

Answering Gauguin's Questions with the LHC



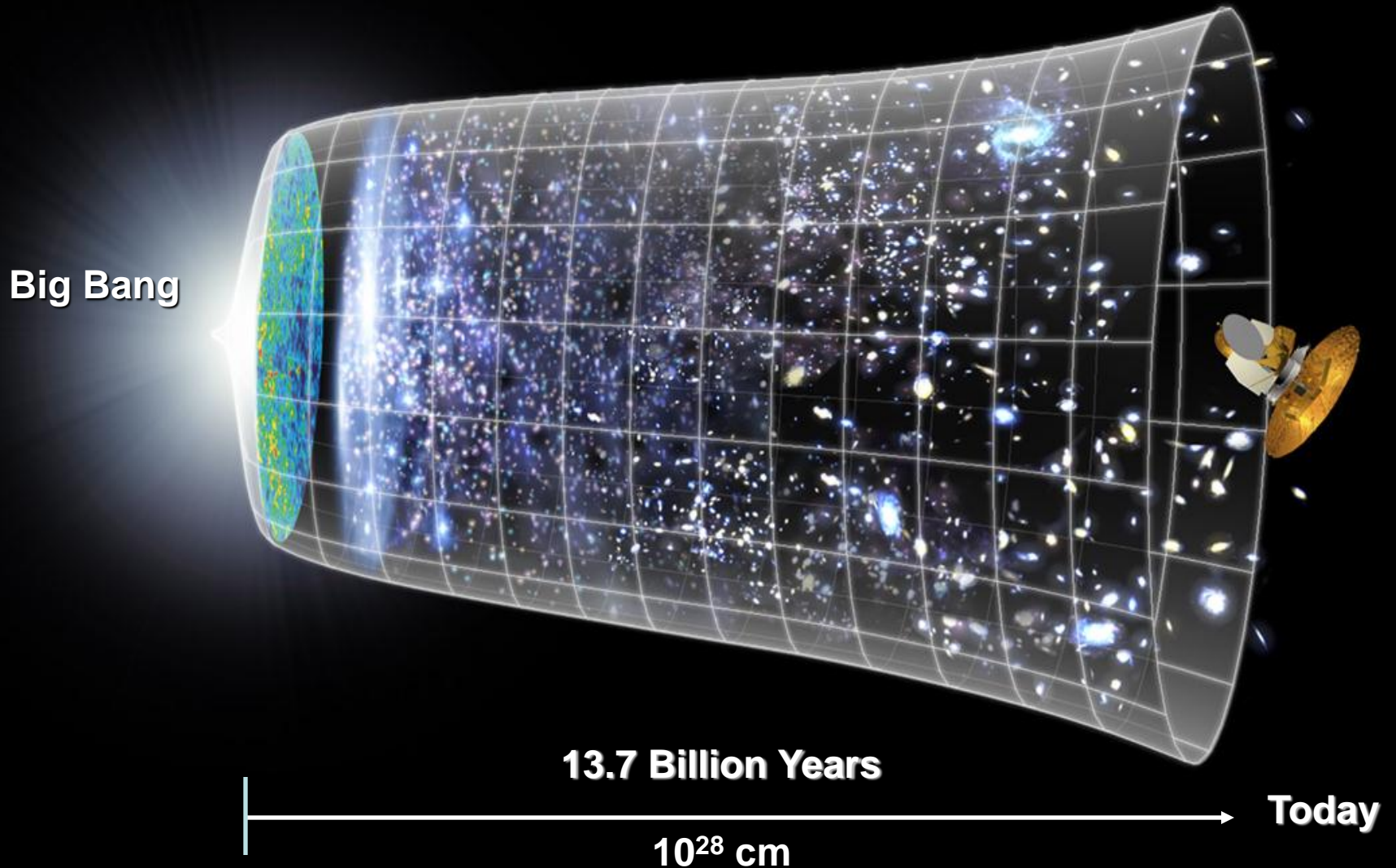
Accelerating Science and Innovation

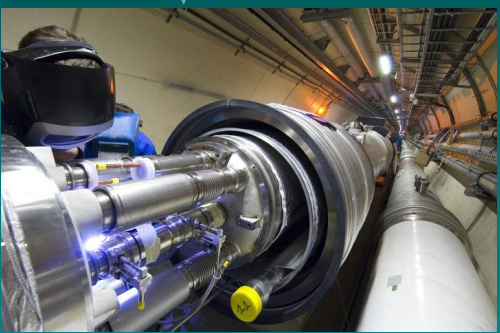
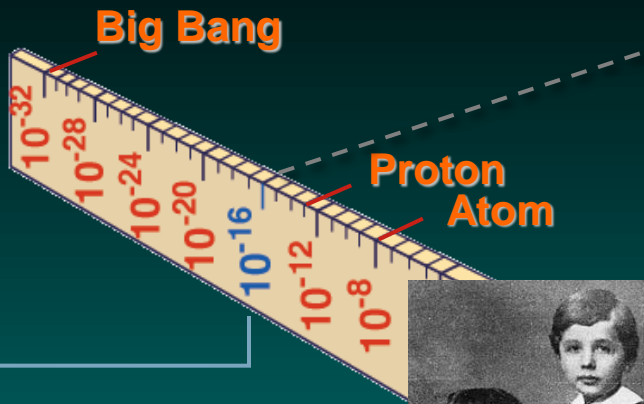
“Where do we come from?
What are we?
Where are we going?”



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

Evolution of the Universe



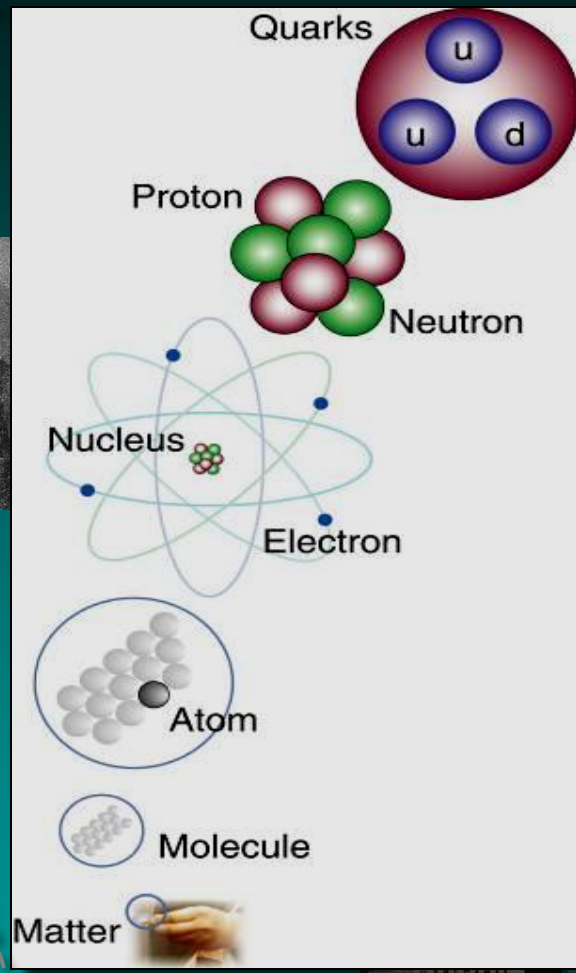


LHC

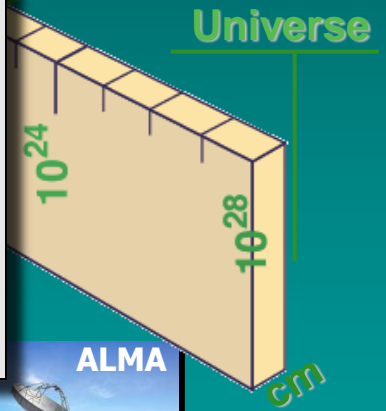
Super-Microscope



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



Radius of Galaxies

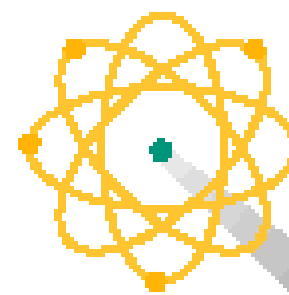


Gauguin's Questions in the Language of Particle Physics

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

Our job is to ask - and answer - these questions

Inside Matter



atoms have electrons ...



orbiting a nucleus ...

which is made of protons ...



... and neutrons

which are made of quarks, up-quarks and down-quarks ...



which are at the current limit of our knowledge

All matter is made of the same constituents

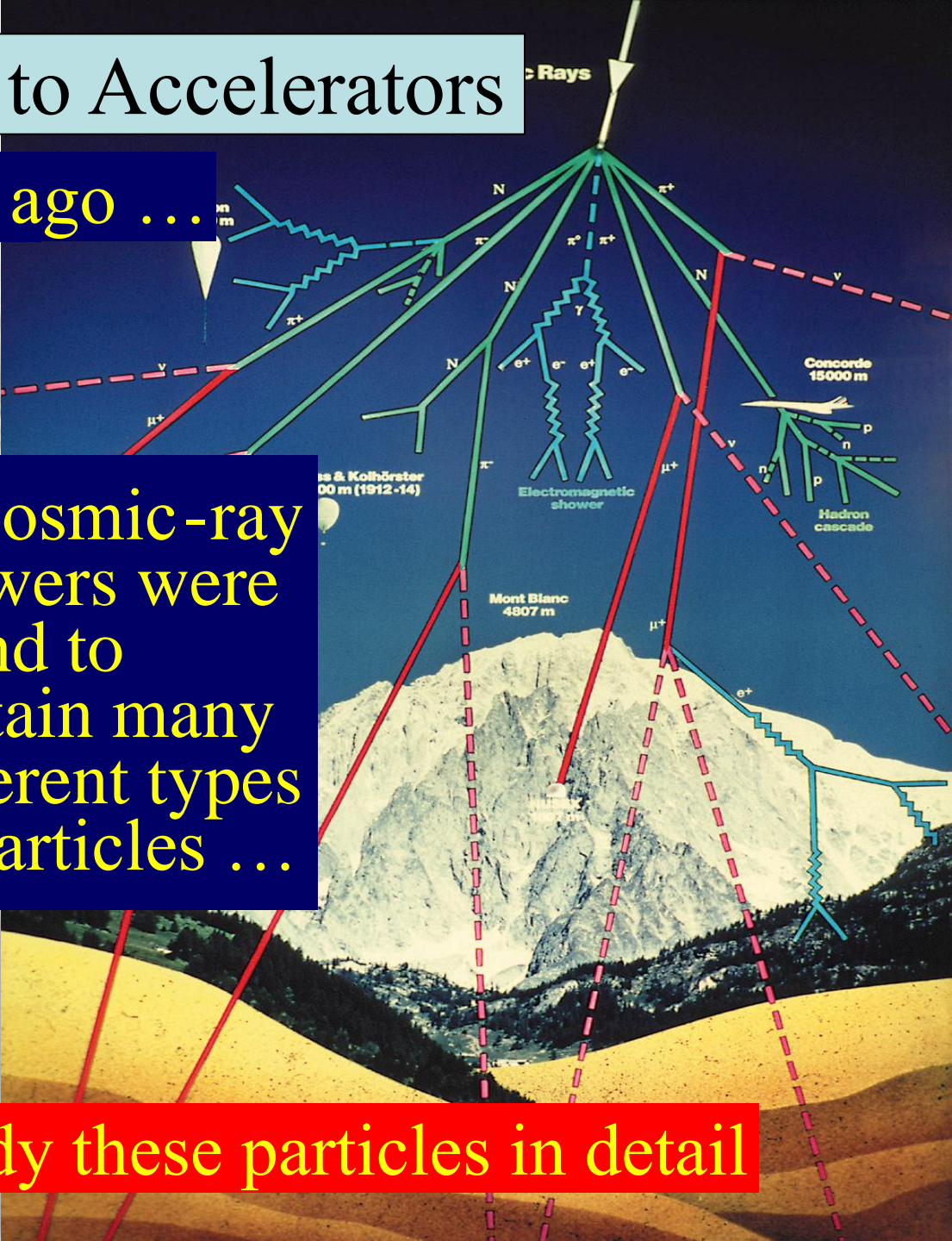
What are they?
What forces between them?

From Cosmic Rays to Accelerators

Discovered a century ago ...

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

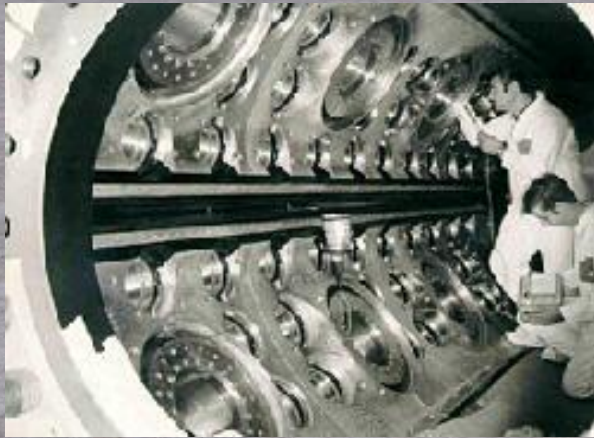
Accelerators study these particles in detail



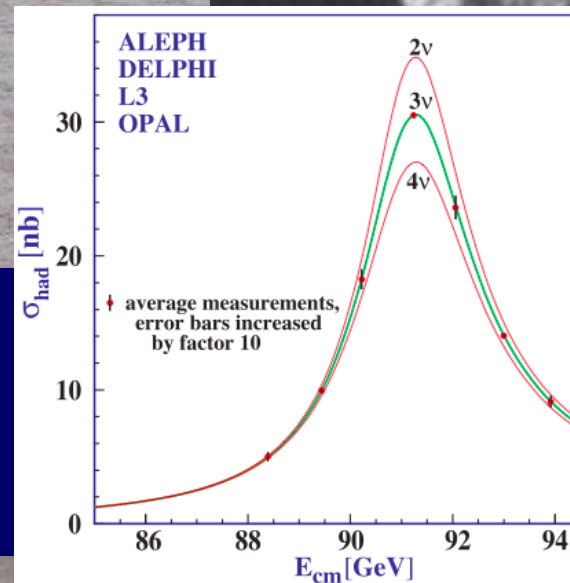
The 'Standard Model' of Particle Physics

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



The fundamental interactions



Gravitation

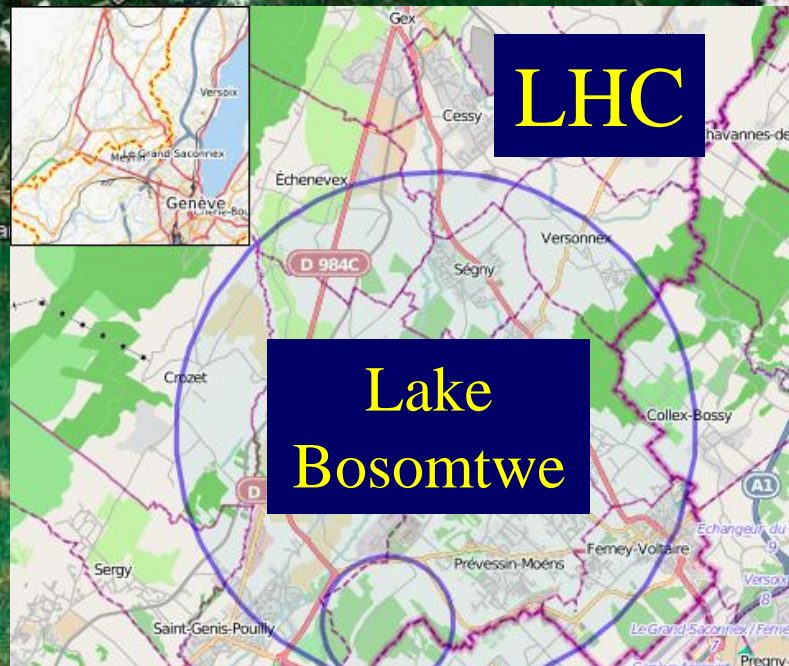
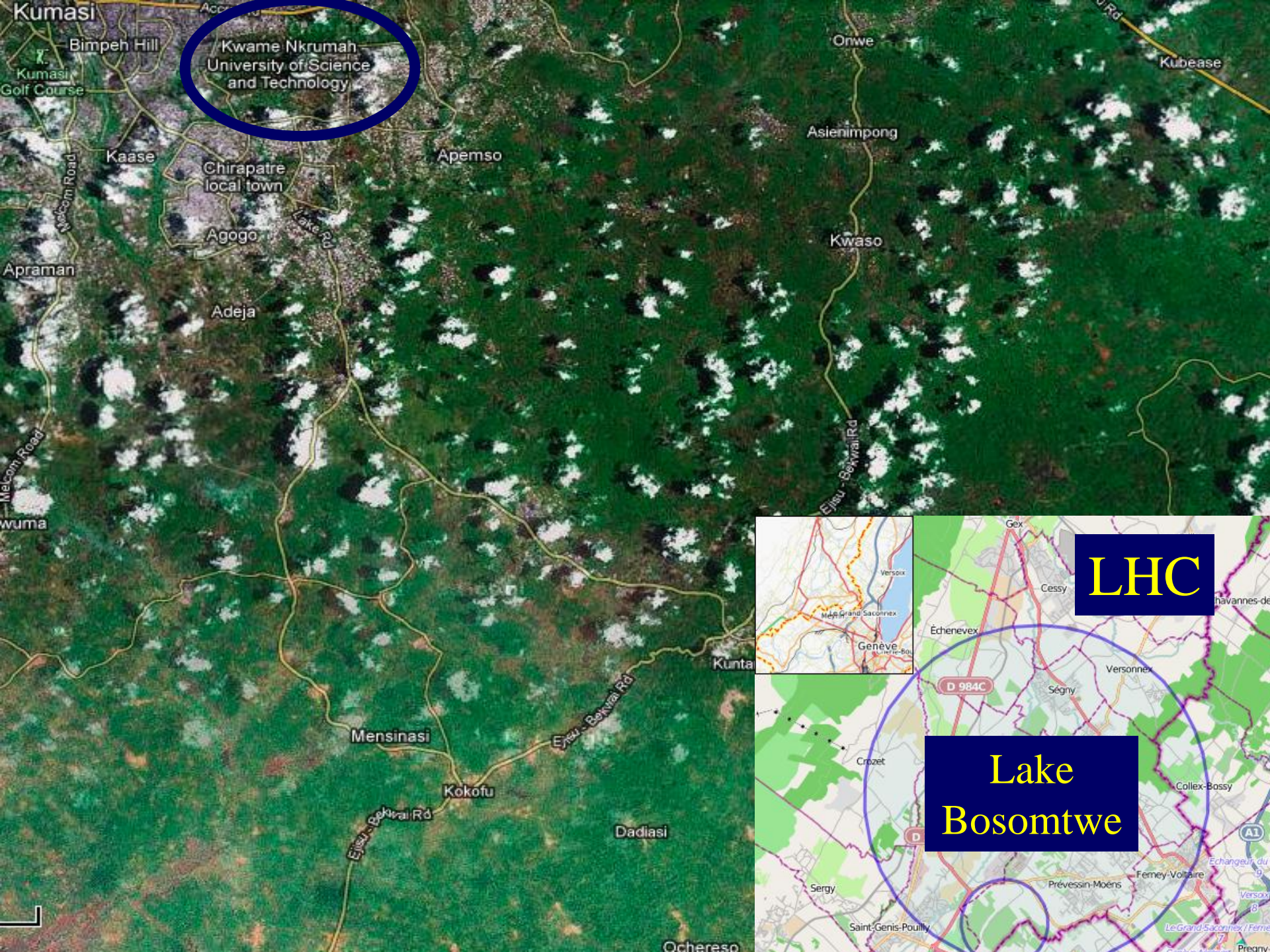
electromagnetism

weak nuclear force

strong nuclear force

Open Questions beyond the Standard Model

- What is the origin of particle masses?
due to a Higgs boson? LHC
- Why so many types of matter particles? LHC
- What is the dark matter in the Universe? LHC
- Unification of fundamental forces? LHC
- Quantum theory of gravity? LHC



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



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

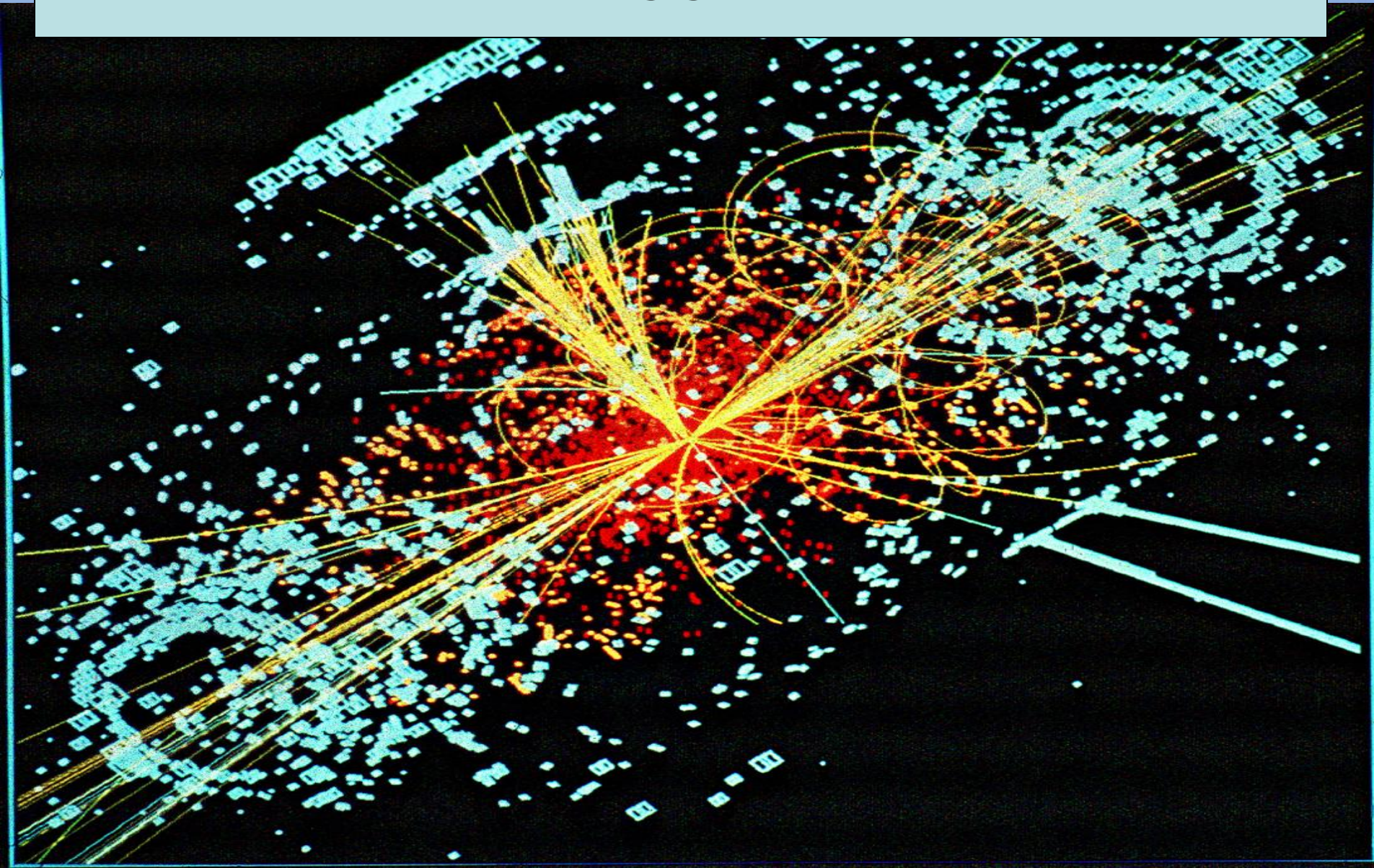


**The LHC will look for
the snowflake:
The Higgs Boson**

Hiker sinks deep,
moves very slowly:
Particle with large mass



A Simulated Higgs Event @ LHC



Dark Matter in the Universe

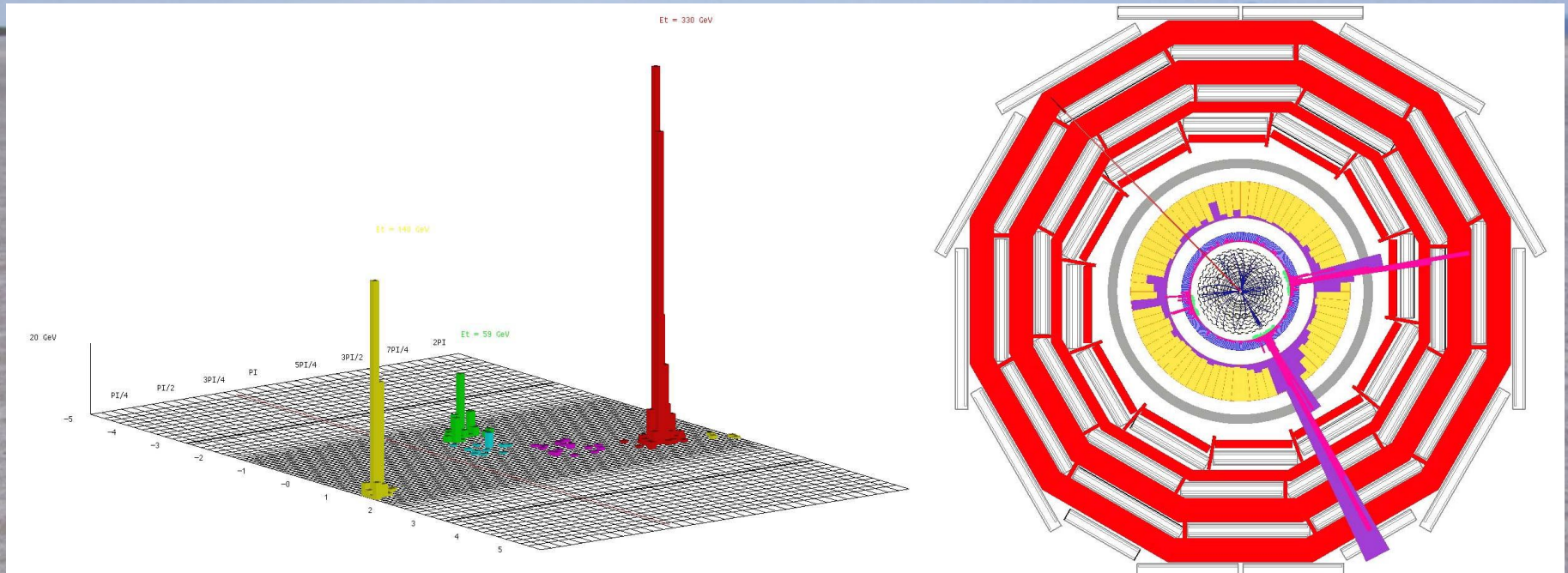


Astronomers say
that most of the
matter in the
Universe is
invisible
Dark Matter

‘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

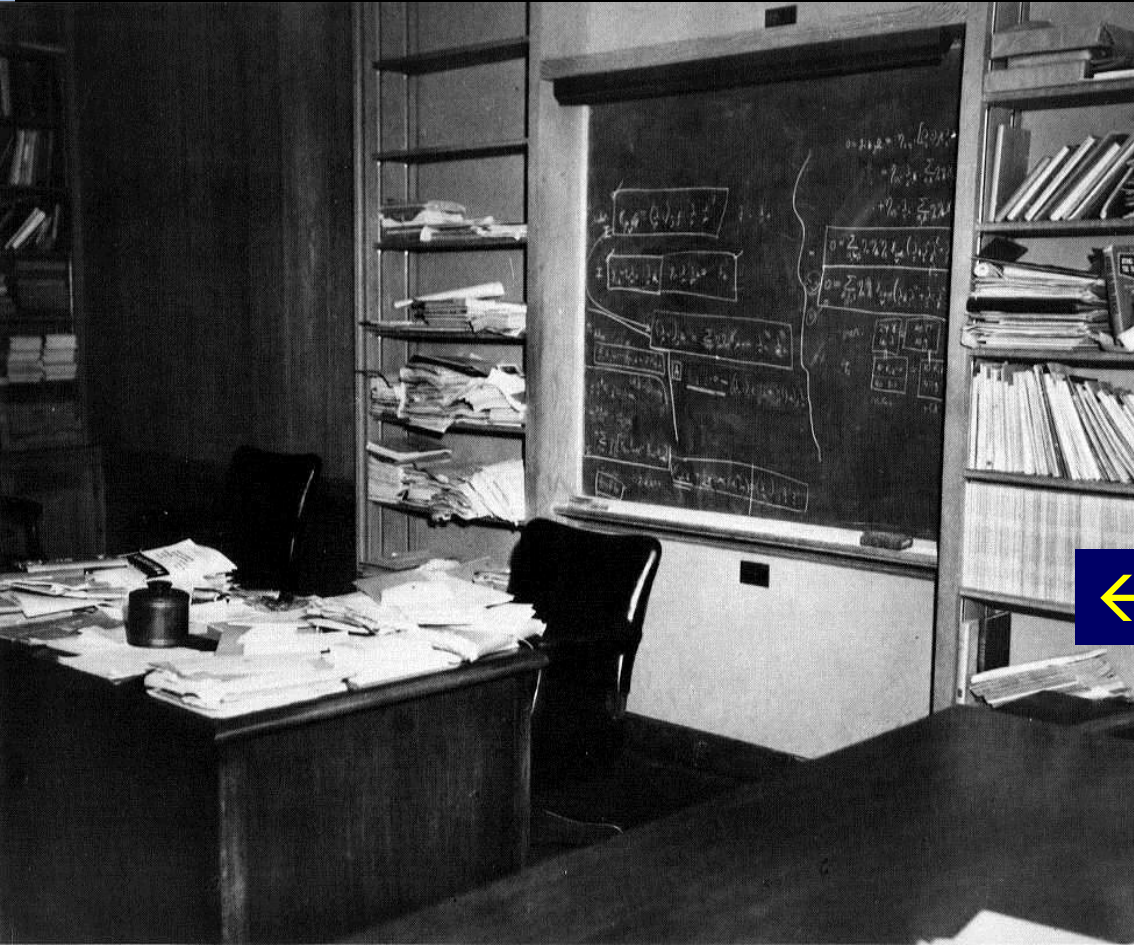


Matter and antimatter not quite equal and opposite: WHY?

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

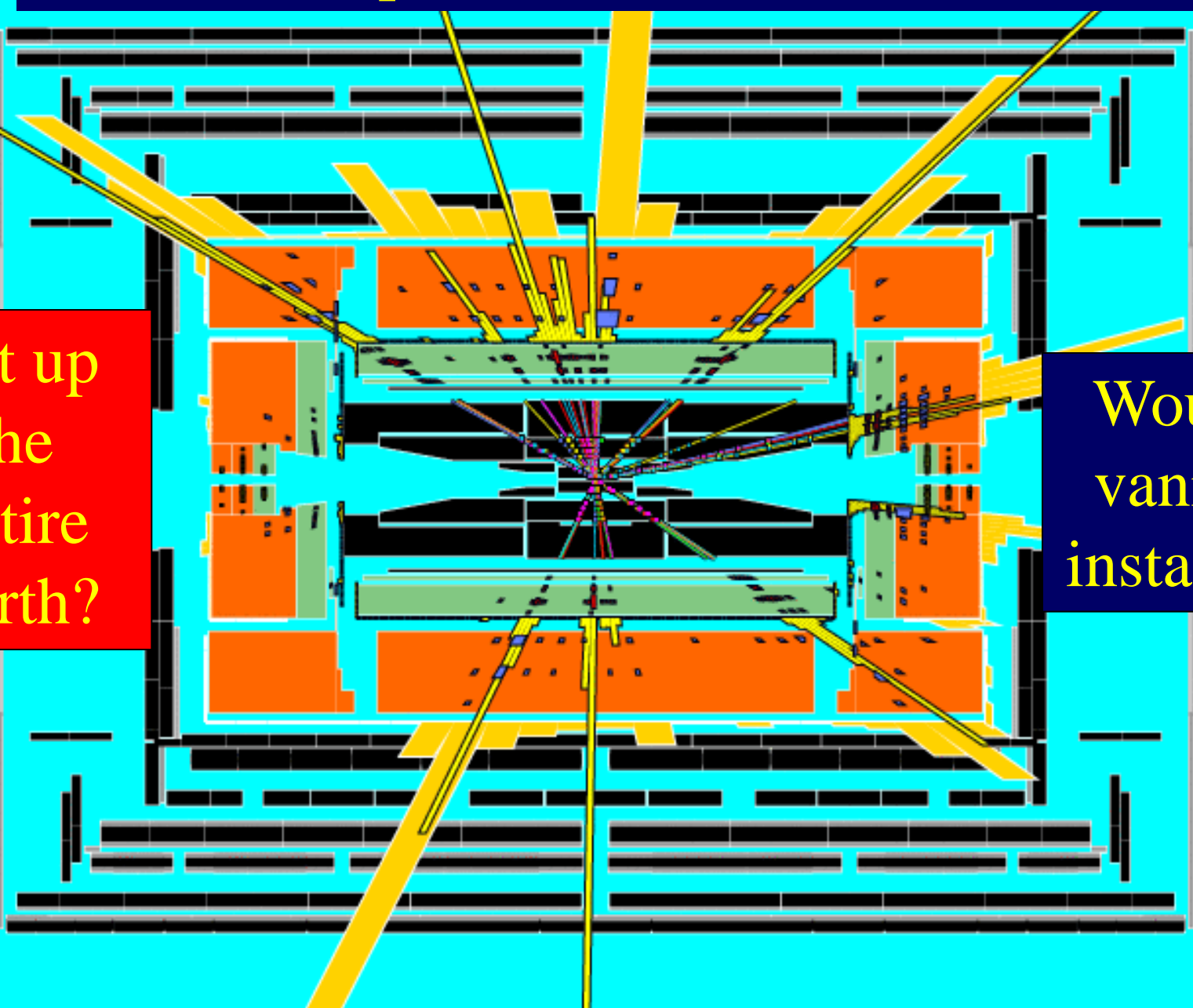


Unification via extra dimensions of space?

Will LHC experiments create black holes?

Eat up
the
entire
Earth?

Would
vanish
instantly



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:

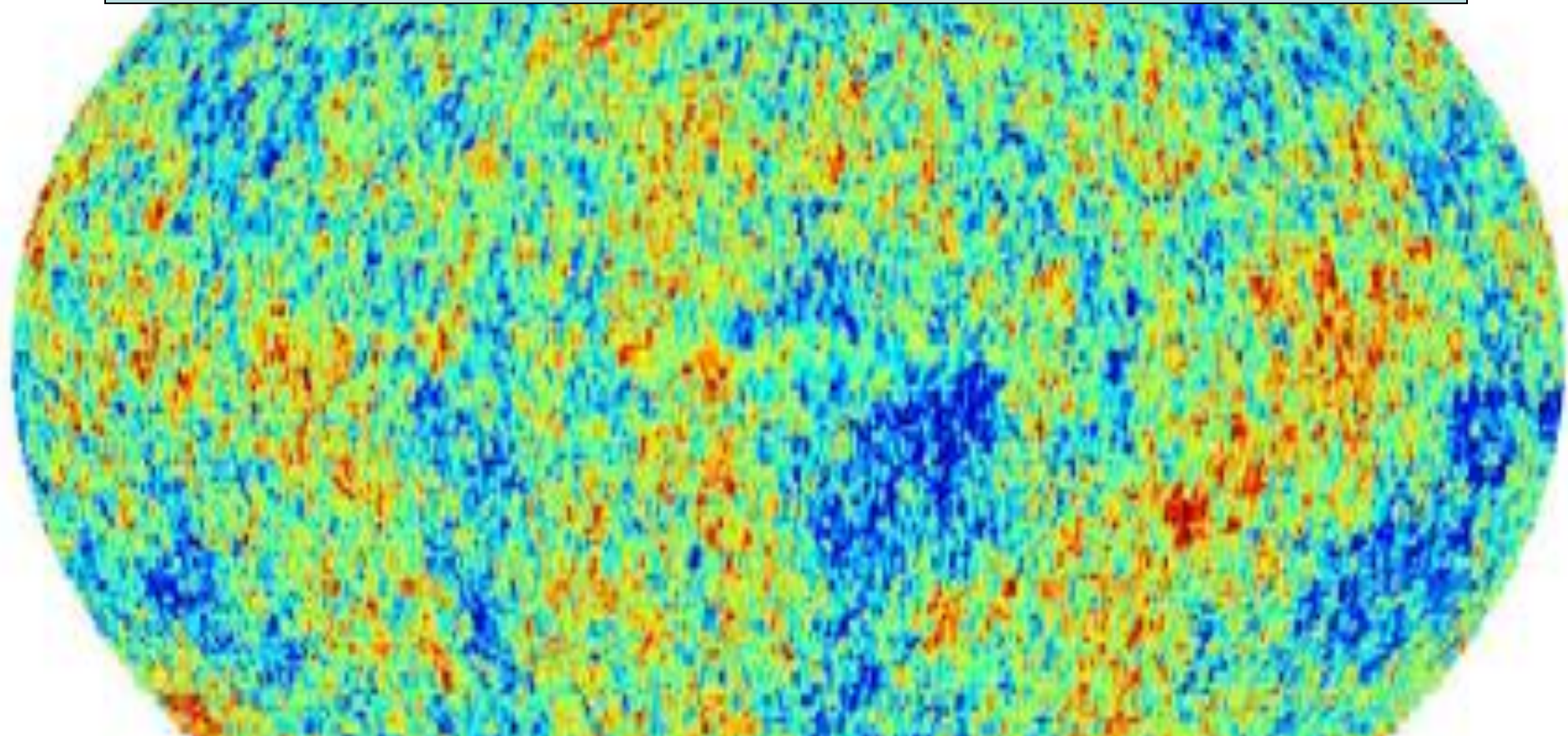
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

The Emptiest Space in the Solar System

A long, brightly lit tunnel filled with complex machinery and pipes, likely a particle accelerator or synchrotron facility. The perspective is from the end of the tunnel, looking down its length. The walls are lined with various pipes, conduits, and structural elements. The lighting is warm and focused on the central path.

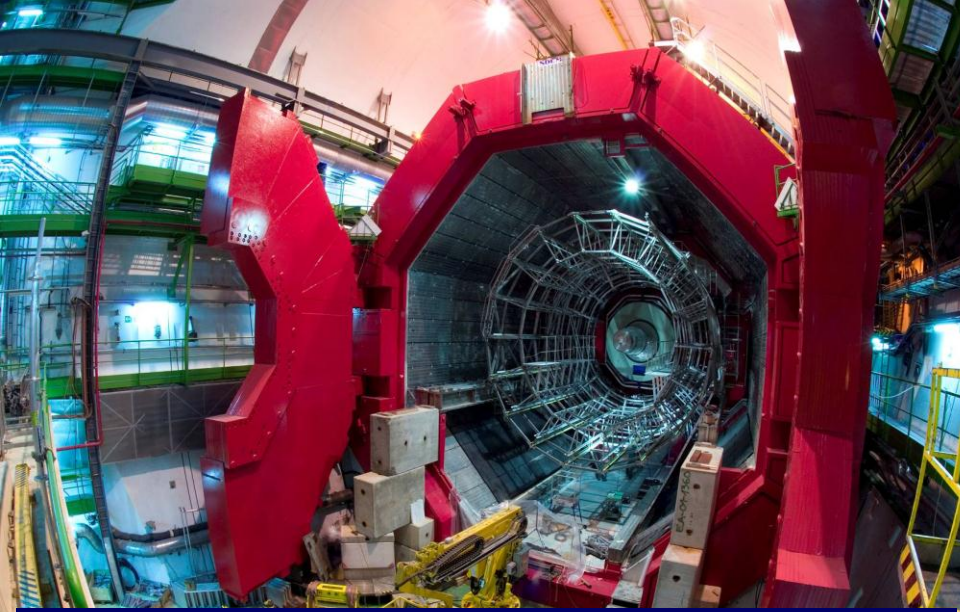
Vacuum similar to interplanetary space:
the pressure in the beam-pipes will be ten
times lower than on the Moon.

Cooler than Outer Space

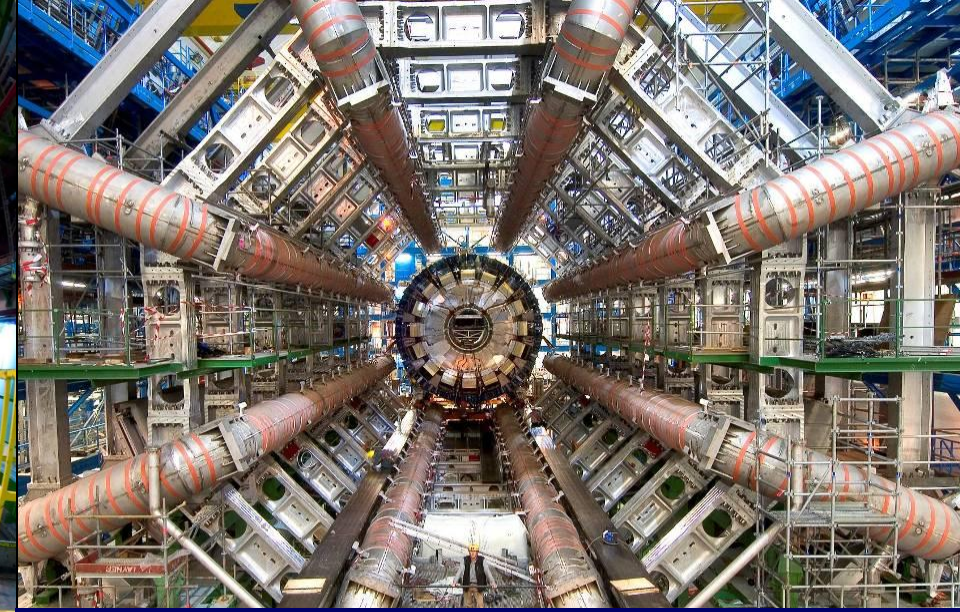


LHC 1.9 degrees above absolute zero = - 271 C

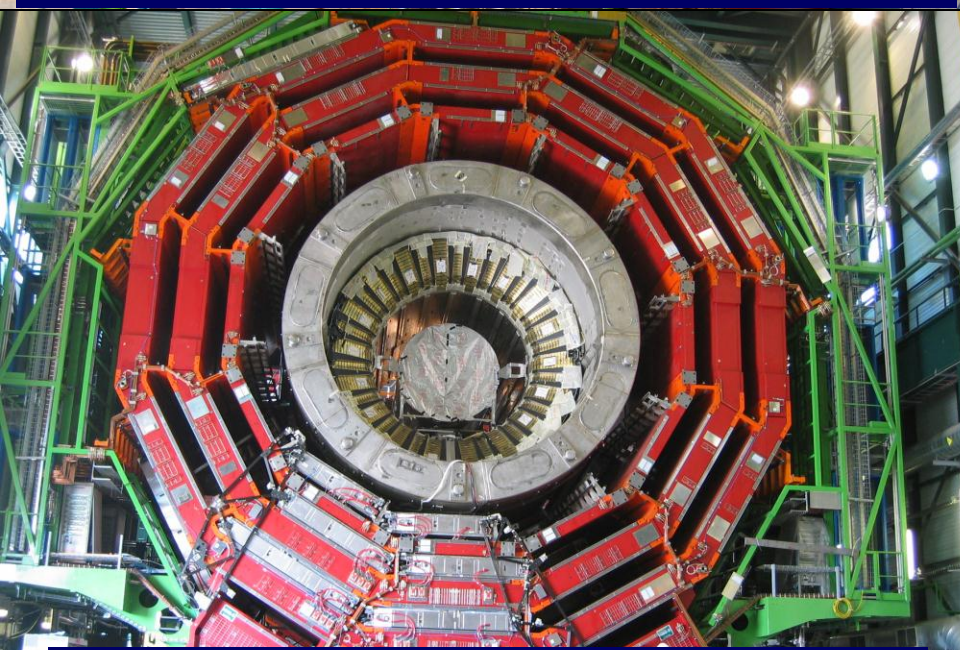
Outer space 2.7 degrees above zero = - 270 C



ALICE: Primordial cosmic plasma



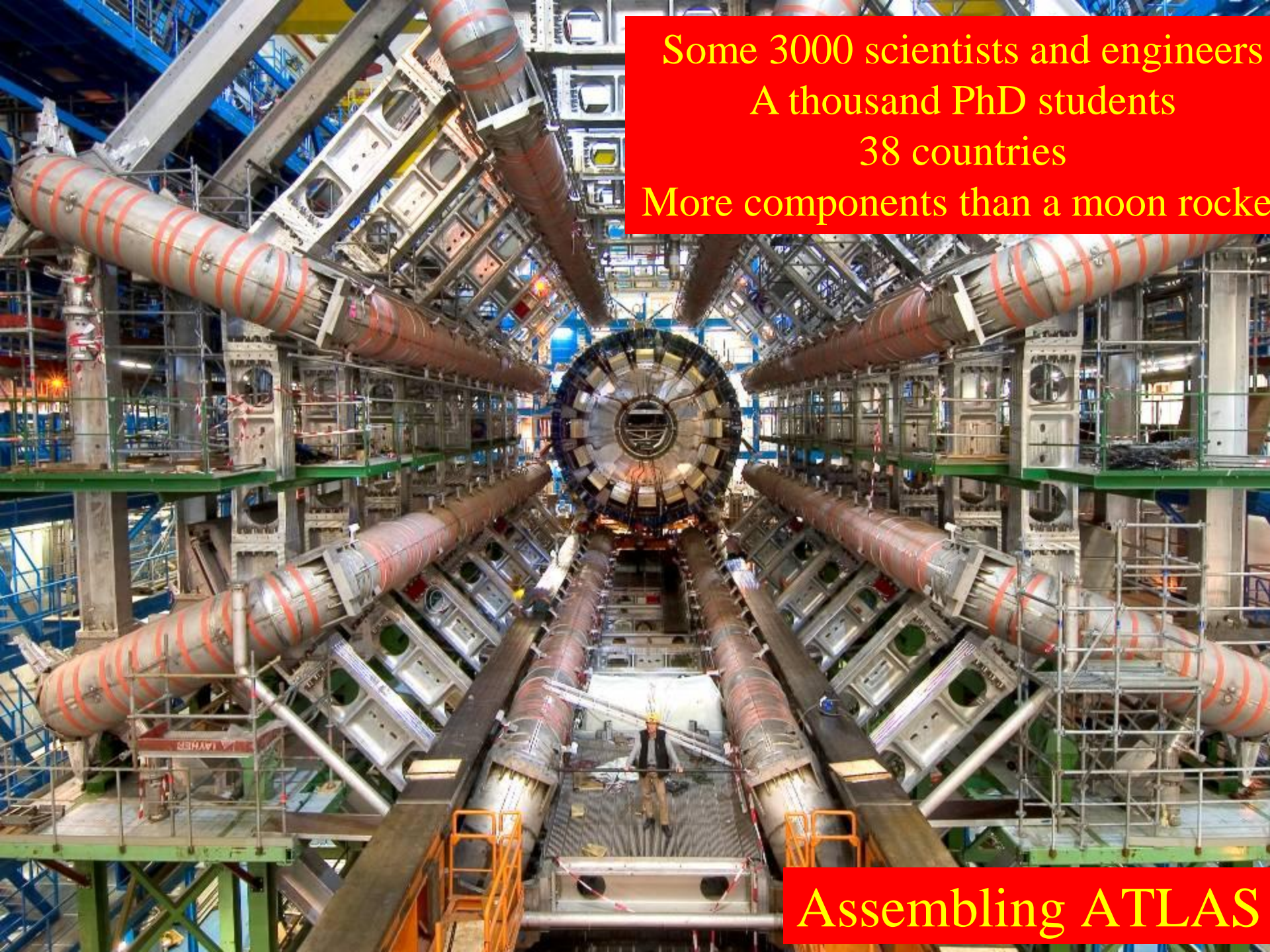
ATLAS: Higgs and supersymmetry



CMS: Higgs and supersymmetry




LHCb: Matter-antimatter difference



Some 3000 scientists and engineers
A thousand PhD students
38 countries
More components than a moon rocke

Assembling ATLAS

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



A billion people watched on TV

Nov. 20th 2009: Jubilation

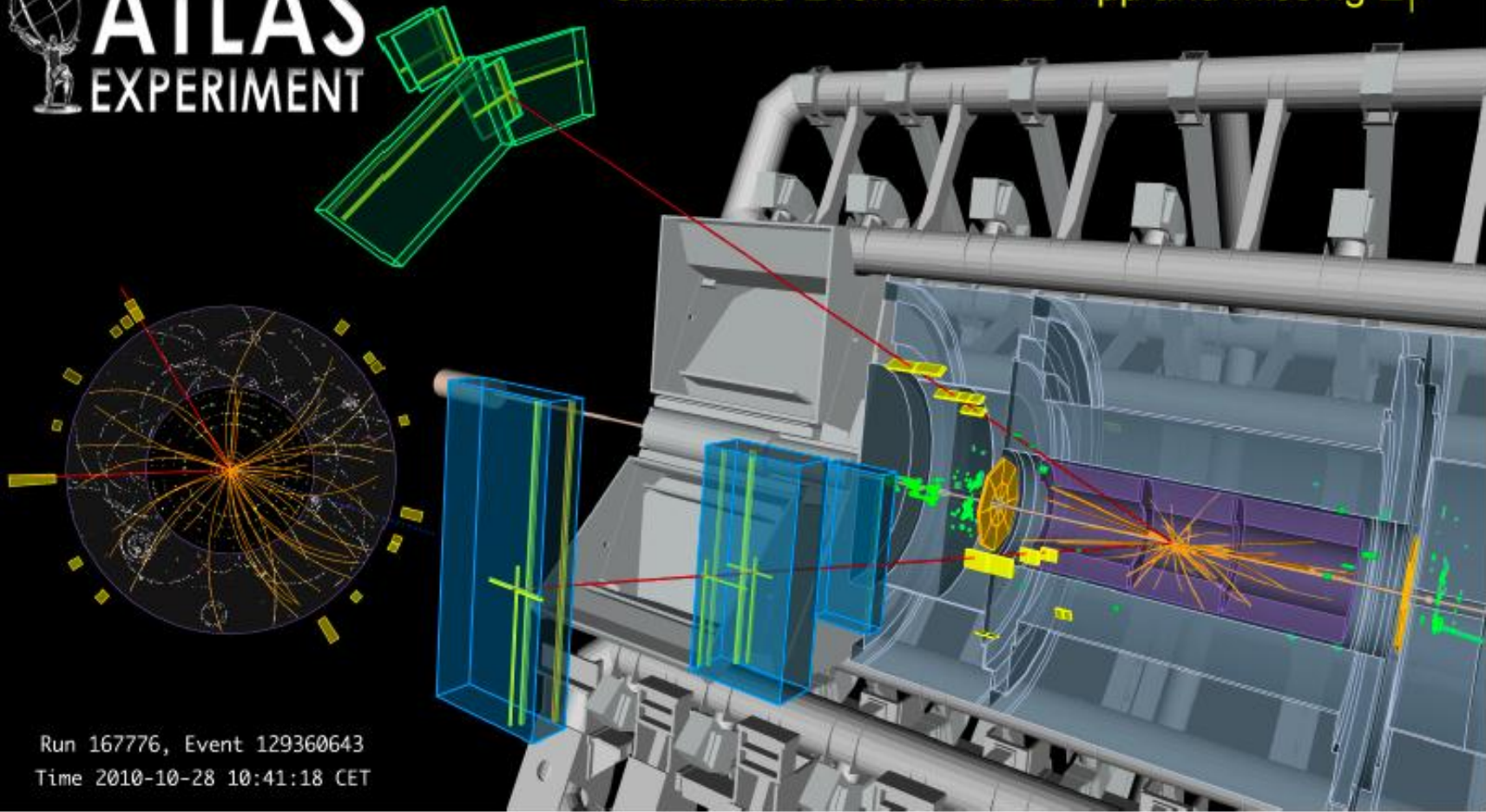


Interesting Events

$m_{\mu\mu}$ 94 GeV, $E_T^{\text{miss}} = 161$ GeV

 **ATLAS**
EXPERIMENT

Candidate Event with a $Z \rightarrow \mu\mu$ and missing E_T

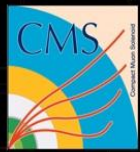


Run 167776, Event 129360643
Time 2010-10-28 10:41:18 CET

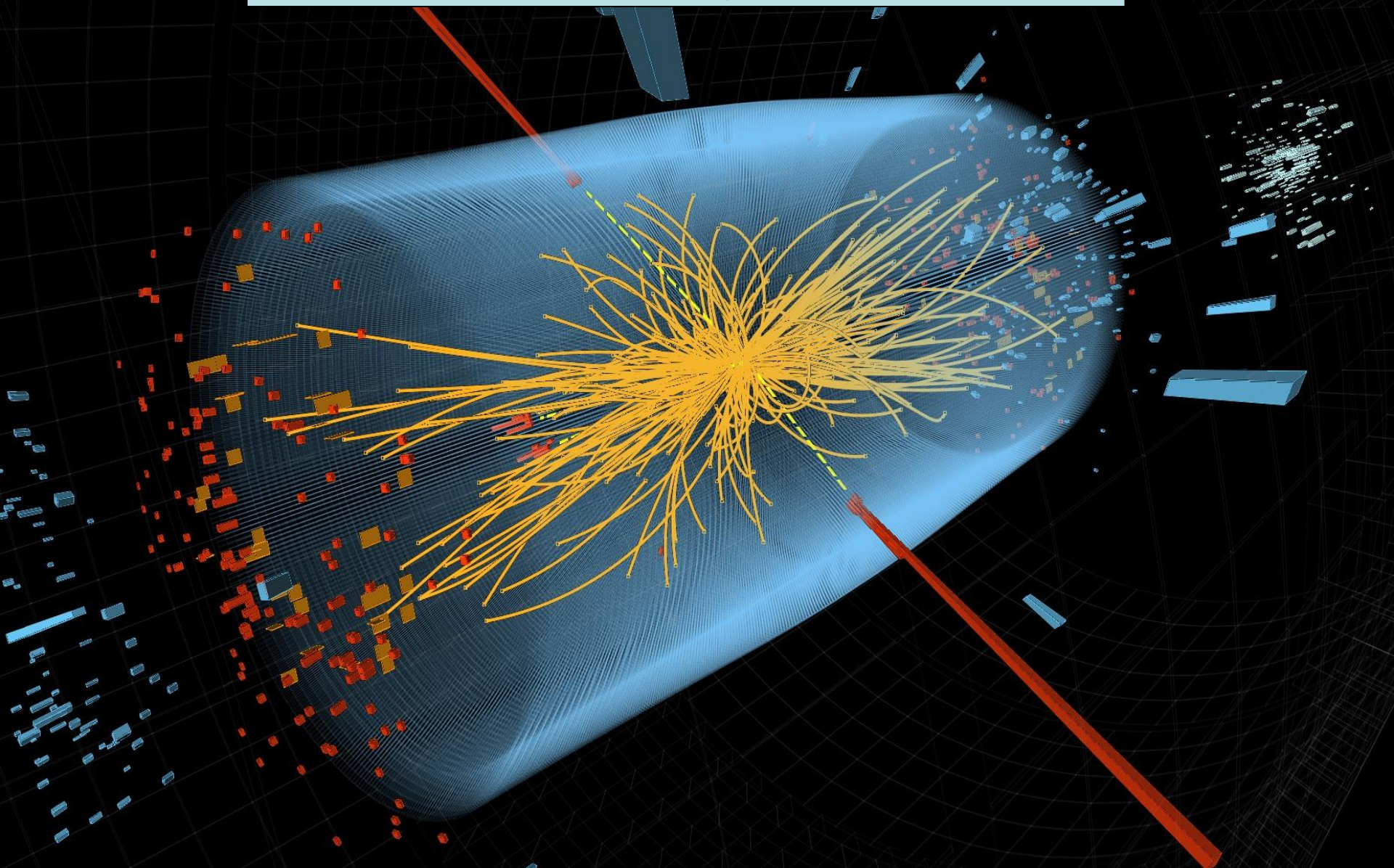
Is the Higgs Boson finally being Revealed?



Mass Higgsteria



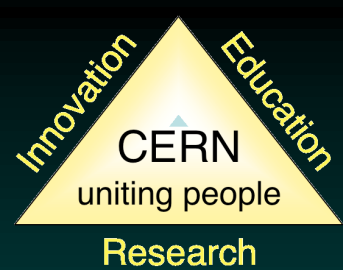
Interesting Events



SAY GOD PARTICLE



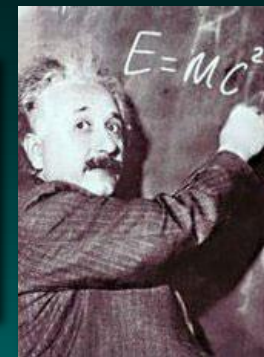
**ONE MORE
GODDAMN TIME**



The Mission of CERN

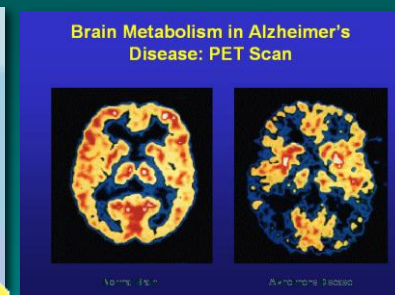
- **Push forward** the frontiers of knowledge

E.g. the secrets of the Big Bang... what matter like within the first moments of the Universe's existence



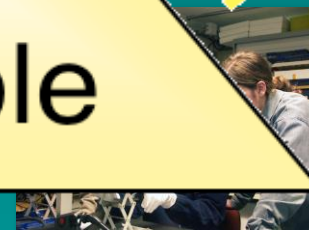
- **Develop** new technologies, accelerators and detectors

Information technology -
Medicine - diagnosis and treatment



- **Train** scientists of tomorrow

CERN
uniting people



- **Unite** people from different countries and cultures

Research



CERN: where the World-Wide Web was born

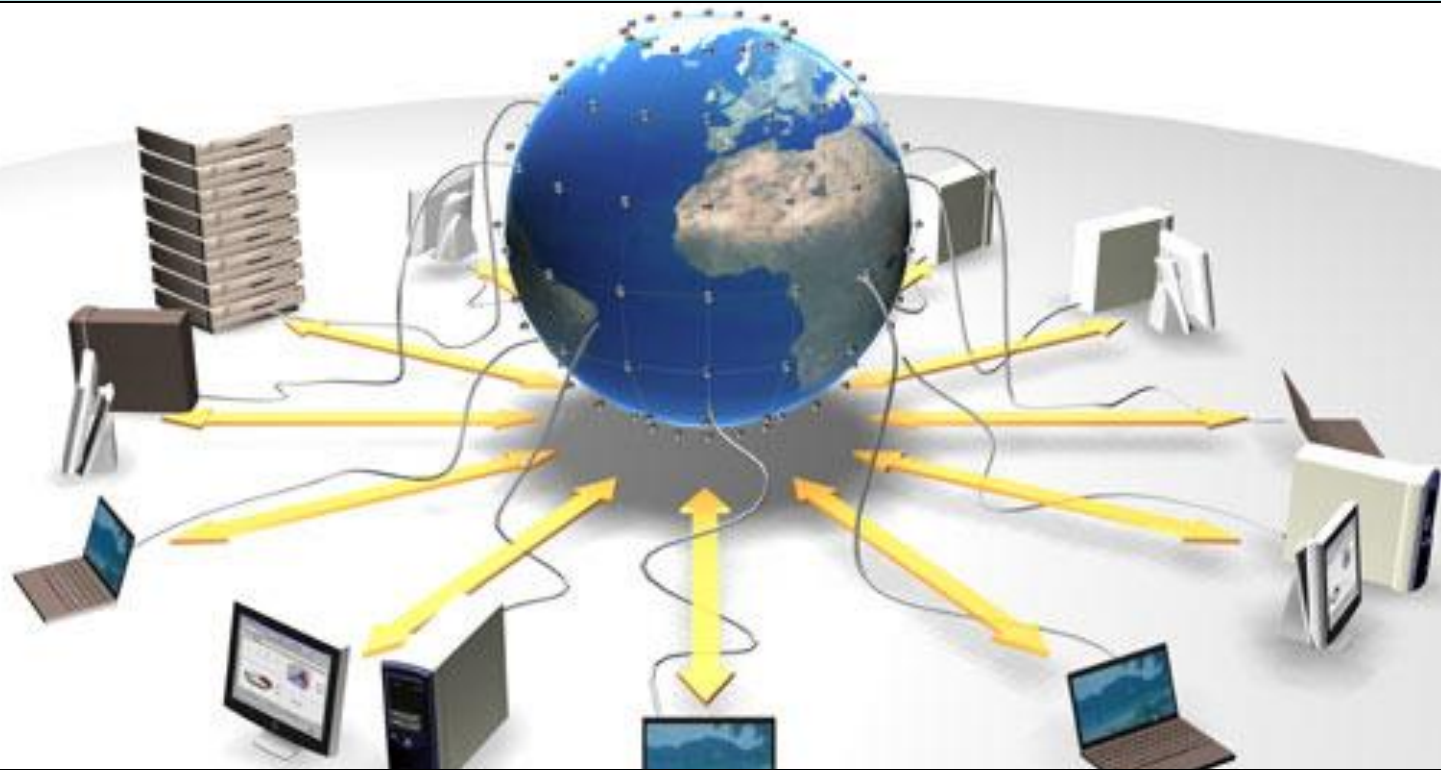


Tim Berners-Lee

invented to enable physicists around the world to collaborate

The first on-line community

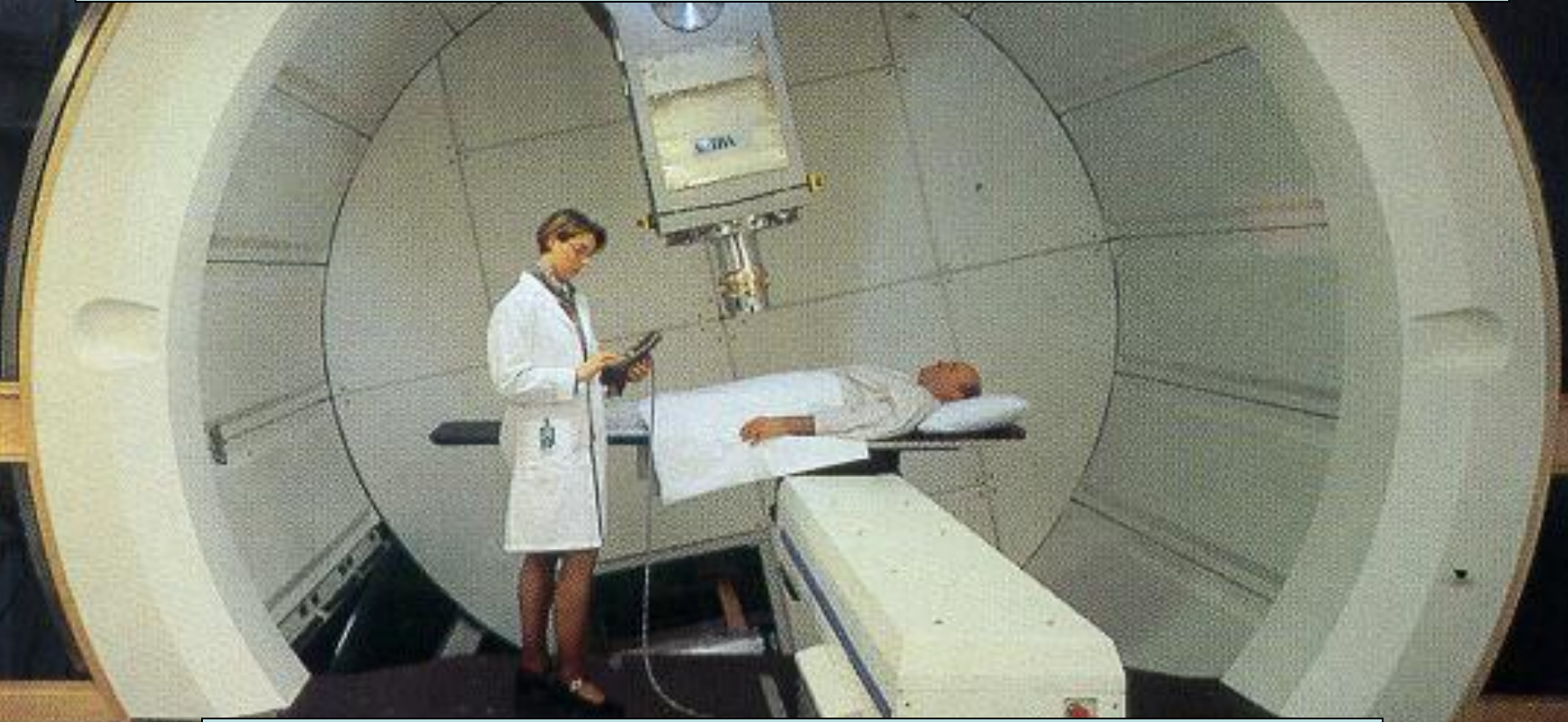
Largest Computer System in the World



200,000 computers all over the world
linked to analyse data from CERN

Grid is new advance in decentralised computing -
from laboratory that invented the World-Wide Web

Accelerators are Us

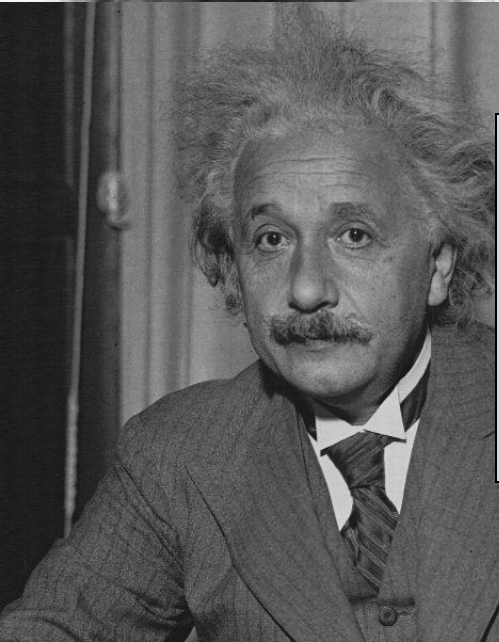


30000 accelerators in the World
Most are used for medicine
Particles for diagnosis, therapy

Innovation is based on Fundamental Science



Electricity
and
Magnetism

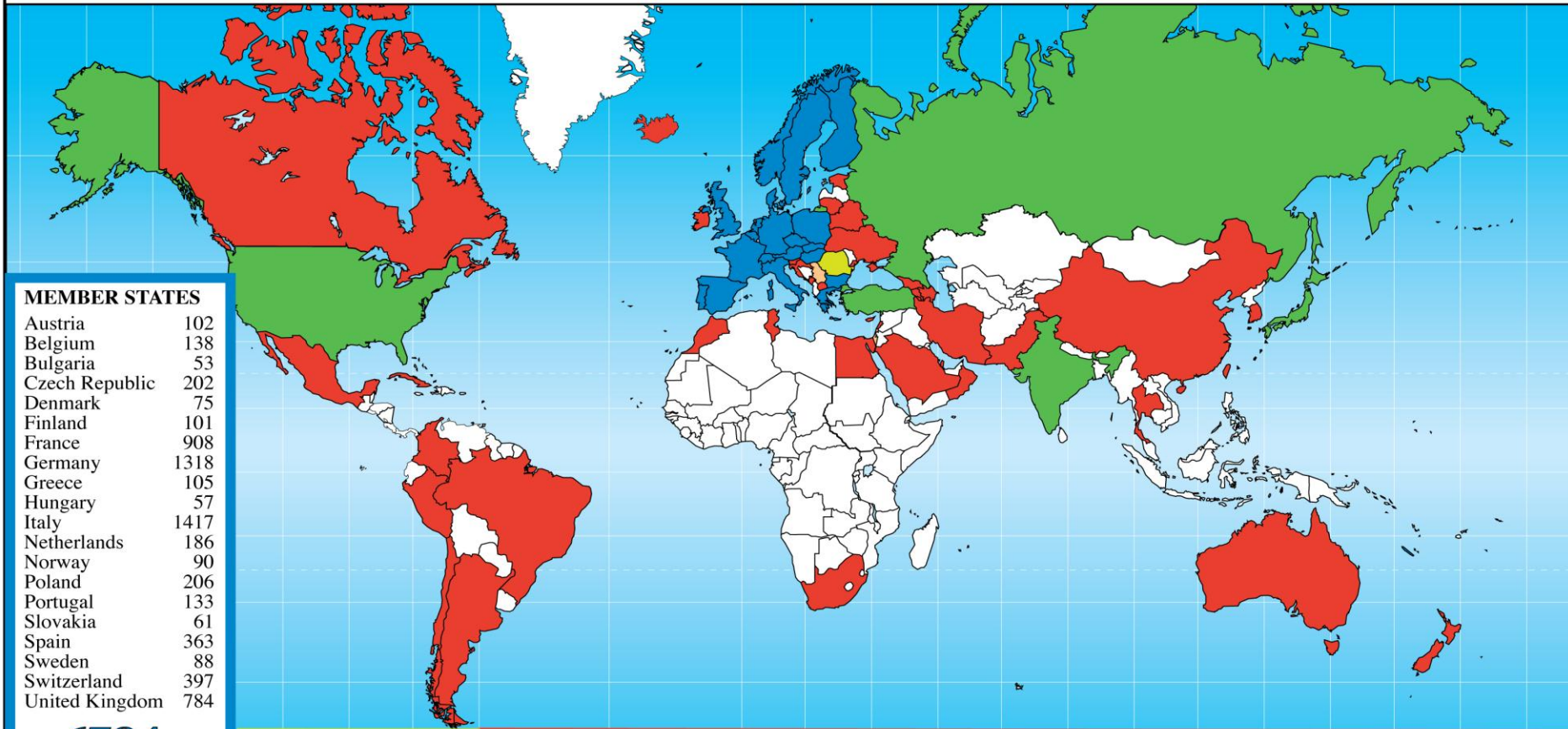


Theory
of
Relativity



Science is ever more global

Distribution of All CERN Users by Nation of Institute on 4 April 2012



MEMBER STATES

Austria	102
Belgium	138
Bulgaria	53
Czech Republic	202
Denmark	75
Finland	101
France	908
Germany	1318
Greece	105
Hungary	57
Italy	1417
Netherlands	186
Norway	90
Poland	206
Portugal	133
Slovakia	61
Spain	363
Sweden	88
Switzerland	397
United Kingdom	784

6784

OBSERVERS

India	134
Japan	225
Russia	859
Turkey	83
USA	1749

3050

CANDIDATE FOR ACCESSION

Romania	78
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ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Israel	67
Serbia	26

OTHERS

Argentina	18
Armenia	13
Australia	28
Azerbaijan	1
Belarus	22
Brazil	102
Canada	170
Chile	4

China	115
China (Taipei)	70
Colombia	10
Croatia	21
Cuba	4
Cyprus	9
Egypt	7
Estonia	17
Georgia	10
Iceland	3

Iran	16
Ireland	10
Korea	91
Lebanon	1
Lithuania	13
Malta	1
Mexico	43
Montenegro	1
Morocco	6
New Zealand	11

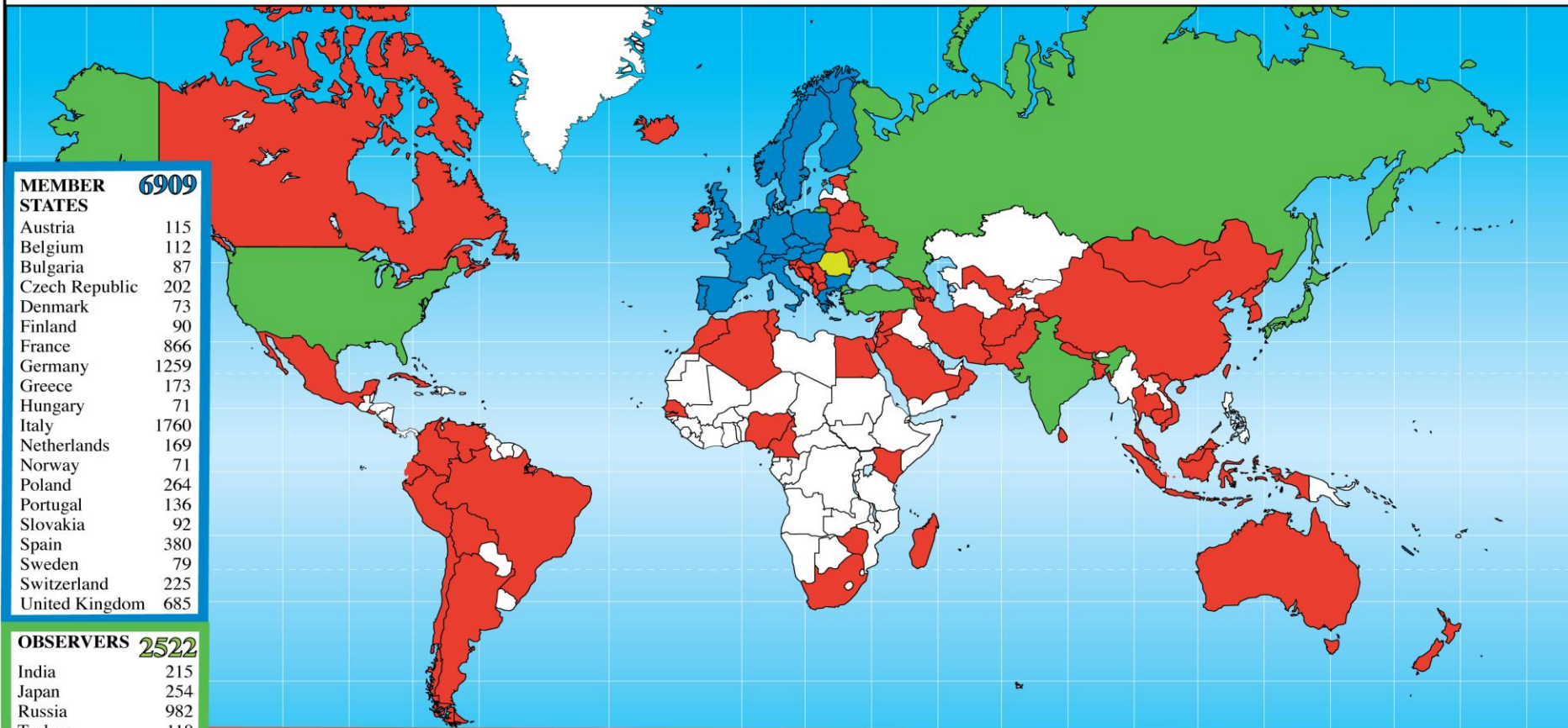
Oman	1
Pakistan	22
Peru	2
Qatar	1
Saudi Arabia	3
Slovenia	38
South Africa	21
Thailand	5
T.F.Y.R.O.M.	2
Tunisia	1

Ukraine	21
Uzbekistan	1

934

Science is ever more global

Distribution of All CERN Users by Nationality on 4 April 2012



MEMBER STATES 6909

Austria	115
Belgium	112
Bulgaria	87
Czech Republic	202
Denmark	73
Finland	90
France	866
Germany	1259
Greece	173
Hungary	71
Italy	1760
Netherlands	169
Norway	71
Poland	264
Portugal	136
Slovakia	92
Spain	380
Sweden	79
Switzerland	225
United Kingdom	685

OBSERVERS 2522

India	215
Japan	254
Russia	982
Turkey	110
USA	961

CANDIDATE FOR ACCESSION 117

Romania	117
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ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP

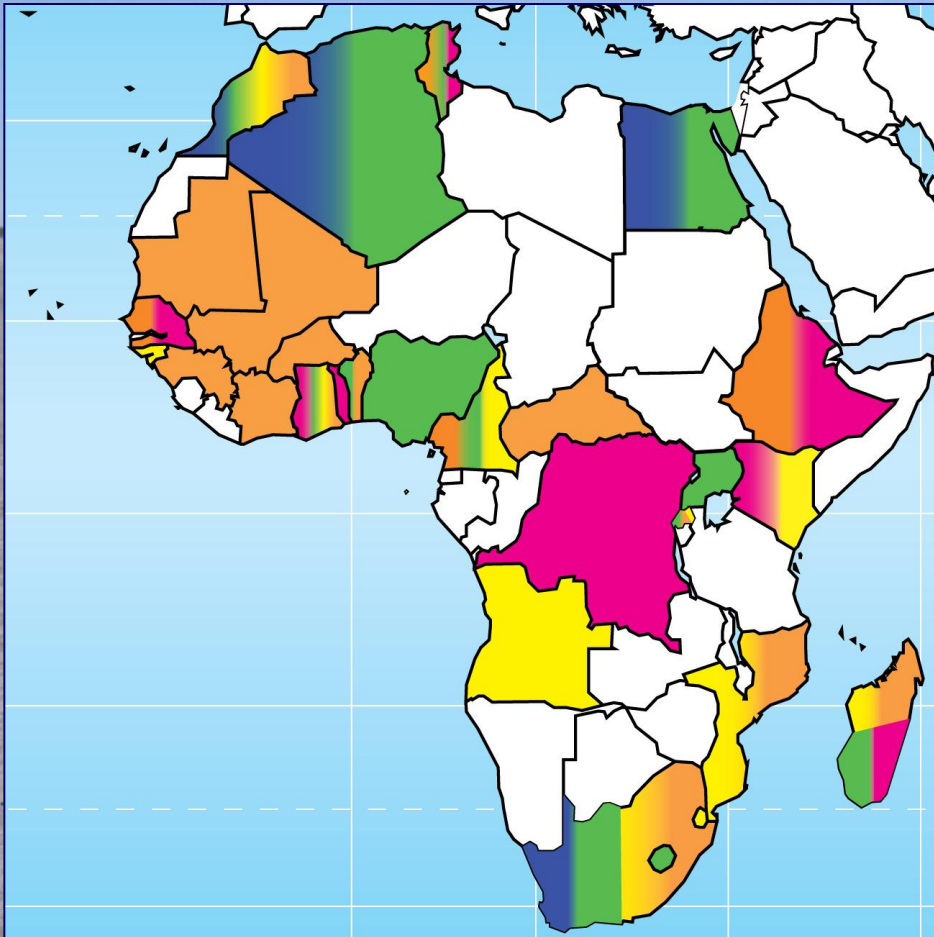
Israel	67
Serbia	39

OTHERS

Afghanistan	1	Bosnia & Herzegovina	2	Cuba	6	Ireland	23	Mexico	63	Peru	5	Tunisia	6
Albania	3	Brazil	98	Cyprus	14	Jordan	2	Moldova	1	Qatar	1	Ukraine	46
Algeria	11	Cambodia	1	Ecuador	2	Kenya	1	Mongolia	1	San Marino	1	Uzbekistan	2
Argentina	16	Cameroon	2	Egypt	9	Korea, D.P.R.	1	Montenegro	2	Saudi Arabia	3	Venezuela	10
Armenia	21	Canada	141	El Salvador	1	Korea Rep.	119	Morocco	13	Senegal	1	Viet Nam	10
Australia	23	Chile	6	Estonia	15	Lebanon	11	Nepal	3	Slovenia	43	Zimbabwe	2
Azerbaijan	6	China	270	Georgia	31	Lithuania	17	New Zealand	8	South Africa	16		
Bangladesh	2	China (Tapei)	48	Hong Kong	1	Luxembourg	3	Nigeria	1	Sri Lanka	6		
Belarus	41	Colombia	29	Iceland	4	Madagascar	3	Oman	1	Syria	1		
Bolivia	2	Costa Rica	2	Indonesia	2	Malaysia	7	Pakistan	44	Thailand	7		
		Croatia	30	Iran	21	Malta	2	Palestine (O.T.)	3	T.F.Y.R.O.M.	3		

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Africa – CERN Collaboration



- Governmental co-operation agreements
- Other scientific contacts
- IT contacts
- Summer students
- High-school teachers
- Digital libraries

Training & education agreements with **Mozambique, Rwanda**
Expressions of interest for participation of students in LHC
experiments by universities in **Madagascar, Ghana**

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



... and also a telescope

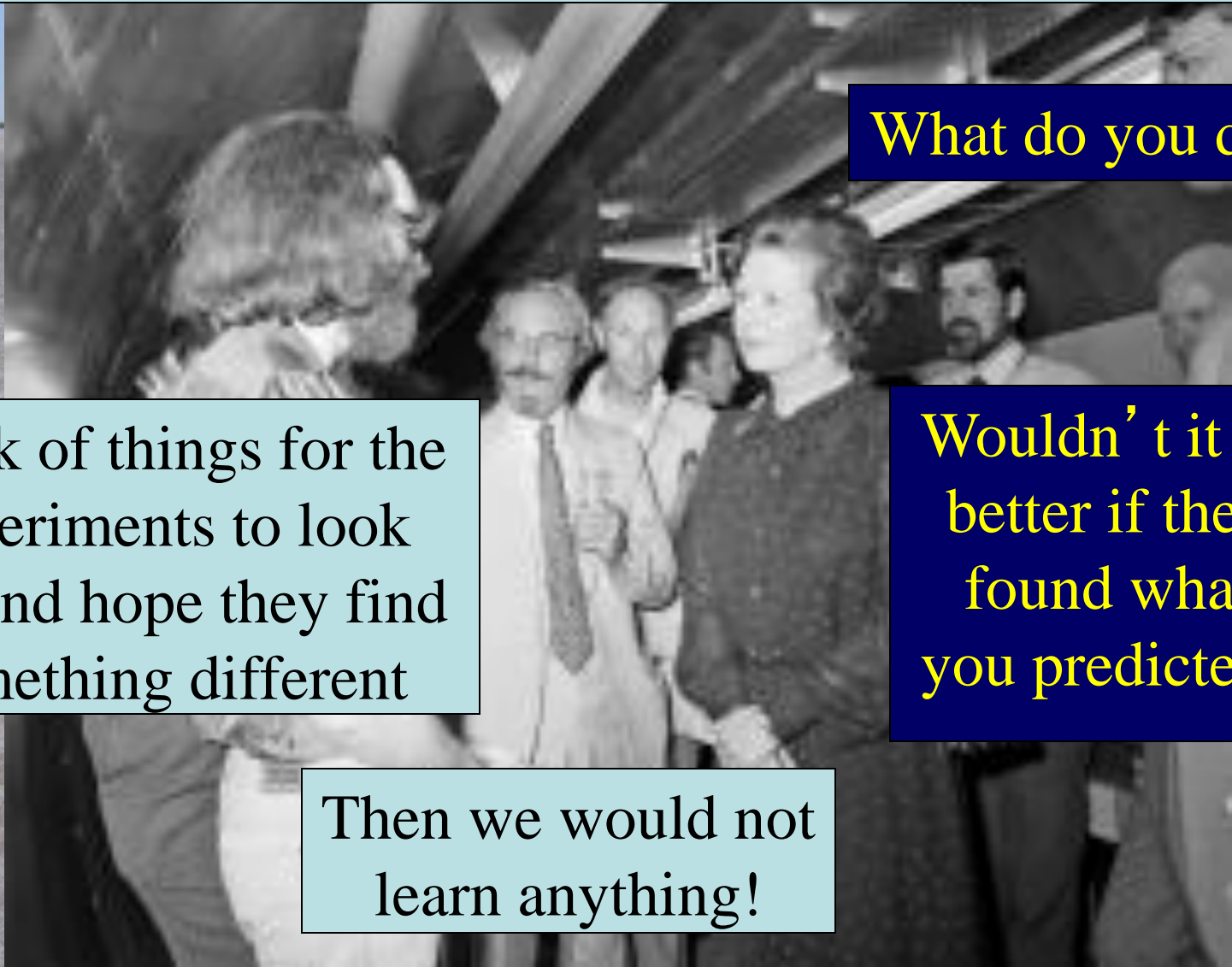
Conversation with Mrs Thatcher: 1982

What do you do?

Think of things for the experiments to look for, and hope they find something different

Wouldn't it be better if they found what you predicted?

Then we would not learn anything!



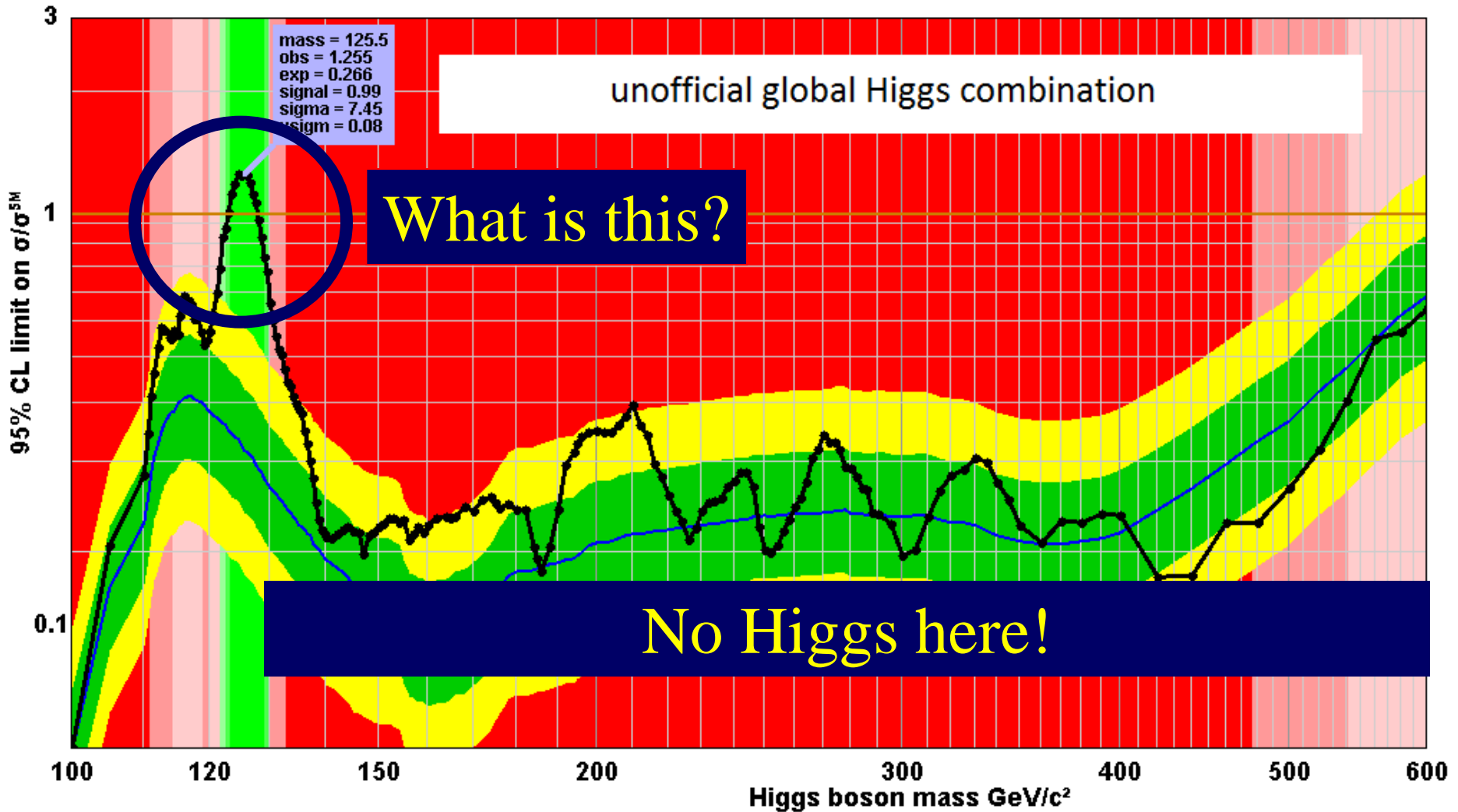
An aerial photograph of a rural landscape, likely in a valley, showing a patchwork of agricultural fields in various shades of brown and green. A large, bright yellow text "Thank you!" is superimposed in the center of the image. The text is bold and has a slight shadow. The background shows a mix of fields, some small clusters of buildings, and a road network. The overall scene is a typical rural landscape from a high-angle perspective.

Thank you!

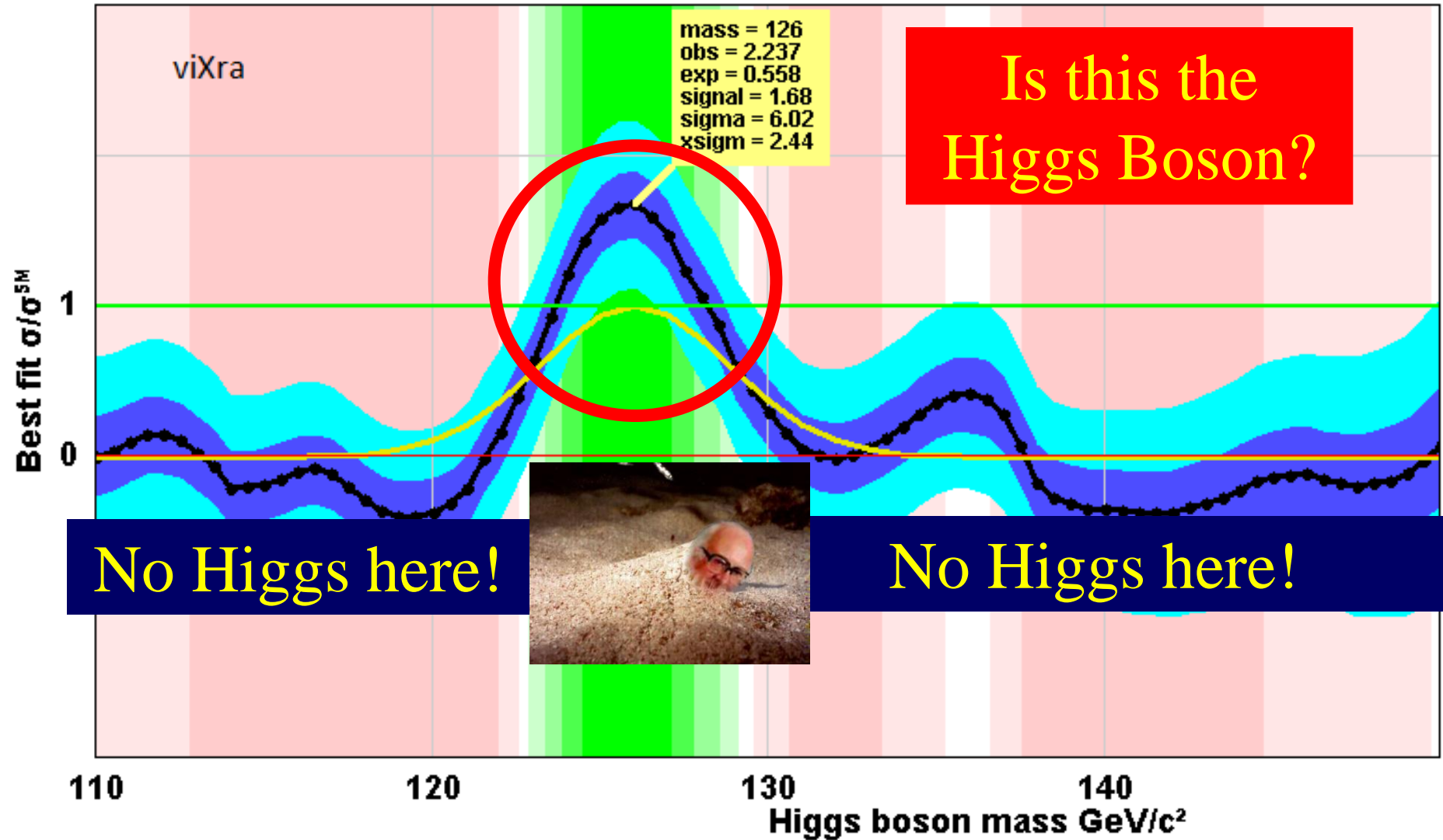
Unofficial Global Combination of July 4th Data

1/fb - 10/fb

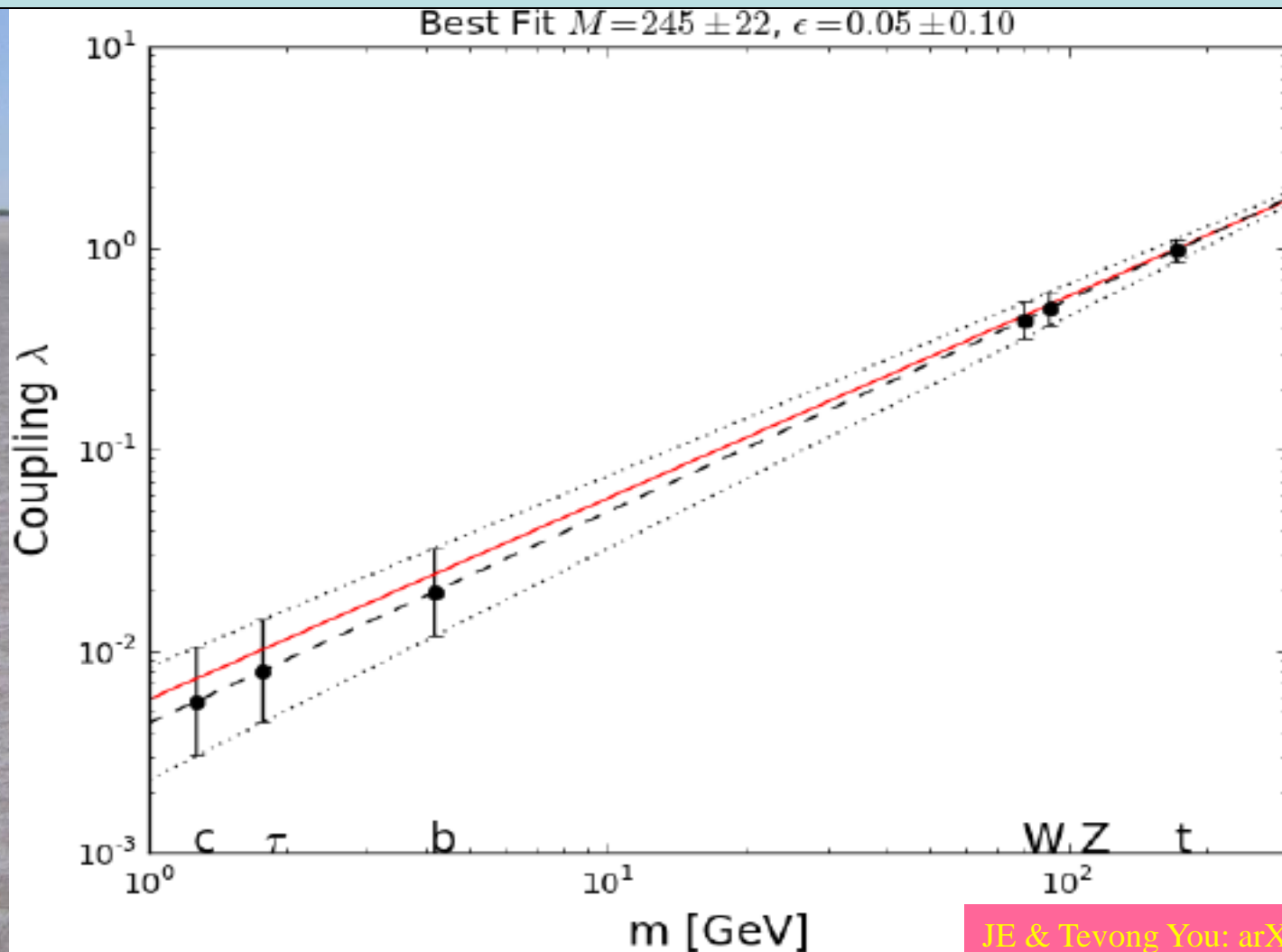
04/07/2012



Unofficial Combination of Higgs Search Data from July 4th



Couplings \sim Mass



JE & Tevong You: arXiv:1207.1693

Scale as expected for Higgs Boson

CERN's Education Activities

Scientists at CERN

Academic Training Programme



Young Researchers

CERN School of High Energy Physics
CERN School of Computing
CERN Accelerator School



Physics Students

Summer Students
Programme

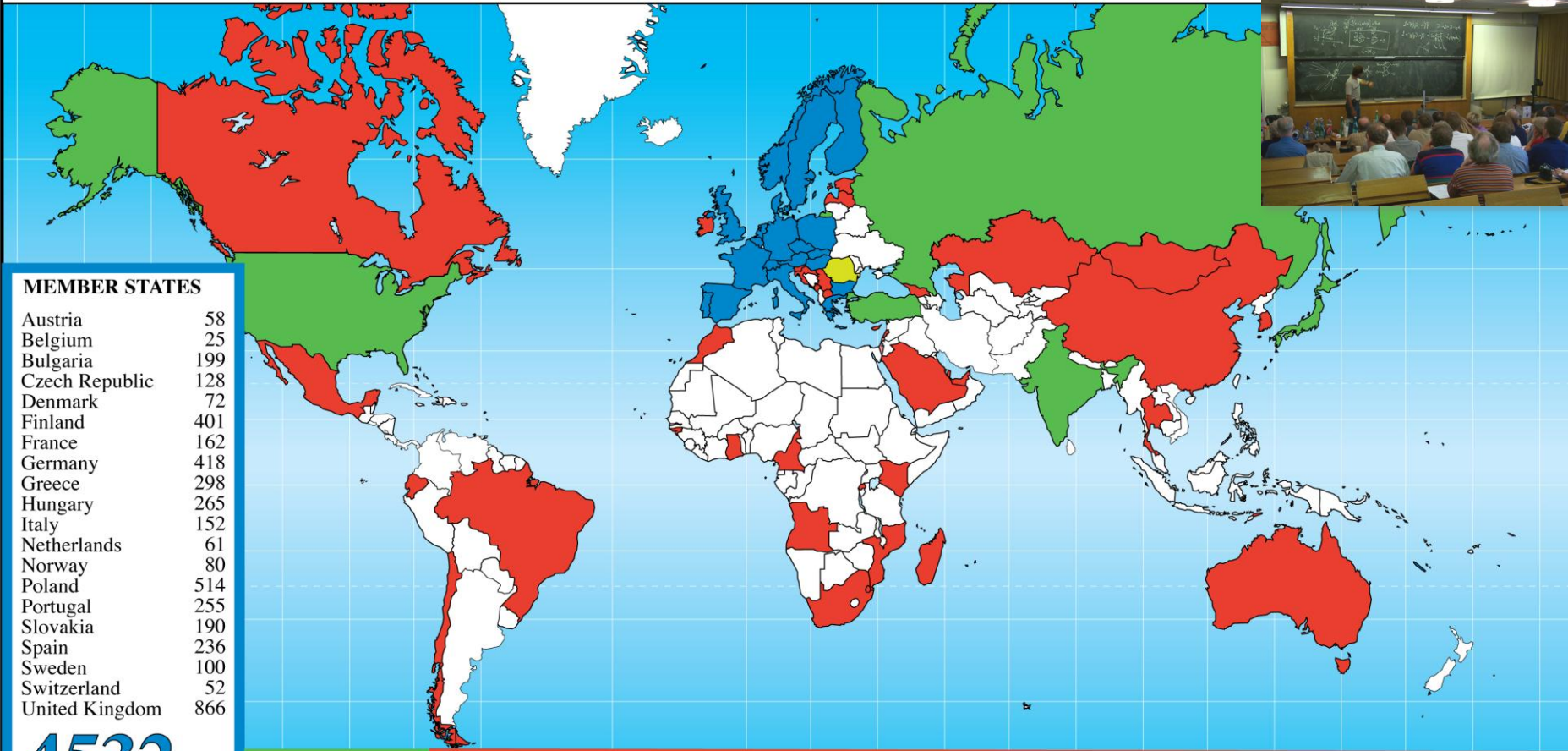


CERN Teacher Schools

International and National Programmes



CERN Teacher Programme: 1998 – 2011



MEMBER STATES

Austria	58
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Denmark	72
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Germany	418
Greece	298
Hungary	265
Italy	152
Netherlands	61
Norway	80
Poland	514
Portugal	255
Slovakia	190
Spain	236
Sweden	100
Switzerland	52
United Kingdom	866

4532

CANDIDATE FOR ACCESSION

Romania	10
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ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Israel	2
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OBSERVER STATES

India	2
Japan	3
Russia	132
Turkey	3
USA	56

196

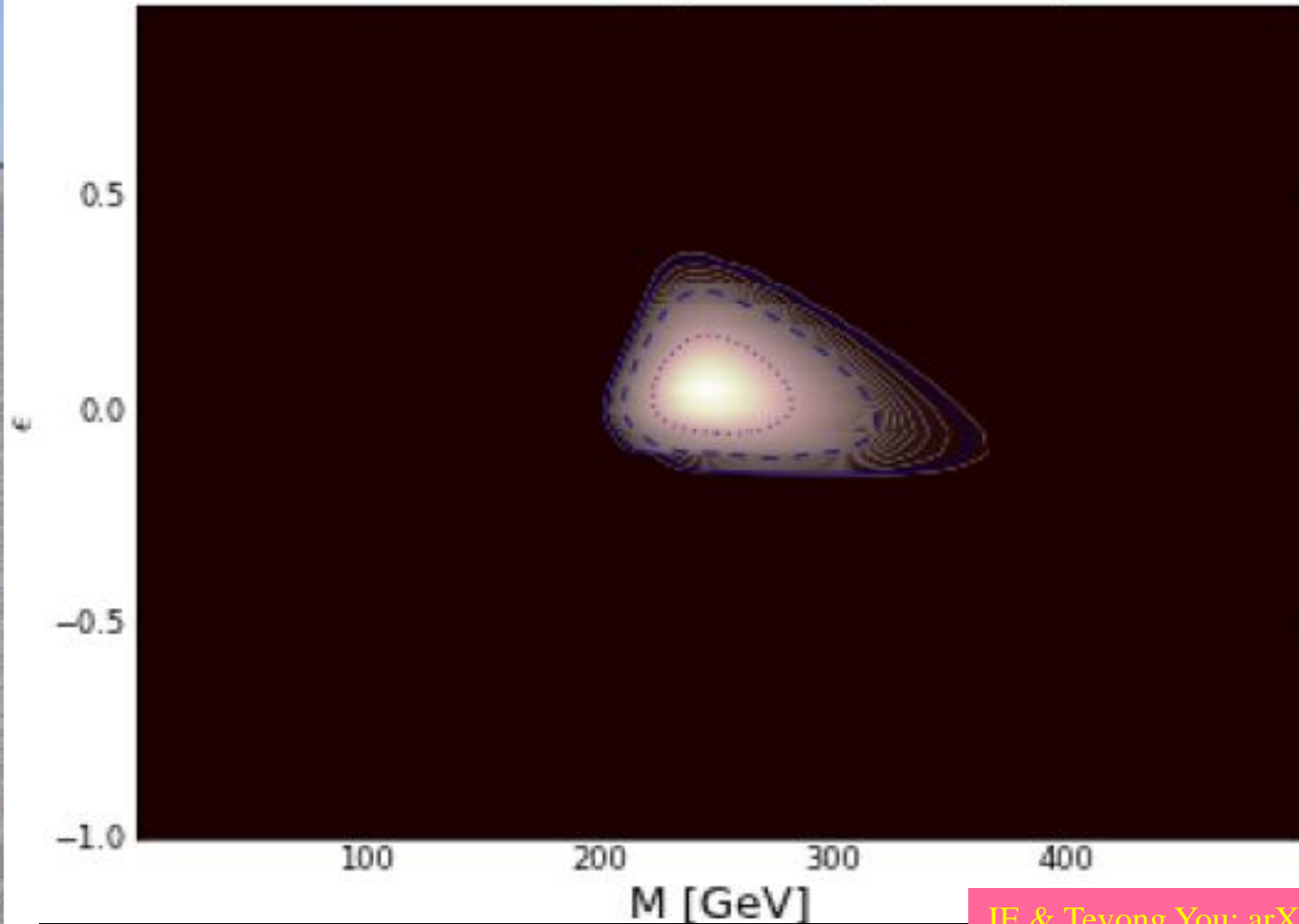
OTHERS

Angola	4	China	1	Kenya	2	Qatar	1	Thailand	4
Australia	3	Croatia	1	Latvia	1	Rwanda	15	T.F.Y.R.O.M.	11
Azerbaijan	1	Cyprus	4	Lebanon	1	Sao Tome	2	Timor-Leste	1
Brazil	53	Ecuador	1	Madagascar	1	Saudi Arabia	1	Ukraine	30
Cameroon	1	Estonia	18	Malta	36	Serbia	10	U.A.E.	1
Canada	1	Georgia	16	Mexico	5	Singapore	2		
Cape Verde	2	Ghana	4	Mongolia	1	Slovenia	21		
Chile	3	Guinea Bissau	1	Montenegro	13	South Africa	6		
		Ireland	3	Morocco	2	South Korea	22		
		Kazakhstan	3	Mozambique	13	Swaziland	1		

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Couplings \sim Mass

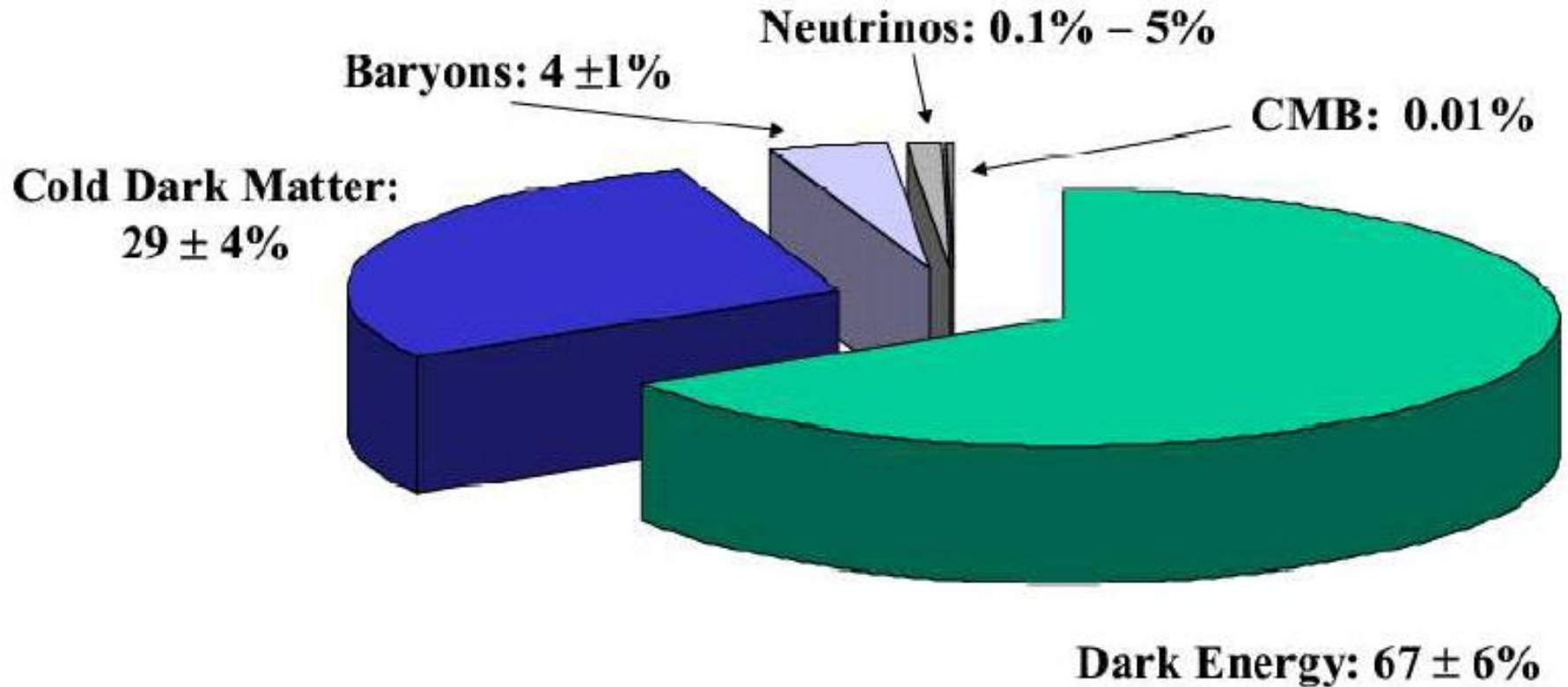
GLOBAL Coupling-Mass Proportionality



JE & Tevong You: arXiv:1207.1693

Scale as expected for Higgs Boson

Strange Recipe for a Universe



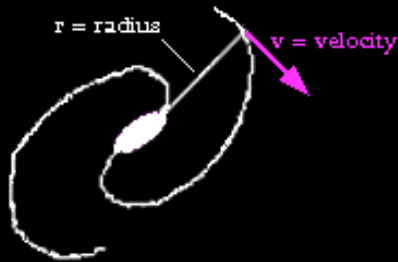
The 'Standard Model' of the Universe indicated by astrophysics and cosmology

Evidence for Dark Matter

Galaxies rotate more rapidly than allowed by centripetal force due to visible matter

X-ray emitting gas held in place by extra dark matter

Even a 'dark galaxy' without stars



Gravity = Centripetal Acceleration

$$\frac{GM}{r^2} = \frac{v^2}{r}$$



How to Create the Matter in the Universe?

Sakharov

- Need a difference between matter and antimatter
observed in the laboratory
- Need interactions able to create matter
present in unified theories
not yet seen by experiment
- Must break thermal equilibrium
Possible in the decays of heavy
particles



Will we be able to calculate using laboratory data?