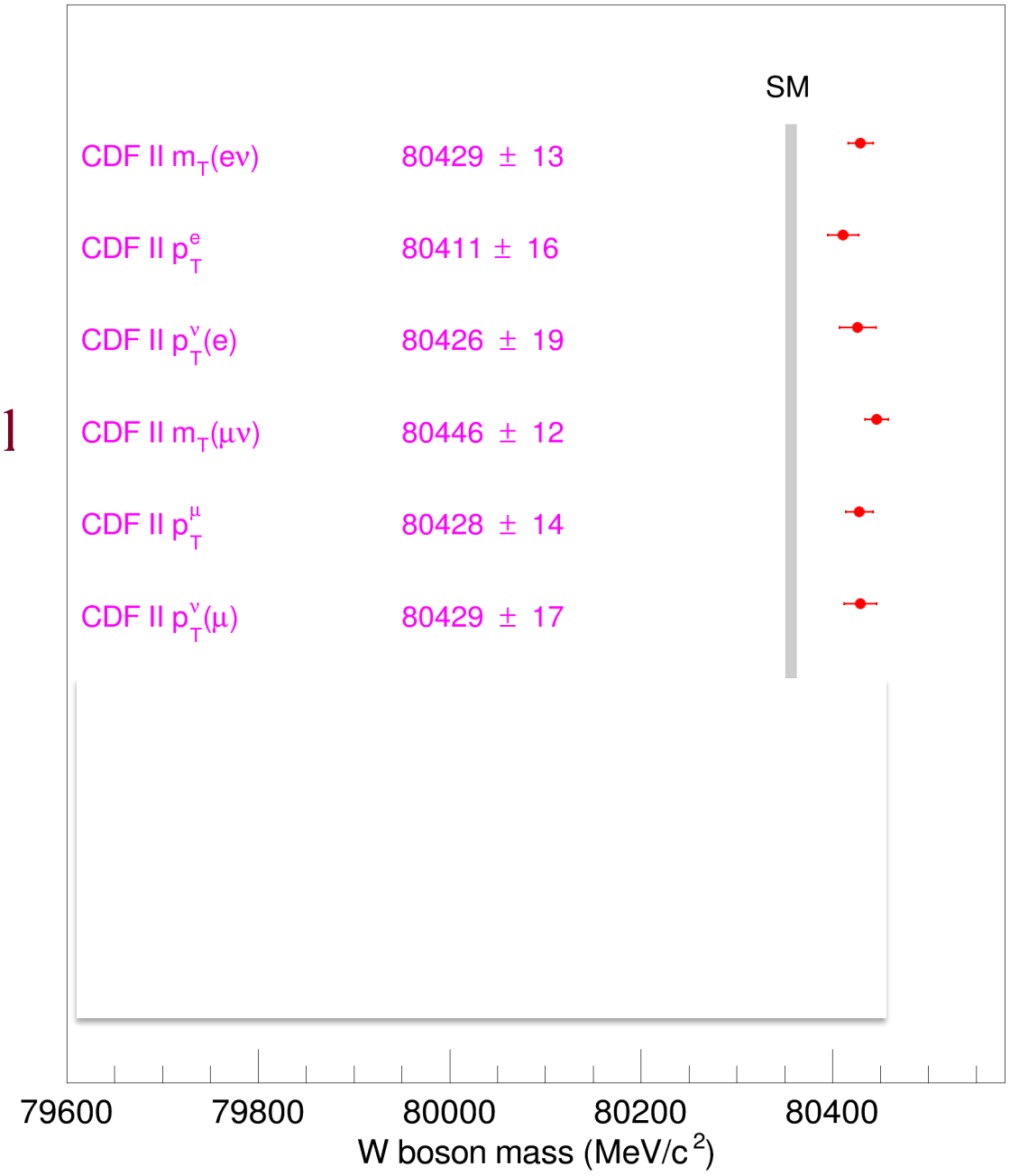
W boson Helps Keep the Earth's Core Molten





Crucial role of W boson in keeping Earth core molten and generate protective magnetic shield against harmful solar radiation

My measurement of
W boson mass is much
higher than Standard Model
theory prediction (80357)



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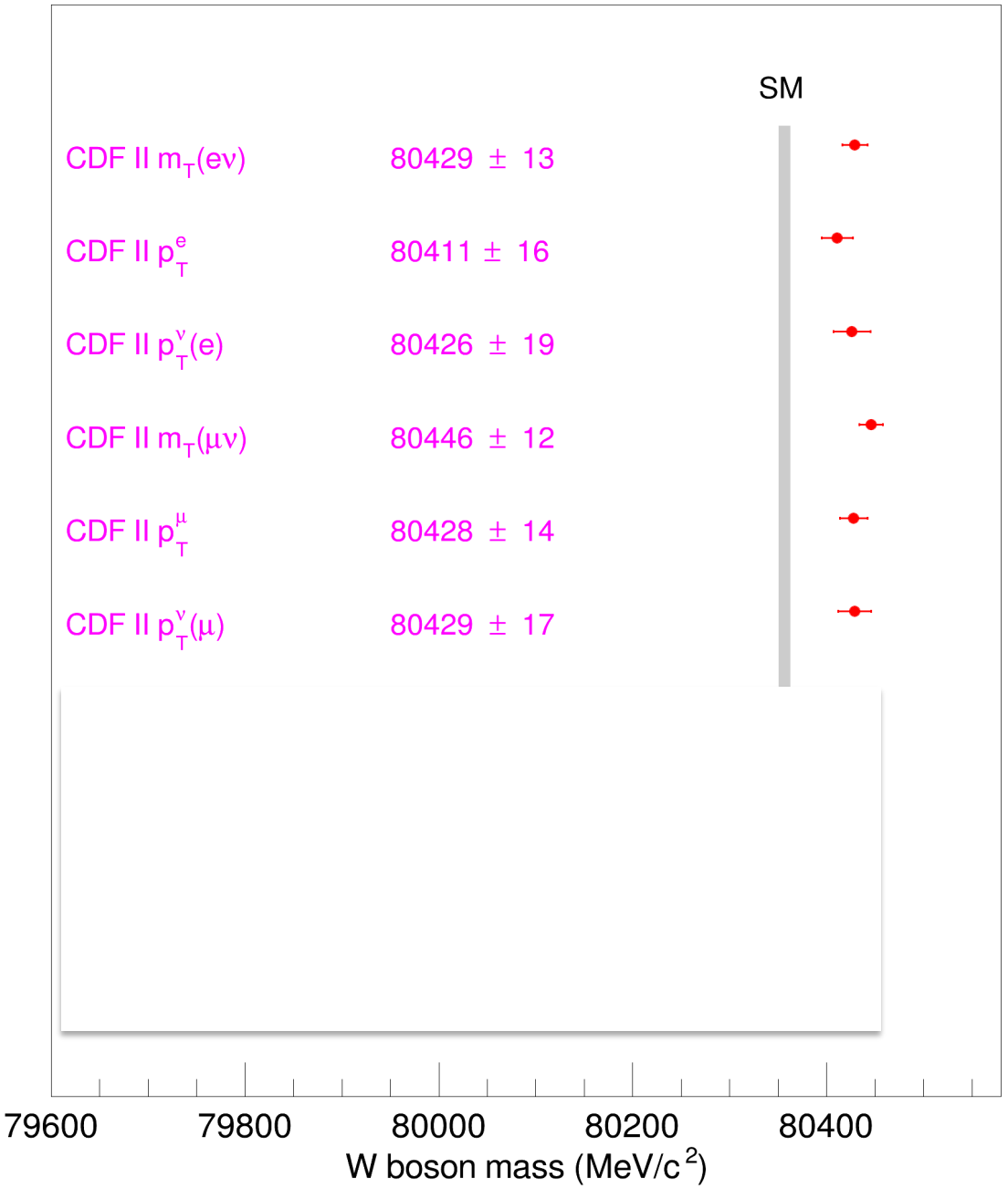
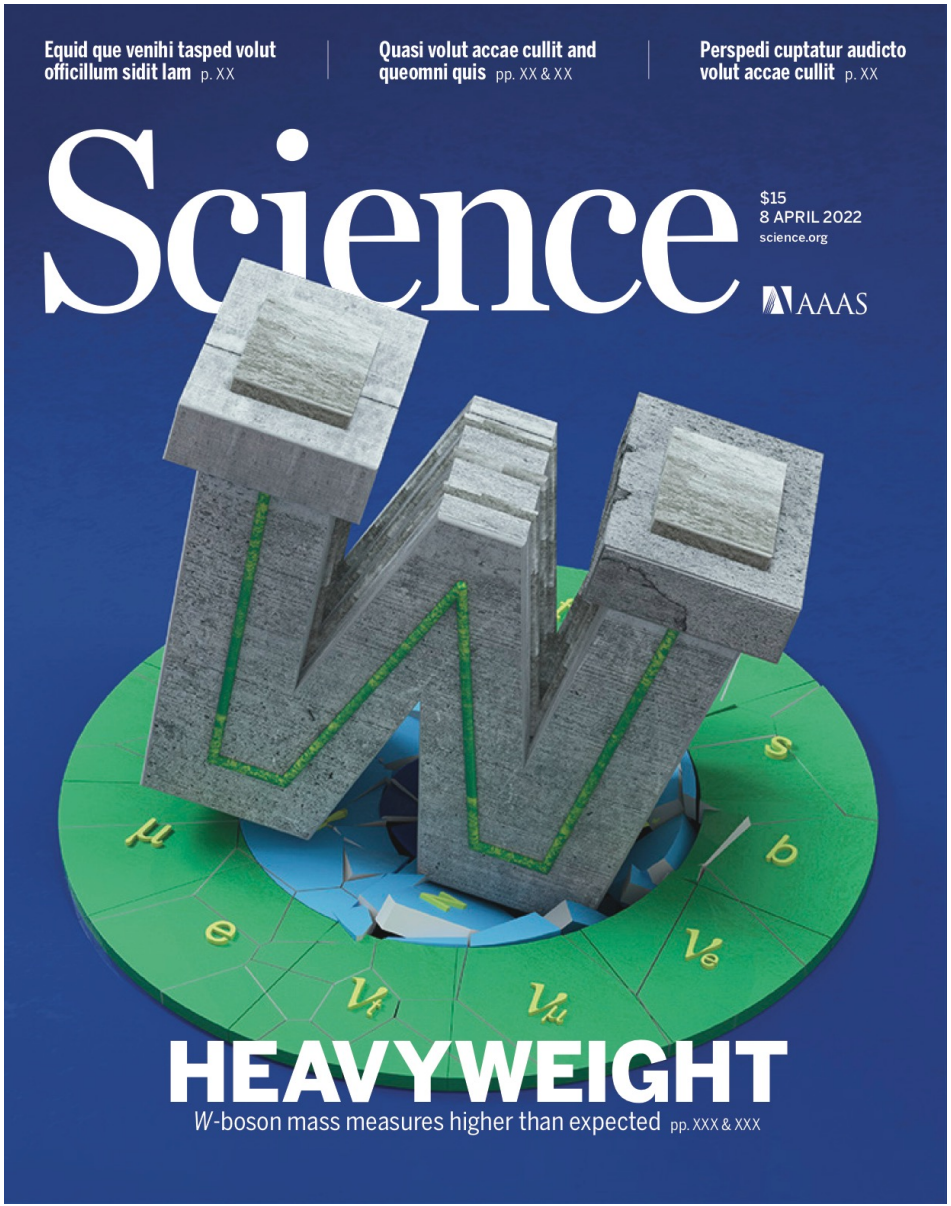
Implies existence of new
physics law of Nature



The Heavyweight W boson – Upset to the Standard Model of Particle Physics



New Physics Implications of Heavyweight W boson

- Modifications of the Higgs Theory
  - Supersymmetry
  - Constituents of the Higgs boson
- Dark Matter particles
- New fundamental forces

nature reviews
physics

March 2024

nature reviews physics https://doi.org/10.1038/s42254-023-00682-0

Perspective Check for updates

The precision measurement of the *W* boson mass and its impact on physics

Ashutosh V. Kotwal

Abstract

As a mediator of the weak nuclear force, the *W* boson influences many properties of fundamental particles and their interactions. Understanding the *W* boson as accurately as possible, including knowing its mass, has been a priority in particle physics for decades. In the past few years, in a succession of increasing-precision measurements by multiple experiments, a significant tension between the measured and predicted mass has been documented by the CDF Collaboration. Furthermore, smaller differences between different measurements exist. Because the *W* boson mass provides a window on new physics, a comparison between different measurement techniques can inform the path to further investigations. This Perspective article overviews the role of the *W* boson mass in the Standard Model of Particle Physics and its extensions, compares and contrasts its measurement techniques and discusses prospects and future directions.

Sections

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Sections

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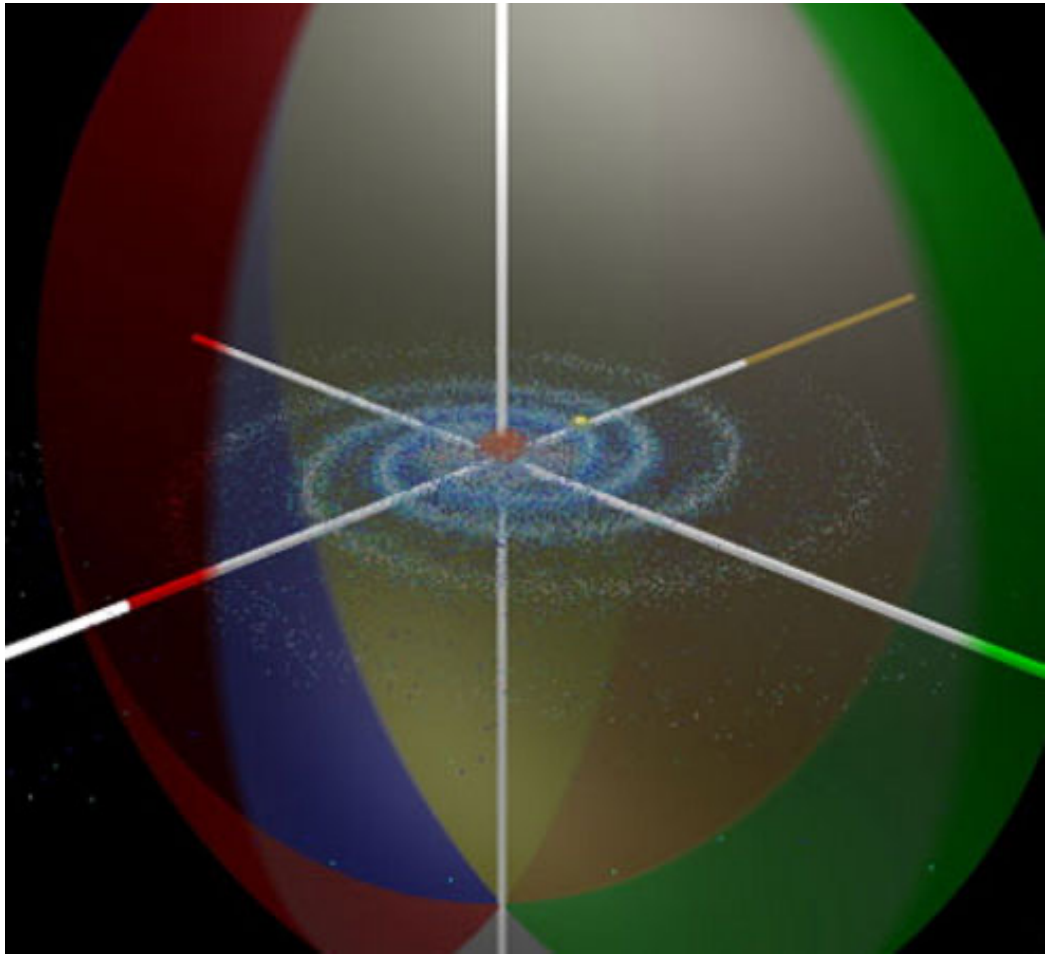
Nature Reviews Physics

The Higgs boson is not the end of the story

The Mystery of Dark Matter

Stars Orbiting a Galaxy

Halo of Invisible Dark Matter around Galaxies



Four times as much dark matter as visible matter

Normal matter radiates away binding energy and condenses into galaxies

40 kpc

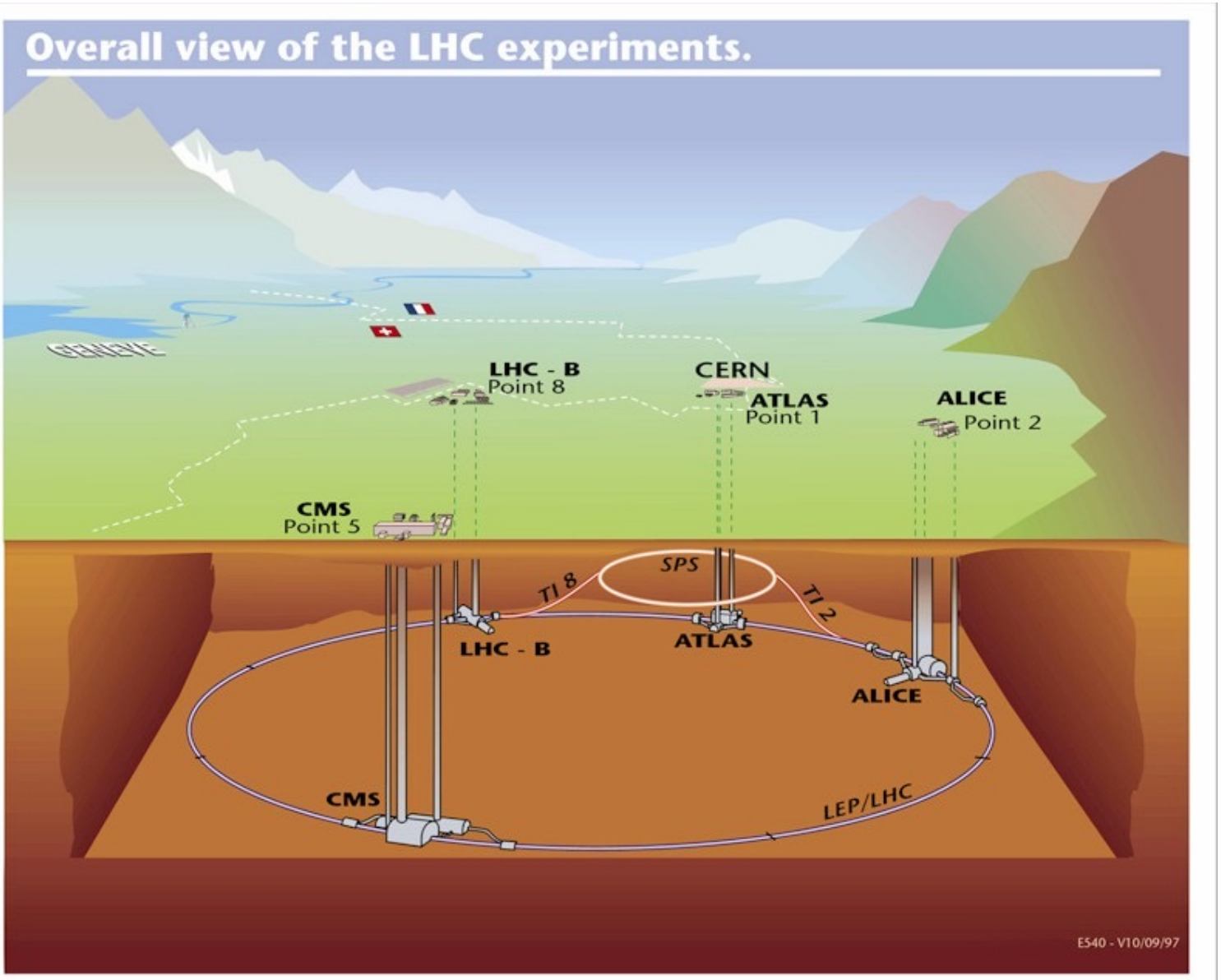
Normal matter radiates away binding energy and condenses into galaxies

But Dark Matter cannot radiate energy so remains a huge cloud

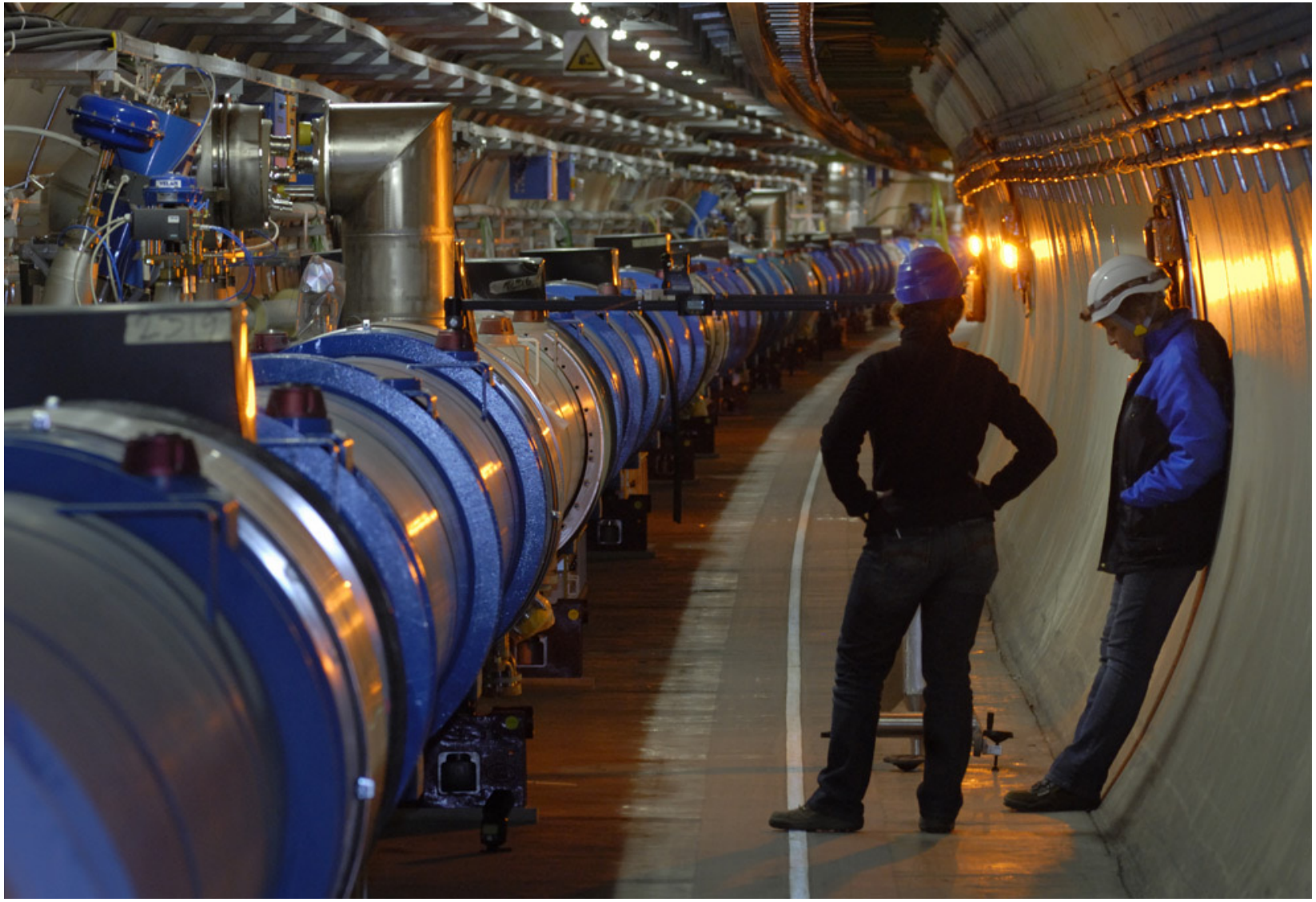
40 kpc

Making Dark Matter at the LHC

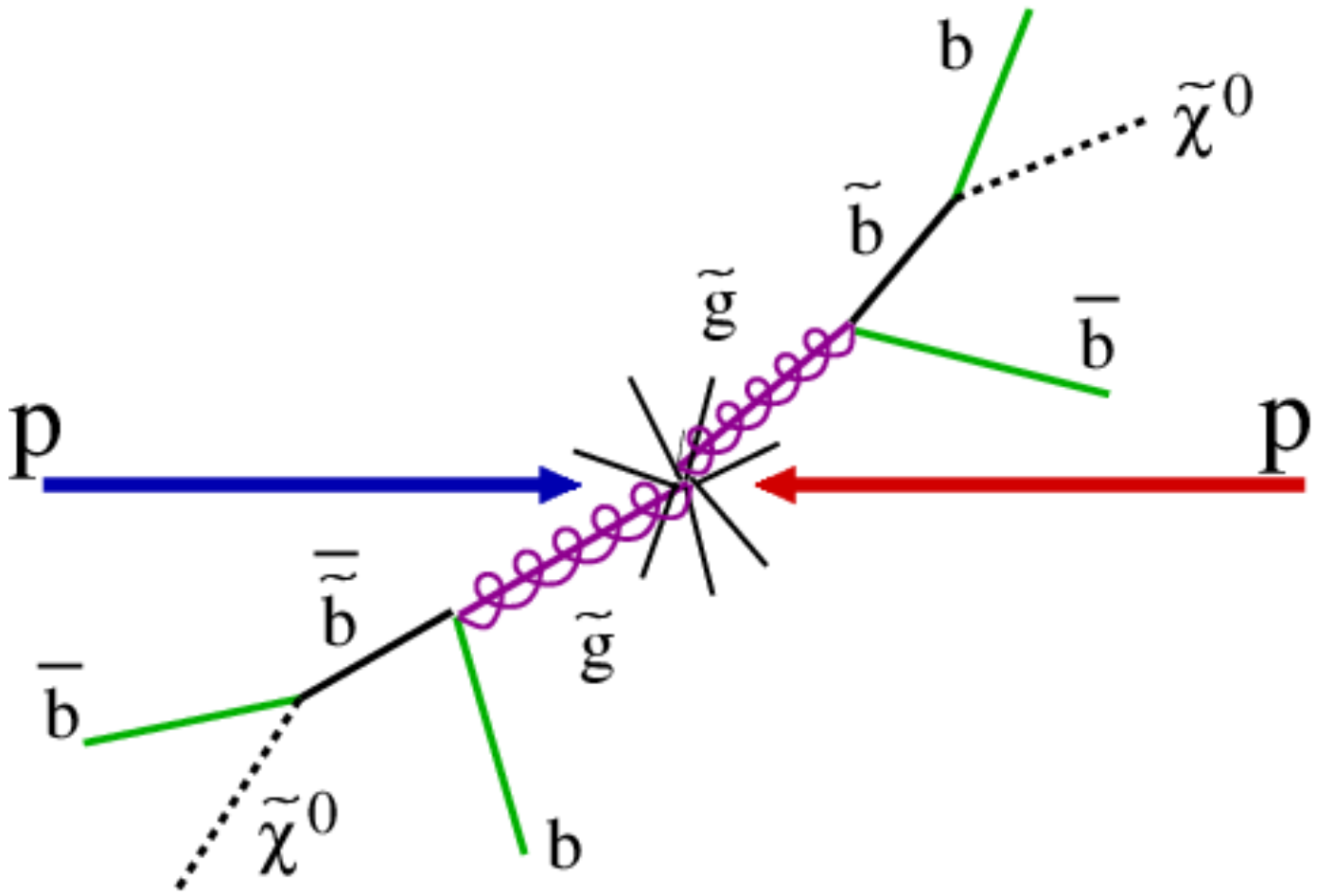
Large Hadron Collider below Geneva, Switzerland



LHC Accelerator in Tunnel



Theory of Production of Dark Matter Particles



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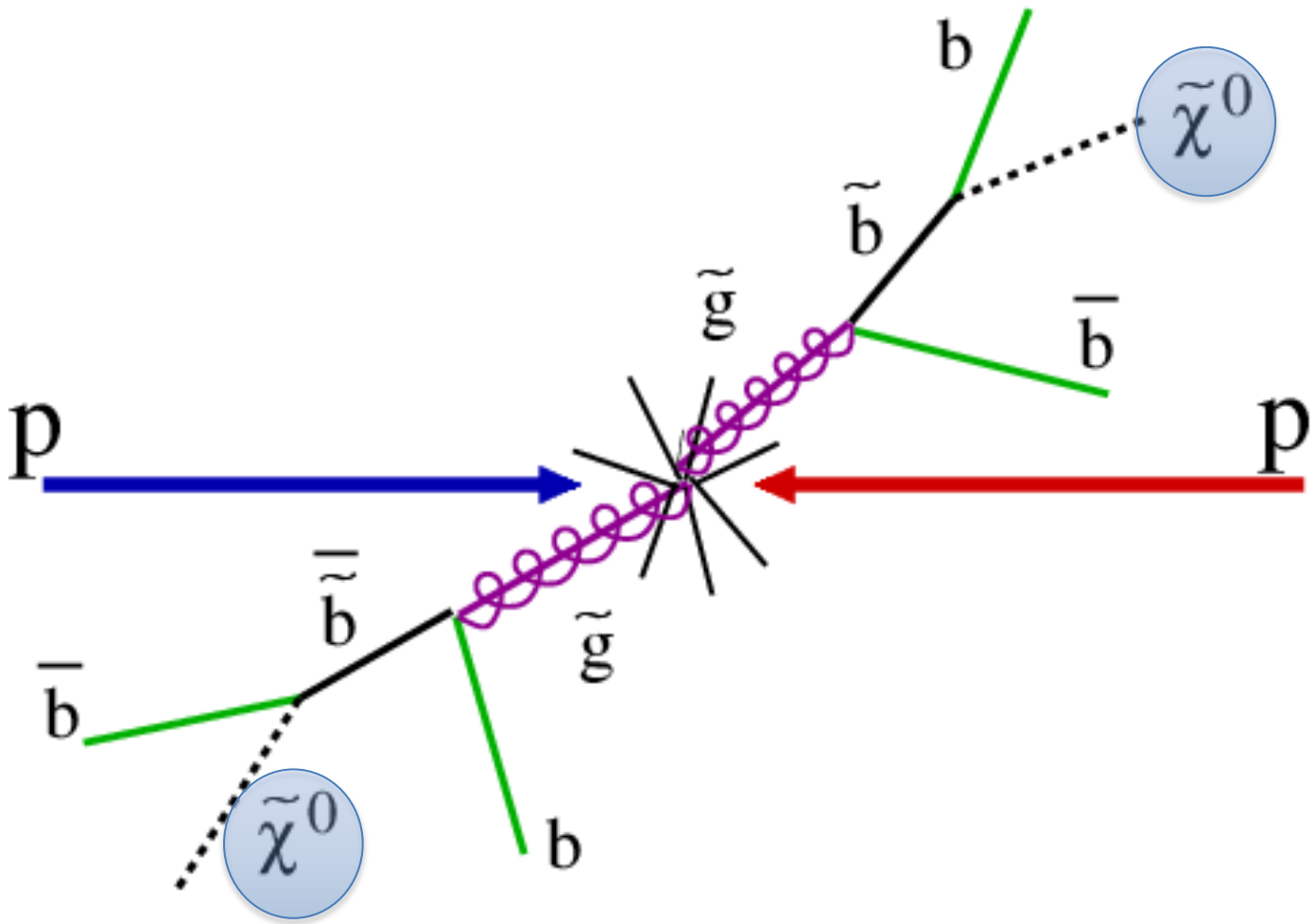
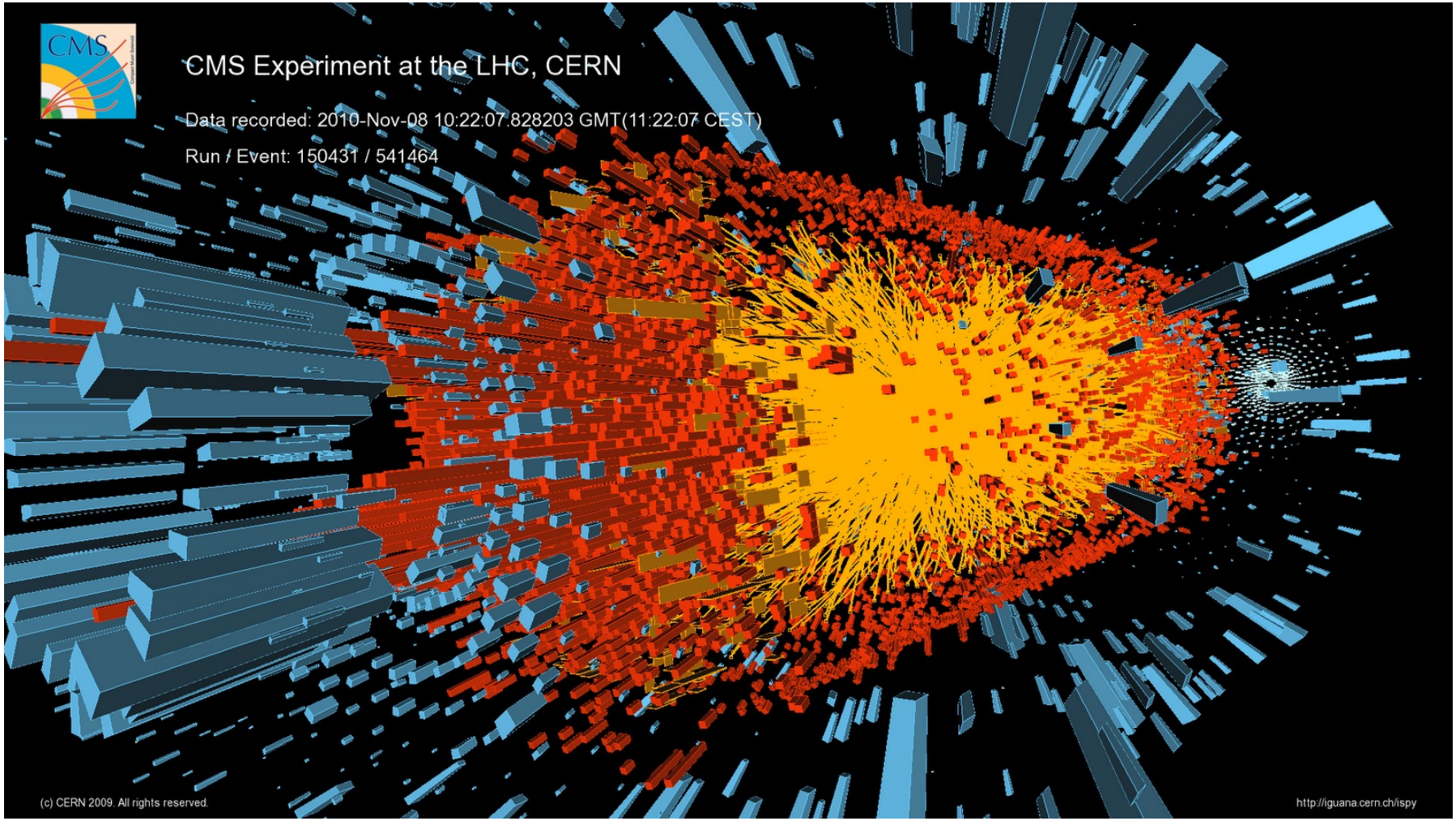
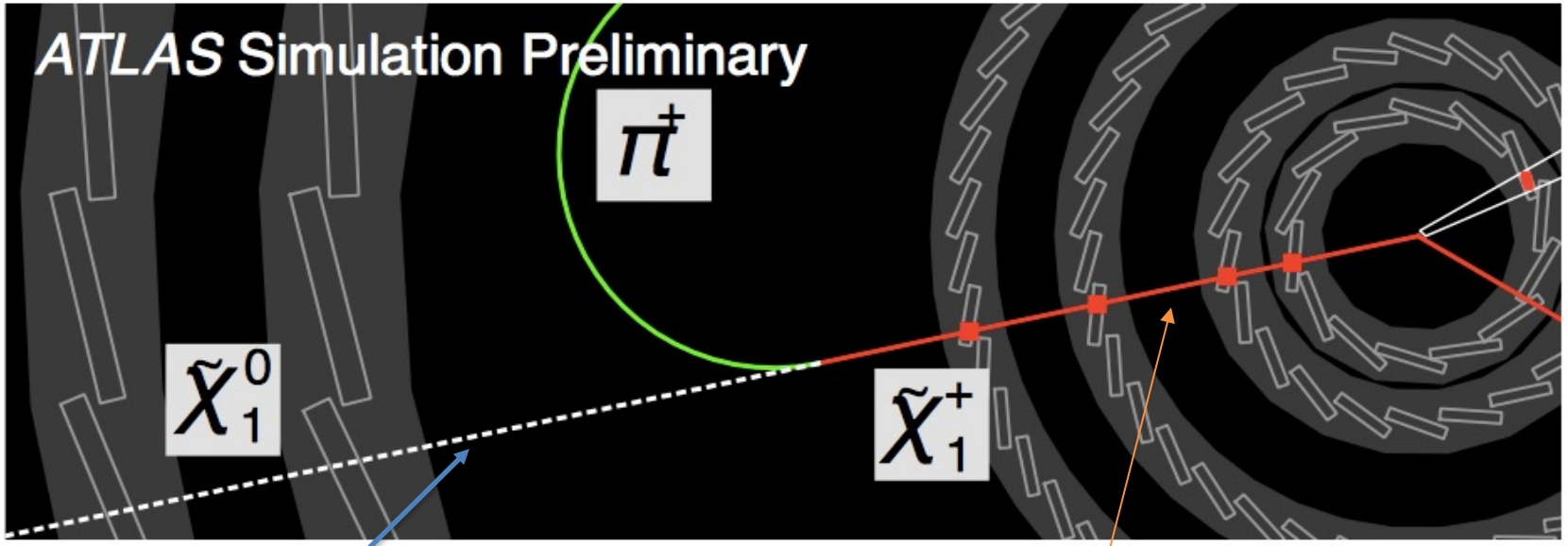


LHC Collisions with very intense beams



Particle Identification using Silicon Sensors



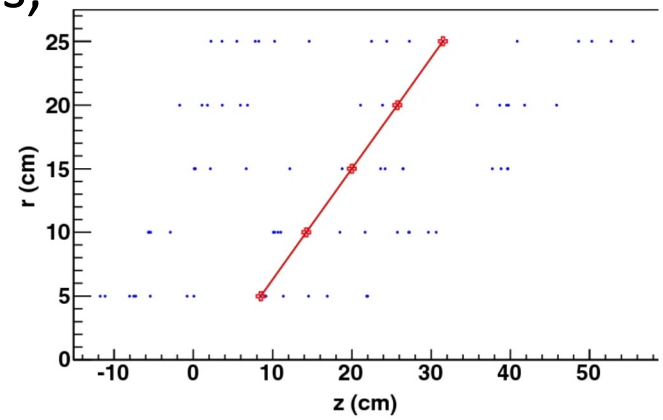
Dark Matter particle

"disappearing particle"

"disappearing particle" signature cannot be recognized at the collision rate of 40 million / second

Invention of Super-fast silicon chip

- Rapid identification of disappearing particles, @ 40 million / second



- A. V. Kotwal, Nucl. Inst. Meth. A 957 (2020) 163427
- A. V. Kotwal, Scientific Reports **11**, 18543 (2021)
- A. V. Kotwal *et al.*, Scientific Reports **14**, 10181 (2024)
- A. V. Kotwal, submitted to Nature Scientific Reports

- Implemented in silicon integrated circuit

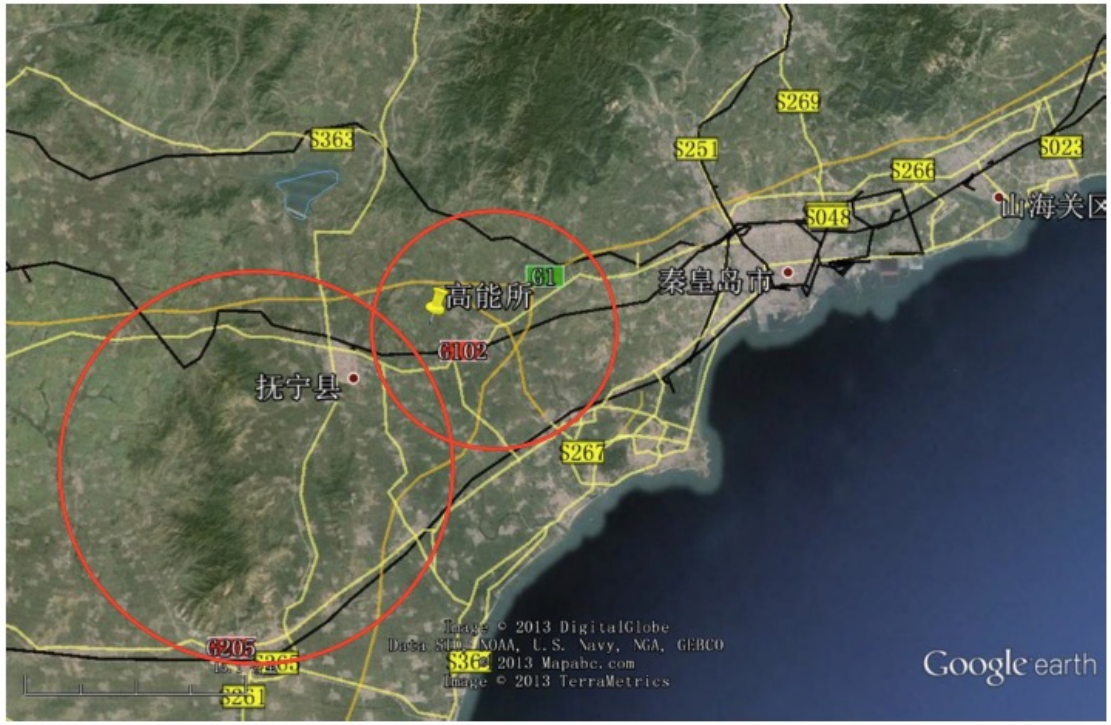
Life after LHC?

- Interest in China, Europe, and USA to build higher-energy colliders
  - Can we build an even bigger (and more expensive) tunnel ?

Life after LHC?

Site

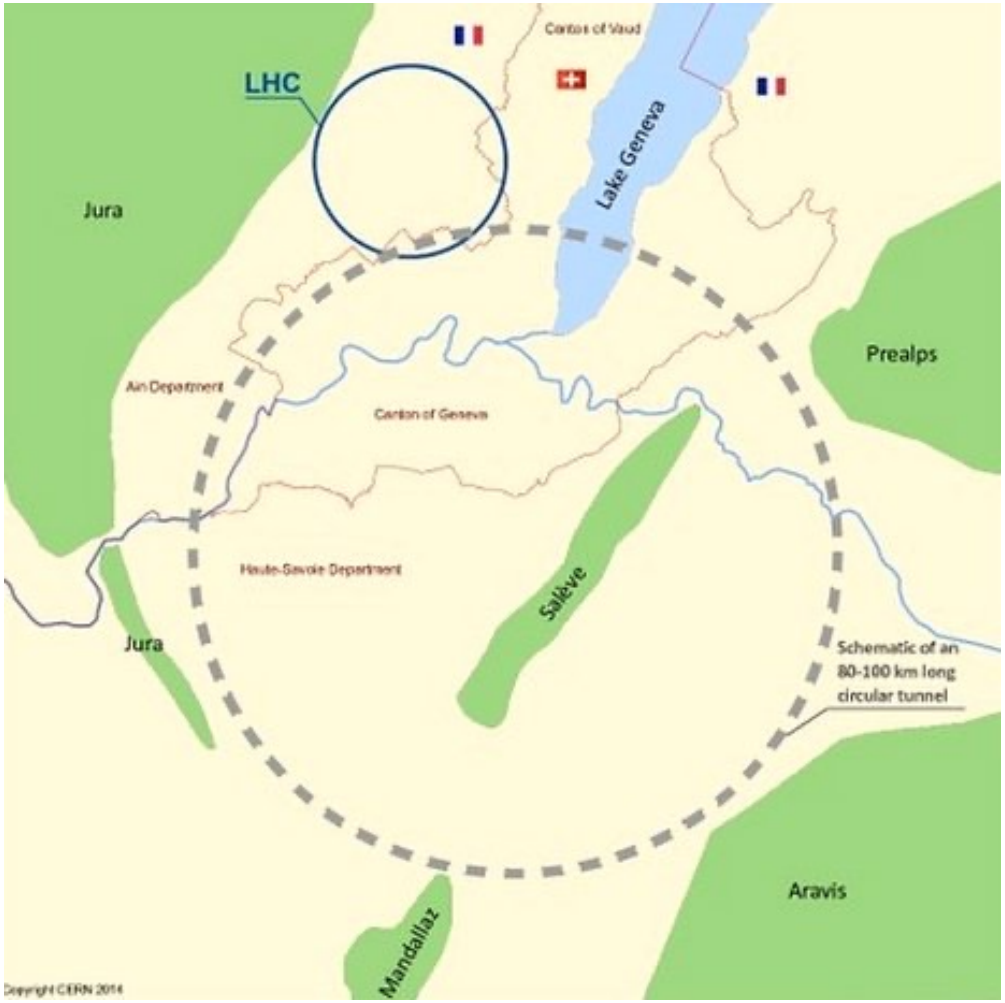
- Preliminary selected: Qinhuangdao (秦皇岛)
- Strong support by the local government



A possible big tunnel east of Beijing, China

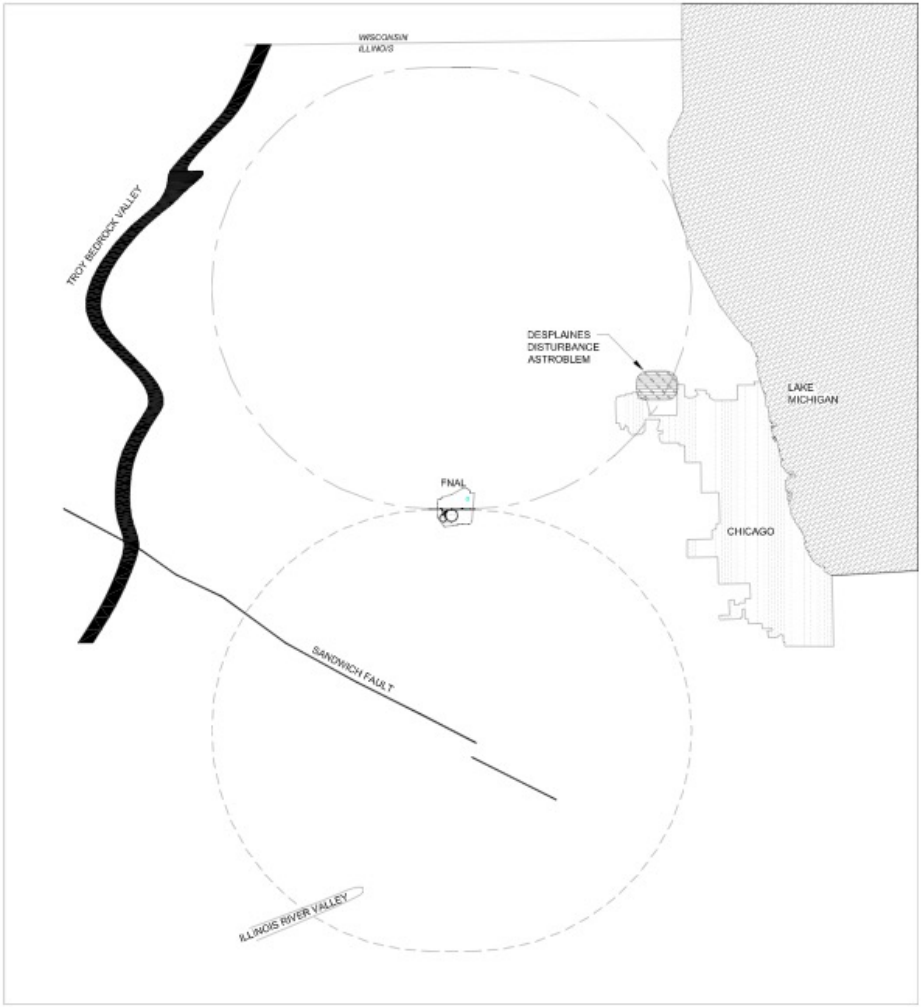
(from presentation by Prof. Yifang Wang, Director of IHEP Beijing, on 13 February 2014, Geneva)

Life after LHC?



A possible big tunnel close to CERN, Geneva, Switzerland

Life after LHC?



A possible even bigger tunnel close to Chicago, USA

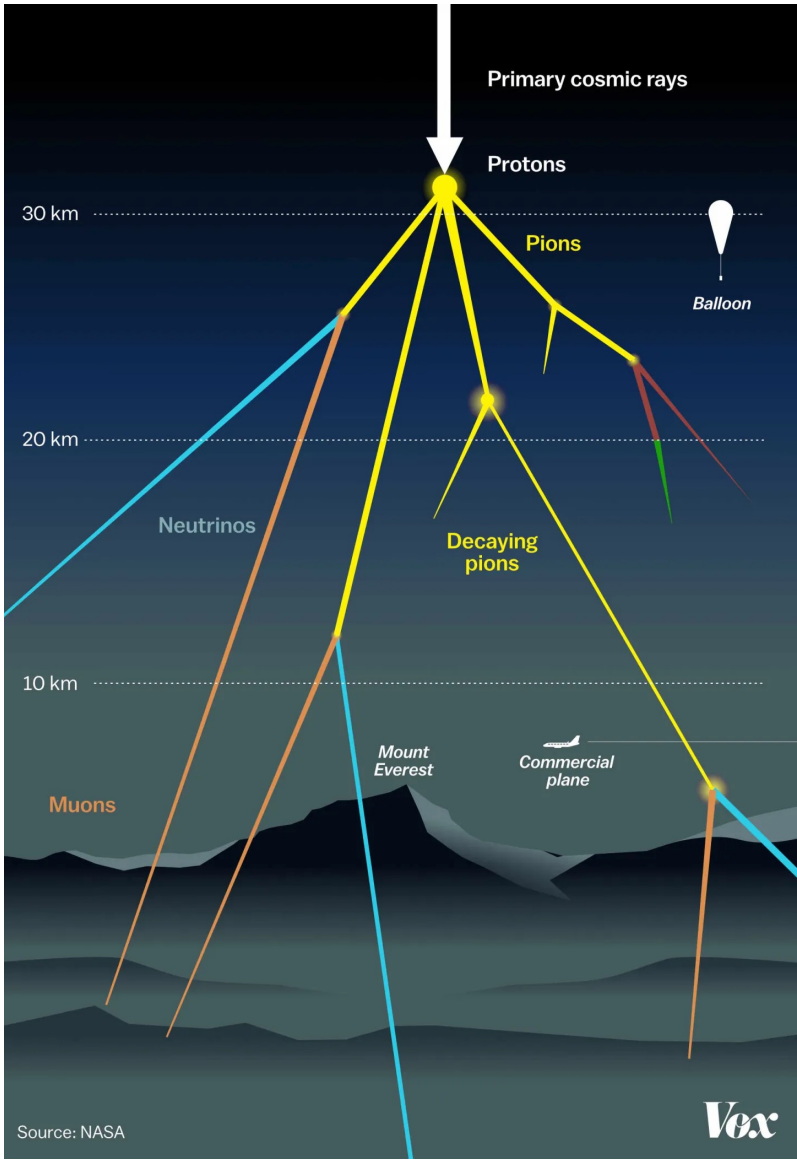
Better Idea – Muon Collider

Muons are short-lived subatomic Particles produced in atmosphere
– rain down on us continuously

We can produce and accelerate them

A muon collider will be 20x higher energy than electron collider

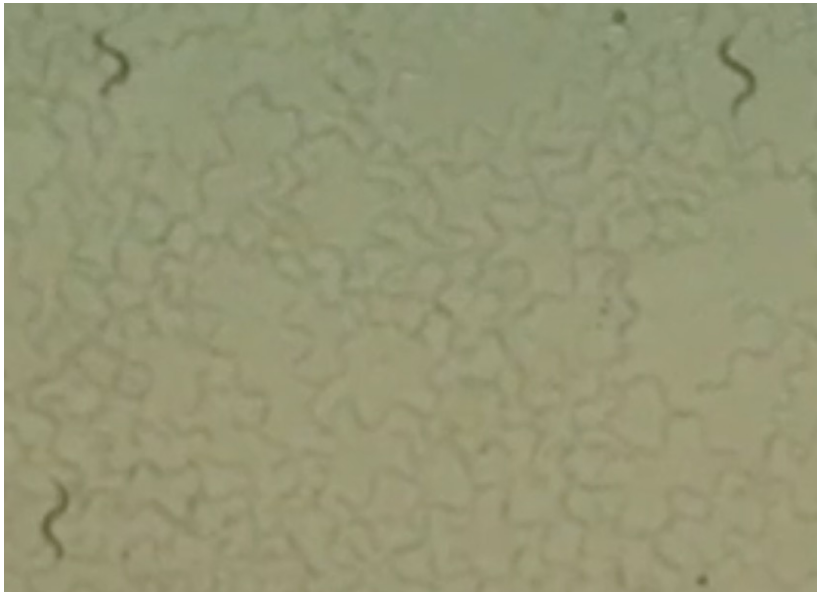
A muon collider will be 10x smaller in size than electron and proton collider



I am working on the design of a muon collider

Bringing Physics Techniques to Biology

Nematodes (worms) 1 mm long routinely used in biology research



Quantitative techniques for recording and analyzing data are routinely used in physics

I am working on bringing these together:

Using AI to identify and digitize worm images, analyze motion using physics principles

I am collaborating with biologists and medical physicists at Duke to use worms as sensors of environmental factors