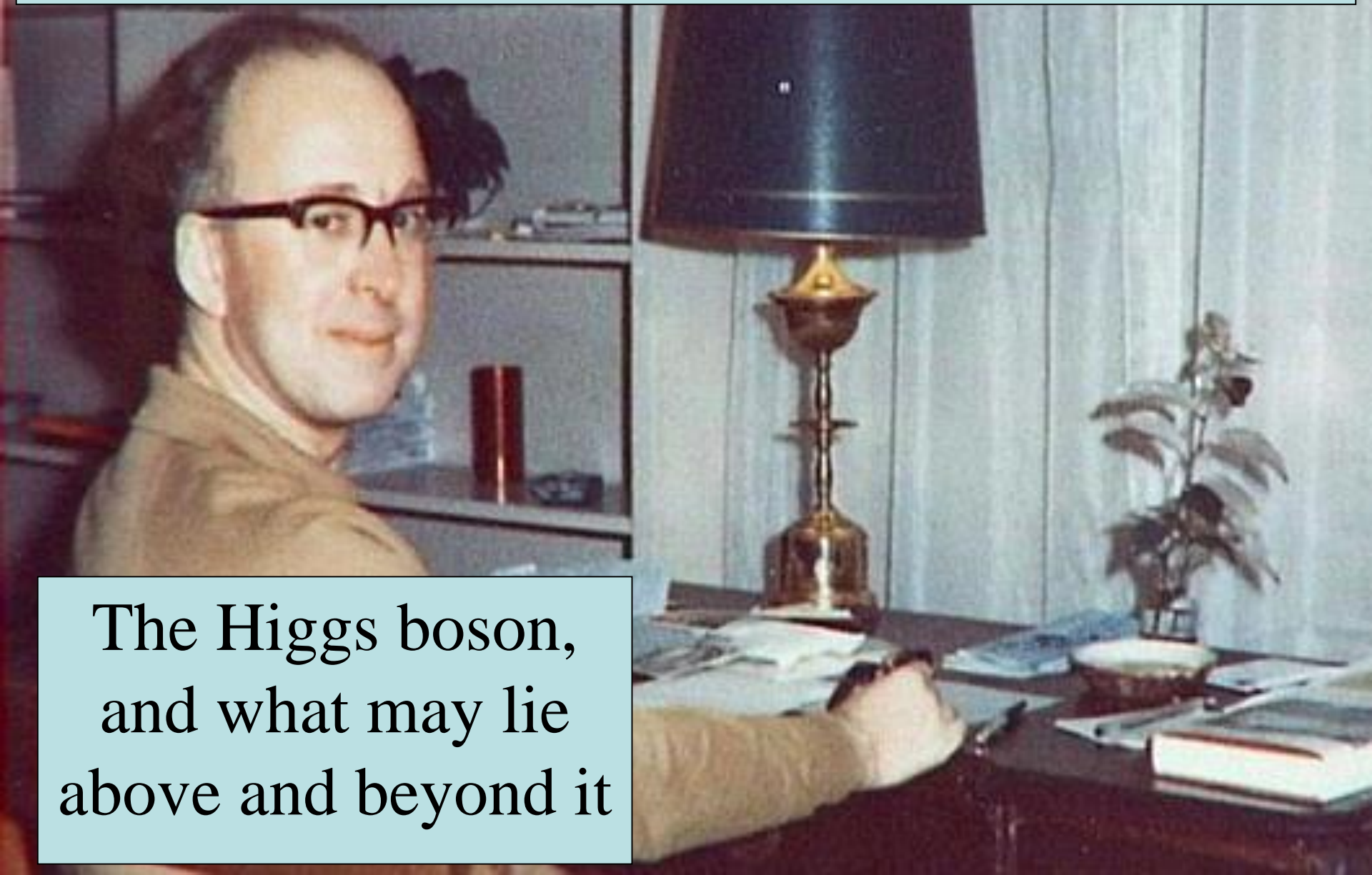


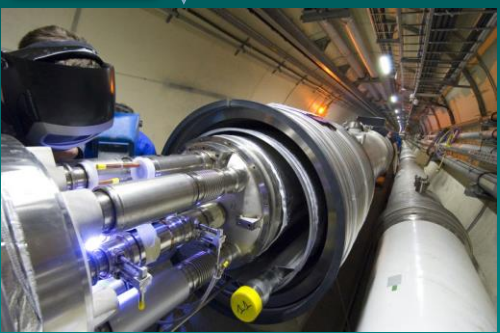
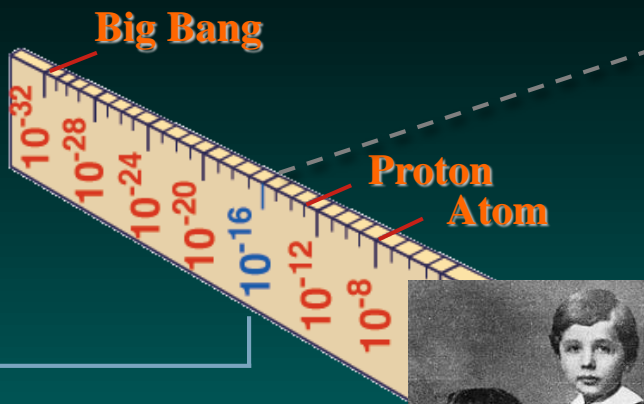
# Is there Life after Higgs?



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





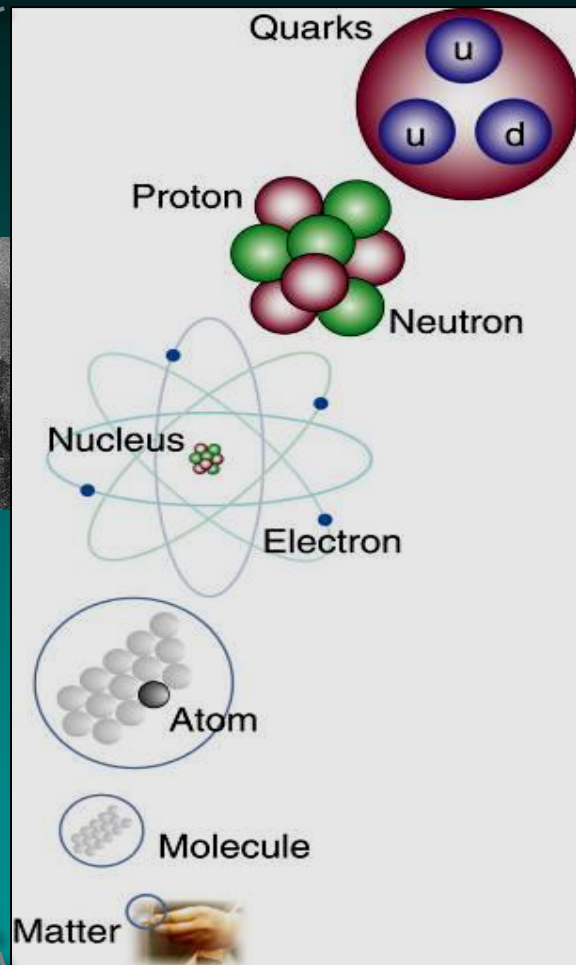


LHC

Super-Microscope

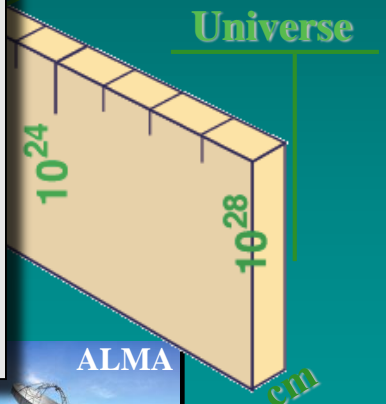


Study physics laws of first moments after Big Bang  
 increasing Symbiosis between Particle Physics,  
 Astrophysics and Cosmology

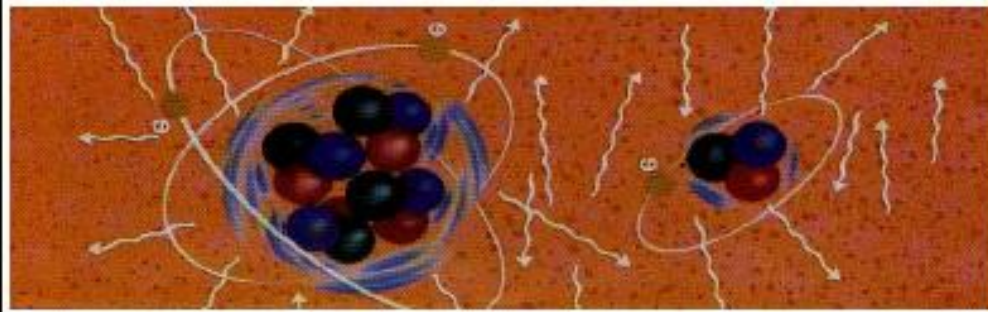


**Dark Matter**

Radius of Galaxies

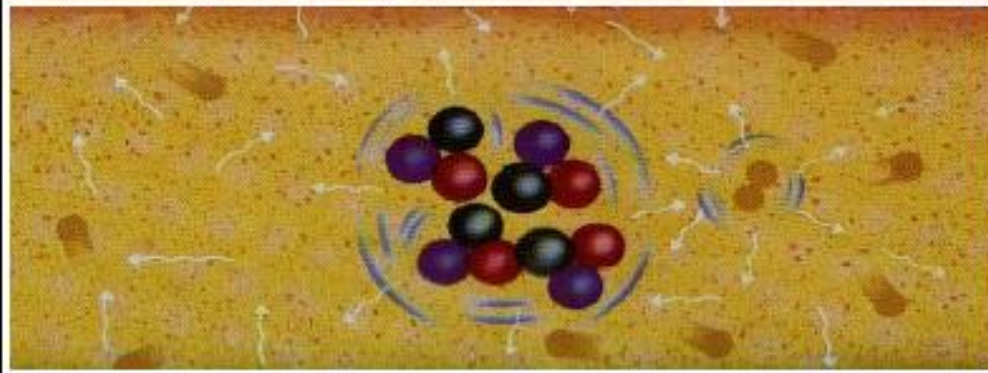


300,000  
years



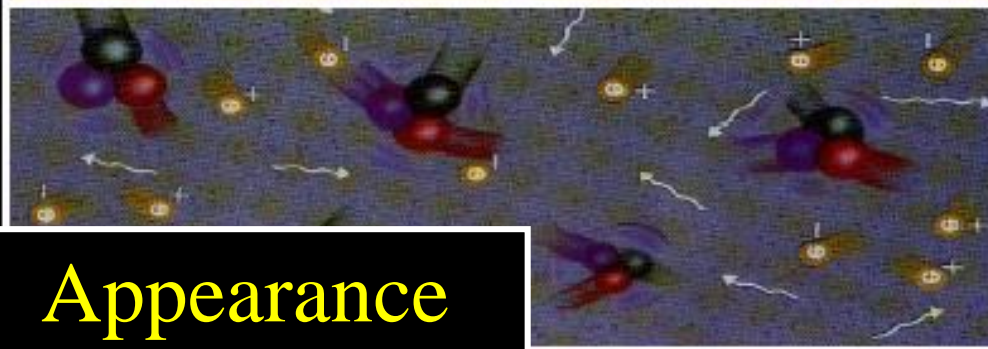
Formation  
of atoms

3  
minutes



Formation  
of nuclei

1 micro-  
second



Formation  
of protons  
& neutrons

1 pico-  
second

Appearance  
of dark matter?



Appearance  
of mass?

Appearance  
of matter?

**BANG!**



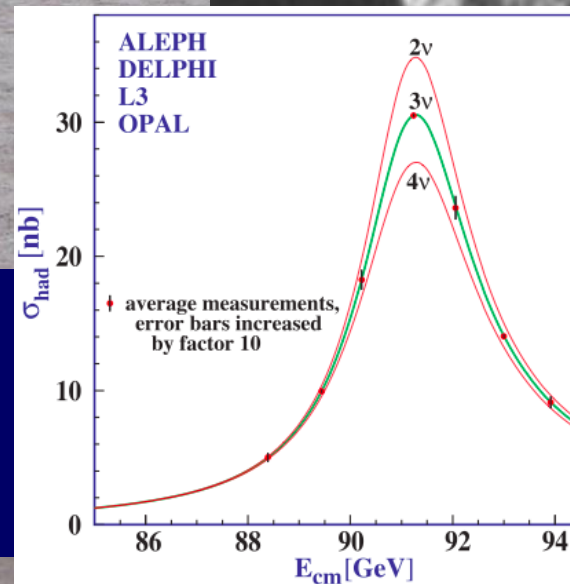
# The 'Standard Model' of Particle Physics

Proposed by Abdus Salam,  
Glashow and Weinberg

Tested by experiments  
at CERN



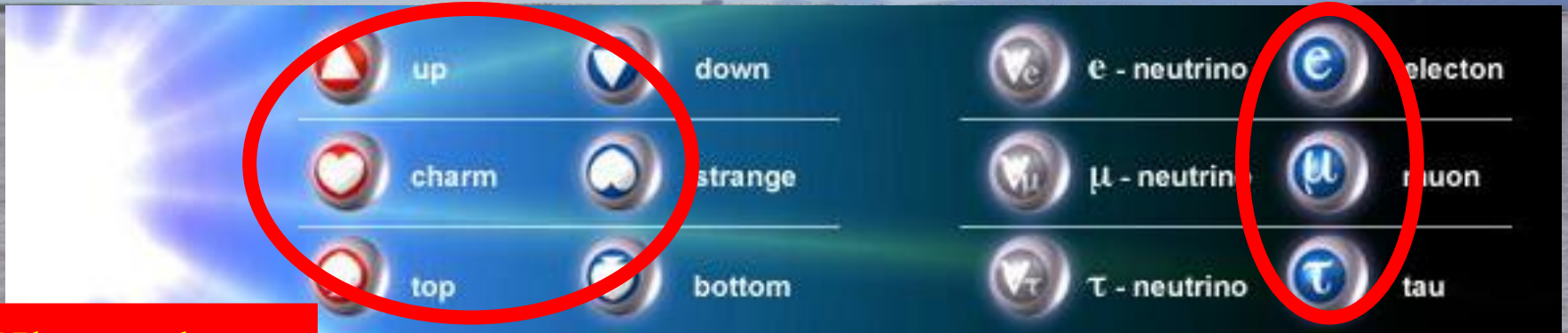
Perfect agreement between  
theory and experiments  
in all laboratories



# The 'Standard Model'

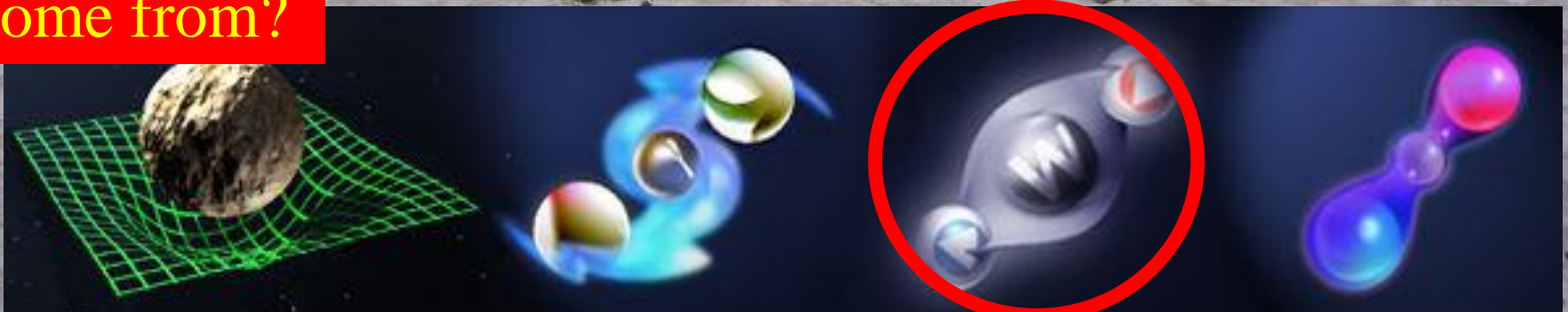
= Cosmic DNA

## 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)



KING'S  
College  
LONDON



# 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.



To answer Gauguin's questions:

## The Large Hadron Collider (LHC)

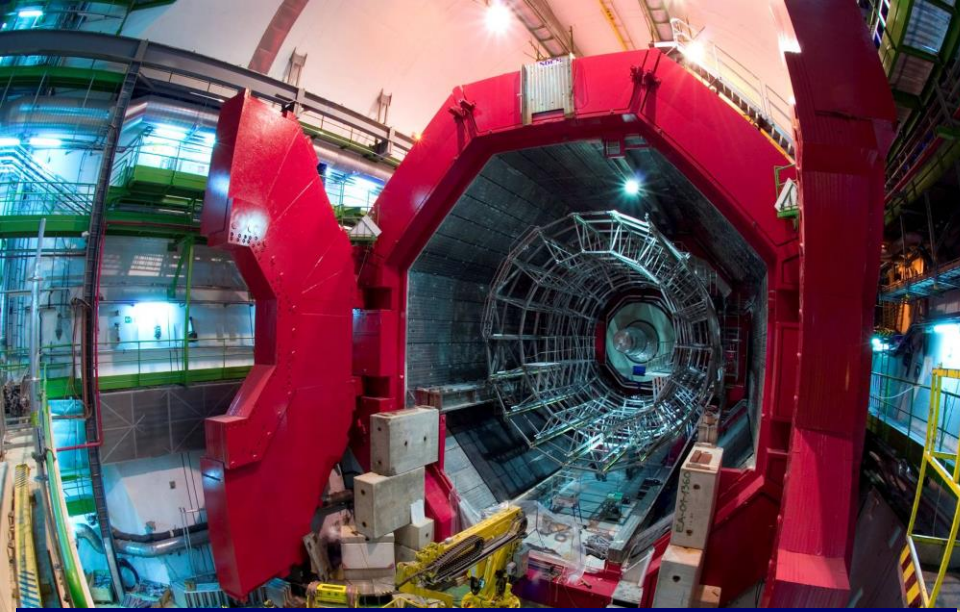
Several thousand billion protons  
Each with the energy of a fly  
99.9999991% of light speed  
A billion collisions a second

Primary targets:

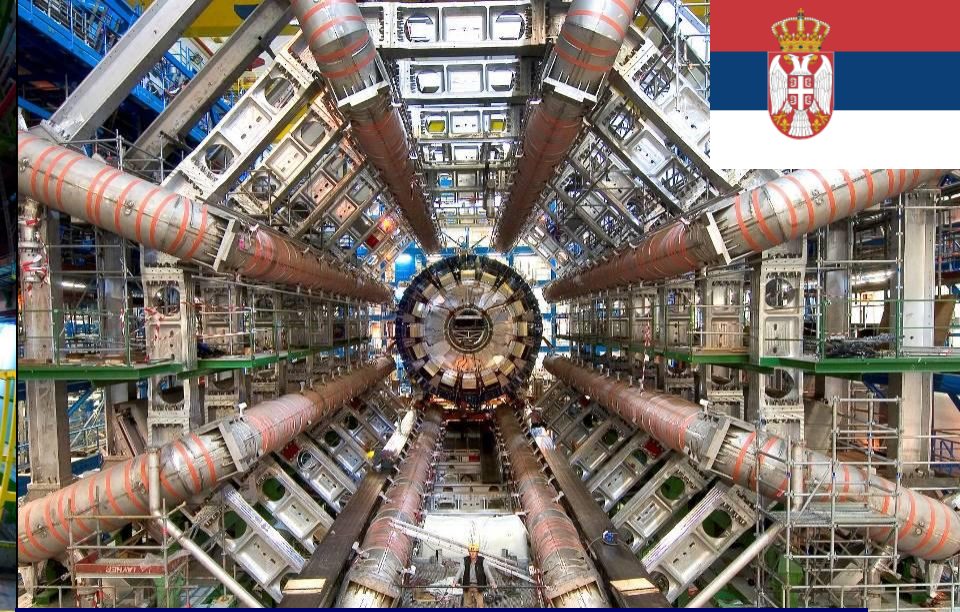
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

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

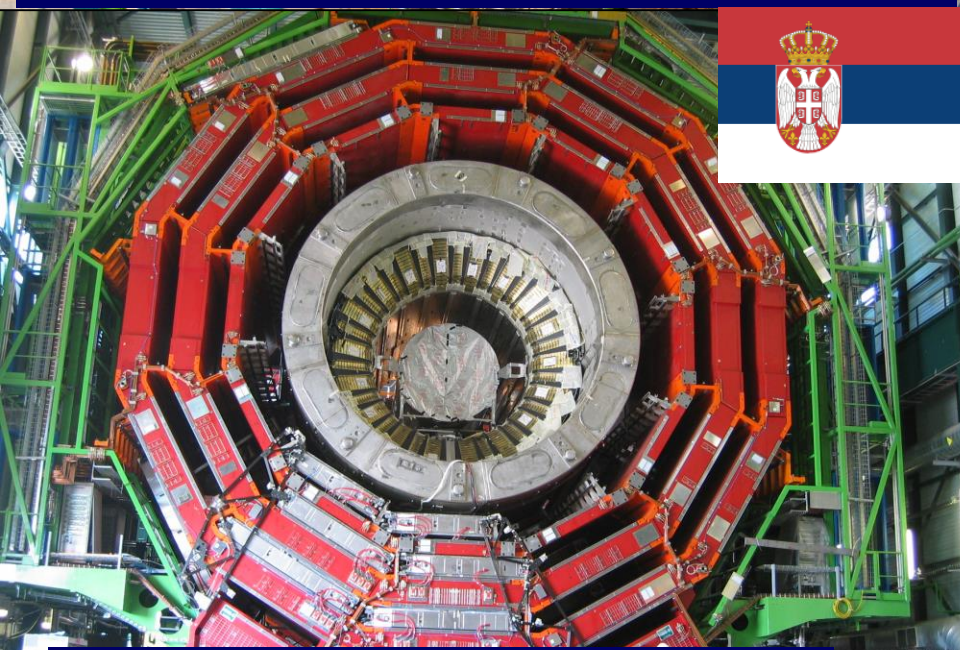




**ALICE: Primordial cosmic plasma**



**ATLAS: Higgs and dark matter**



**CMS: Higgs and dark matter**



**LHCb: Matter-antimatter difference**



# The Discovery of the Higgs Boson



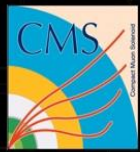
Mass Higgsteria



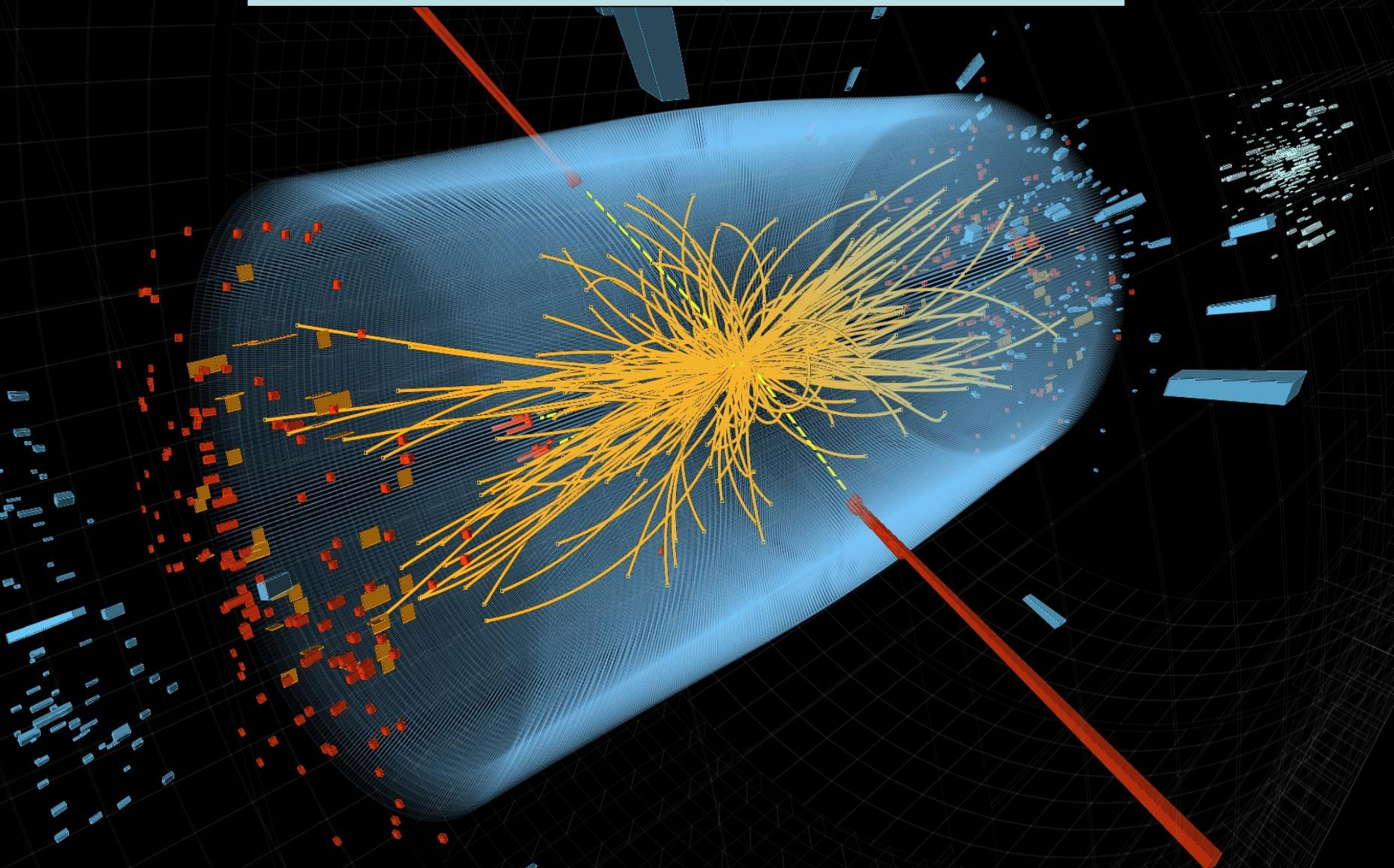
# A Simulated Higgs Event @ LHC





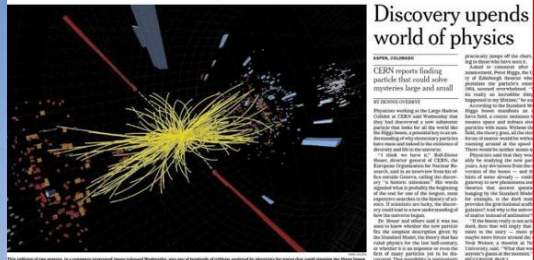


# Interesting Events





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



### Discovery upends world of physics

CERN reports finding particle that could solve mysterious large and small...  
Physicists have found a particle that looks like the Higgs boson, the elusive particle that gives other particles mass. The discovery, announced Thursday by the European Organization for Nuclear Research (CERN), upends the world of physics and opens a new chapter in the quest to understand the universe.

The Economist  
A giant leap for science  
Finding the Higgs boson

ヒッグス粒子発見か  
新素粒子検出 年内に結論  
日米欧2チーム

Le Monde  
Science : la matière dévoilée  
Milhares de moradores de bairros sociais em risco de perderem RSI

Science : la matière dévoilée  
Le boson de Higgs, particule manquante pour expliquer l'univers, vient d'être découvert  
Le physicien du CERN de Genève est prouvé s'écrouler à 900000

The Gazette  
EL PAIS  
fallada la partícula clave para a comprensión del universo

В ТЕАТРЫ БУДУТ ПУСКАТЬ ПО МОБИЛЬНЫМ ТЕЛЕФОНАМ  
MK  
ПОСЛЕДНИЙ КИРПИЧ В СТЕНУ МИРОЗДАНИЯ

AD ALGEMEEN DAGBLAD  
Eindelijk gelijk na 48 jaar  
Zieke Kaj en zijn moeder toch samen in de VS

Frankfurter Allgemeine  
Masse macht's  
Große Mehrheit im

CHINADAILY  
THURSDAY, July 5, 2012  
DANGEROUS MOVE  
IMPORTANT MATTER  
MOVIE PLOT

THE HINDU  
Elusive particle found, looks like Higgs boson  
CERN physicists hail evidence of game-changing discovery of subatomic particle

CORRIERE DELLA SERA  
La particella che può svelare i segreti dell'universo  
Ritrovato a oggi il voto sui nuovi consiglieri

gazeta  
WYBORCZA.PL  
Czastke Higgsa fizycy najpierw wymyślił, potem szukali 40 lat  
BOSKA MASA

বিশ্বনাথের 'স্বপ্ন' দর্শন  
সত্যেন্দ্রনাথকে বিনয় প্রণাম  
'পেয়েছি, যা খুঁজছিলাম'



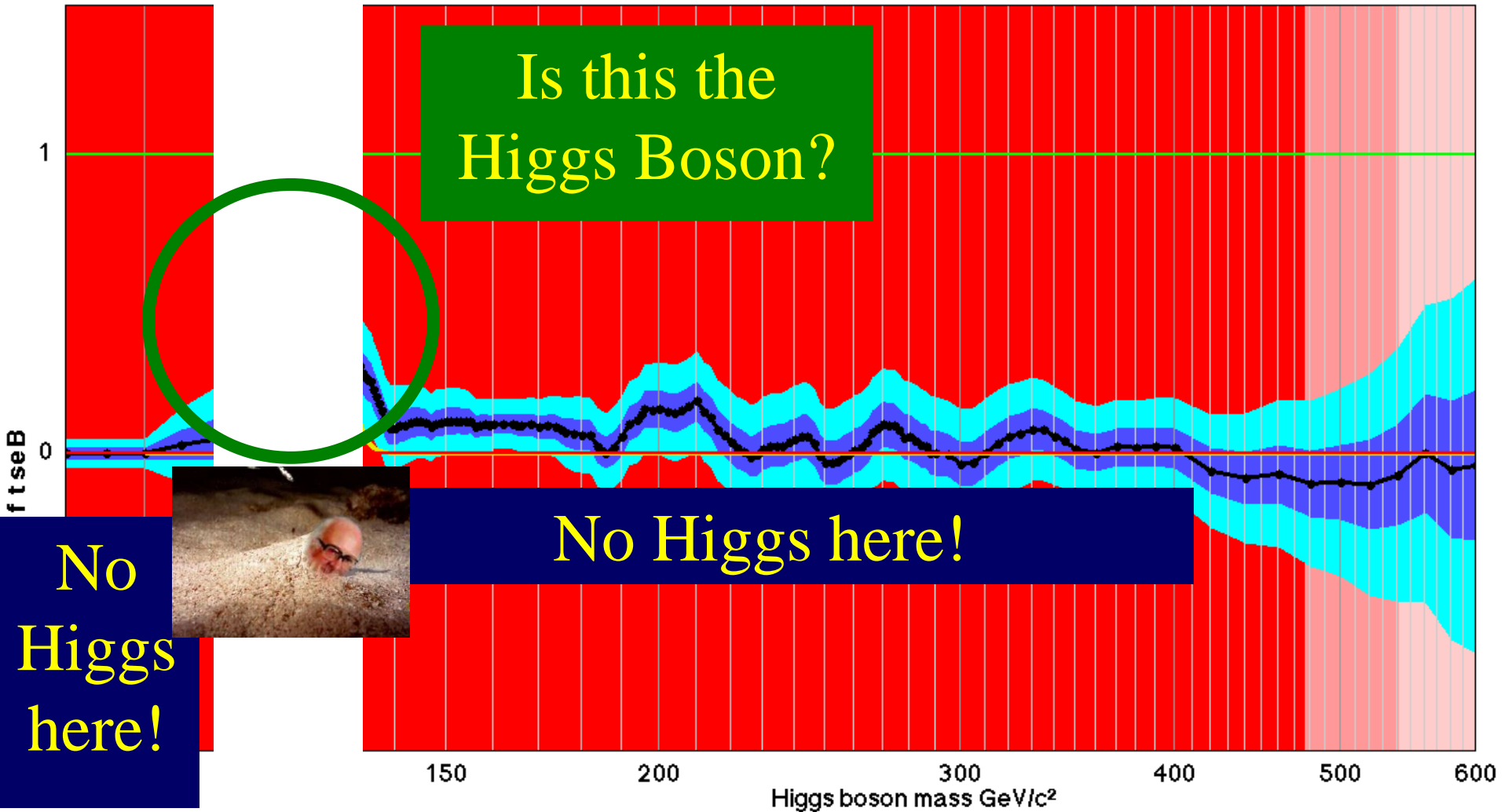
# Higgsdependence Day!



# Unofficial Combination of Higgs Data

1/fb - 10/fb

06/03/2013





# The Particle Higgsaw Puzzle

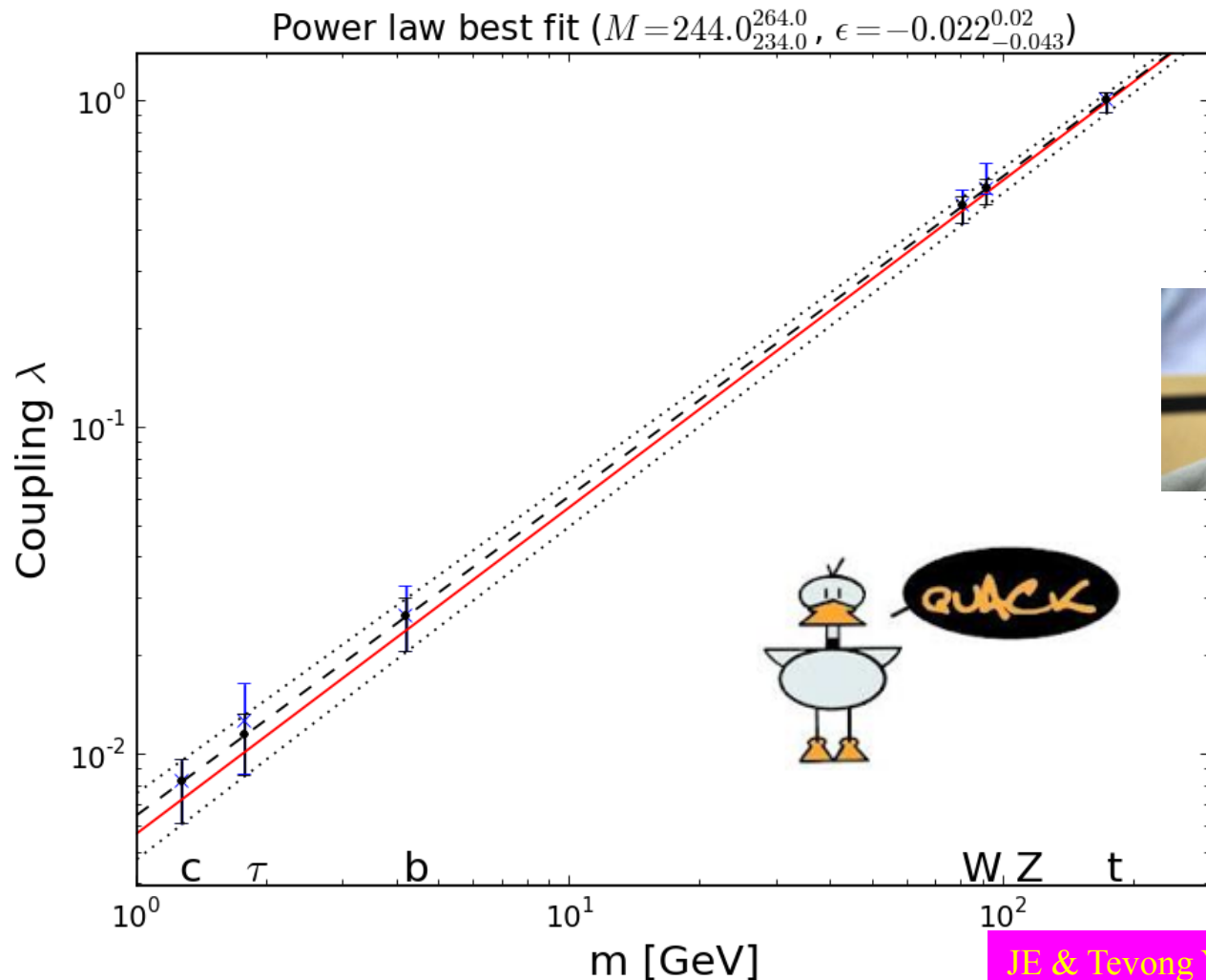
The background of the slide is a blue gradient with a pattern of interlocking puzzle pieces. In the center, one puzzle piece is missing, revealing a white surface underneath. The missing piece is a complex, irregular shape with several protrusions and indentations, resembling a particle or a specific configuration in physics. The lighting is dramatic, with a bright spot on the white surface and shadows on the surrounding blue pieces.

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](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?

- **LHC Run 2** inflation
- Quantum gravity
- ...

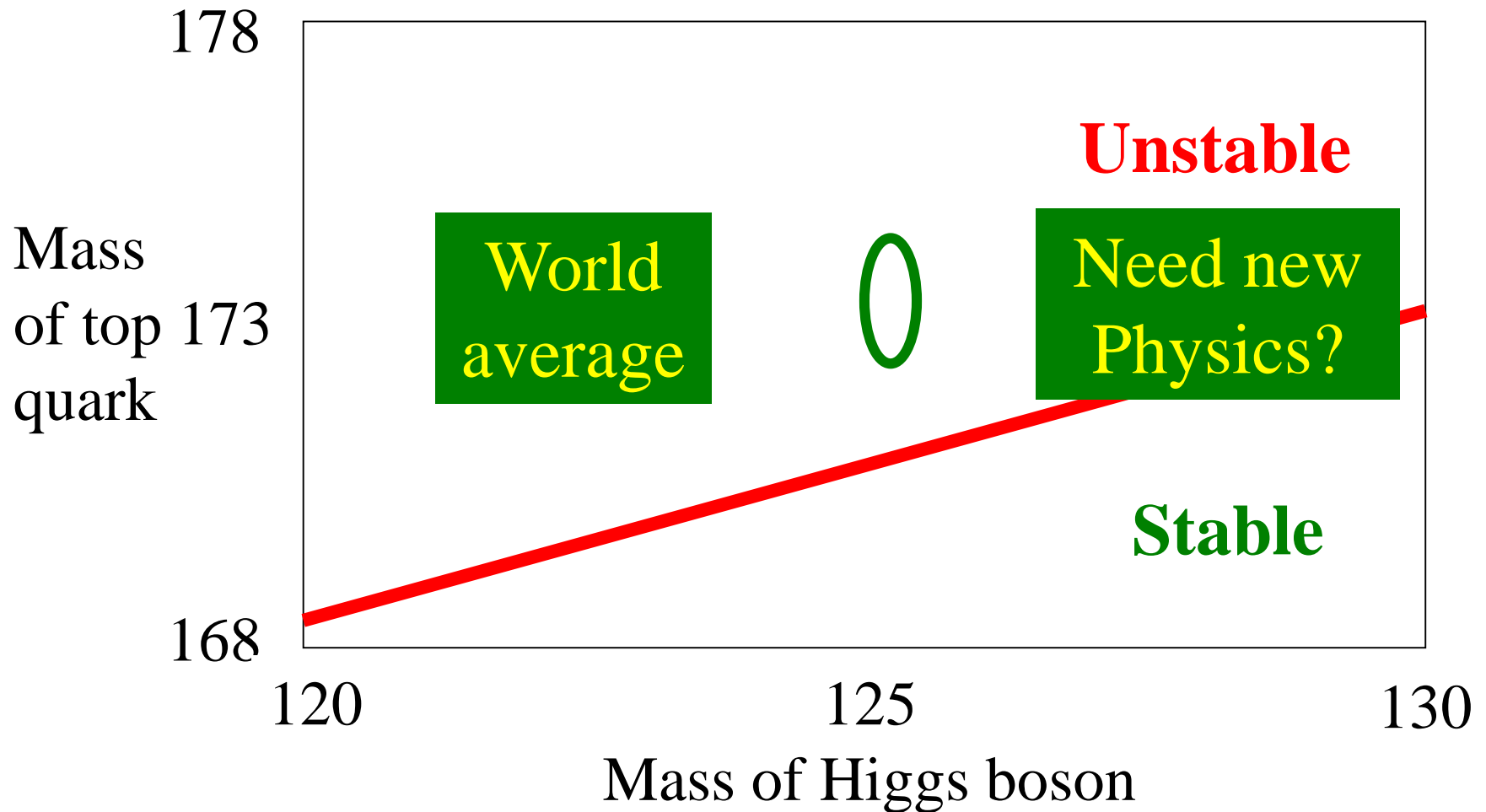
*The Standard Model*

*Is Not Enough*  
**007<sup>5</sup>**

ALBERT R. BROCCOLI'S SON PRODUCTIONS PRESENTS PIERCE BROSNAN in JAMES BOND **007<sup>5</sup>**  
*"THE WORLD IS NOT ENOUGH"* SOPHIE MARCEAU ROBERT CARULY DENISE RICHARDS ROBBIE COLTRANE and JOHN TENCH  
DESIGNED BY LINDY HEARMING COSTUME DESIGNER DAVID ARNOLD EXECUTIVE PRODUCERS JIM CLARK JIMMERSON ADRIAN BUDALE and JIMMERSON PETER JARANT  
PRODUCED BY ANTHONY WATKINS and NEAL PURVIS and ROBERT WADE PRODUCED BY NEAL PURVIS and ROBERT WADE and BRUCE FERRISTEN  
WRITTEN BY MICHAEL G. WILSON and BARBARA BROCCOLI DIRECTED BY MICHAEL APTEID

# Is “Empty Space” Unstable?

- Depends on masses of Higgs boson and top quark





# Will the cosmic pint 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

# Dark Matter in the Universe

The background of the slide is a composite image. On the left, there is a large, bright spiral galaxy with a glowing core and distinct arms. On the right, there is a field of stars, some of which are highlighted with green and yellow outlines, possibly representing dark matter candidates or specific astronomical objects.

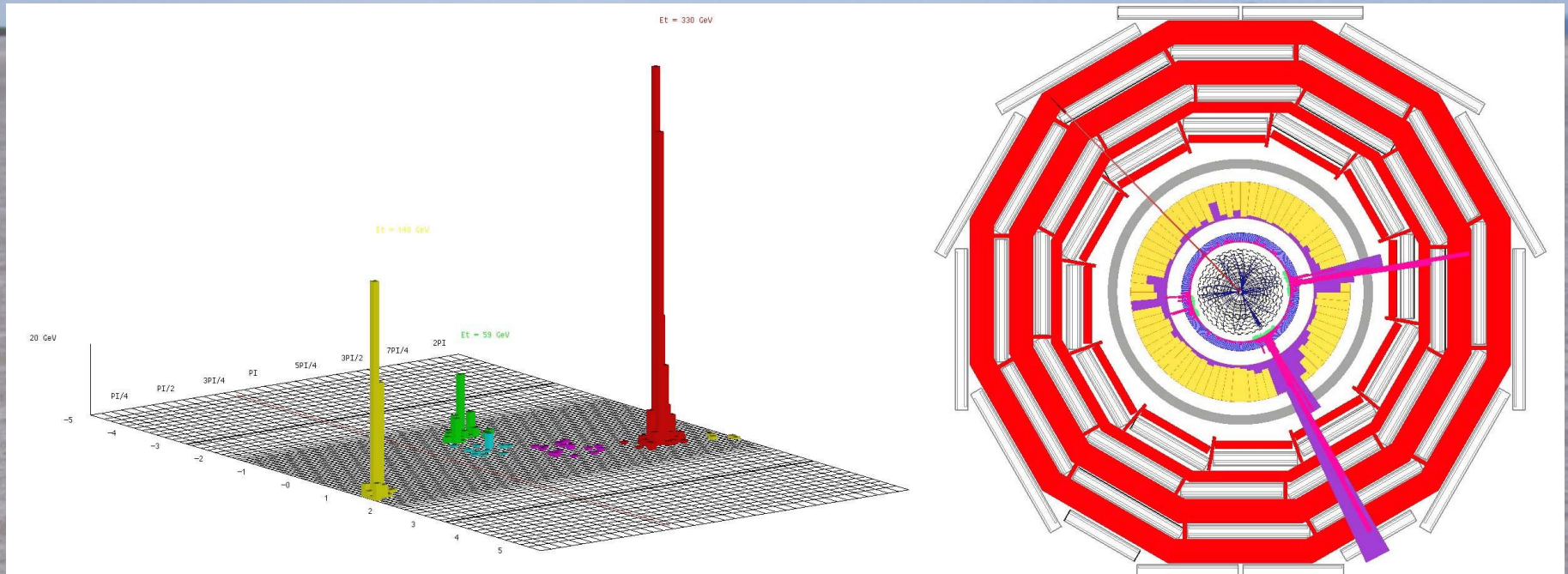
Astronomers say  
that most of the  
matter in the  
Universe is  
invisible  
Dark Matter

**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

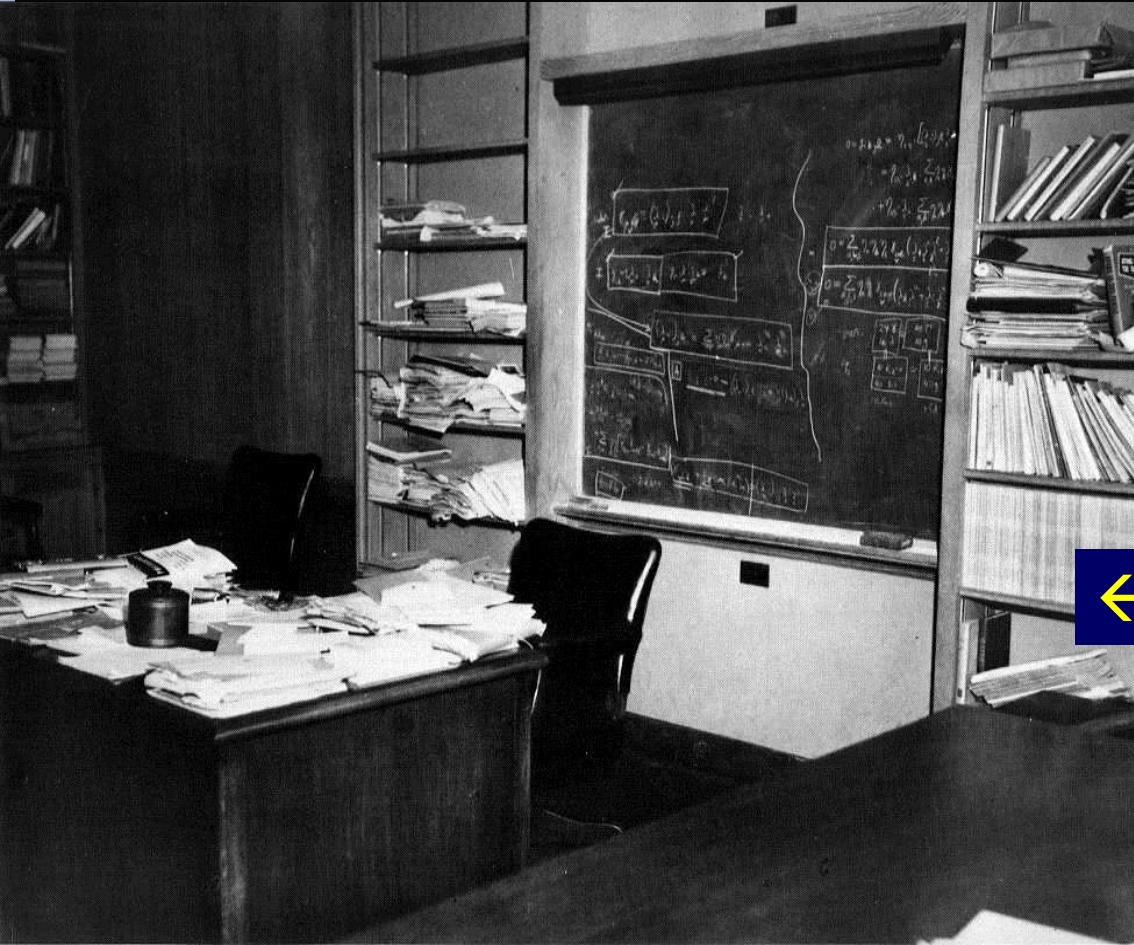


Matter and antimatter not quite equal and opposite: WHY?

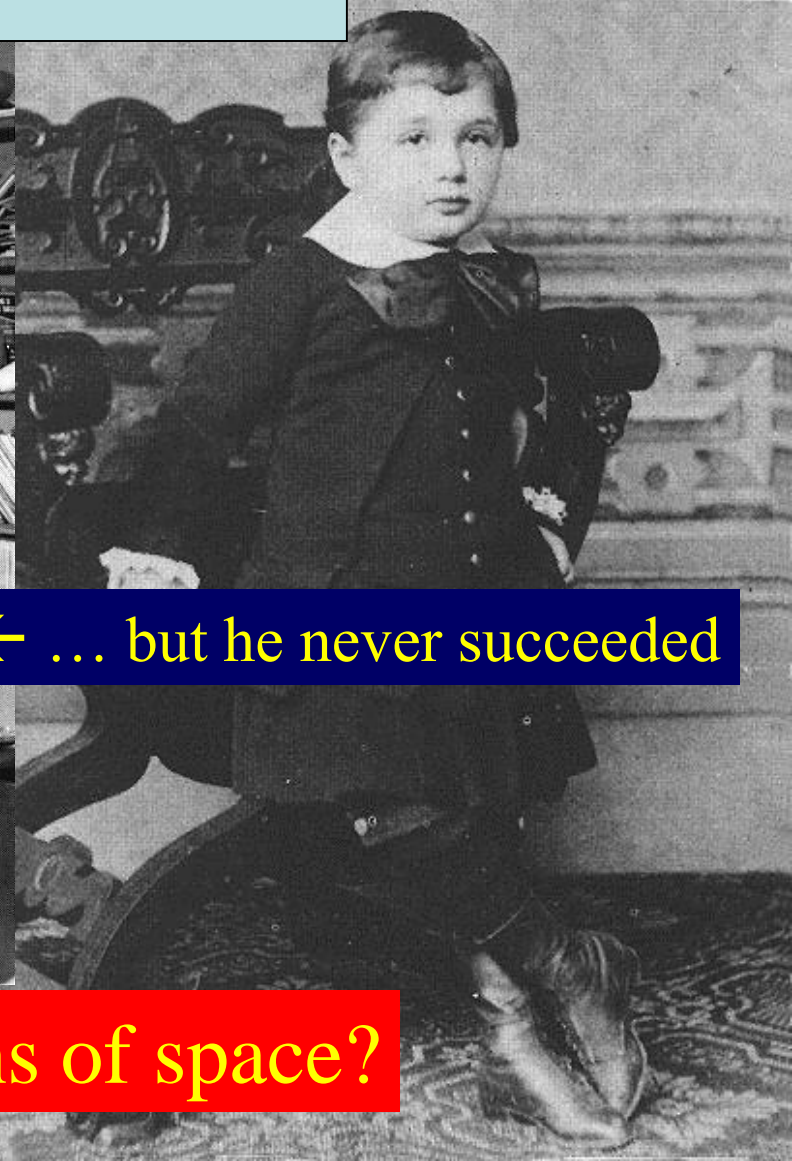
Why does the Universe mainly contain matter, not antimatter?

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?

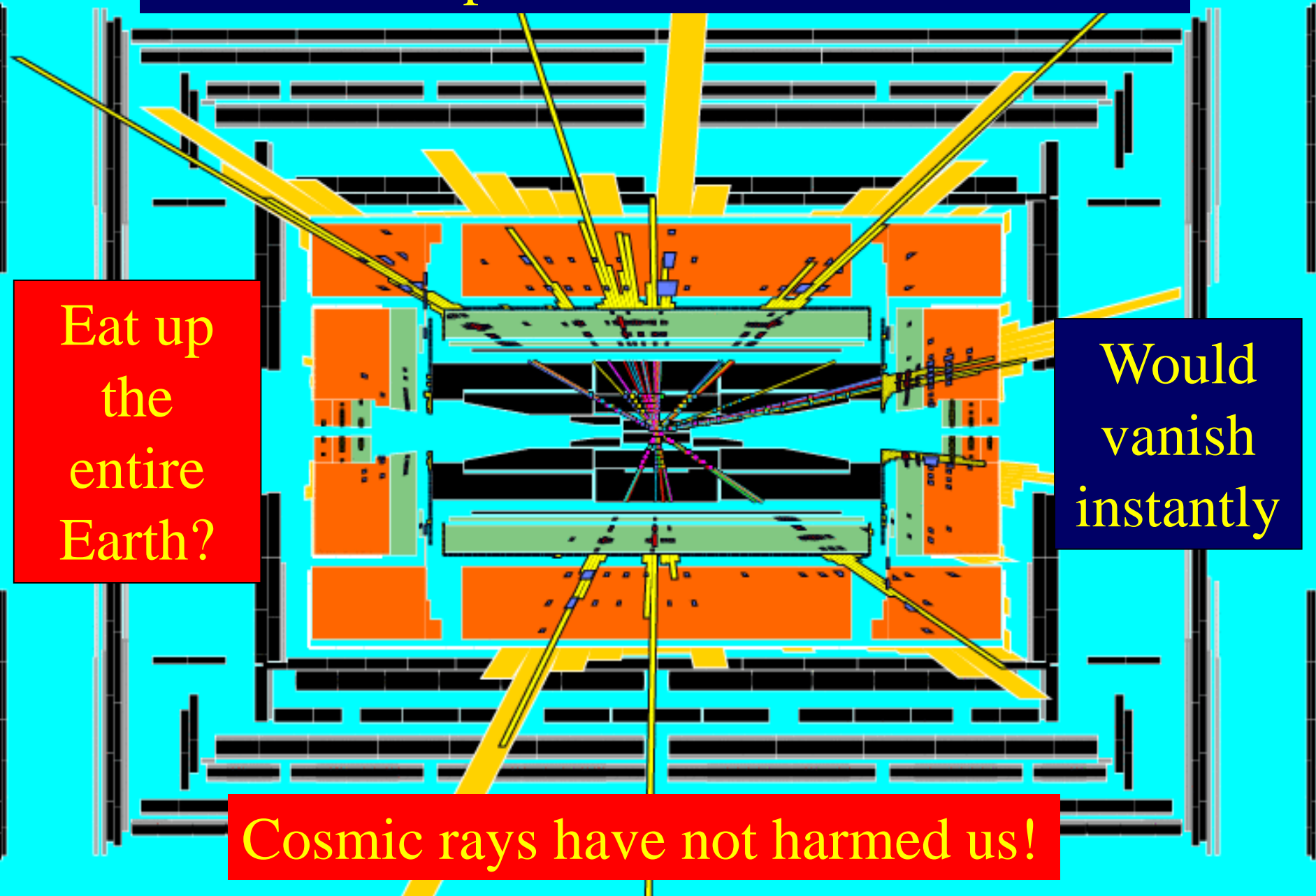


# Will LHC experiments create black holes?

Eat up  
the  
entire  
Earth?

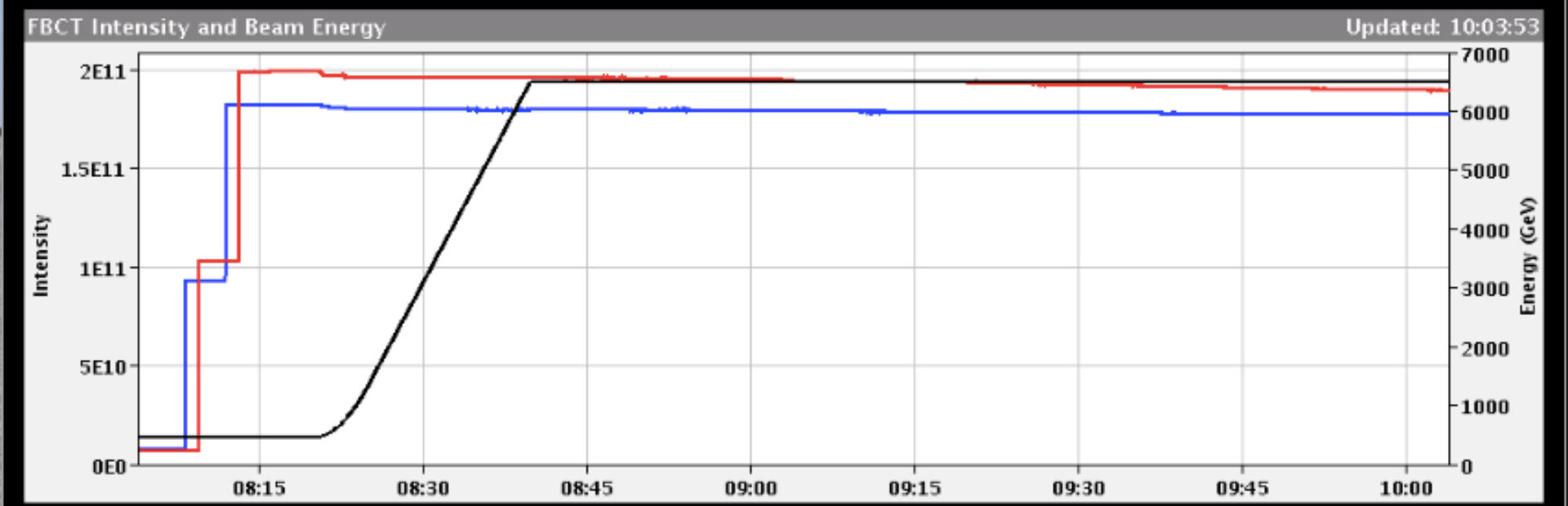
Would  
vanish  
instantly

Cosmic rays have not harmed us!



# BEAM SETUP: ADJUST

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



BIS status and SMP flags		B1	B2
Comments (21-May-2015 09:22:03) test collisions at 13 TeV	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
-------------------------	--------------	---------	--------------	---------

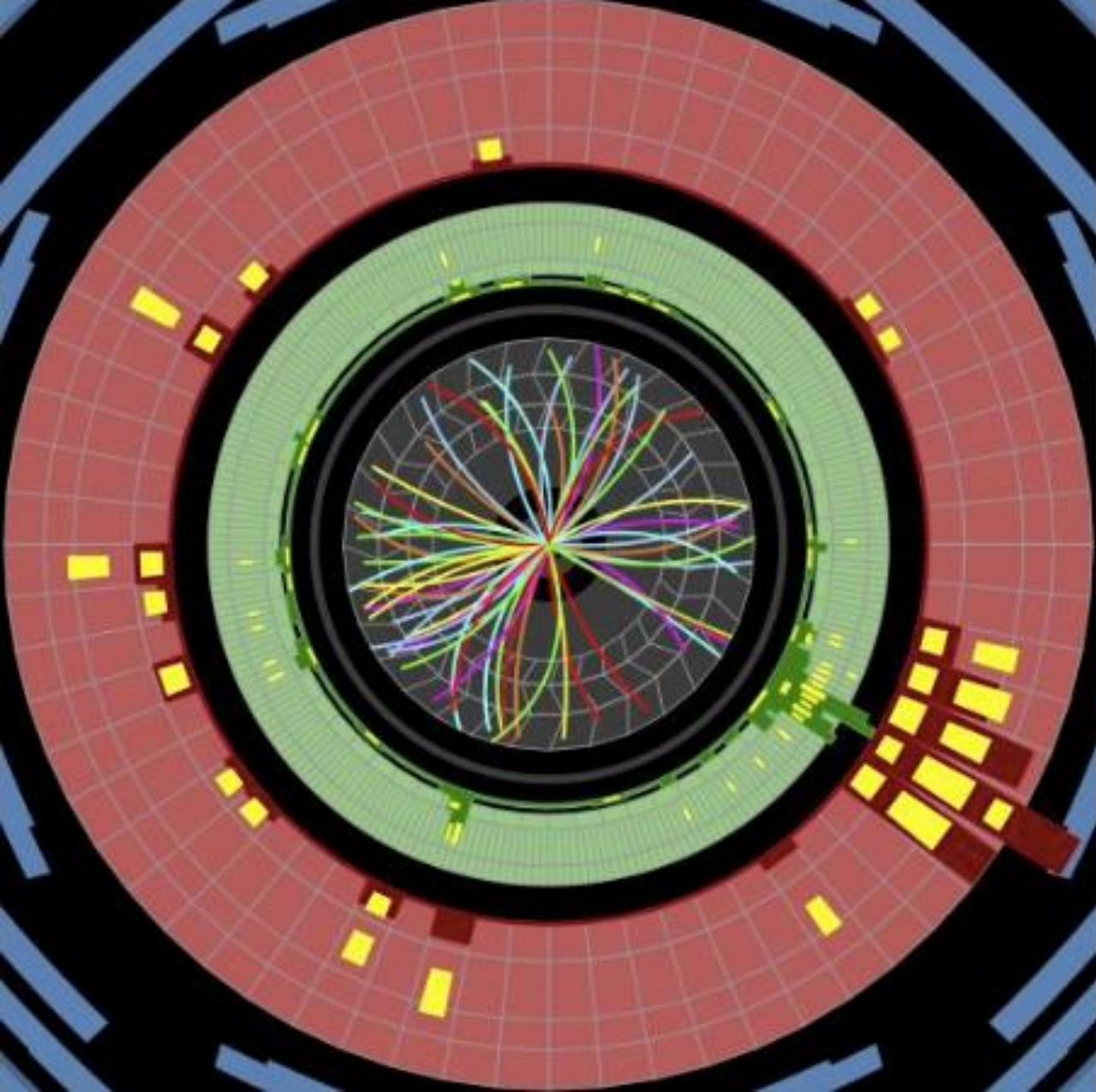




CMS Experiment at LHC, CERN  
Data recorded: Wed May 20 22:51:10 2015 CEST  
Run/Event: 245155 / 123300843  
Lumi section: 363  
Orbit/Crossing: 94976371 / 208



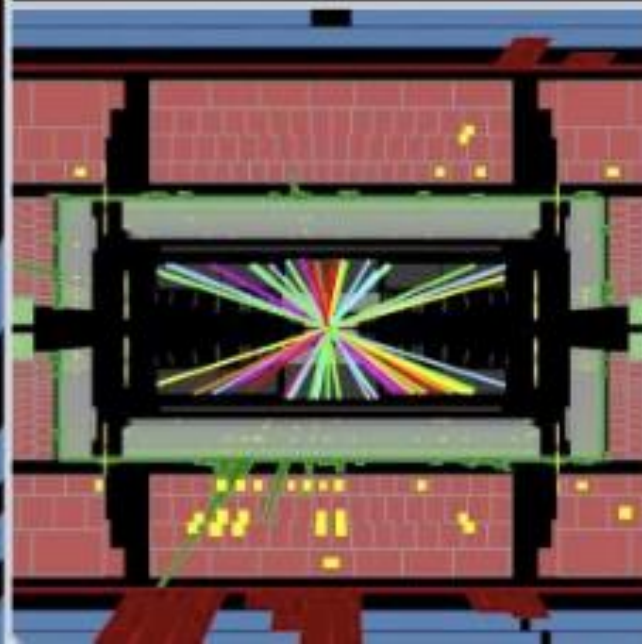
**First high-energy collisions of Run 2**



**ATLAS**  
EXPERIMENT

Run Number: 265532, Event Number: 3280065

Date: 2015-05-20 22:51:50 CEST



First low-energy collisions of Run 2



# Next Steps at the High-Energy Frontier?



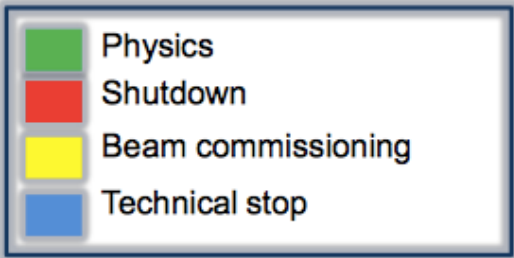
Where do we go from there?

50km linear  $e^+e^-$  collider?

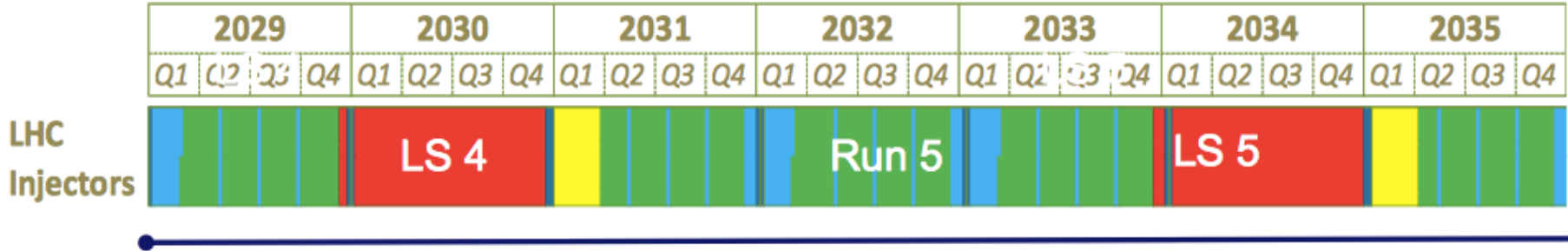
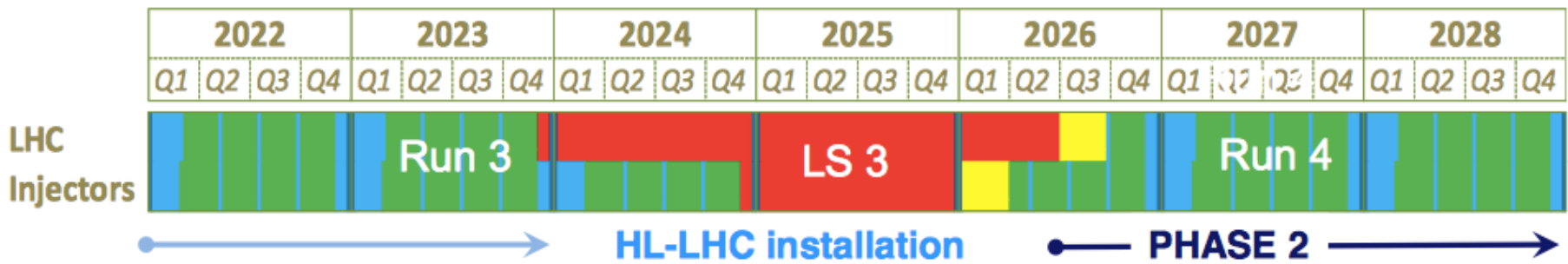
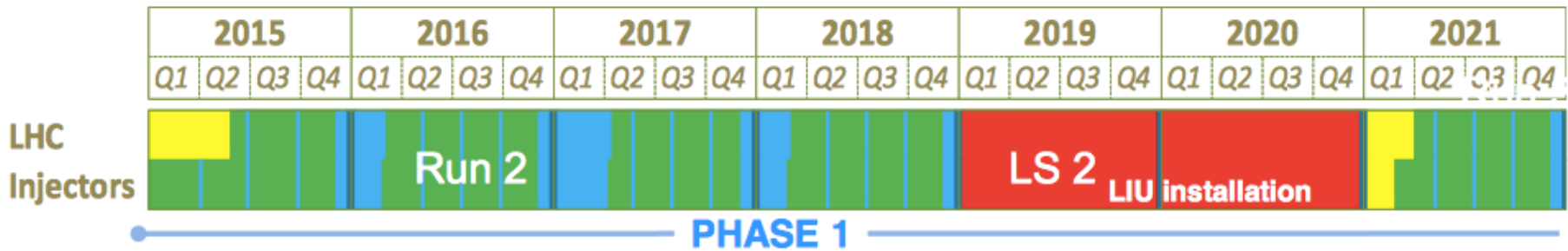
100km circumference pp,  $e^+e^-$  collider?

# 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