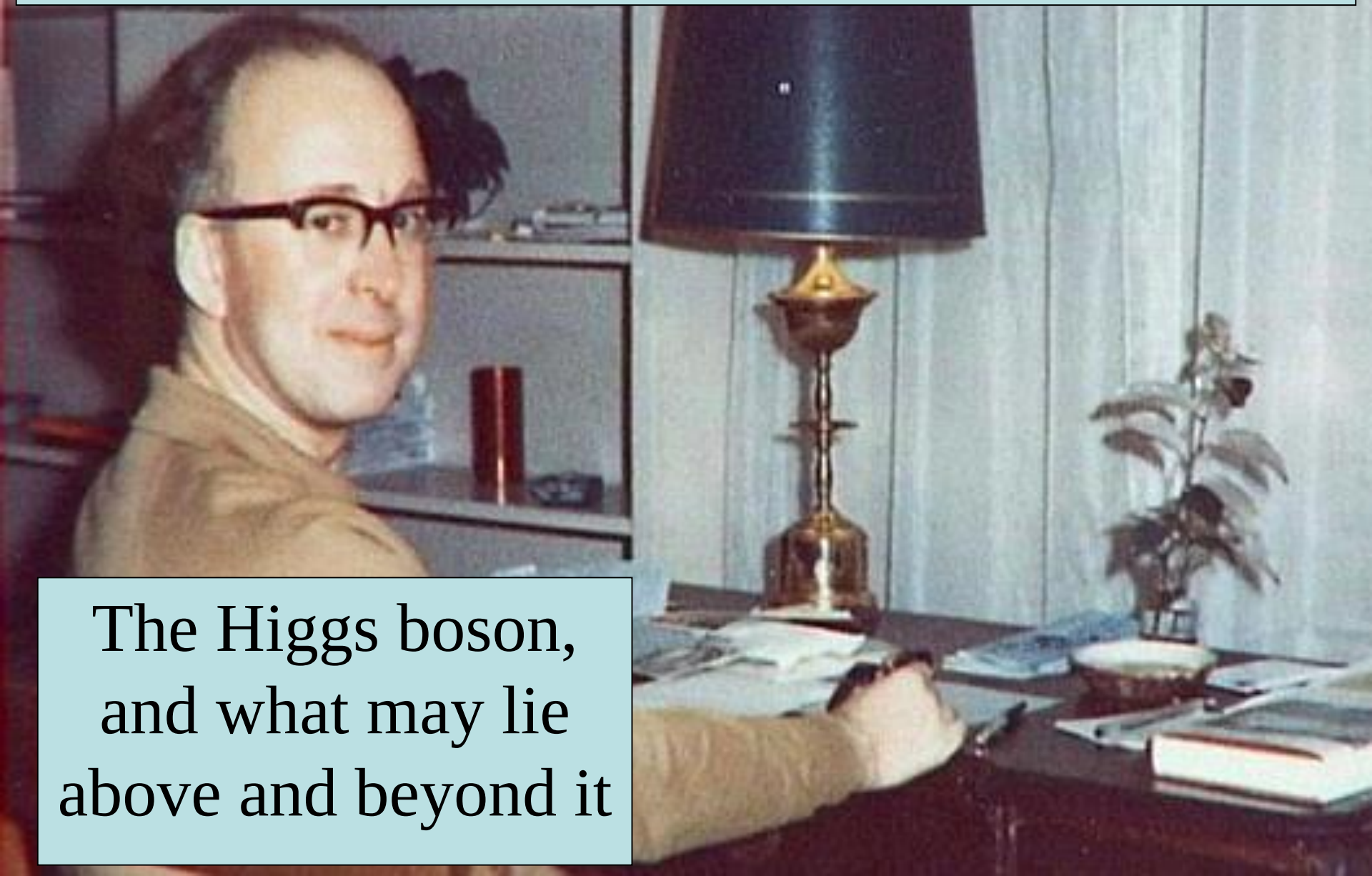
Is there Life after Higgs?

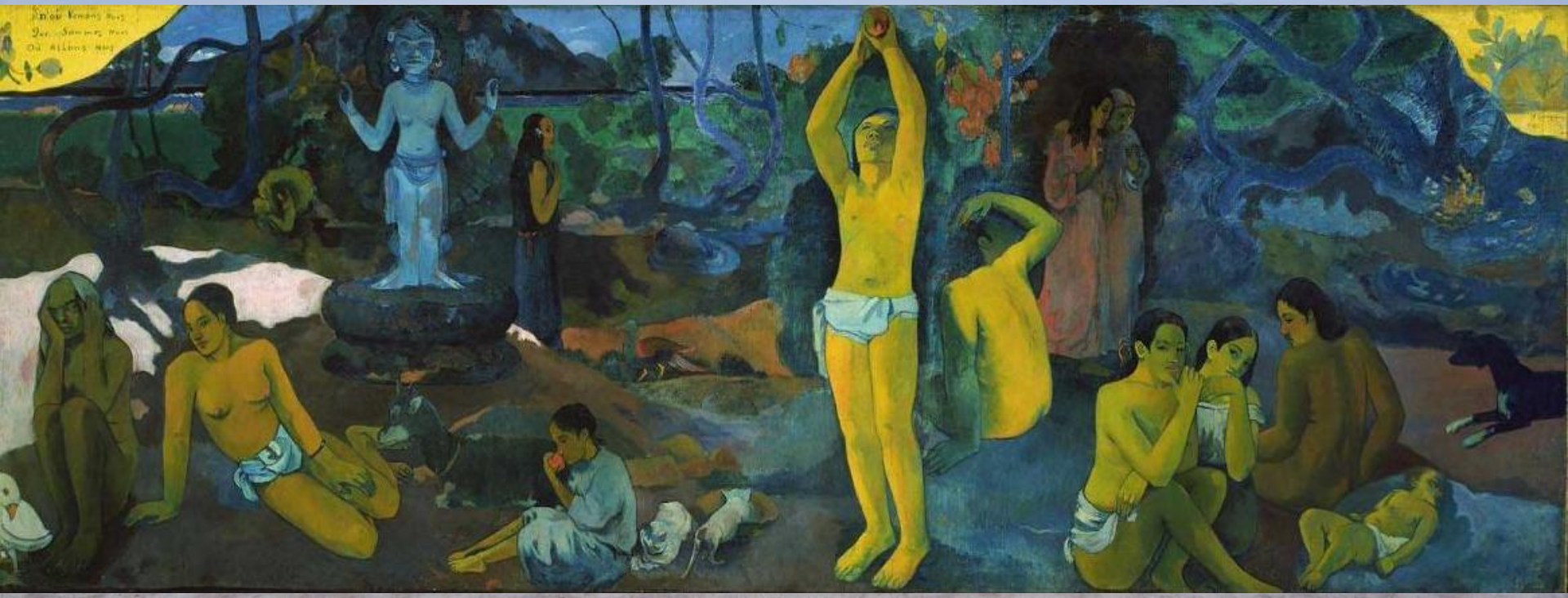


The Higgs boson, and what may lie above and beyond it

“Where do we come from?

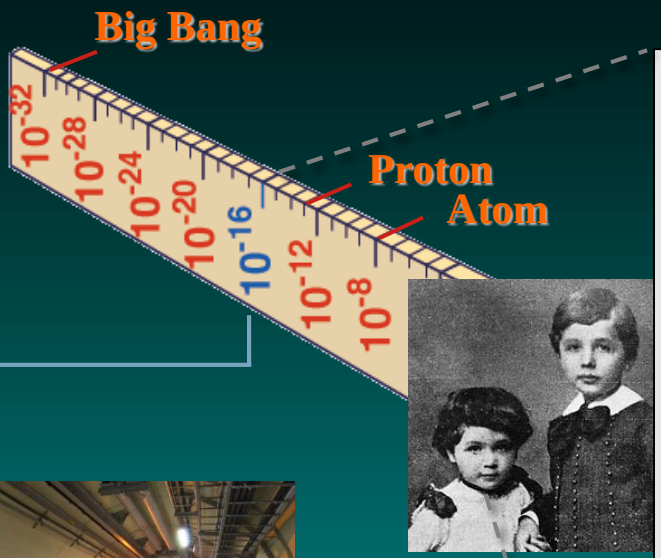
What are we?

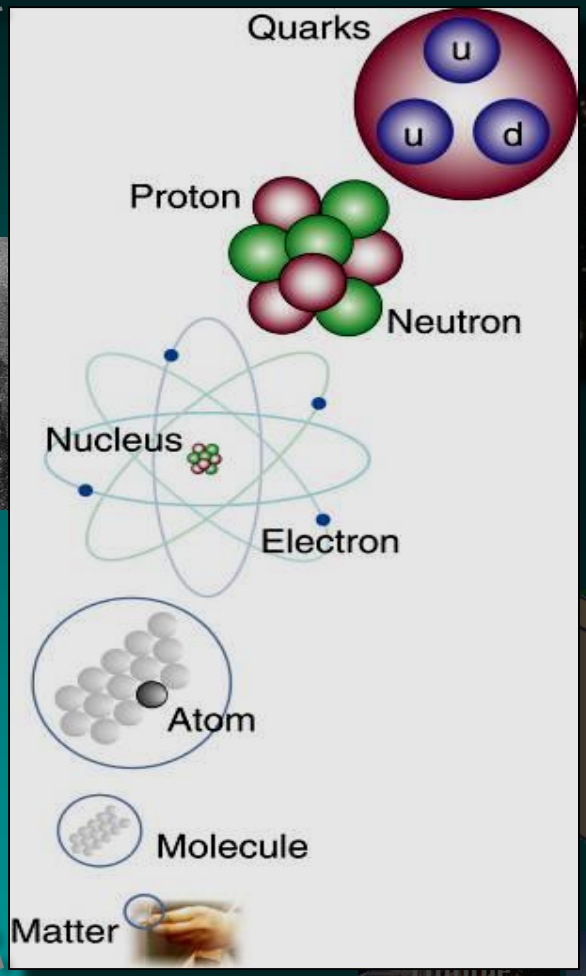
Where are we going?”



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

/Users/johne/Desktop/YoungEinsteins.png

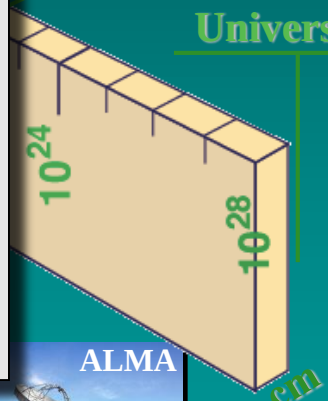


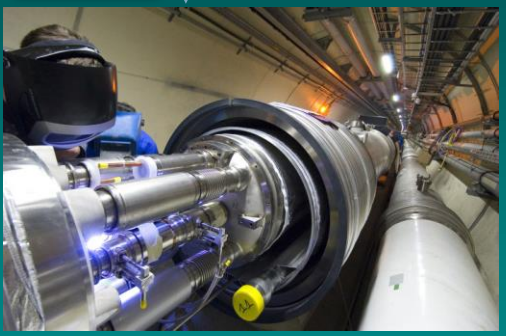


Dark Matter

Radius of Galaxies

Universe





LHC

Super-Microscope

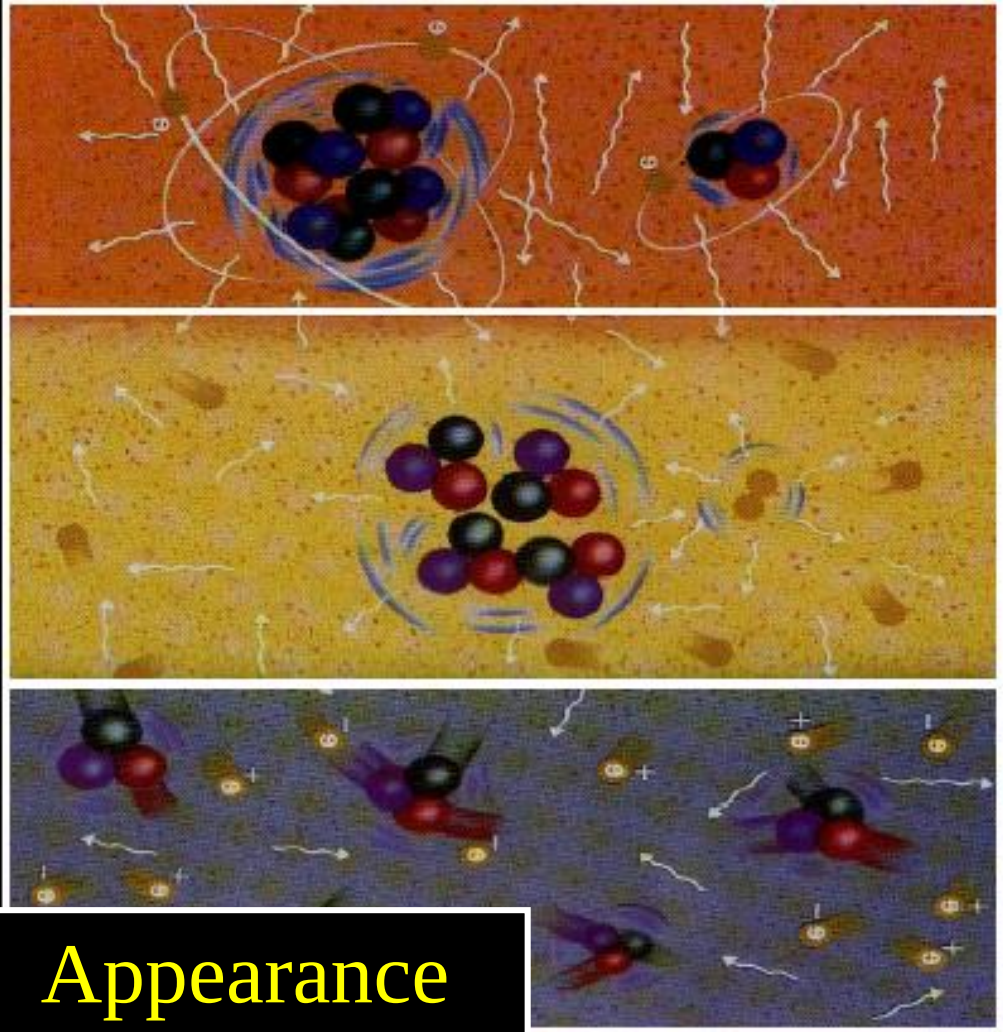
Study physics laws of first moments after Big Bang
increasing Symbiosis between Particle Physics,
Astrophysics and Cosmology

300,000 years

3 minutes

1 micro-second

1 pico-second



Formation of atoms

Formation of nuclei

Formation of protons & neutrons

Appearance of mass?

Appearance of dark matter?

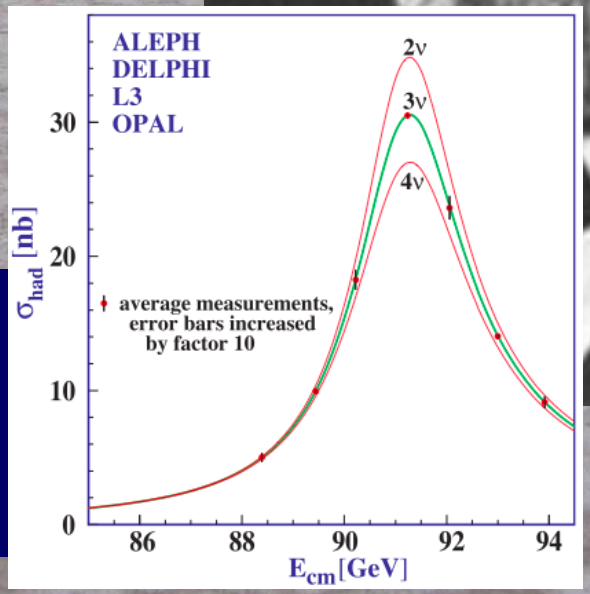
Appearance of matter?

BANG!

The ‘Standard Model’ of Particle Physics

Proposed by Abdus Salam, Glashow and Weinberg

Tested by experiments at CERN

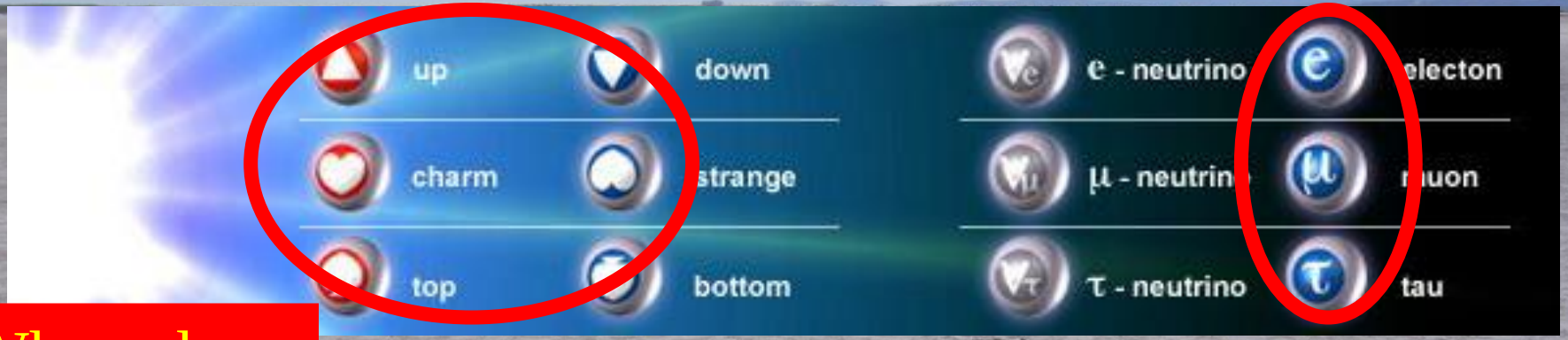


Perfect agreement between theory and experiments in all laboratories

The ‘Standard Model’

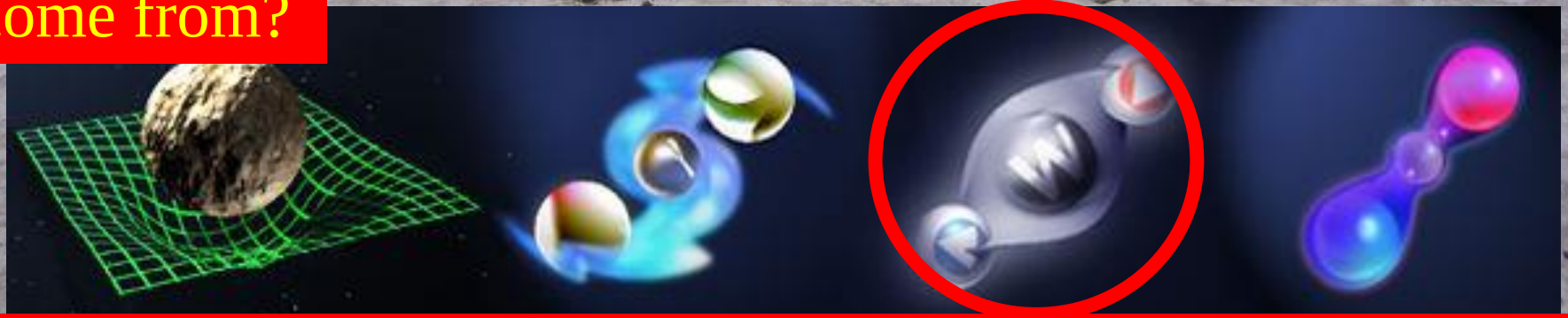
= Cosmic DNA

The matter particles



Where does mass come from?

The fundamental interactions



Gravitation electromagnetism weak nuclear force strong nuclear force

Gauguin's Questions in the Language of Particle Physics

- What is matter made of?
  - Why do things weigh?

- **What is the origin of matter?** LHC Run 2
- **What is the dark matter that fills the Universe?** LHC Run 2
- **How does the Universe evolve?**
- **Why is the Universe so big and old?** LHC Run 2
- **What is the future of the Universe?** LHC Run 2

Our job is to ask - and answer - these questions

Why do Things Weigh?

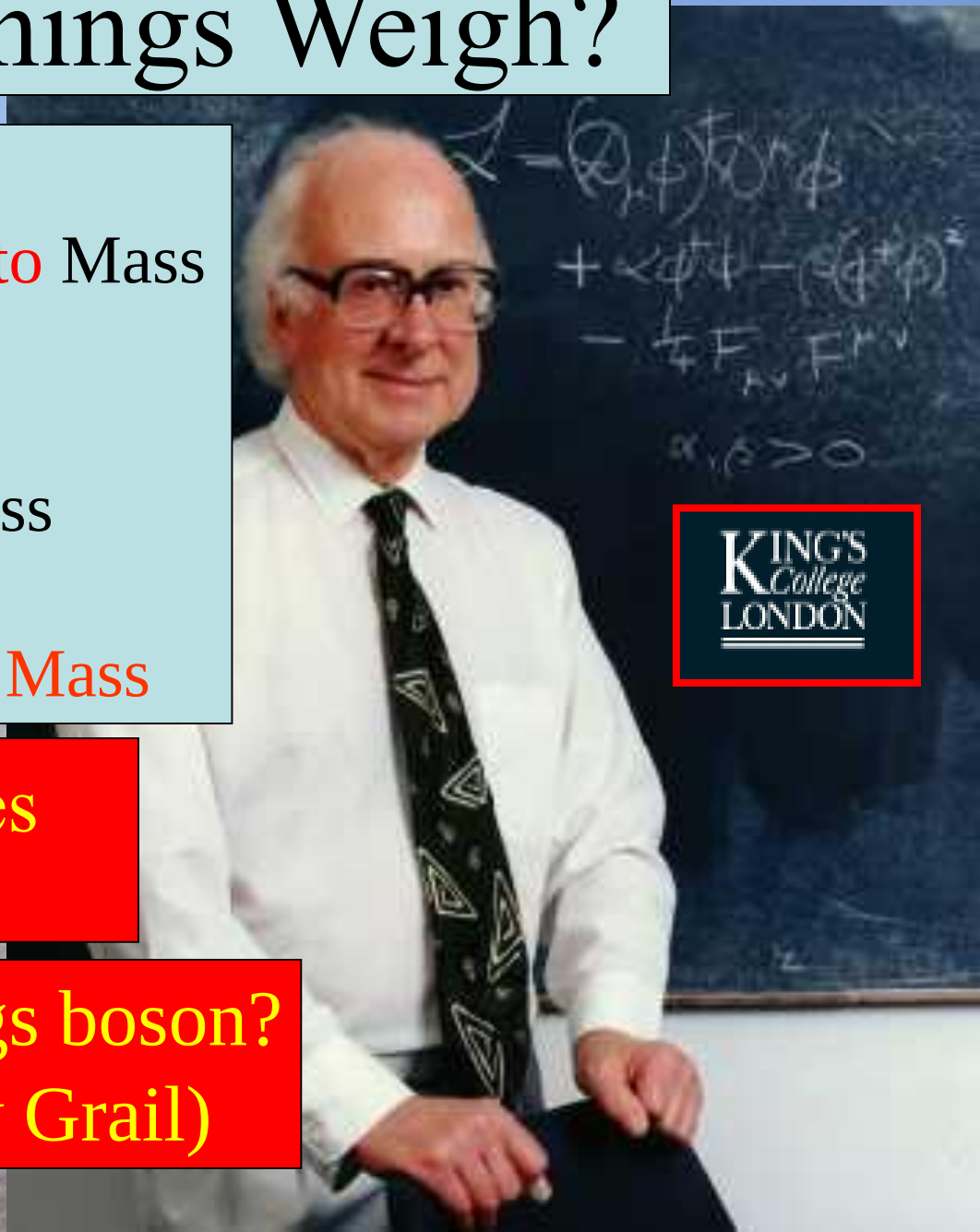
Newton:

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)

Think of a Snowfield

The LHC looked for the snowflake: The Higgs Boson

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

A Phenomenological Profile of the Higgs Boson

- First attempt at systematic survey

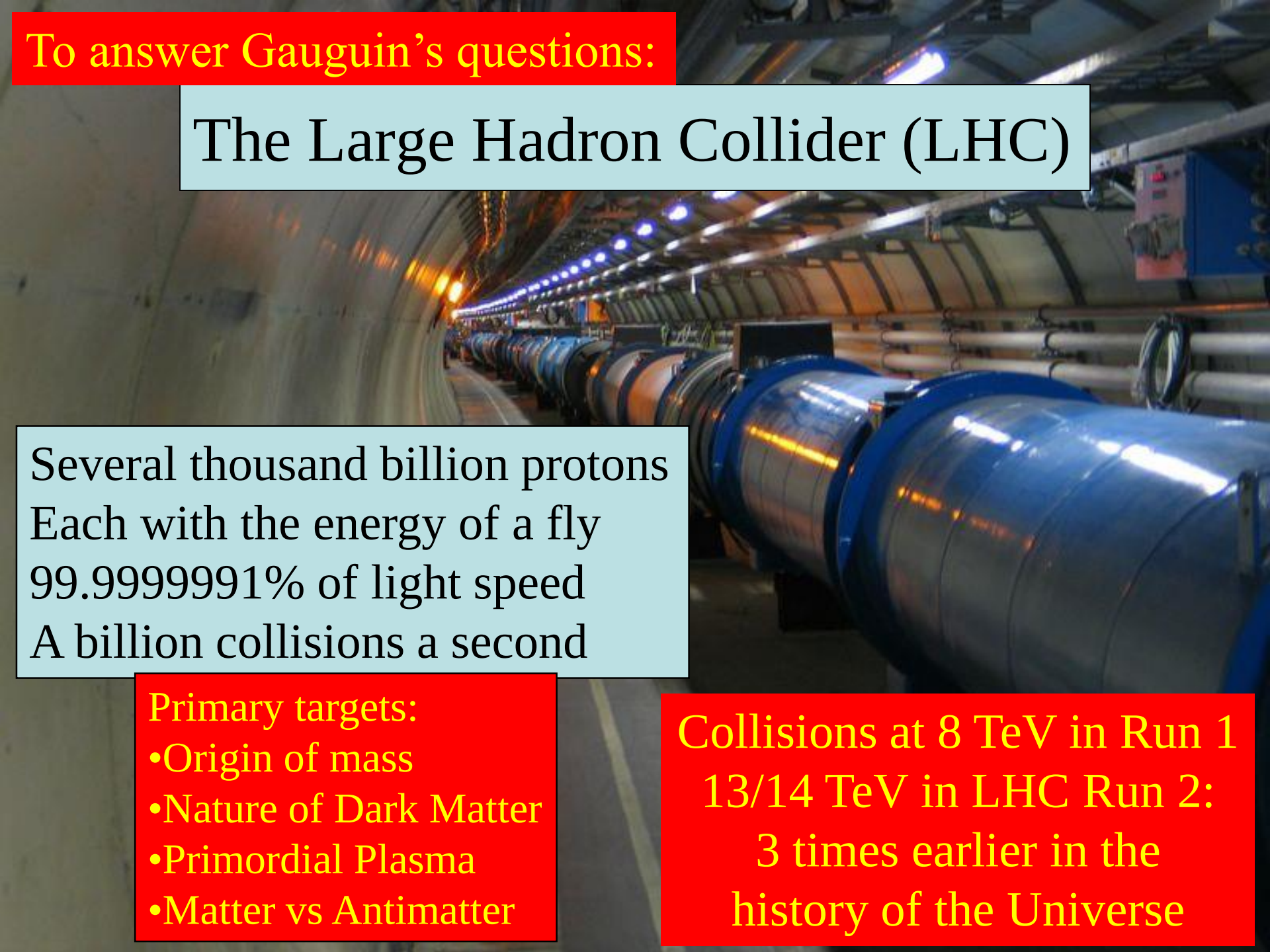
A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

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.



To answer Gauguin's questions:

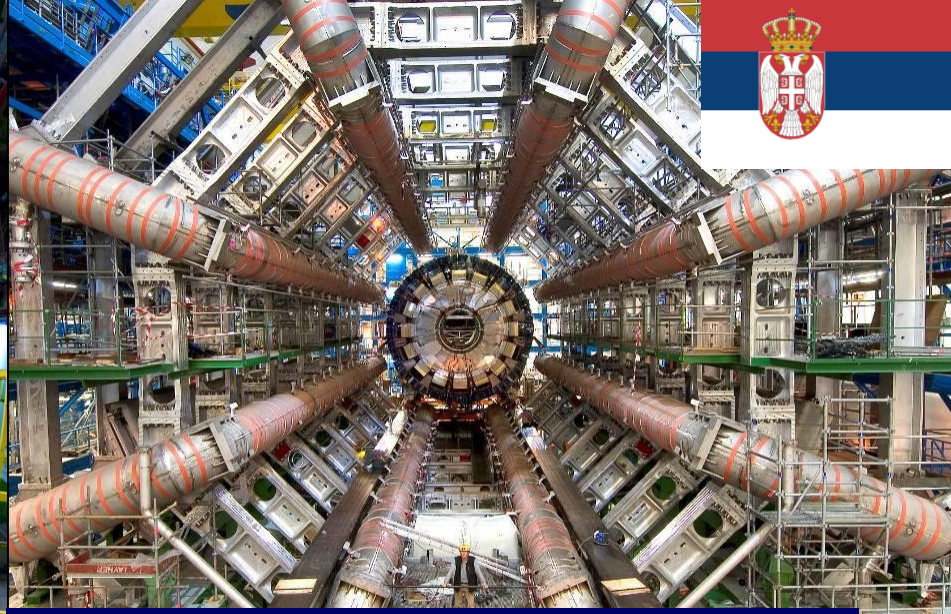
The Large Hadron Collider (LHC)

Several thousand billion protons
Each with the energy of a fly
99.9999991% of light speed
A billion collisions a second

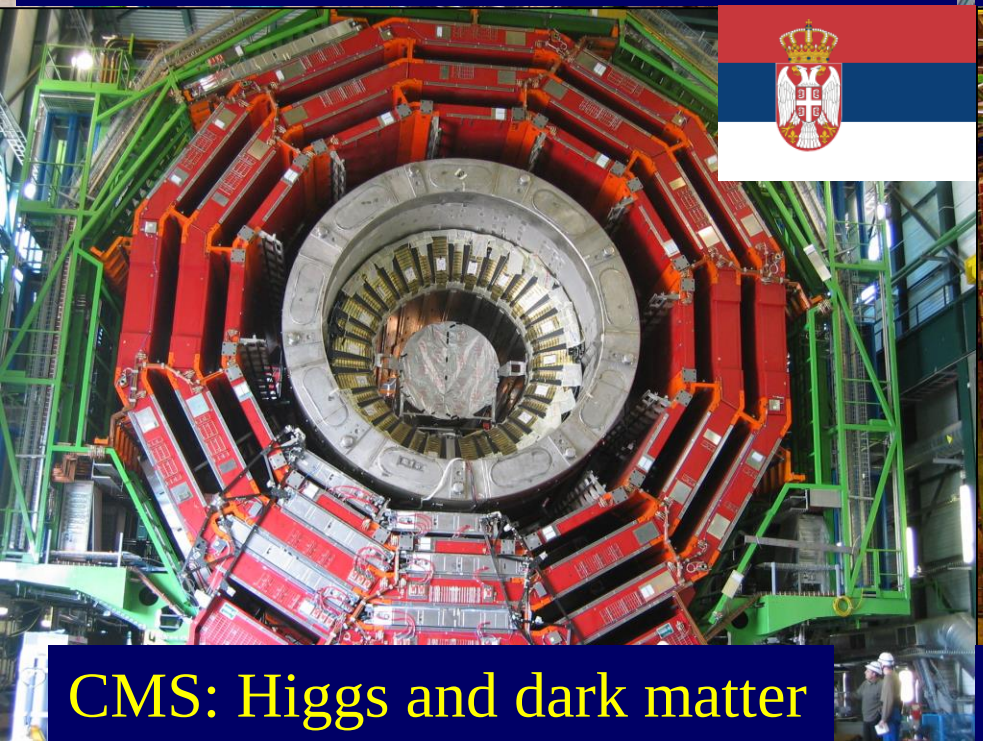
Primary targets:
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

Collisions at 8 TeV in Run 1
13/14 TeV in LHC Run 2:
3 times earlier in the
history of the Universe

ALICE: Primordial cosmic plasma



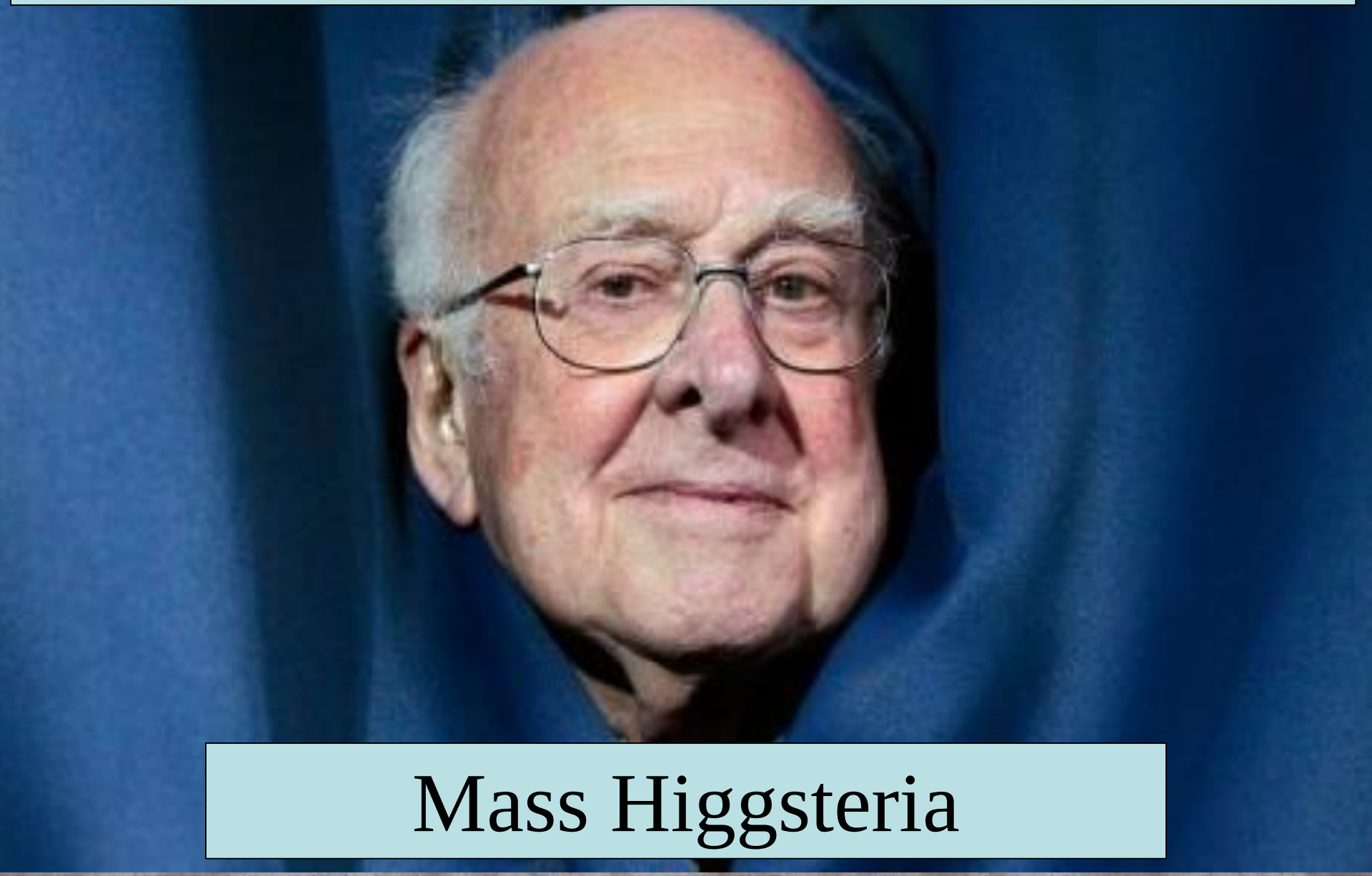
ATLAS: Higgs and dark matter



CMS: Higgs and dark matter

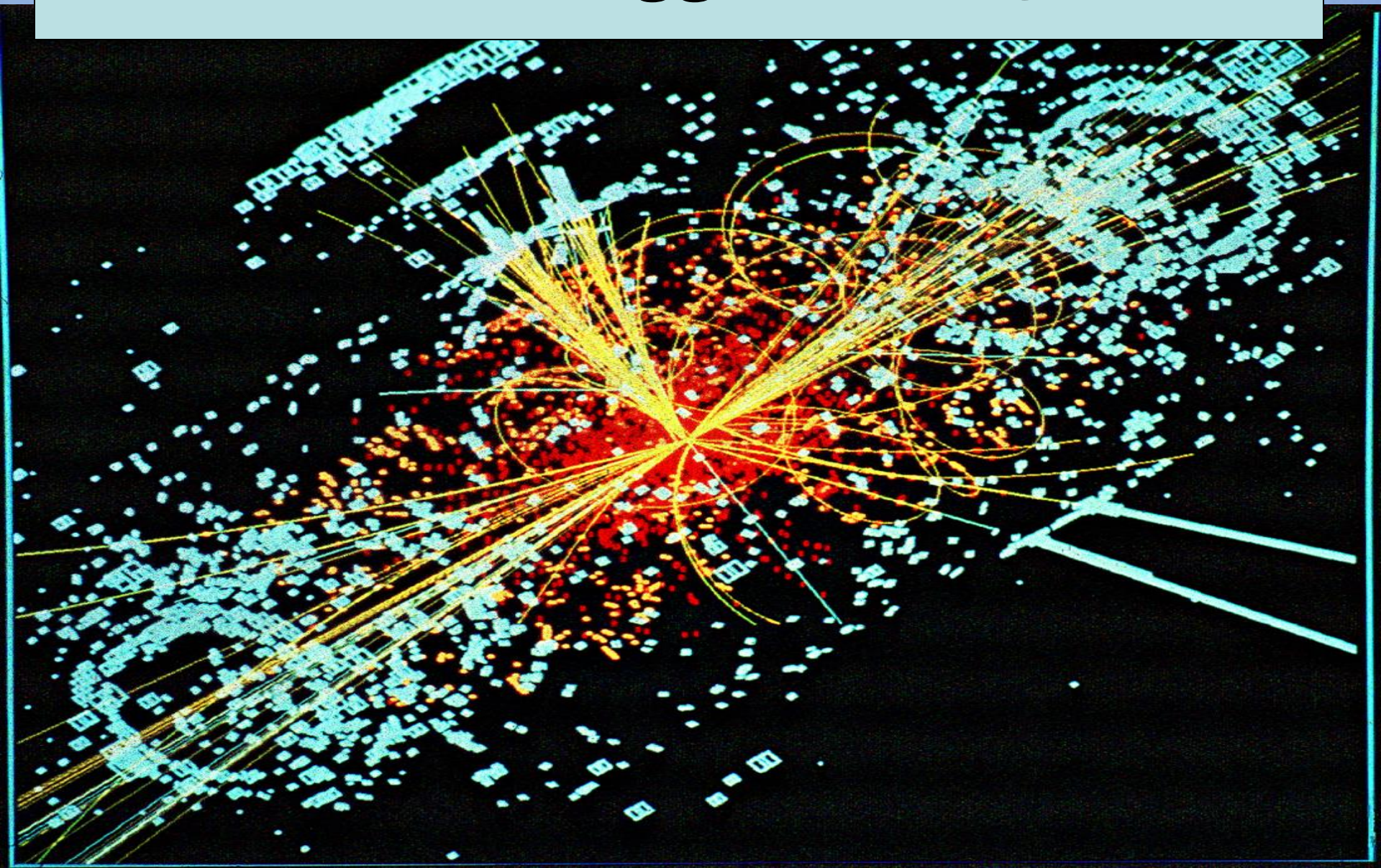
LHCb: Matter-antimatter difference

The Discovery of the Higgs Boson

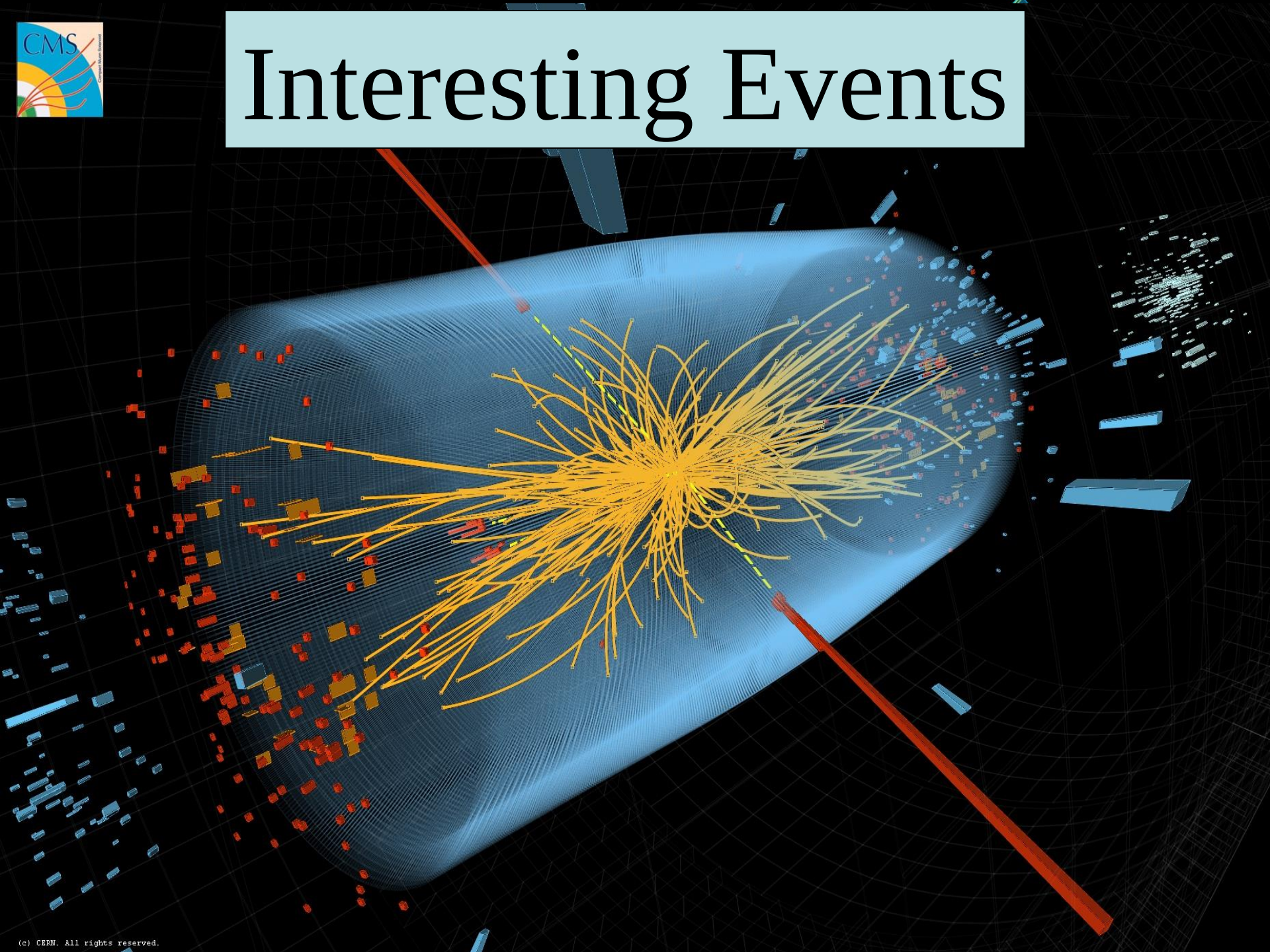


Mass Higgsteria

A Simulated Higgs Event @ LHC



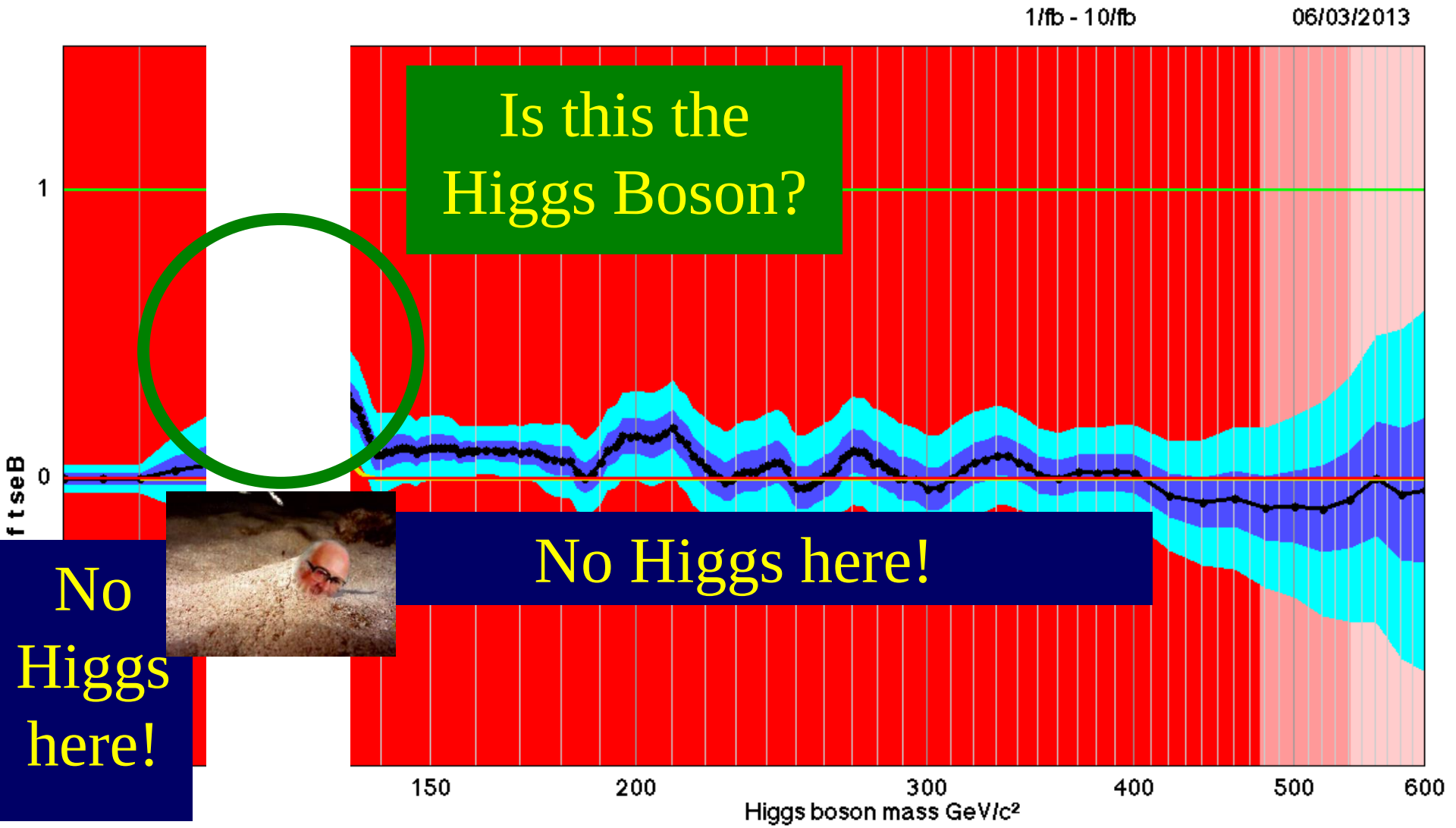
Interesting Events



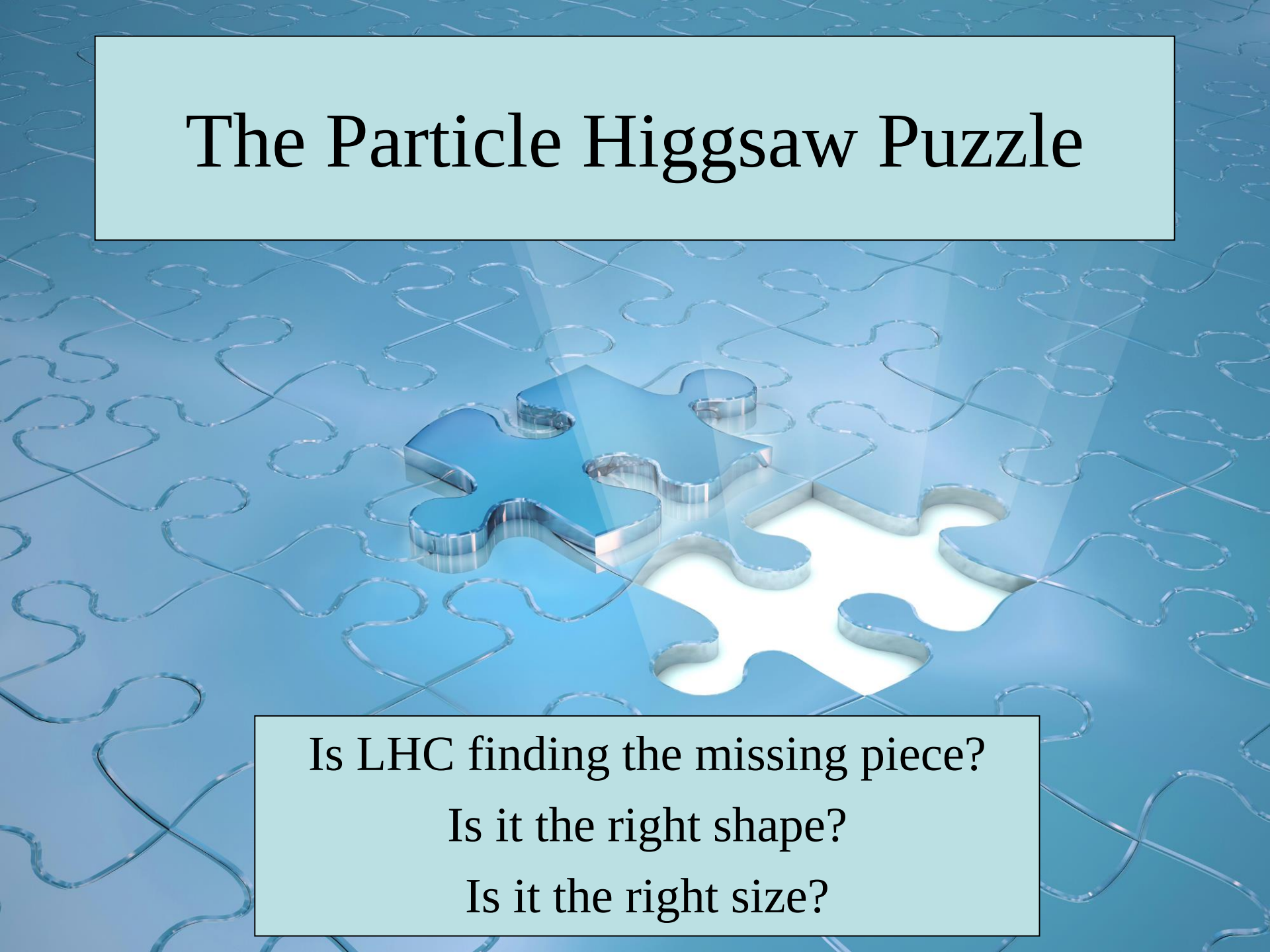
July 4th 2012
The discovery of a new particle

Higgsdependence Day!

Unofficial Combination of Higgs Data



The Particle Higgsaw Puzzle

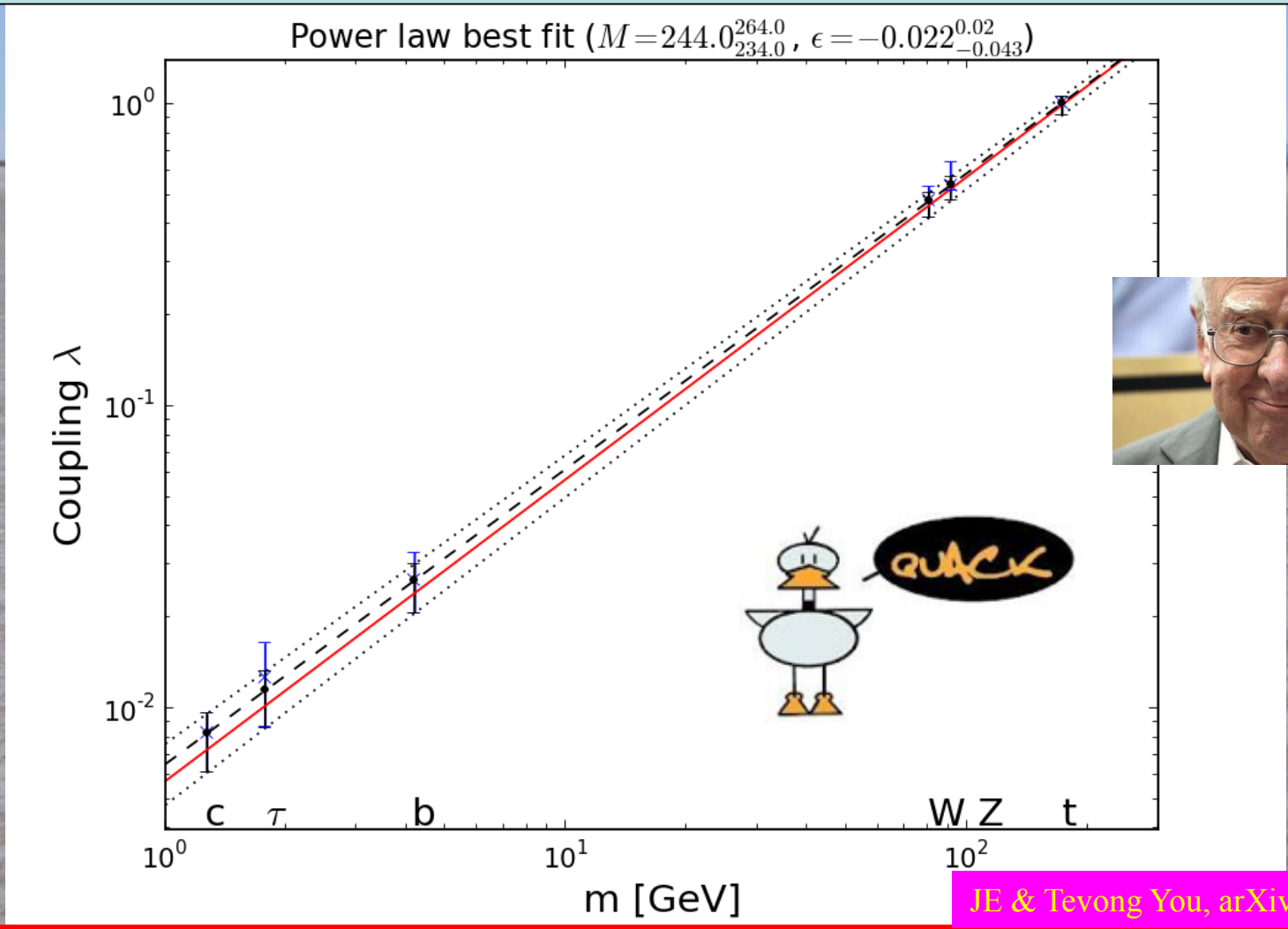


Is LHC finding the missing piece?

Is it the right shape?

Is it the right size?

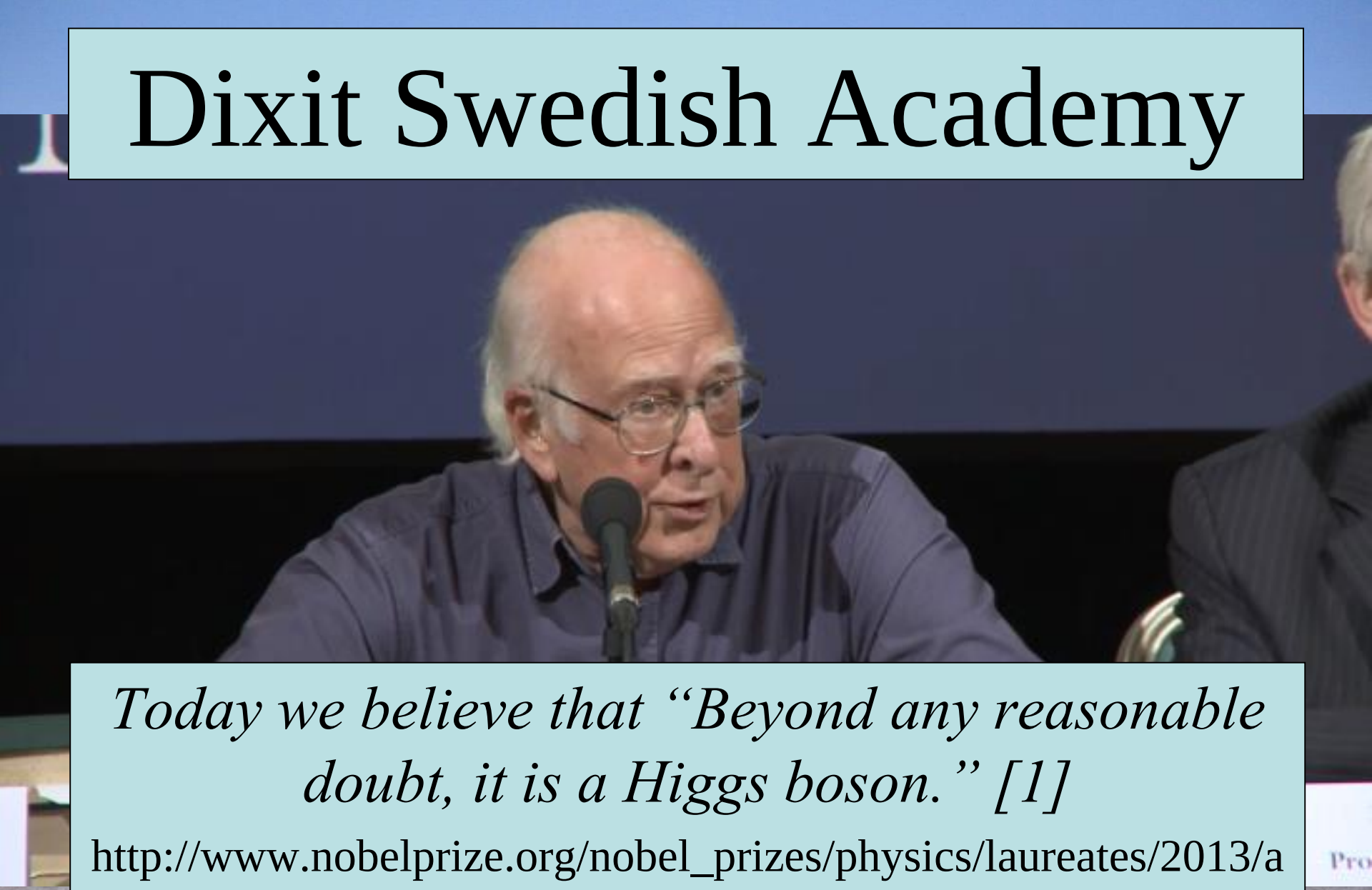
It Walks and Quacks like a Higgs



JE & Tevong You, arXiv:1303.3879

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

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

Without Higgs …

… there would be no atoms

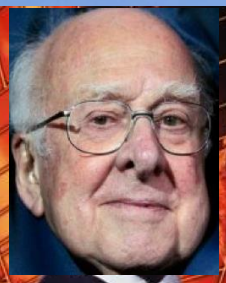
- massless electrons would escape at the speed of light

… 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!



LHC Run 2 space is unstable

- Dark matter LHC Run 2
- Origin of matter LHC Run 2
- Masses of neutrinos

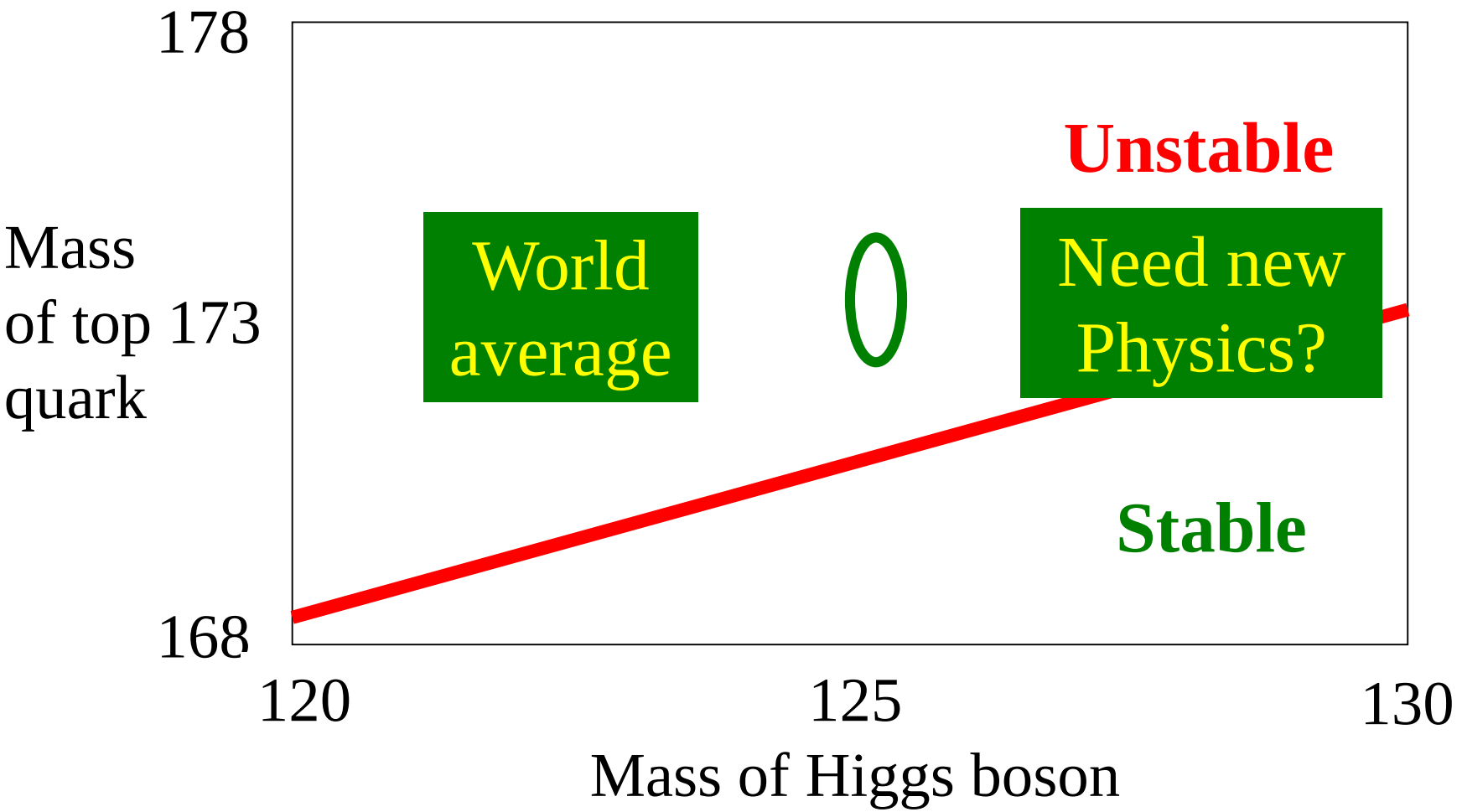
LHC Run 2 weak force so strong?

- C LHC Run 2 inflation
- Quantum gravity
- …

The Standard Model

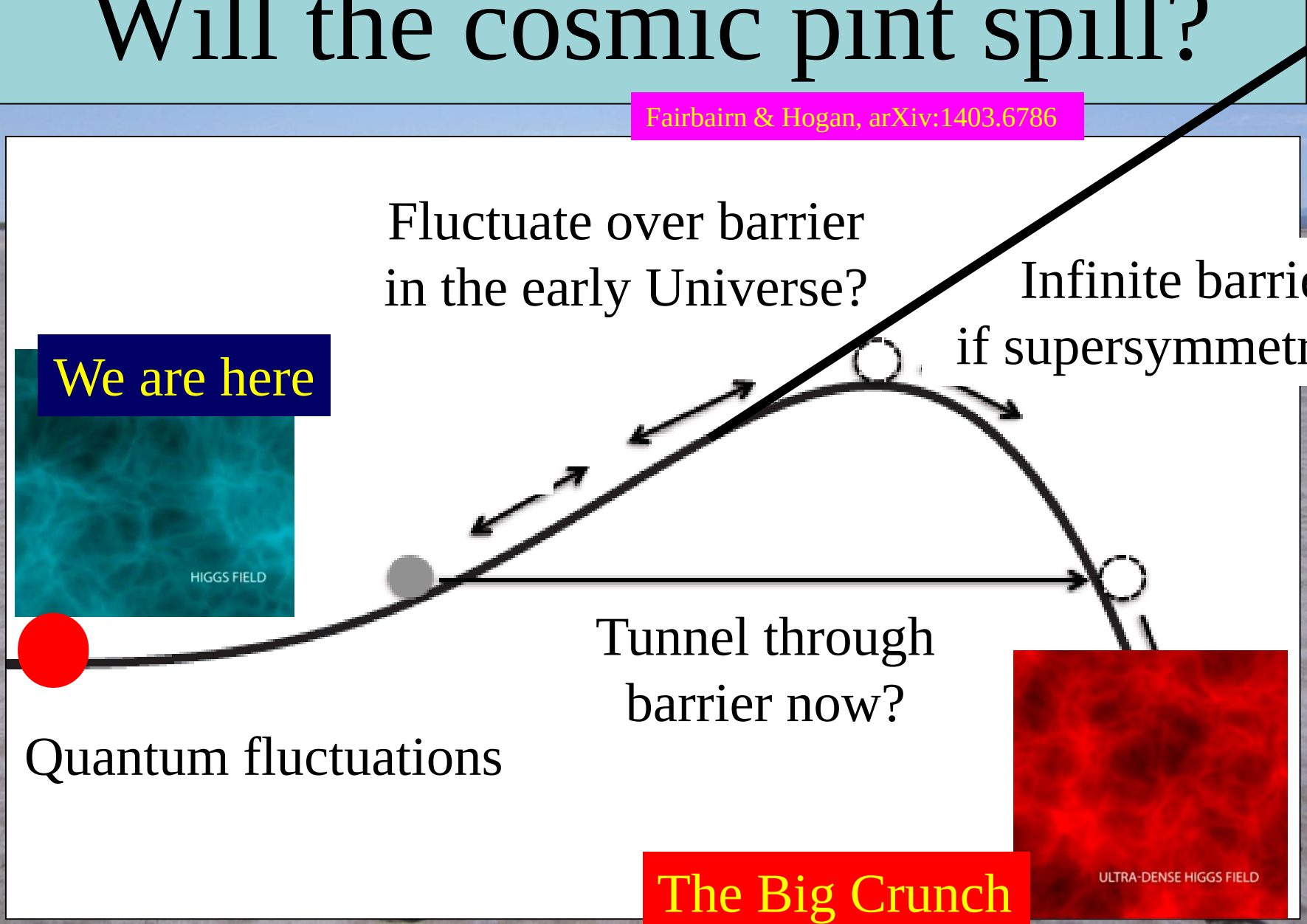
Is “Empty Space” Unstable?

- Depends on masses of Higgs boson and top quark



Will the cosmic pint spill?

Fairbairn & Hogan, arXiv:1403.6786



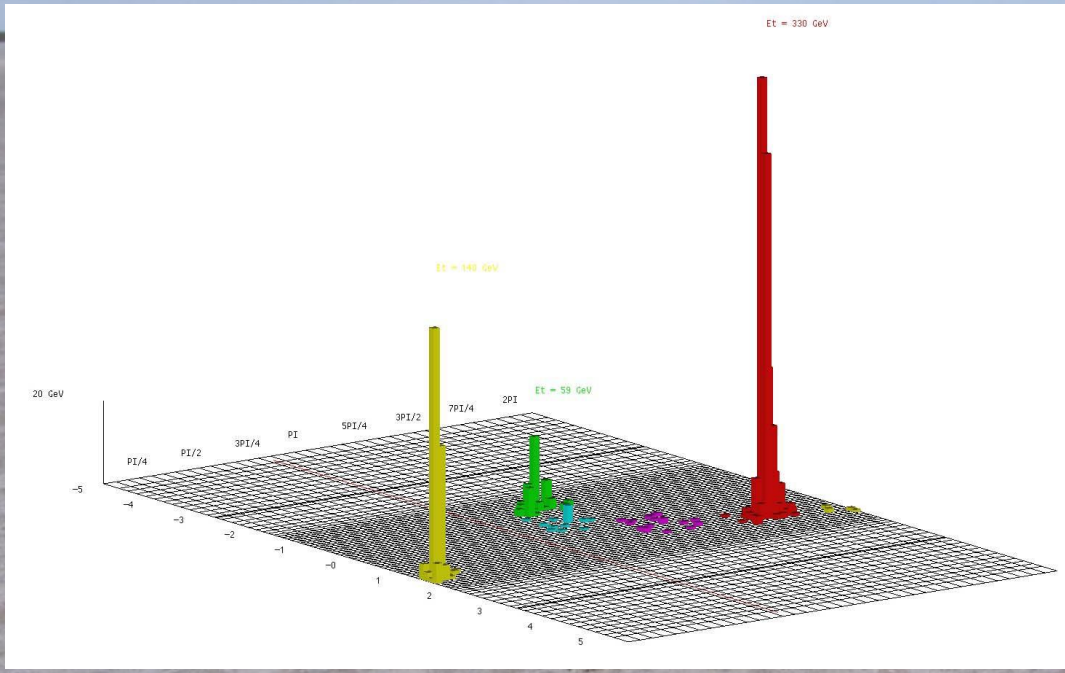
Dark Matter in the Universe

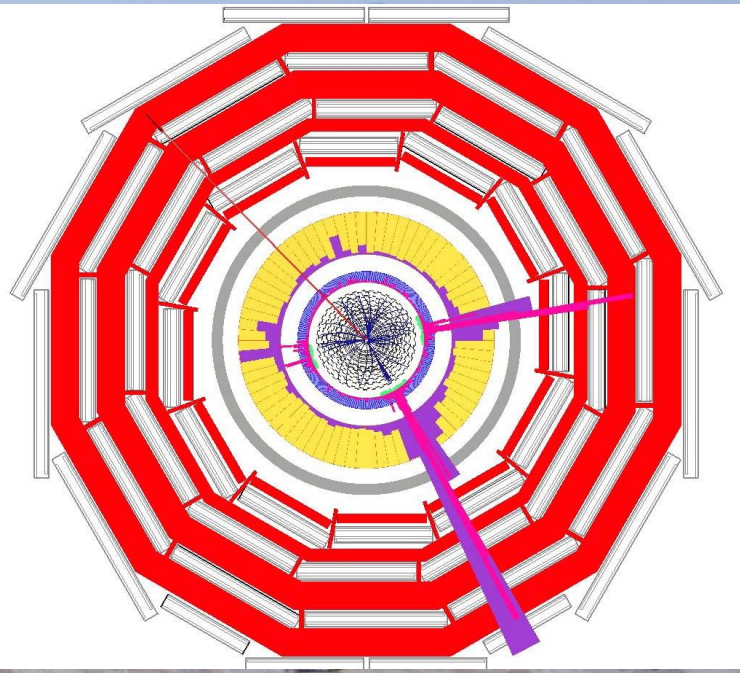
Astronomers say that most of the matter in the Universe is invisible
Dark Matter

Supersymmetric particles?

We are looking 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

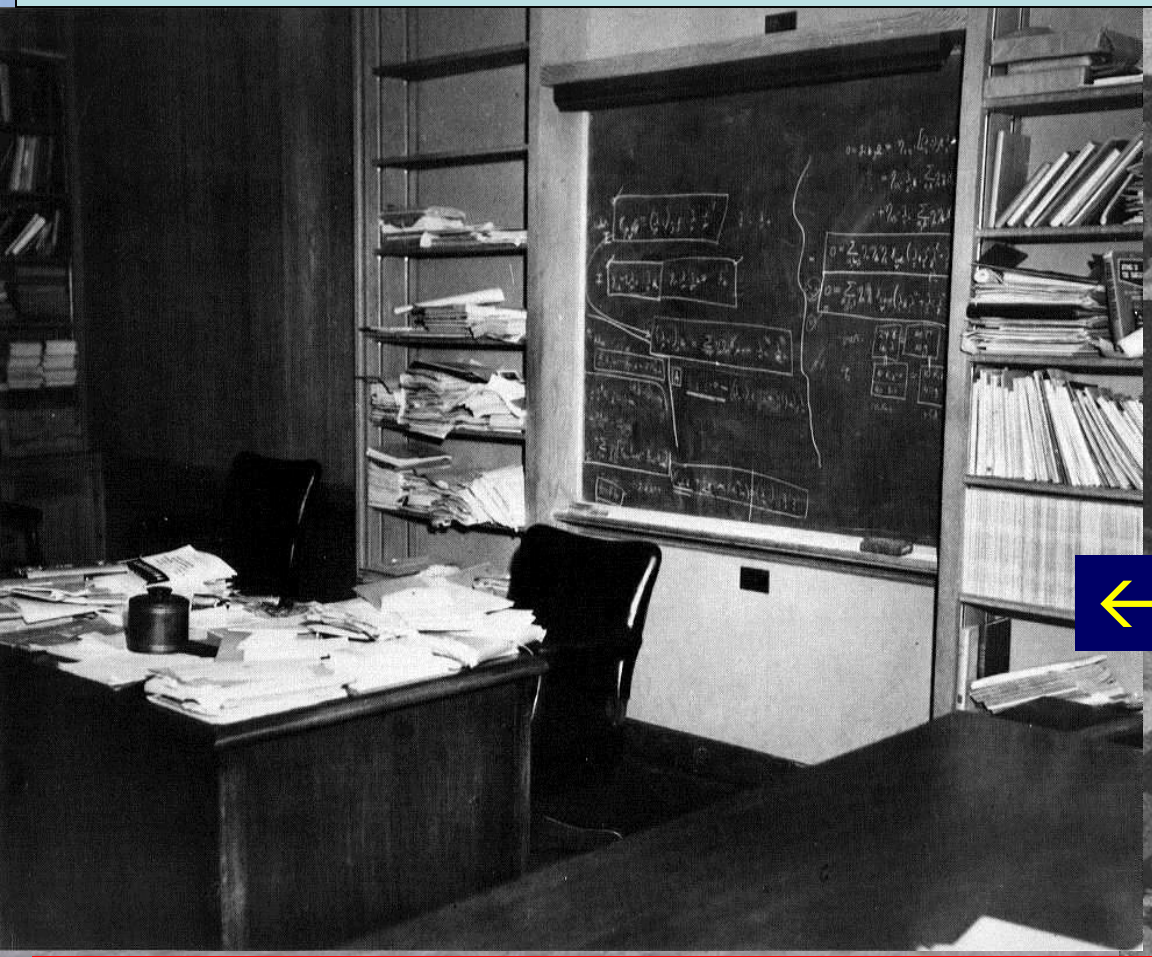
Used in PET scanners

Matter and antimatter not quite equal and opposite: WHY?

Why does the Universe mainly contain matter, not antimatter?

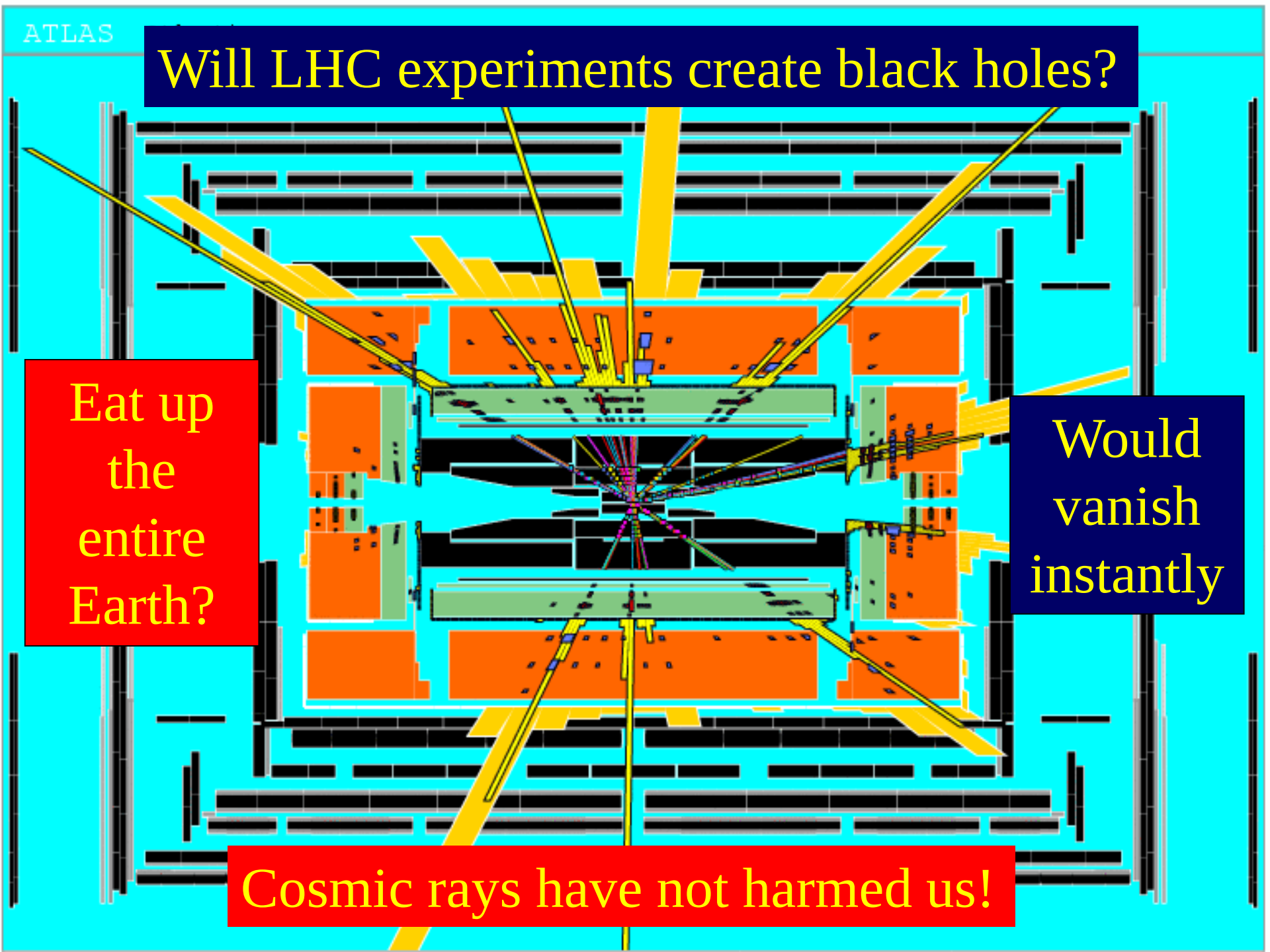
Experiments at LHC and elsewhere looking for answers

Unify the Fundamental Interactions: Einstein's Dream …



← … but he never succeeded

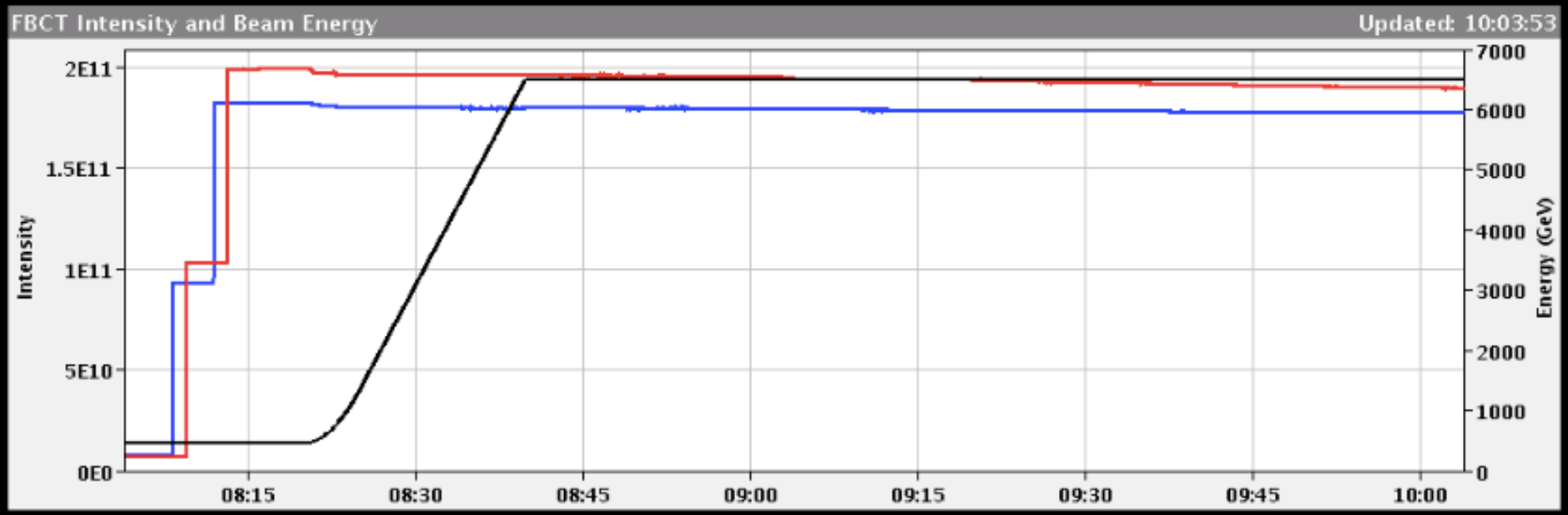
Unification via extra dimensions of space?


ATLAS
Will LHC experiments create black holes?
Eat up the entire Earth?
Would vanish instantly
Cosmic rays have not harmed us!

LHC Page1 | Fill: 3746 | E: 6500 GeV | t(SB): 00:00:00 | 21-05-15 10:03:53

BEAM SETUP: ADJUST

Energy:	6500 GeV	I(B1):	1.84e+11	I(B2):	1.81e+11

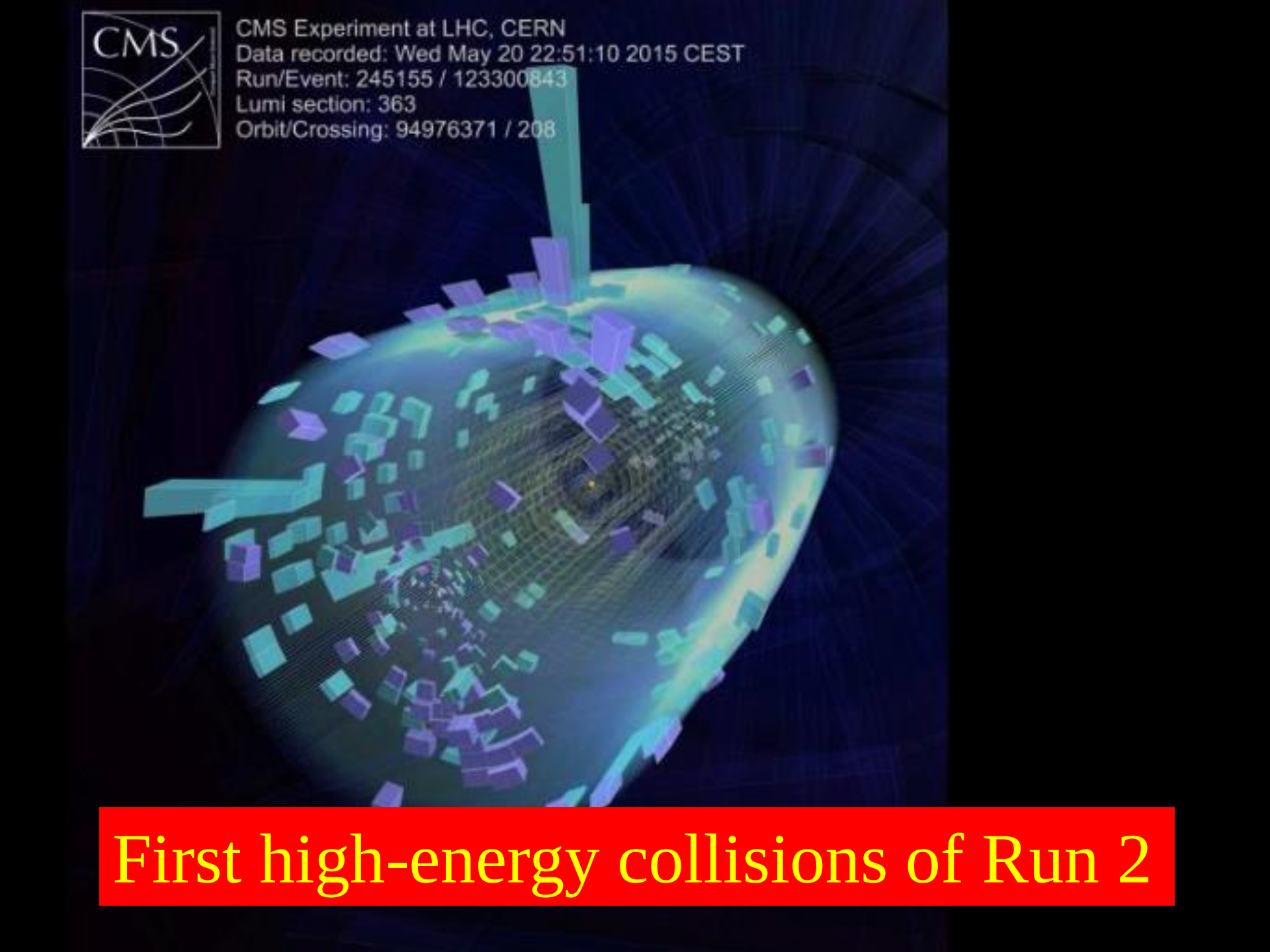


Comments (21-May-2015 09:22:03)
test collisions at 13 TeV

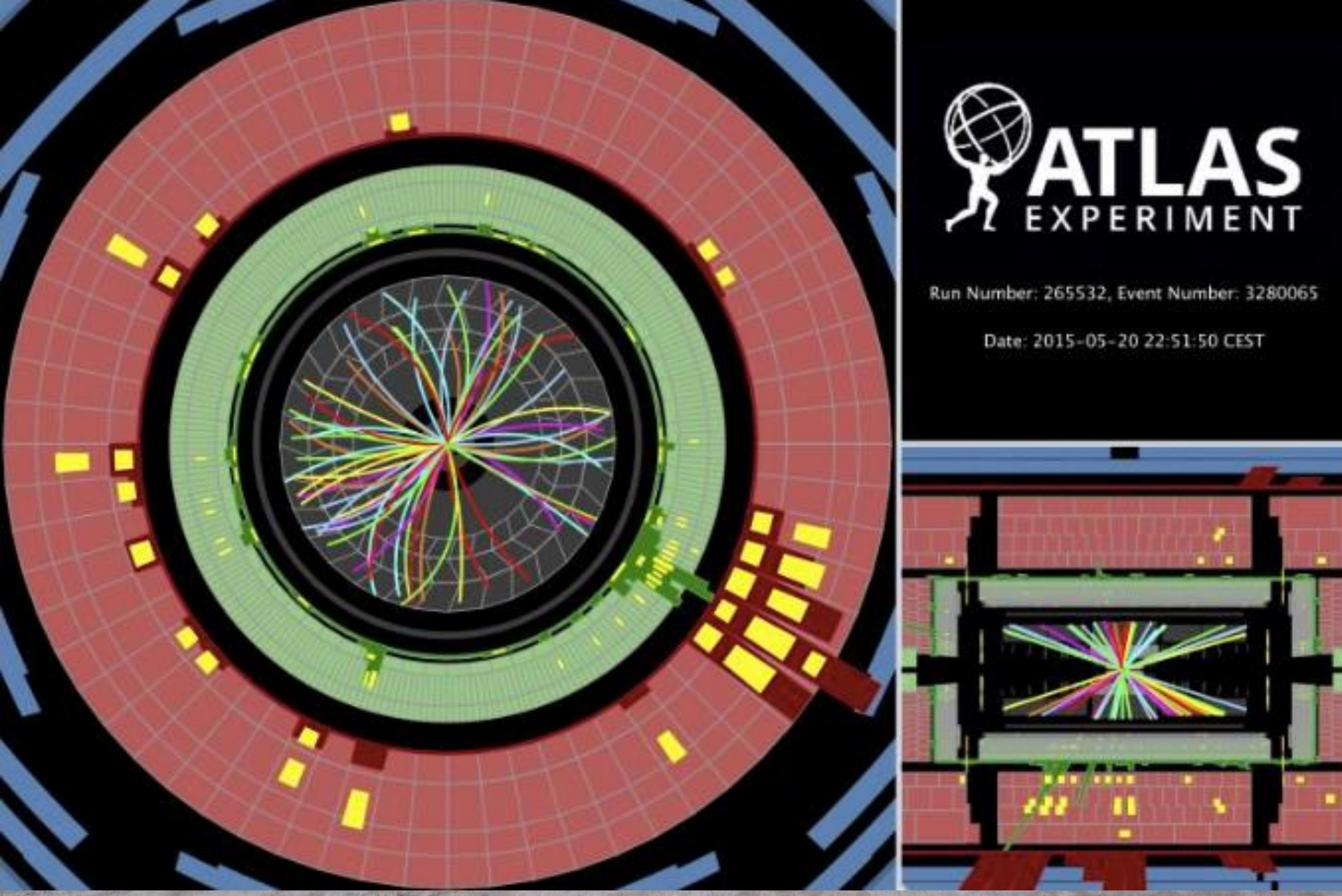
BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	true	true

First collisions at 13 TeV

AFS: Single_2b+1p_1_1_1 | PM Status B1: ENABLED | PM Status B2: ENABLED

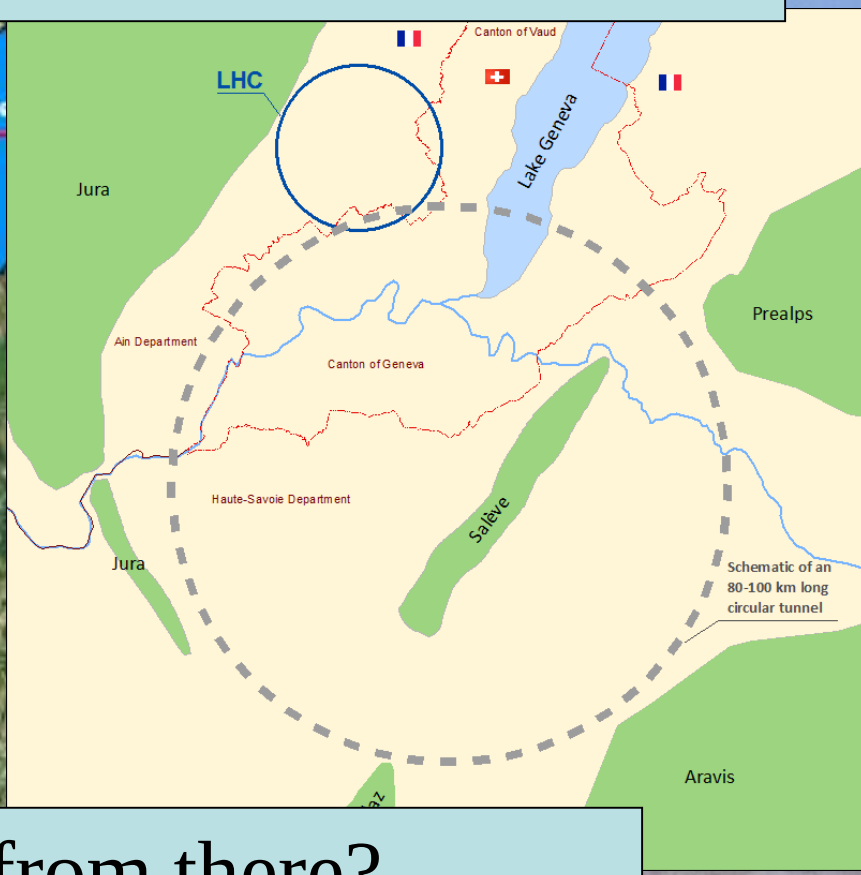


First high-energy collisions of Run 2



First low-energy collisions of Run 2

Next Steps at the High-Energy Frontier?



Where do we go from there?

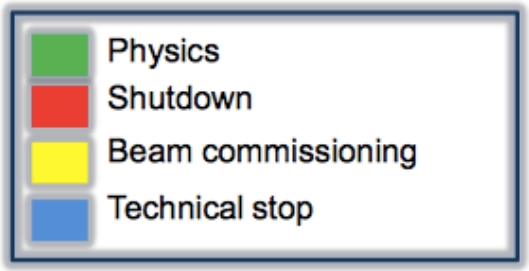
50km linear e^+e^- collider?

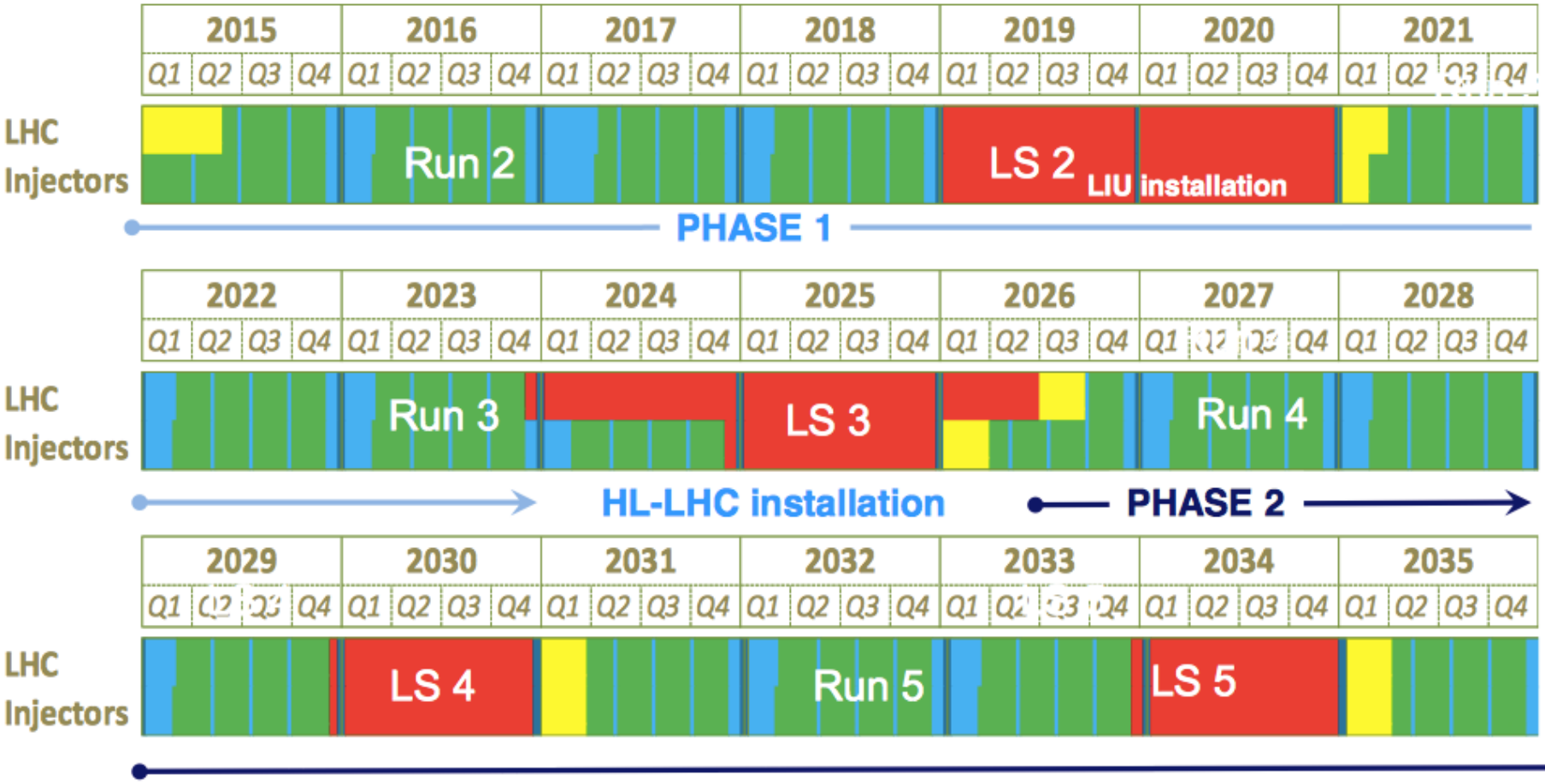
100km circumference pp, e^+e^- collider?

The LHC timeline

LHC roadmap: according to MTP 2016-2020

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC





Future Circular Colliders

The vision:

explore 10 TeV scale directly (100 TeV pp) + indirectly (e^+e^-)


The LHC is the world's most powerful microscope …
… and also a telescope looking into the past, and perhaps the future