

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



The aim of particle physics:
What is matter in the Universe made of?

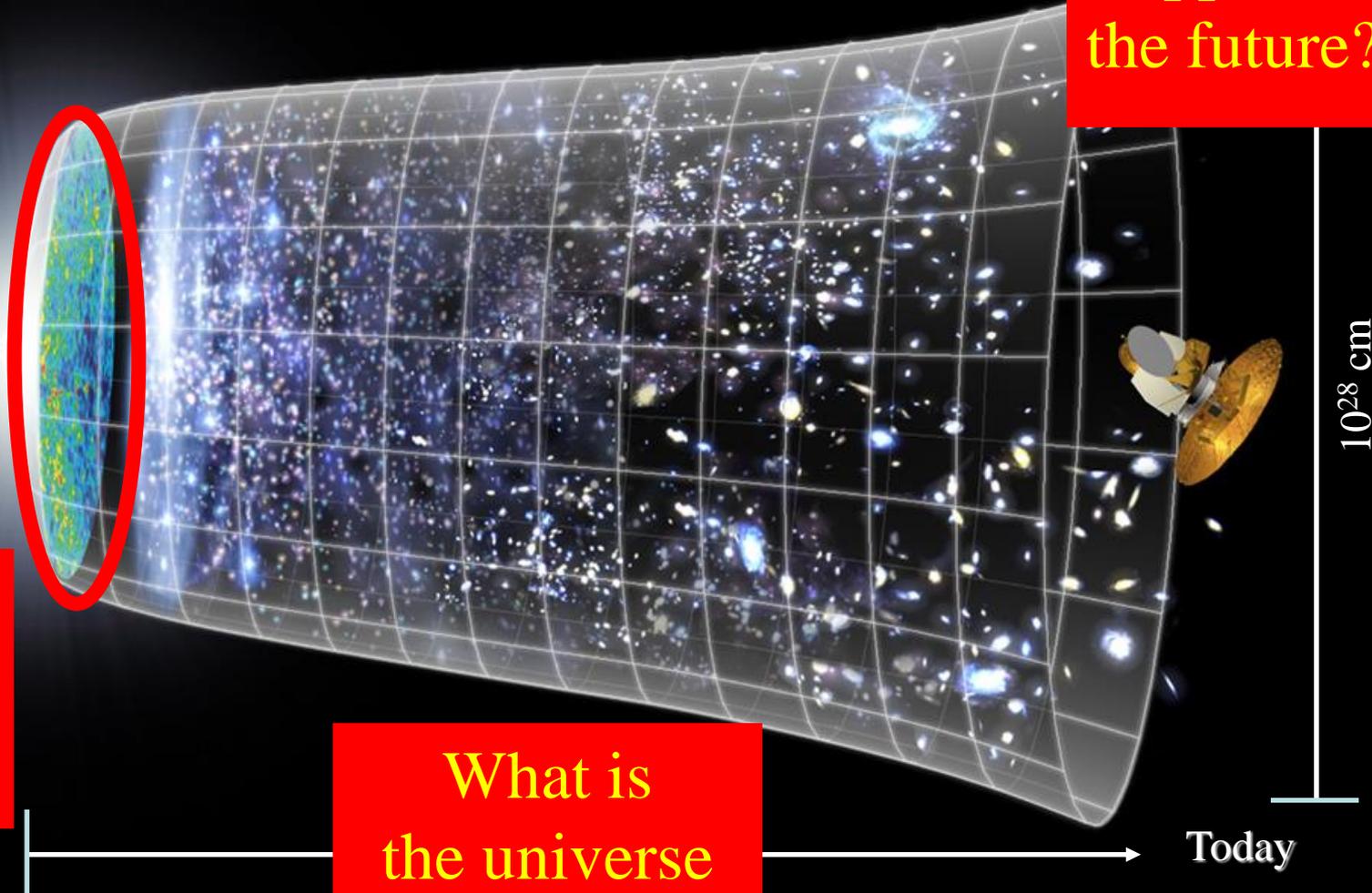
John Ellis

KING'S
College
LONDON

Evolution of the Universe

What will happen in the future?

Big Bang



What happened then?

What is the universe made of?

Today

10^{28} cm

Gauguin's Questions in the Language of Particle Physics

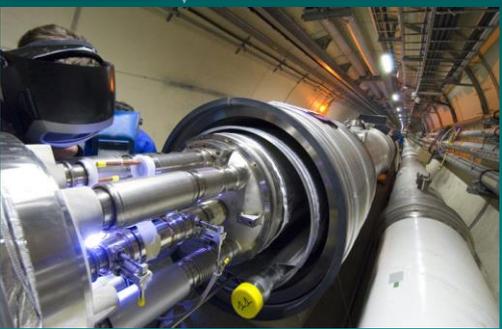
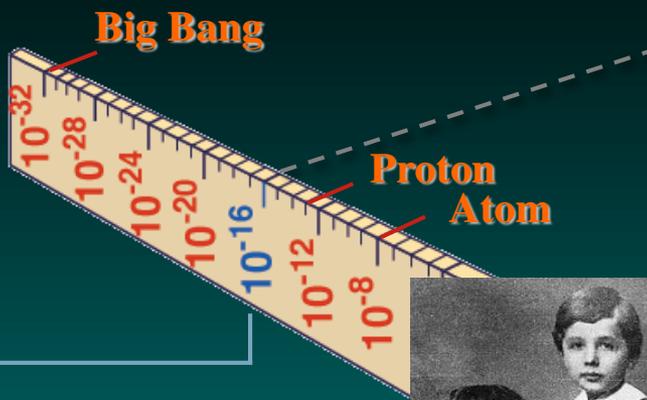
- What is matter made of?
 - Why do things weigh?



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

Our job is to ask - and answer - these questions

Need physics beyond what we know

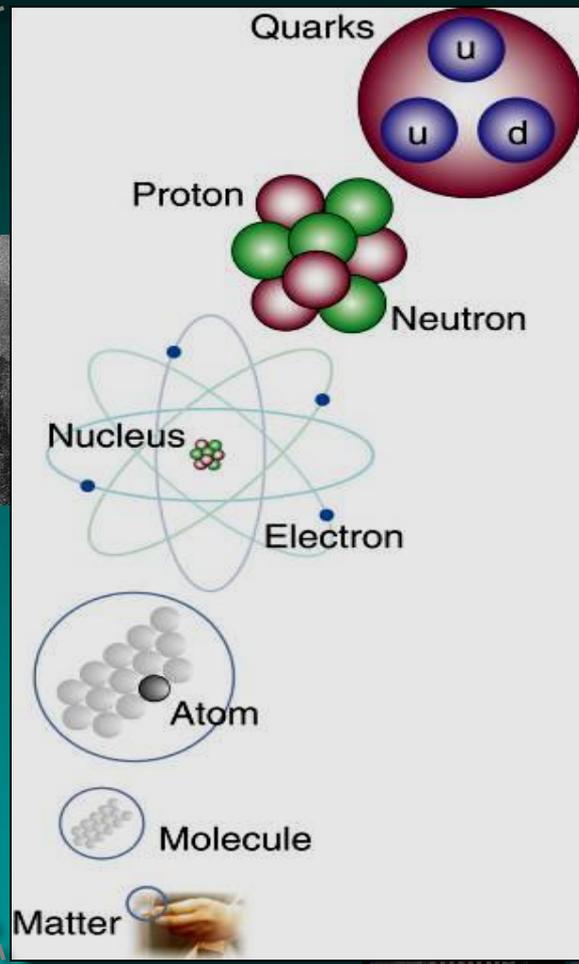


LHC

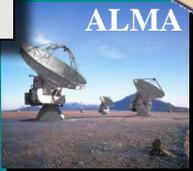
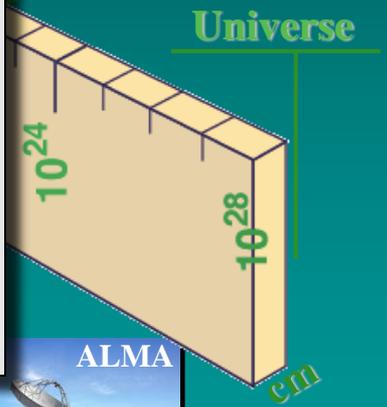
Super-Microscope



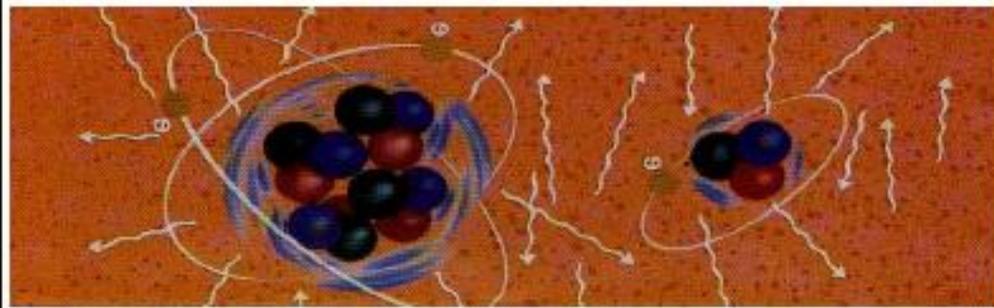
Study physics laws of first moments after Big Bang
 increasing Symbiosis between Particle Physics,
 Astrophysics and Cosmology



Radius of Galaxies

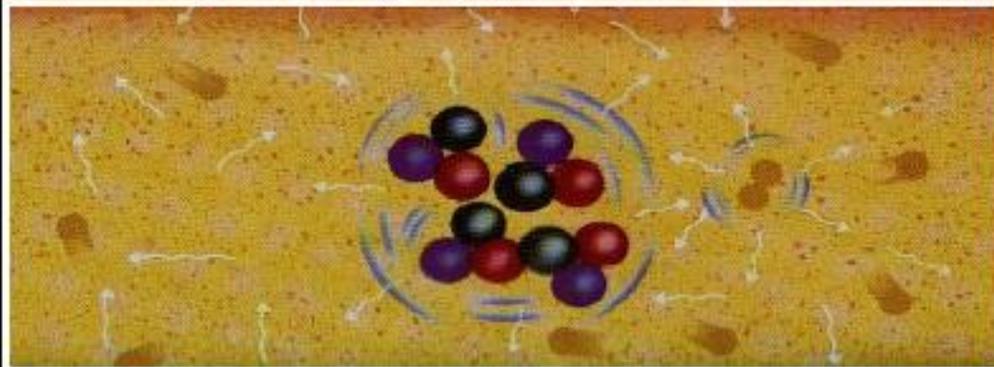


300,000
years



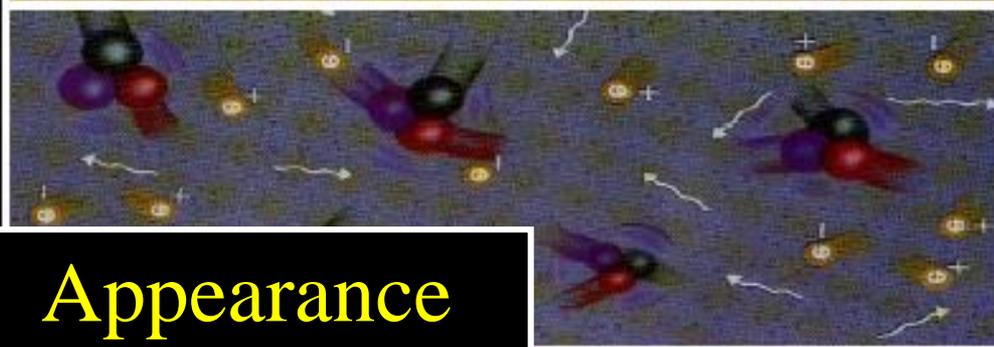
Formation
of atoms

3
minutes



Formation
of nuclei

1 micro-
second



Formation
of protons
& neutrons

1 pico-
second

Appearance
of dark matter?



Appearance
of mass?

BANG!

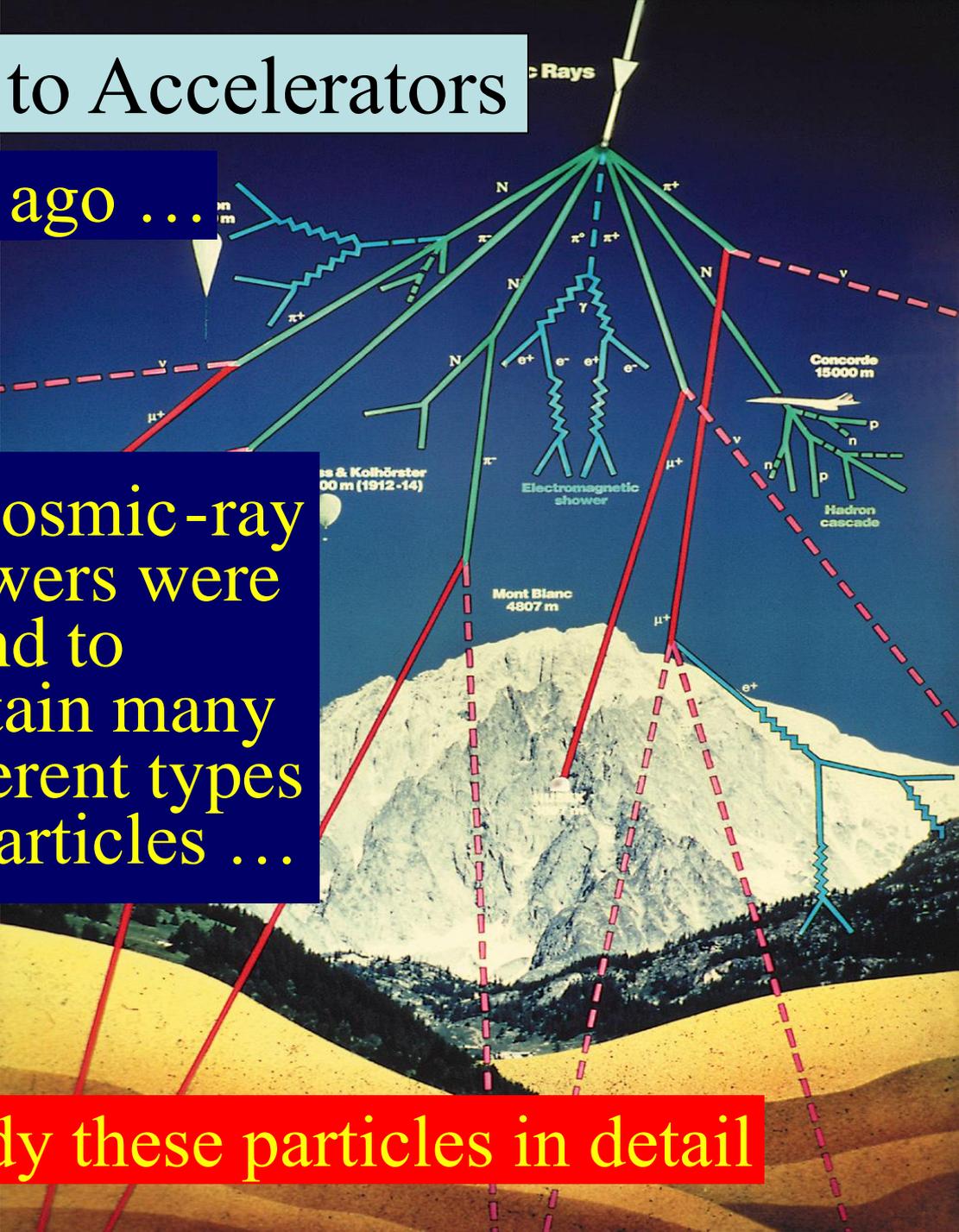
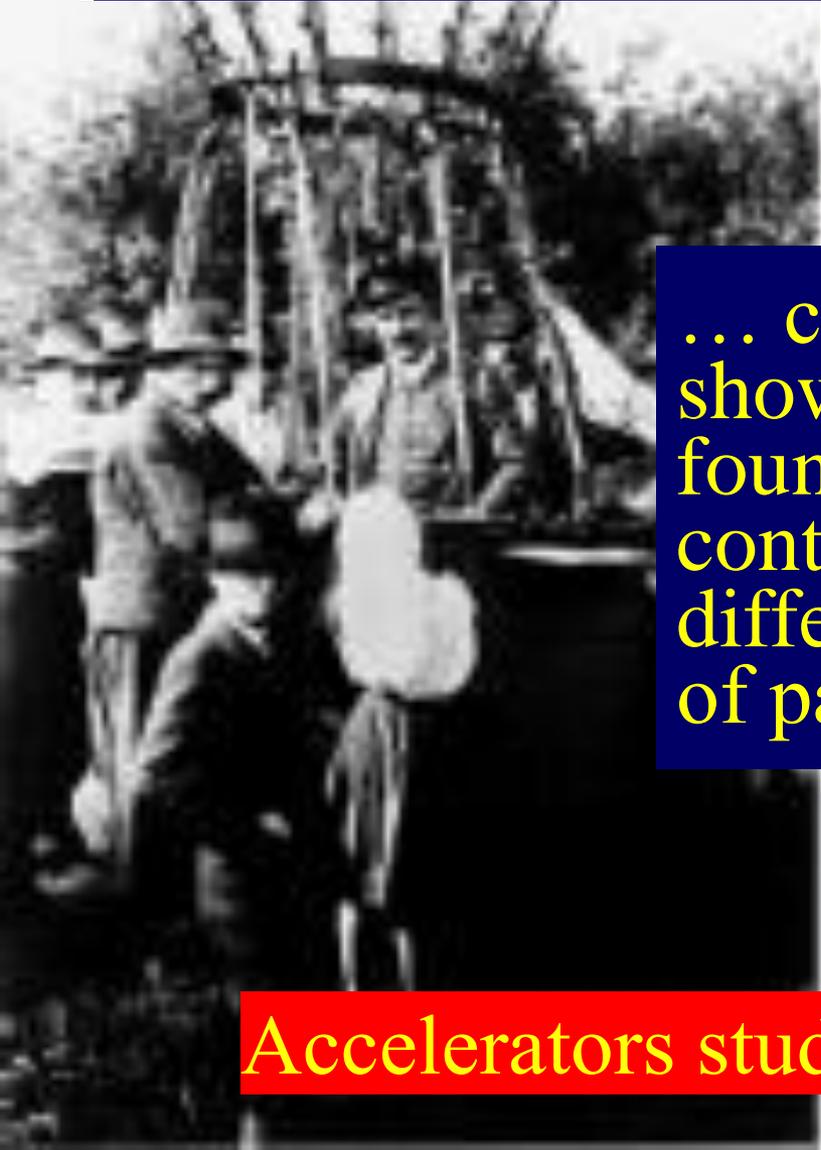
Appearance
of matter?

From Cosmic Rays to Accelerators

Discovered a century ago ...

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

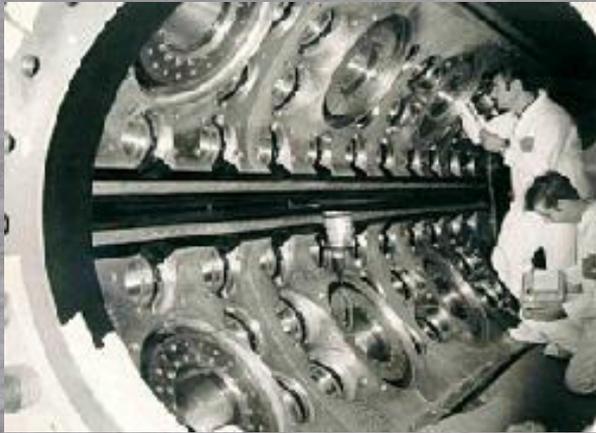
Accelerators study these particles in detail



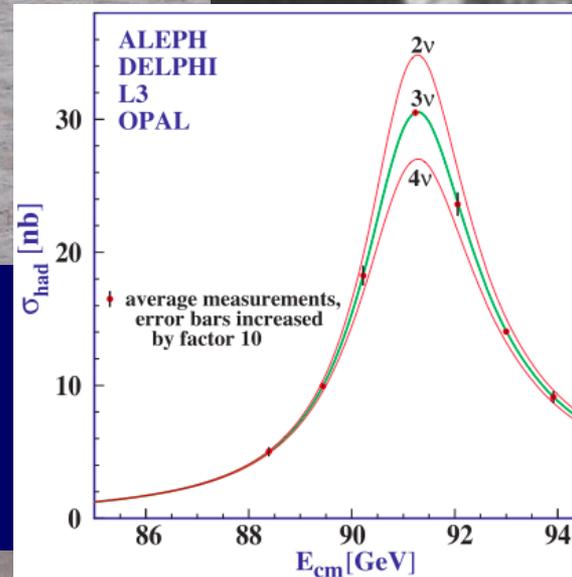
The 'Standard Model' of Particle Physics

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

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Gravitation

electromagnetism

weak nuclear force

strong nuclear force

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



**The LHC discovered
the snowflake:
The Higgs Boson**

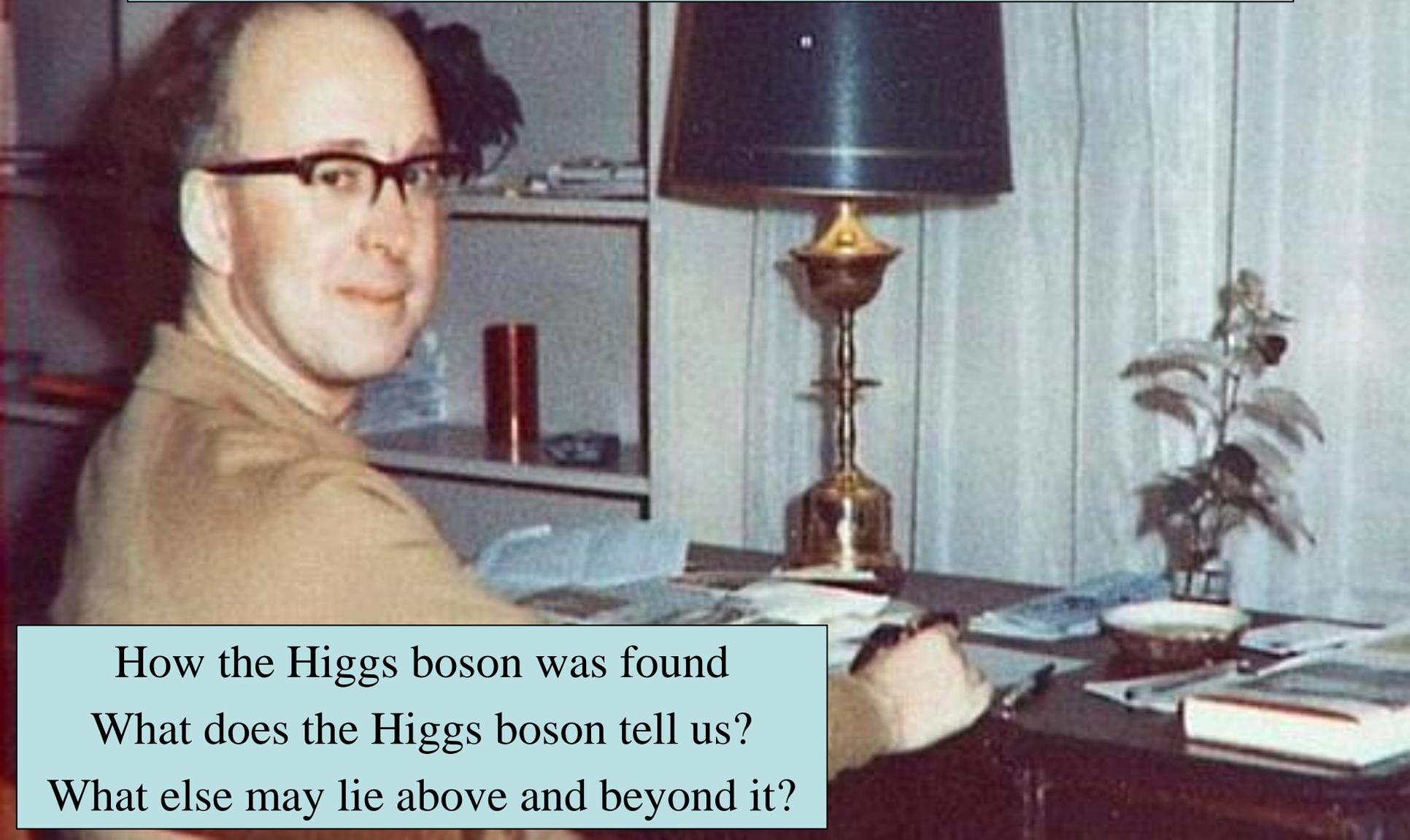
Hiker sinks deep,

moves very slowly:

Particle with large mass



The Higgs Boson & Beyond



How the Higgs boson was found
What does the Higgs boson tell us?
What else may lie above and beyond it?

1975

A Phenomenological Profile of the Higgs Boson

- First attempt at systematic survey

A PHENOMENOLOGICAL PROFILE OF THE HIGGS BOSON

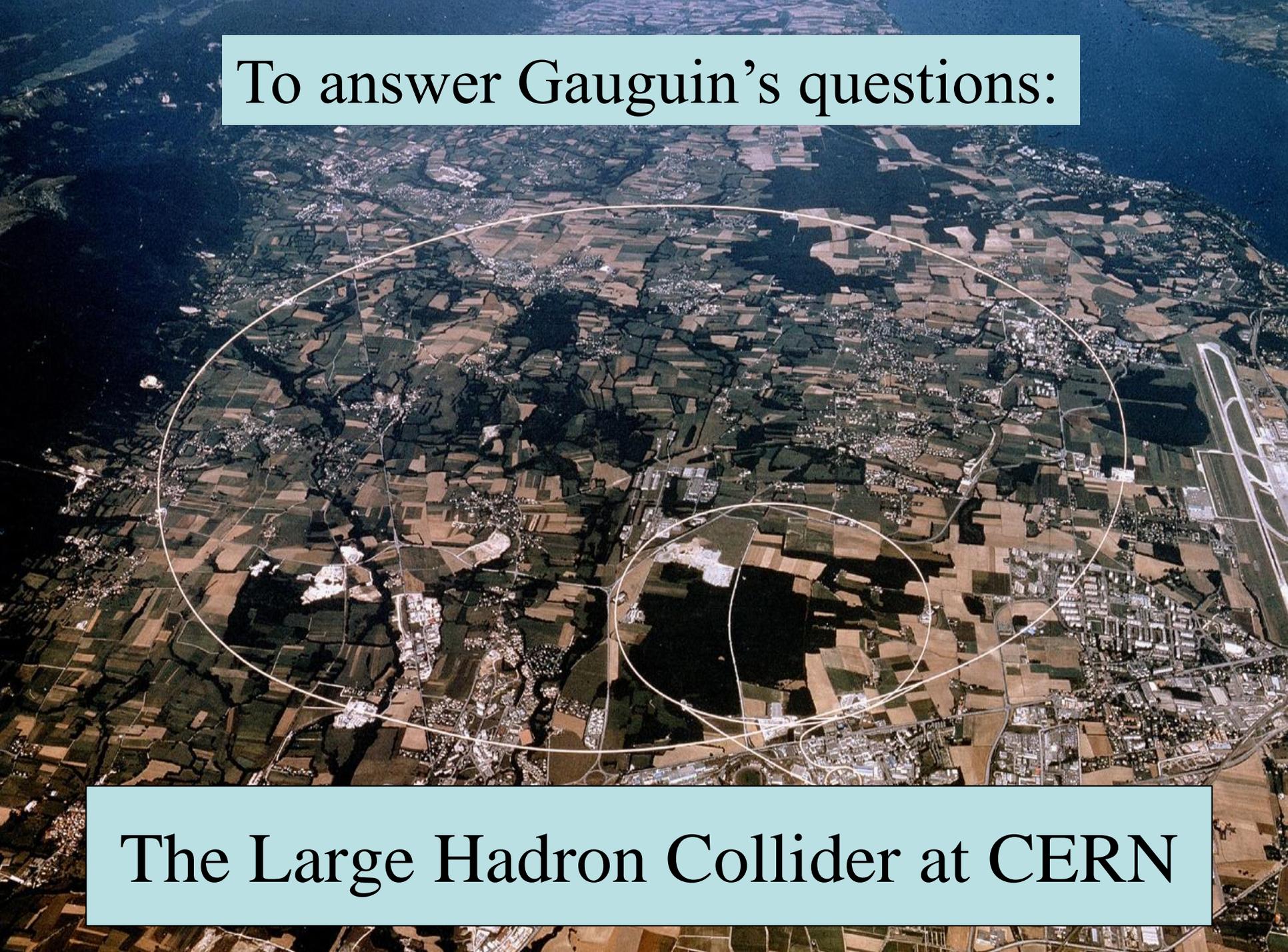
John ELLIS, Mary K. GAILLARD * and D.V. NANOPOULOS **
CERN, Geneva

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 at CERN

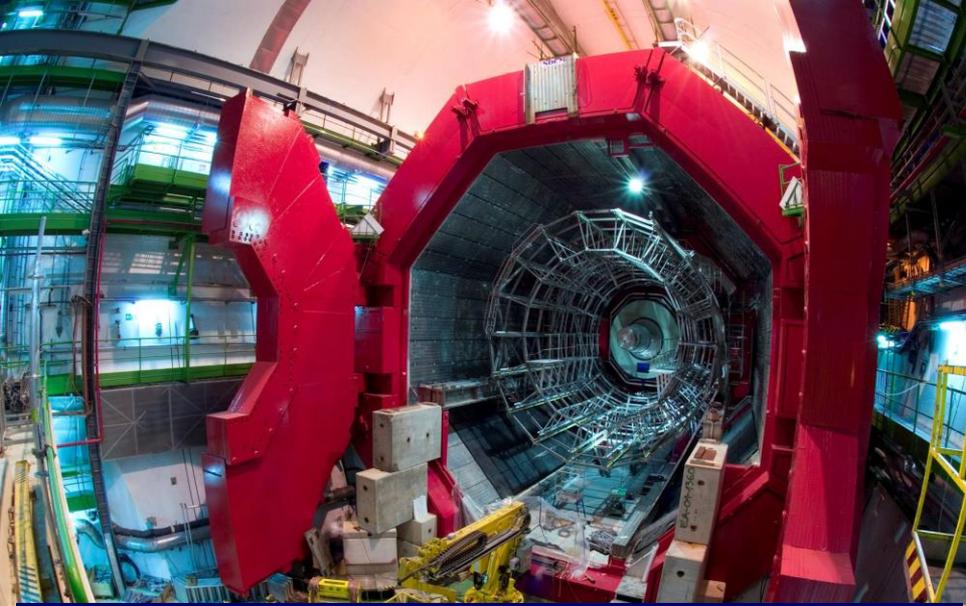
To answer these questions:

The Large Hadron Collider (LHC)

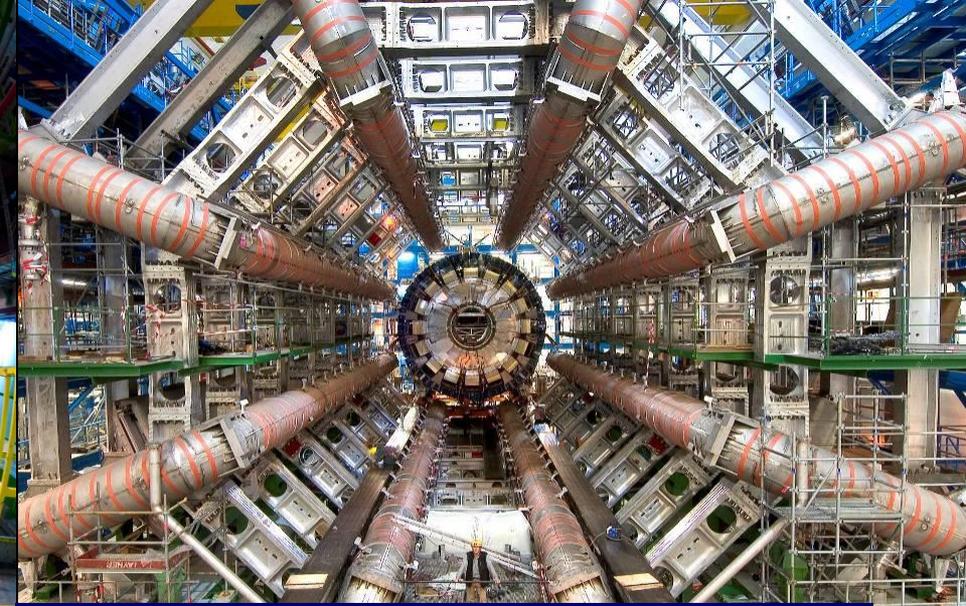
Several thousand billion protons
Each with the energy of a fly
99.9999991% of light speed
Orbit 27km ring 11 000 times/second
A billion collisions a second

Primary targets:

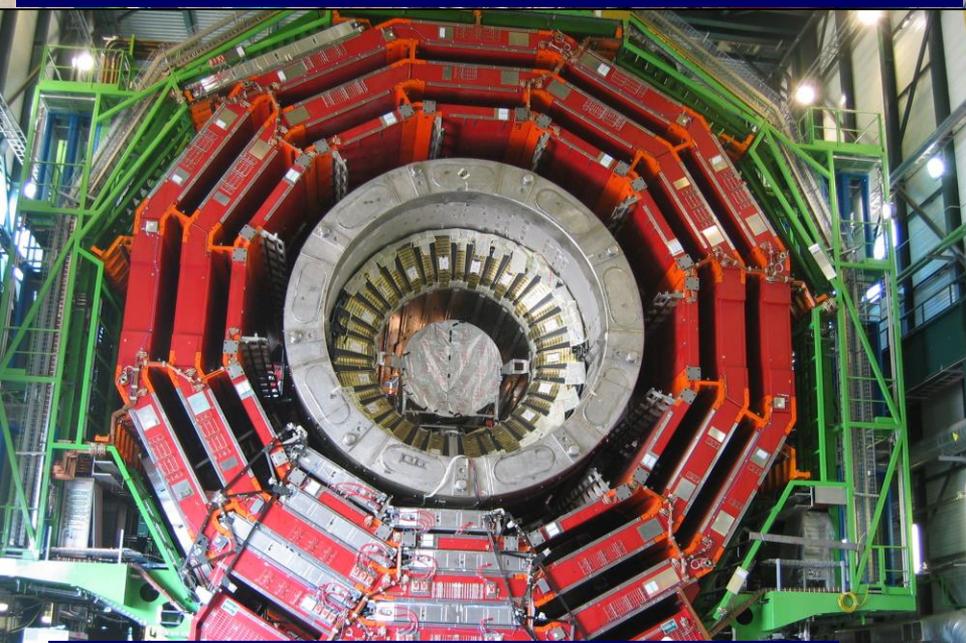
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter



ALICE: Primordial cosmic plasma



ATLAS: Higgs and dark matter



CMS: Higgs and dark matter



LHCb: Matter-antimatter difference

Scientists from around the World



MEMBER STATES

7889

Austria	117
Belgium	120
Bulgaria	96
Czech Republic	244
Denmark	67
Finland	111
France	868
Germany	1342
Greece	237
Hungary	76
Israel	65
Italy	2045
Netherlands	168
Norway	67
Poland	350
Portugal	127
Romania	134
Slovakia	124
Spain	447
Sweden	85
Switzerland	200
United Kingdom	771

OBSERVERS

2718

Japan	314
Russia	1187
USA	1217

ASSOCIATE MEMBERS

745

India	357
Lithuania	35
Pakistan	65
Turkey	173
Ukraine	115

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP

118

Cyprus	26
Serbia	57
Slovenia	35

OTHERS

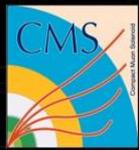
1872

Afghanistan	1	Bolivia	4	Egypt	31	Kazakhstan	5	Mongolia	2	Philippines	3	Thailand	22
Albania	3	Bosnia & Herzegovina	2	El Salvador	1	Kenya	3	Montenegro	11	Saint Kitts and Nevis	1	T.F.Y.R.O.M.	2
Algeria	14	Brazil	135	Estonia	15	Korea Rep.	185	Morocco	20	Saudi Arabia	2	Tunisia	5
Argentina	27	Burundi	1	Georgia	46	Kyrgyzstan	1	Myanmar	1	Senegal	1	Uruguay	1
Armenia	19	Cameroon	1	Ghana	1	Latvia	2	Nepal	10	Singapore	4	Uzbekistan	4
Australia	31	Canada	161	Hong Kong	1	Lebanon	23	New Zealand	5	South Africa	56	Venezuela	10
Azerbaijan	10	Chile	20	Indonesia	11	Luxembourg	2	Nigeria	3	Sri Lanka	6	Viet Nam	13
Bangladesh	11	China	510	Iran	51	Madagascar	4	North Korea	1	Sudan	1	Zambia	1
Belarus	48	Colombia	45	Iraq	1	Malaysia	15	Oman	3	Swaziland	1	Zimbabwe	2
Benin	1	Croatia	41	Ireland	16	Malta	9	Palestine (O.T.)	7	Syria	1		
		Cuba	12	Jordan	1	Mauritius	1	Paraguay	2	Taiwan	51		
		Ecuador	6			Mexico	82	Peru	7				

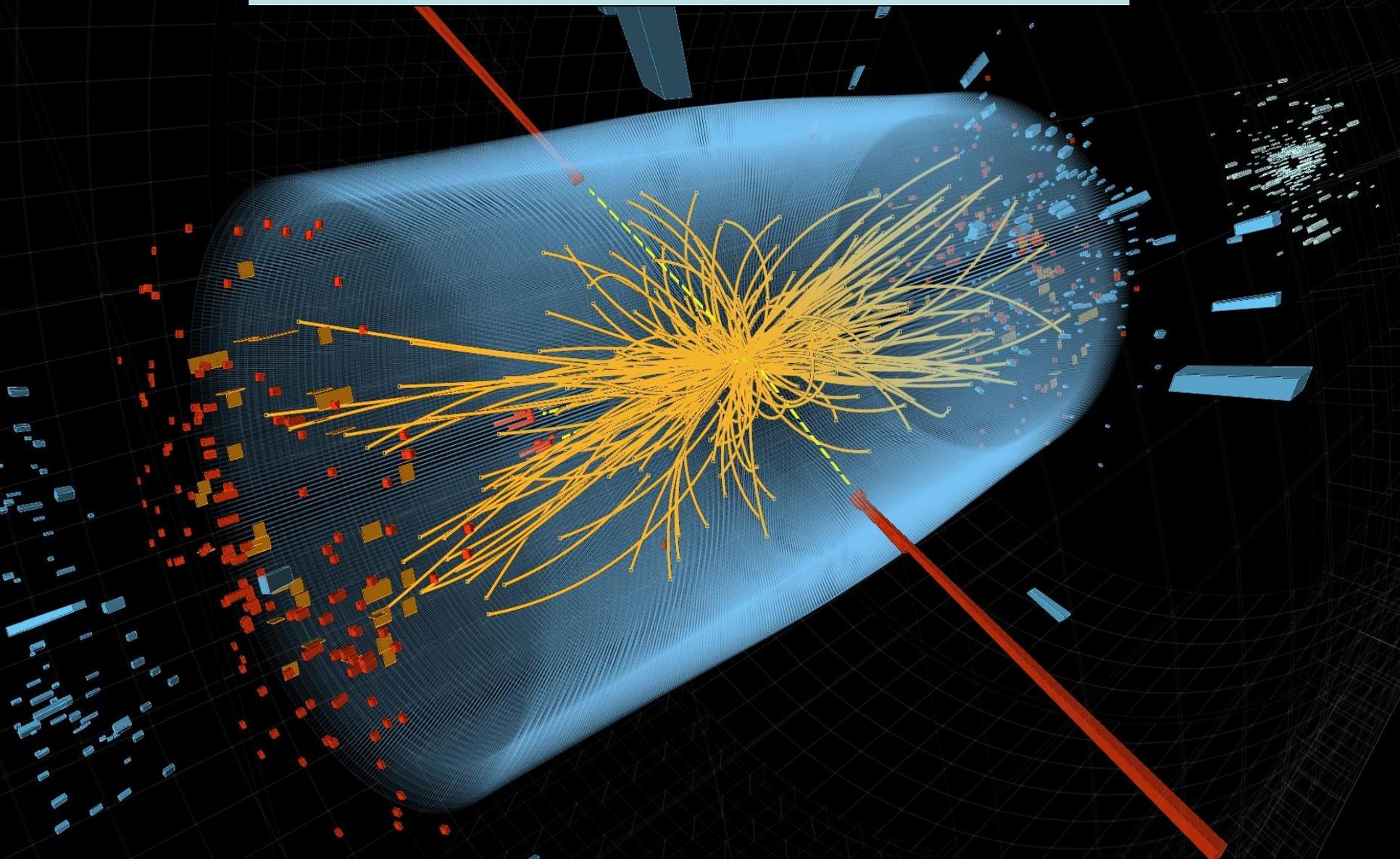
2012: The discovery of the Higgs Boson



Mass Higgsteria



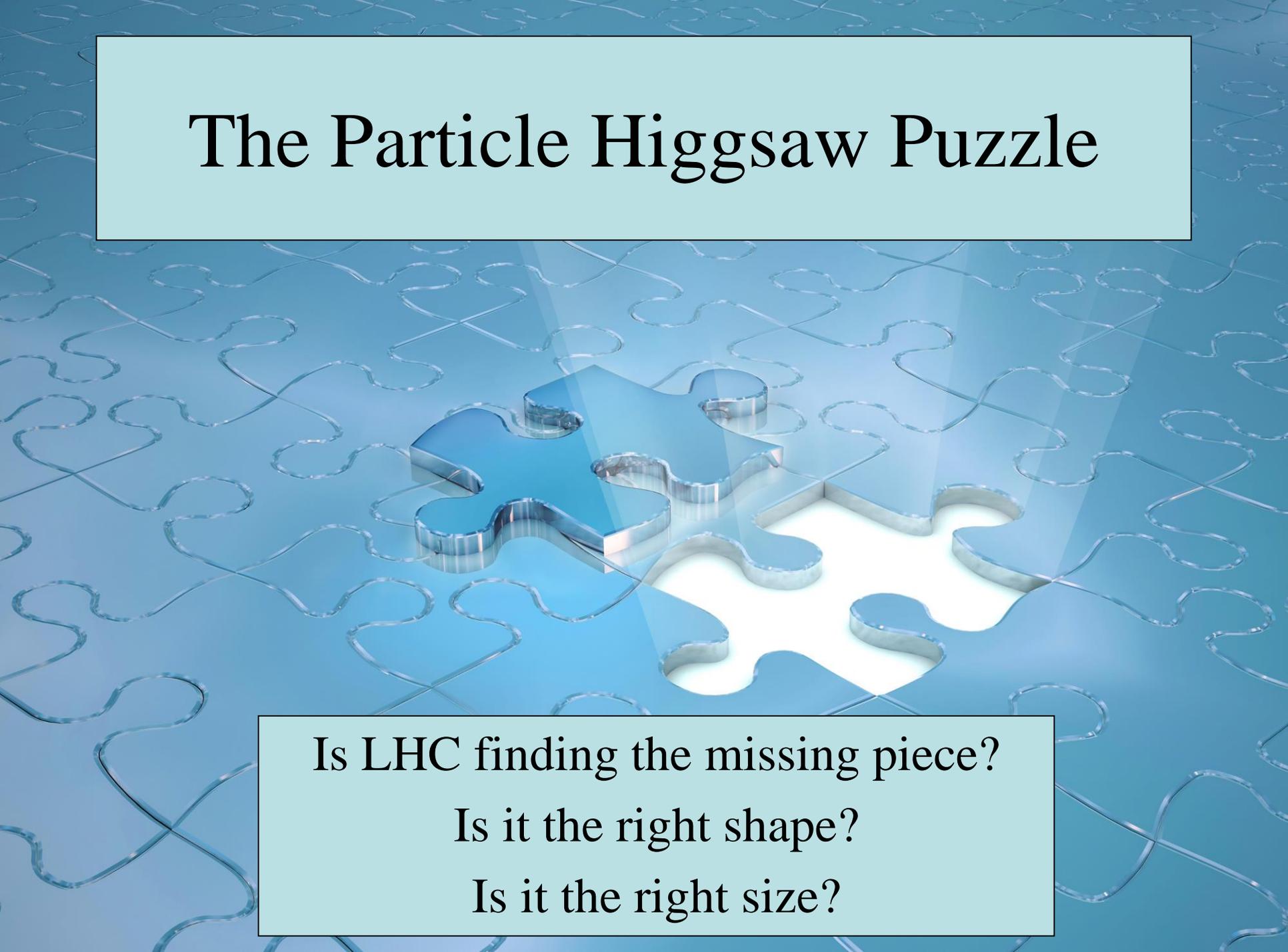
Interesting Events



Higgsdependence Day!



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 a puzzle.

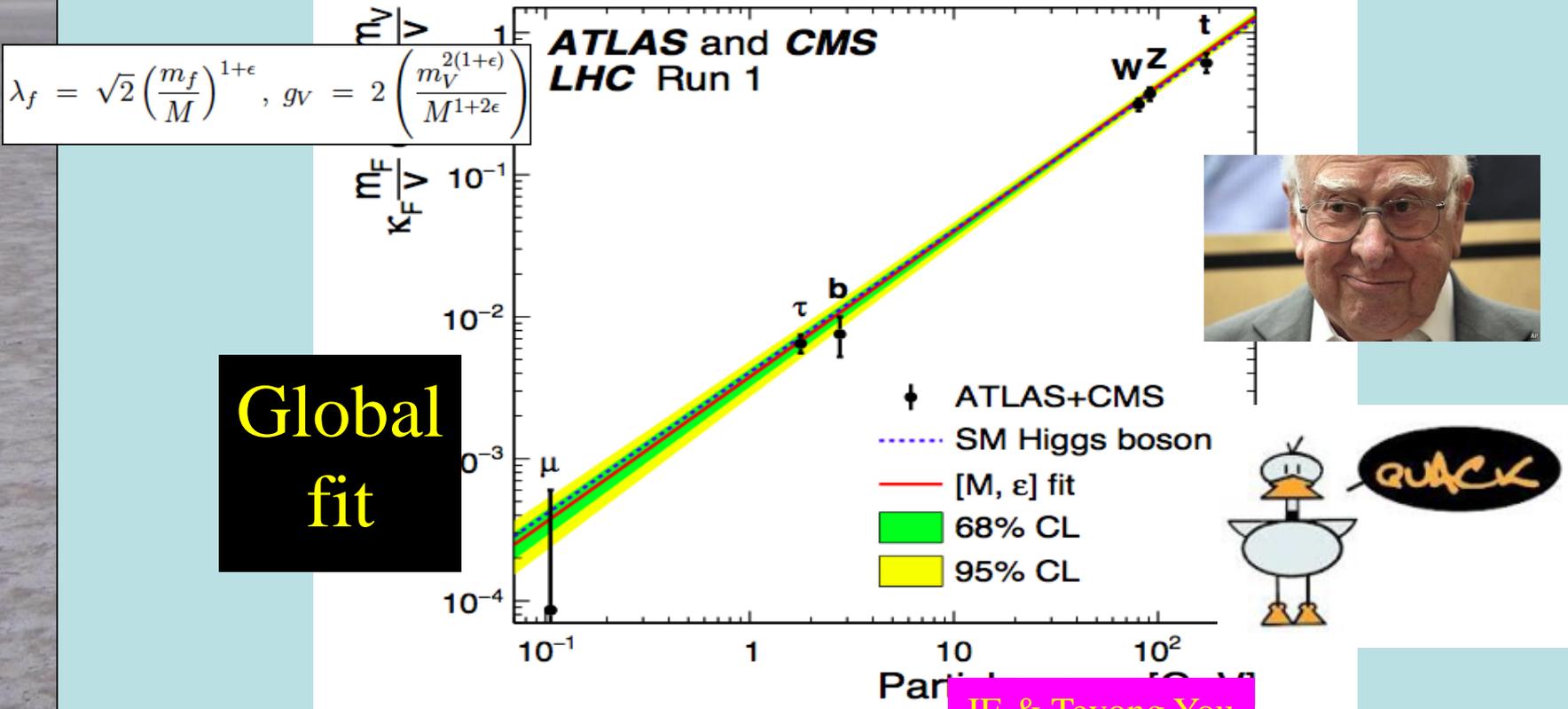
Is LHC finding the missing piece?

Is it the right shape?

Is it the right size?

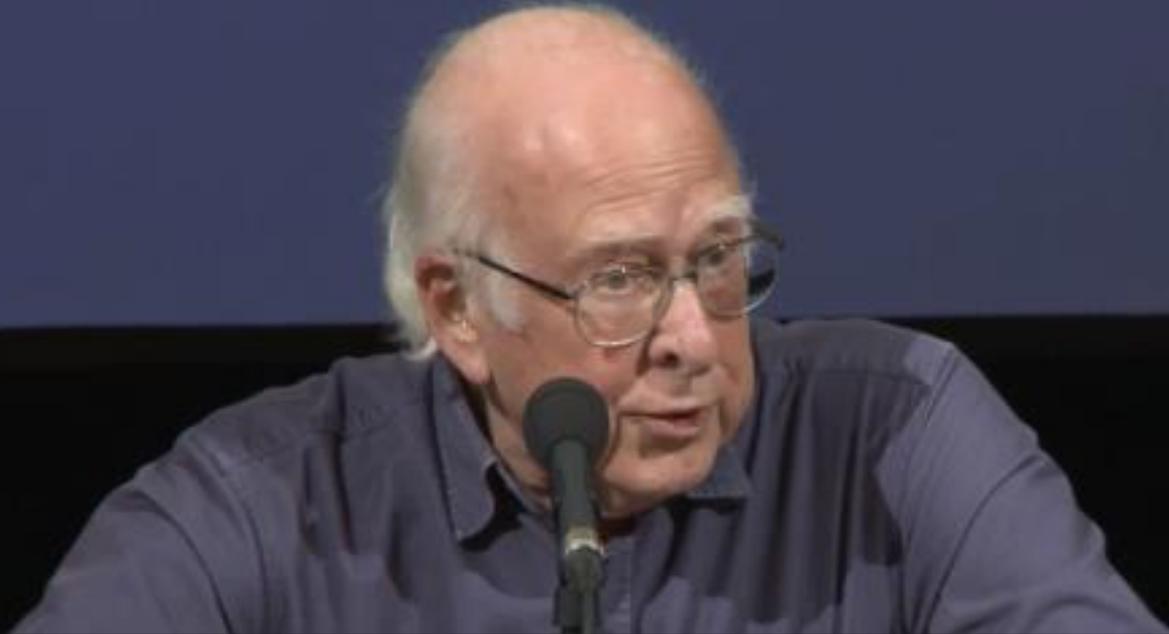
It Walks and Quacks like a Higgs

- Do couplings scale \sim mass? With scale = v ?



- Blue** dashed line = Standard Model

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!

Should it have Collapsed already?

Fluctuate over barrier
in the early Universe?

Not if
infinite barrier:
Supersymmetry?

We are here



HIGGS FIELD

Tunnel through
barrier now?

Quantum fluctuations

The Big Crunch



ULTRA-DENSE HIGGS FIELD

The Dark Matter Hypothesis

- Proposed by Fritz Zwicky, based on observations of the Coma galaxy cluster
- The galaxies move too quickly
- The observations require a stronger gravitational field than provided by the visible matter
- **Dark matter?**



The Rotation Curves of Galaxies

- Measured by Vera Rubin
- The stars also orbit ‘too quickly’
- Her observations also required a stronger gravitational field than provided by the visible matter
- **Further strong evidence for dark matter**



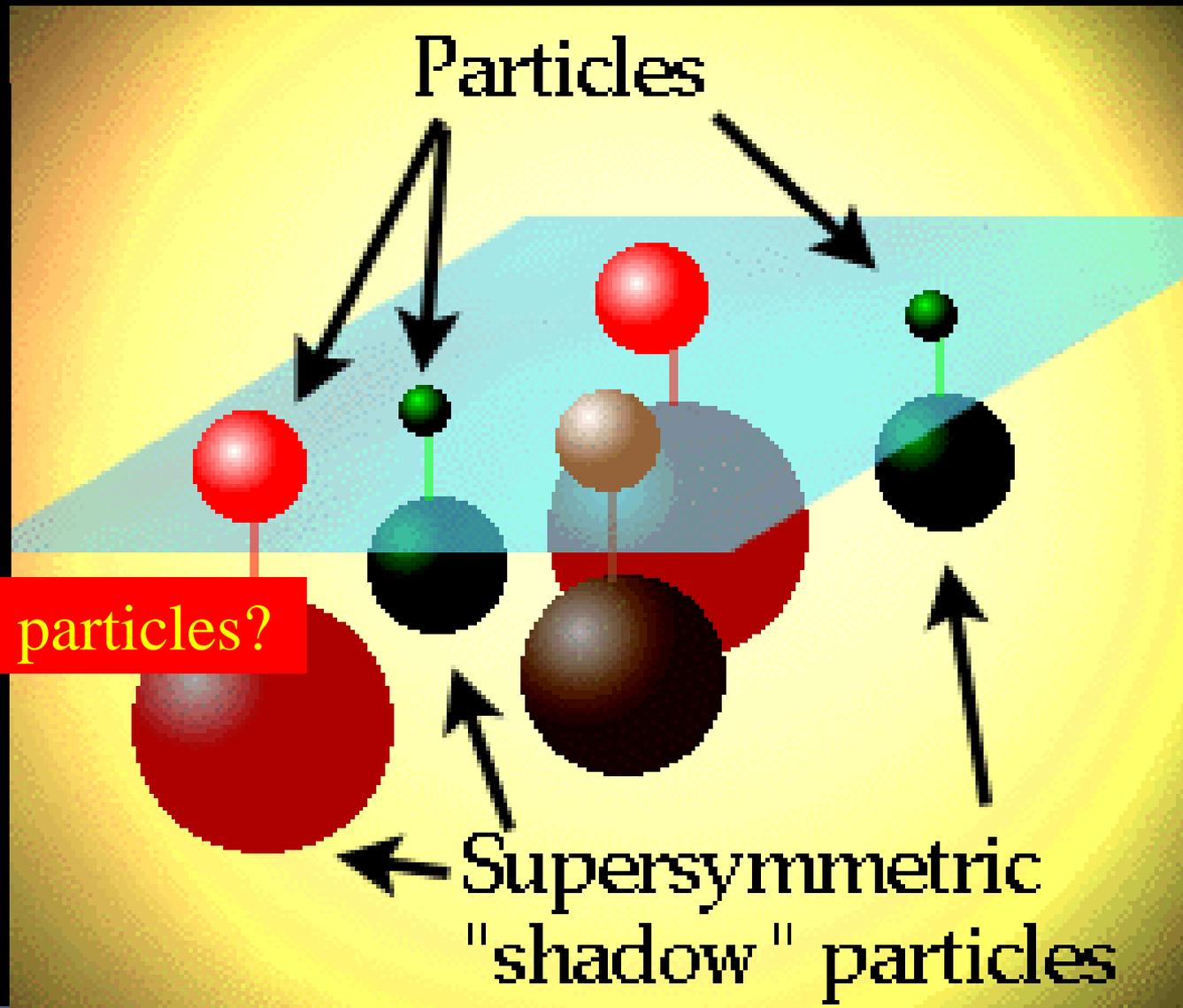
Scanned at the American
Institute of Physics

What is the Dark Matter in the Universe?

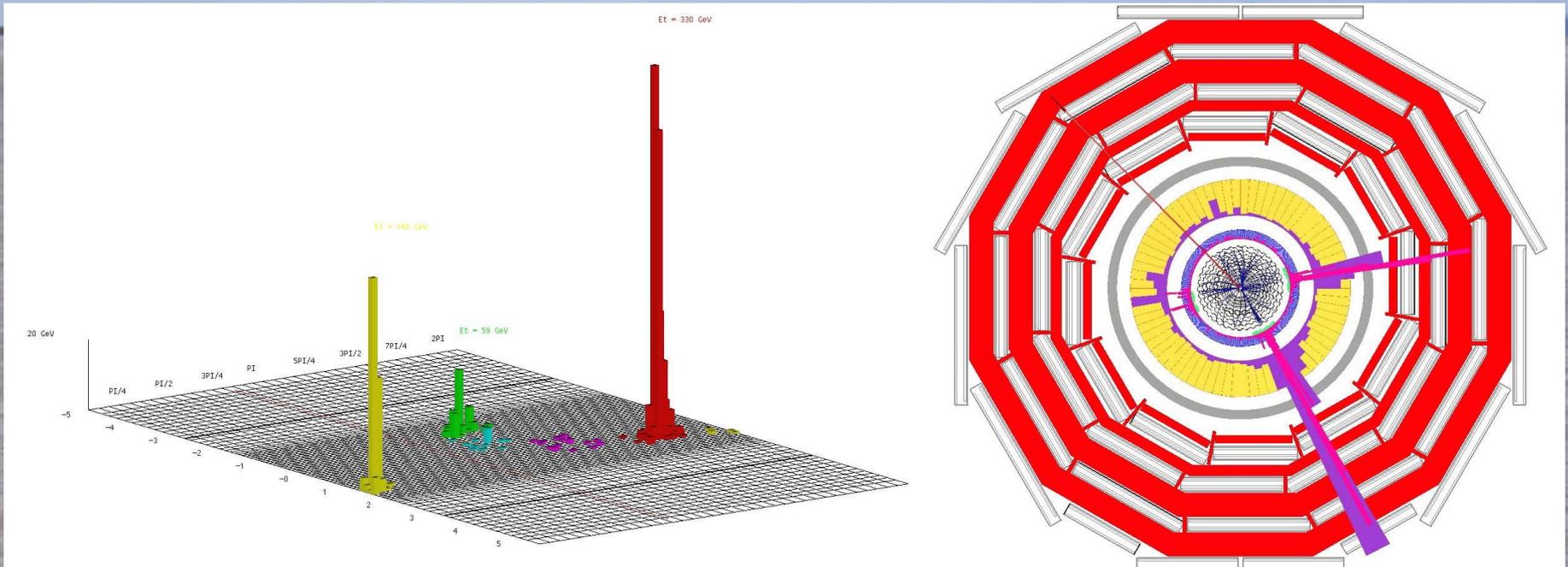
Astronomers say
that most of the
matter in the
Universe is
invisible
Dark Matter

Made of unknown particles?

We are
searching for
them at the
LHC



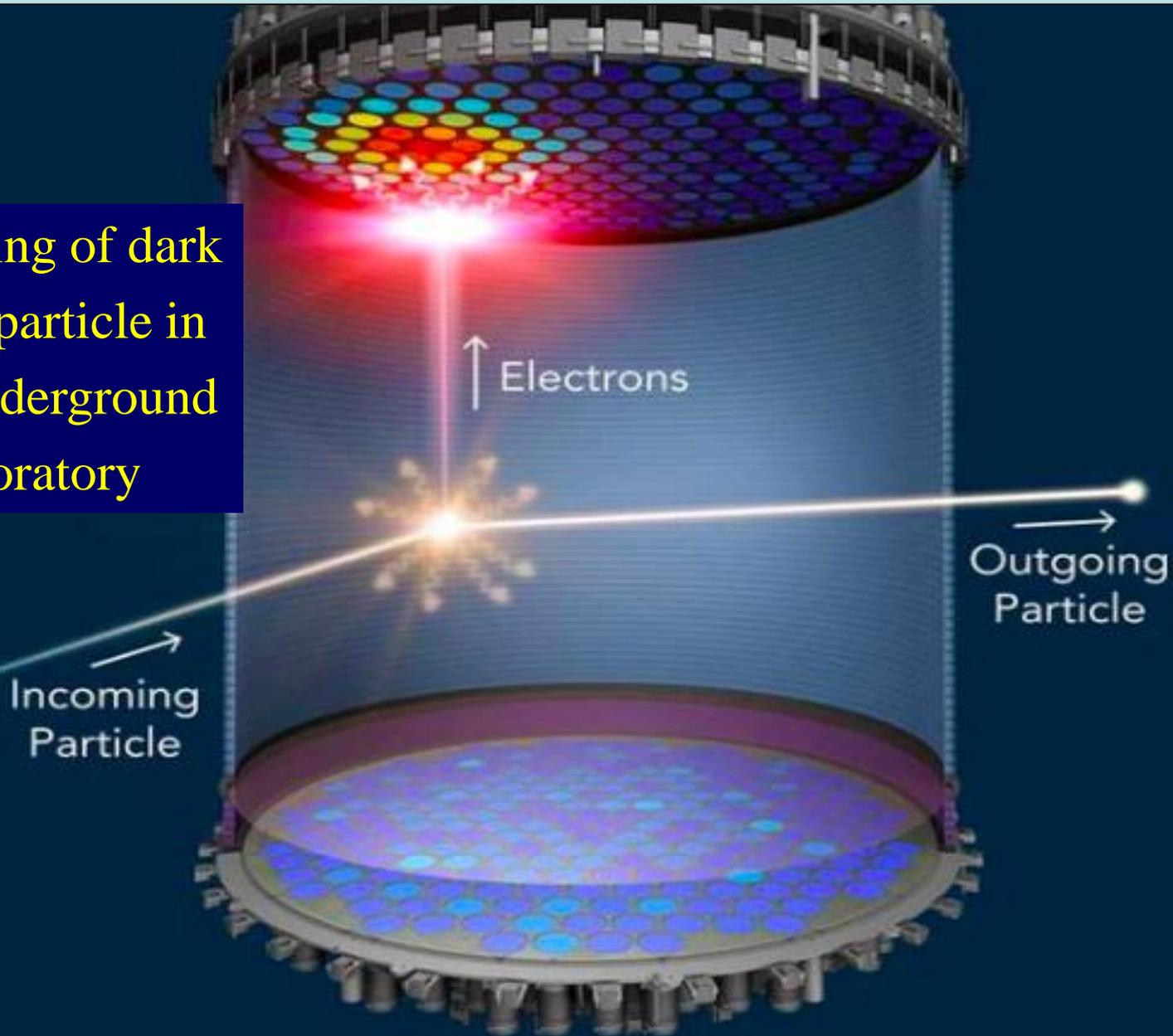
Classic Dark Matter Signature



Missing transverse energy
carried away by dark matter particles

Direct Dark Matter Detection

Scattering of dark matter particle in deep underground laboratory



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?

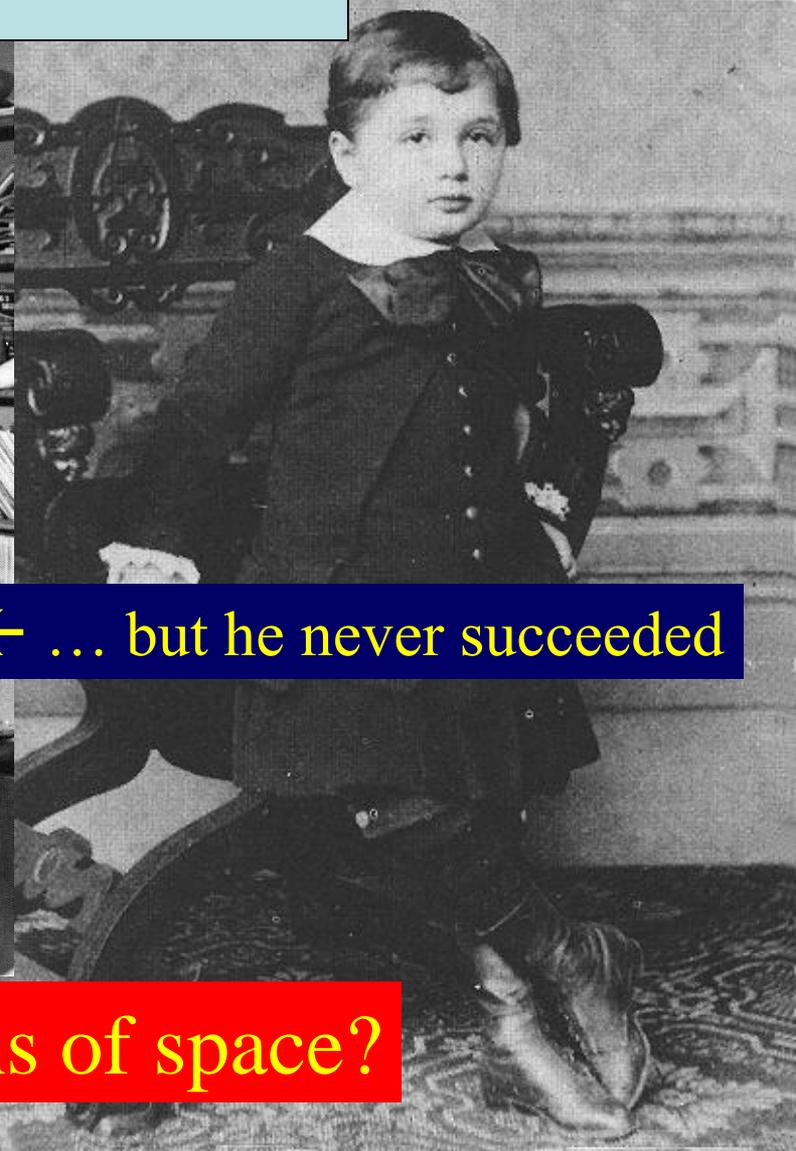
Why does the Universe mainly contain matter, not antimatter?

Experiments at LHC and elsewhere looking for answers

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



← ... but he never succeeded



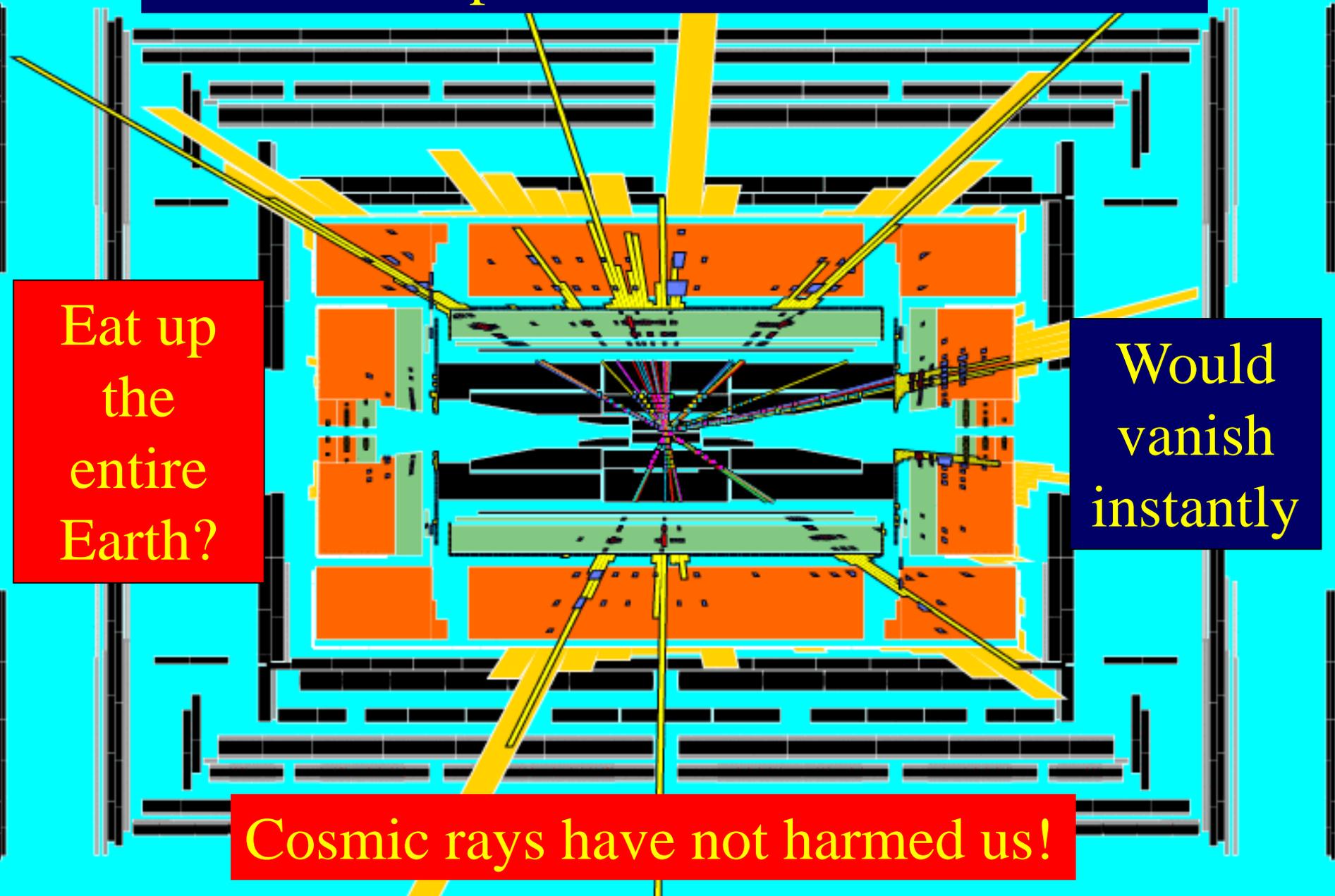
Unification via extra dimensions of space?

Will LHC experiments create black holes?

Eat up
the
entire
Earth?

Would
vanish
instantly

Cosmic rays have not harmed us!



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



... and also a telescope
addressing Gauguin's
questions