

Answering Gauguin's Questions about the Universe



*International
High-School
Teachers
2024*

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

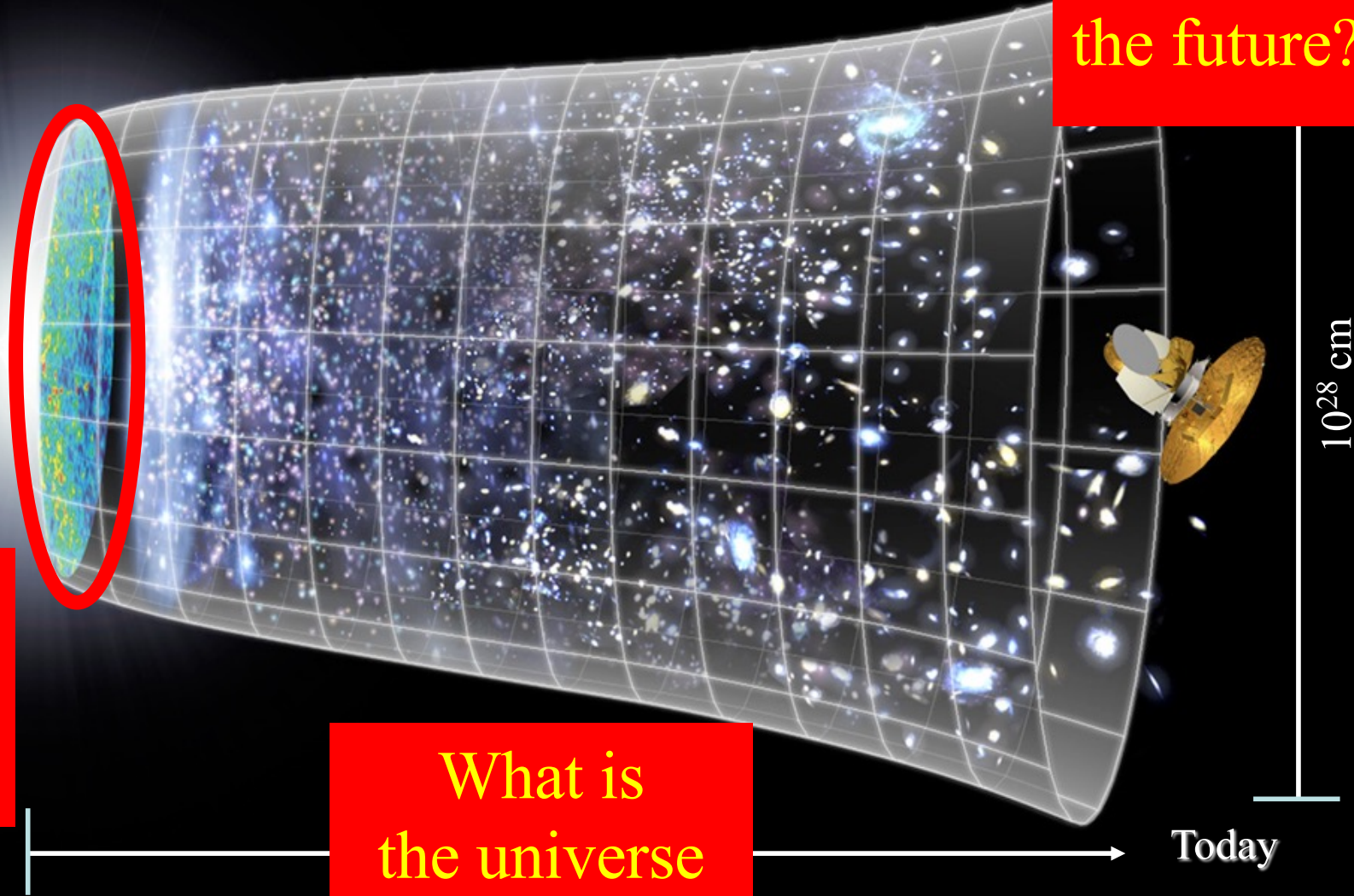
John Ellis

KING'S
College
LONDON

Evolution of the Universe

What will happen in the future?

Big Bang

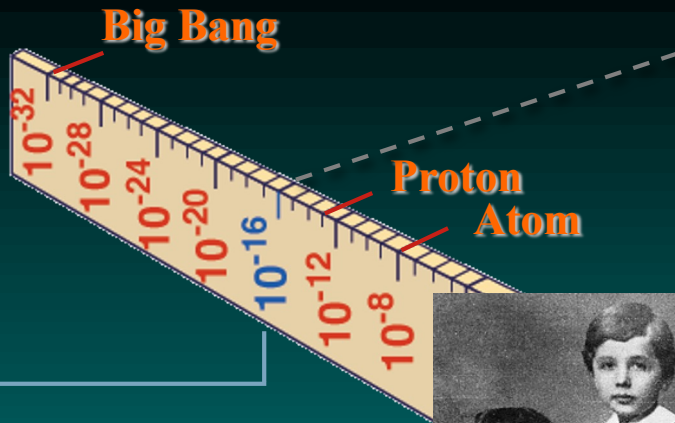


What happened then?

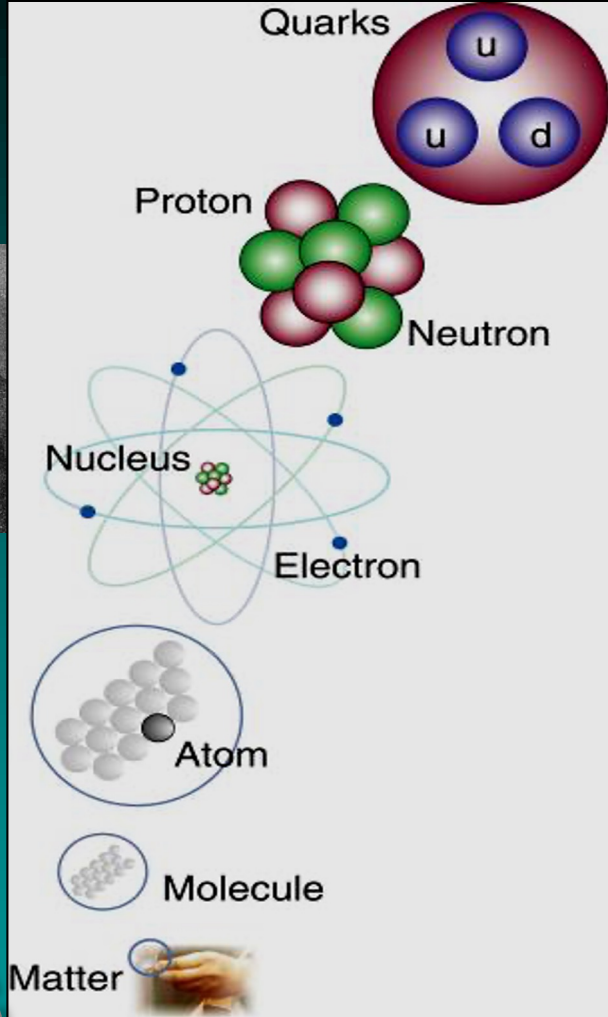
What is the universe made of?

Today

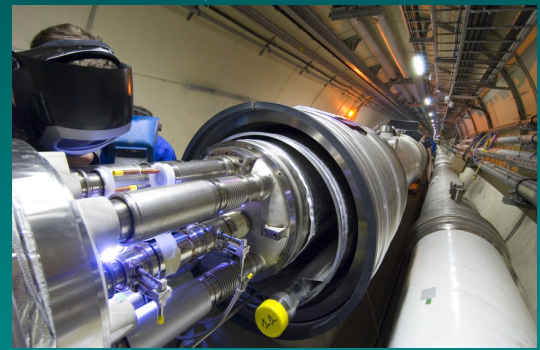
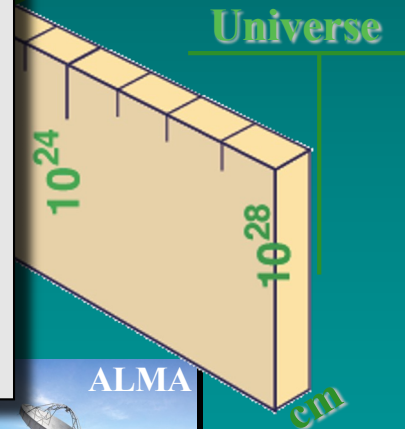
10^{28} cm



Dark matter!



Radius of Galaxies



LHC

Super-Microscope



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



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

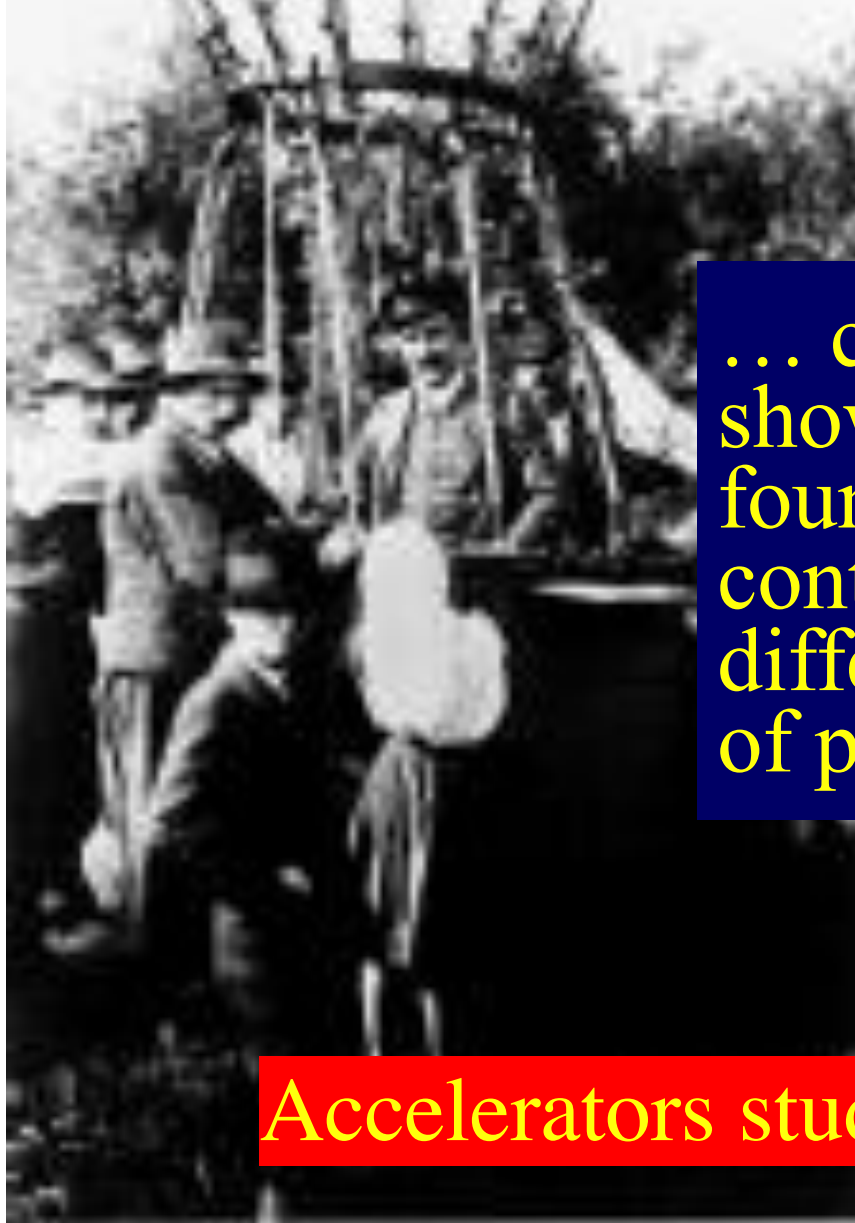
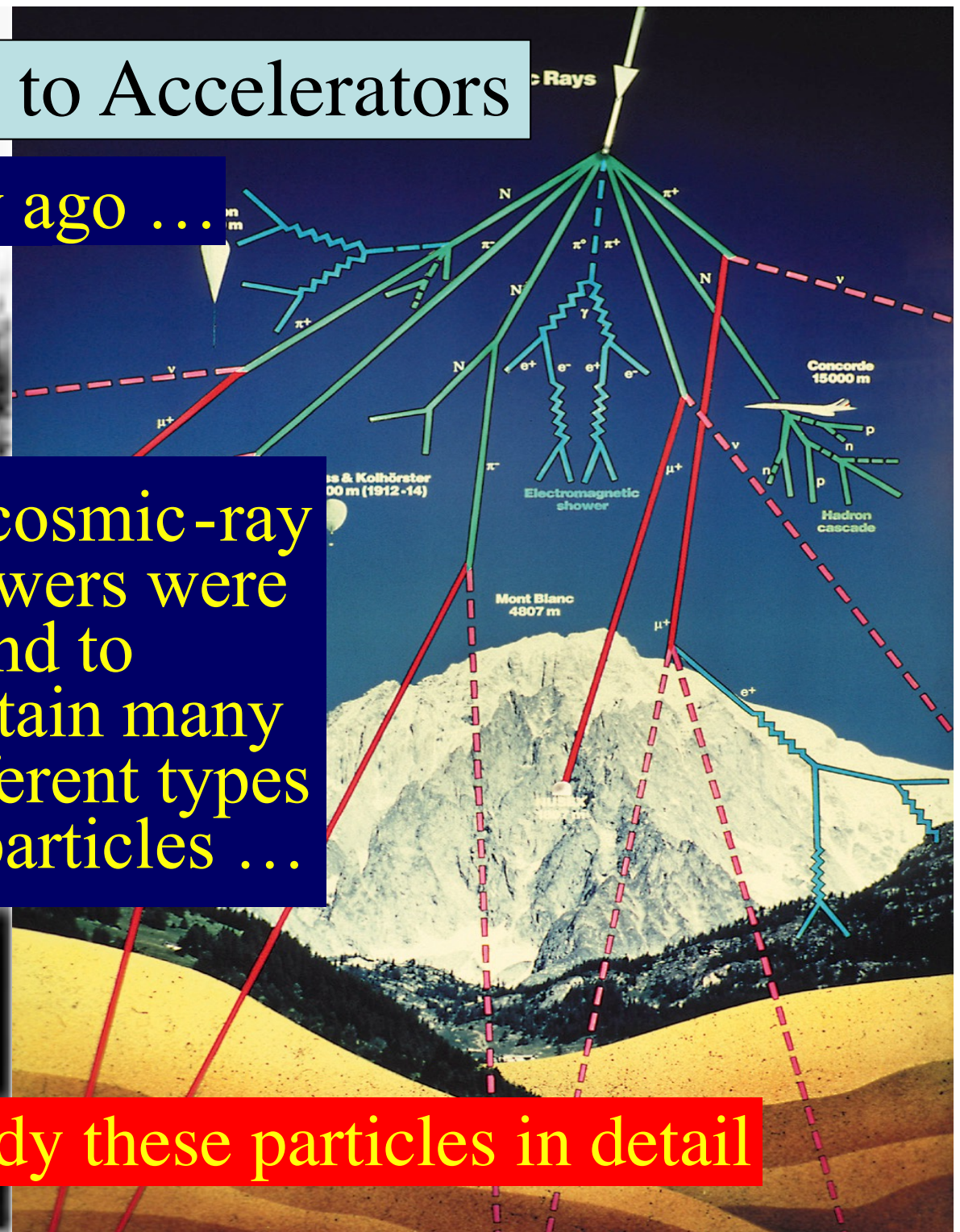
Need physics beyond what we know

From Cosmic Rays to Accelerators

Discovered a century ago ...

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

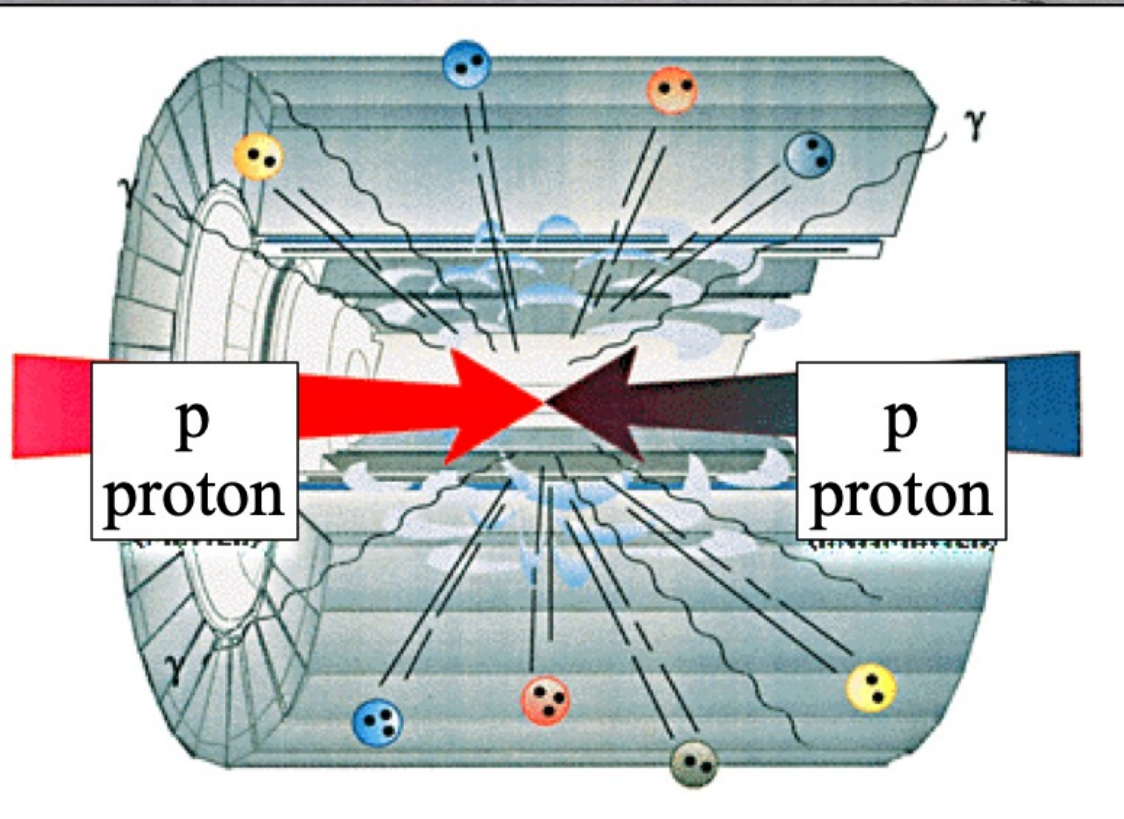
Accelerators study these particles in detail



Experiments with Accelerators

In order to study particles, we need super-microscopes using high energies to probe small distances:

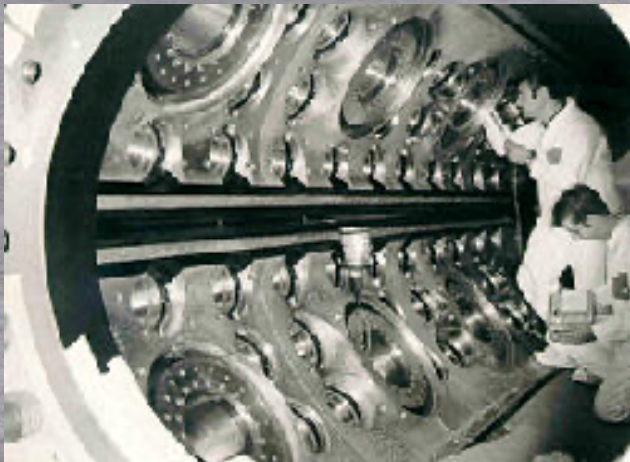
Particle Colliders



Collisions reproduce the conditions at beginning of Big Bang

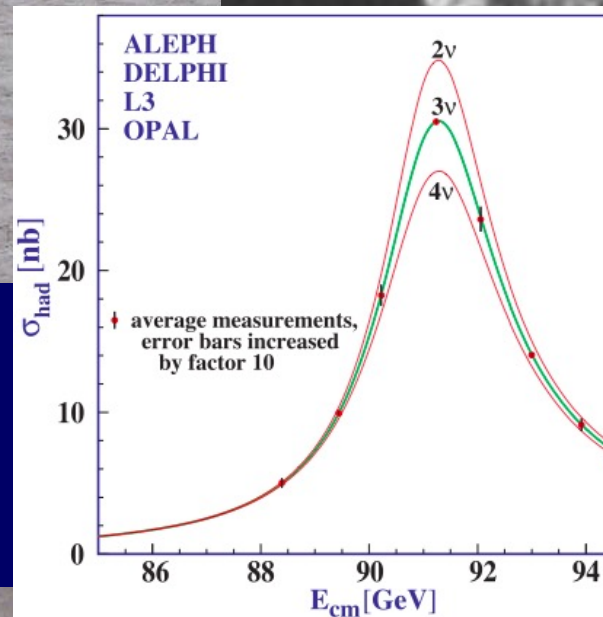
The 'Standard Model' of Particle Physics

Proposed by Abdus Salam,
Glashow and Weinberg



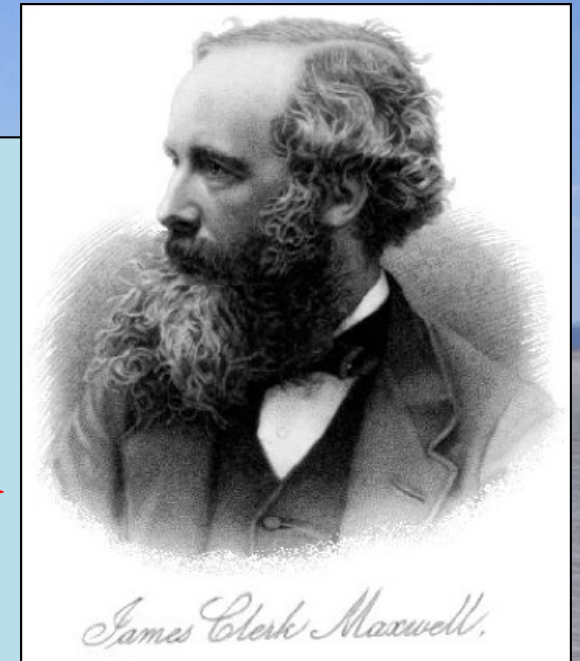
Tested by experiments
at CERN

Perfect agreement between
theory and experiments
in all laboratories



Electromagnetic Interactions

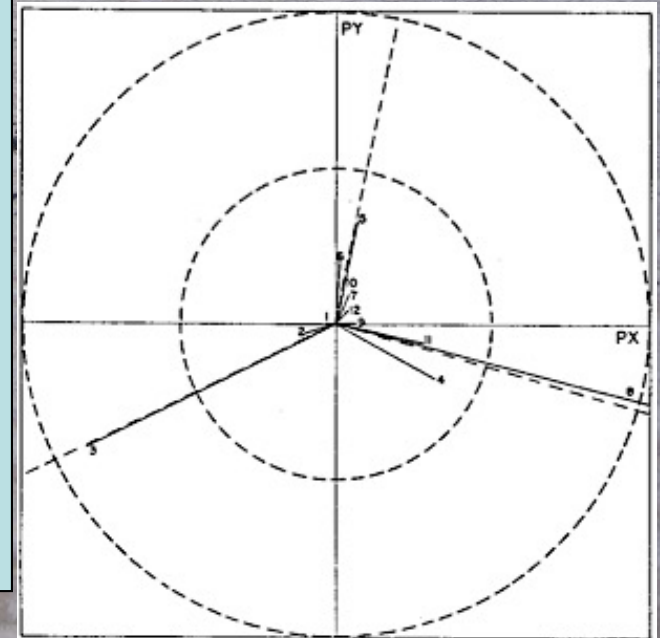
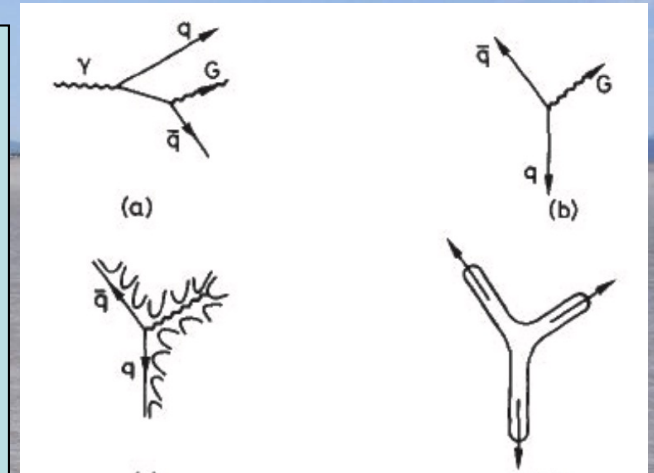
- James Clerk Maxwell
- Professor at King's 1860 – 1865
- **Unified theory of electricity and magnetism**
- Predicted electromagnetic waves
- Identified light as due to these waves
- Calculated the velocity of light
- ...



One scientific epoch ended and another began with James Clerk Maxwell - *Albert Einstein*

Strong Nuclear Interactions

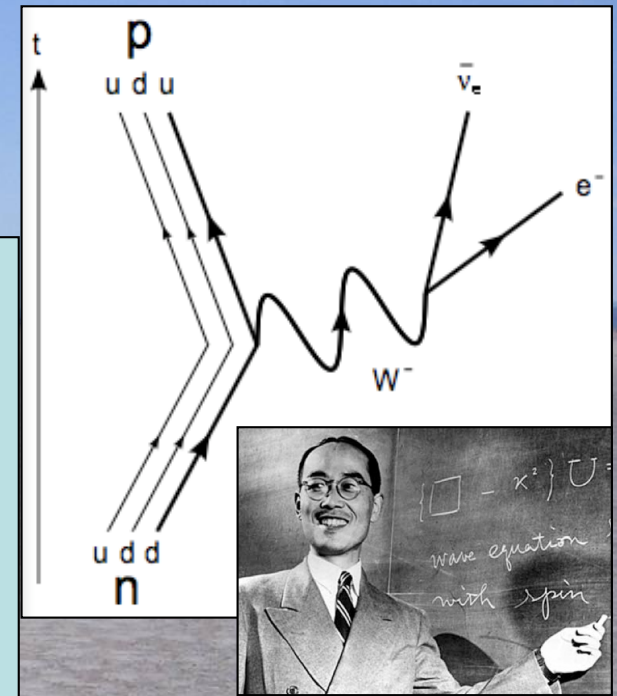
- Theory modelled after Maxwell
- Carried by massless ‘gluons’, analogues of photon
- In 1976 JE, Mary Gaillard, Graham Ross suggested discovery method in 3-jet events
- Radiation of gluon by quark
- Discovered at DESY laboratory in Hamburg in 1979
- **Second force particle discovered**



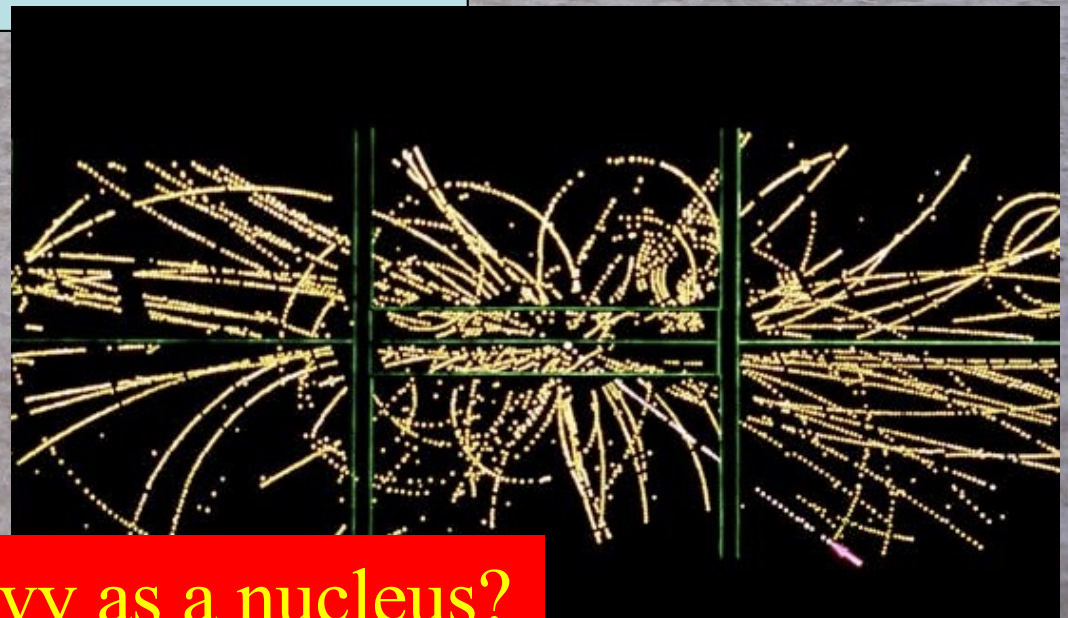
Weak Interactions

Radioactivity due to weak interactions
(β decay)

W boson - carrier of weak interaction
postulated by Yukawa



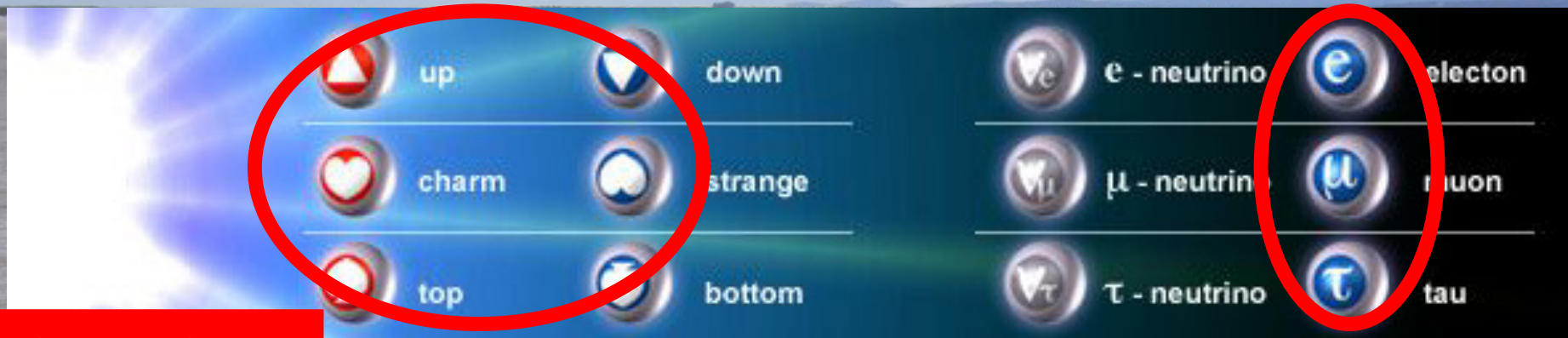
Discovered at CERN in
1983 by Carlo Rubbia et al



Why is it as heavy as a nucleus?

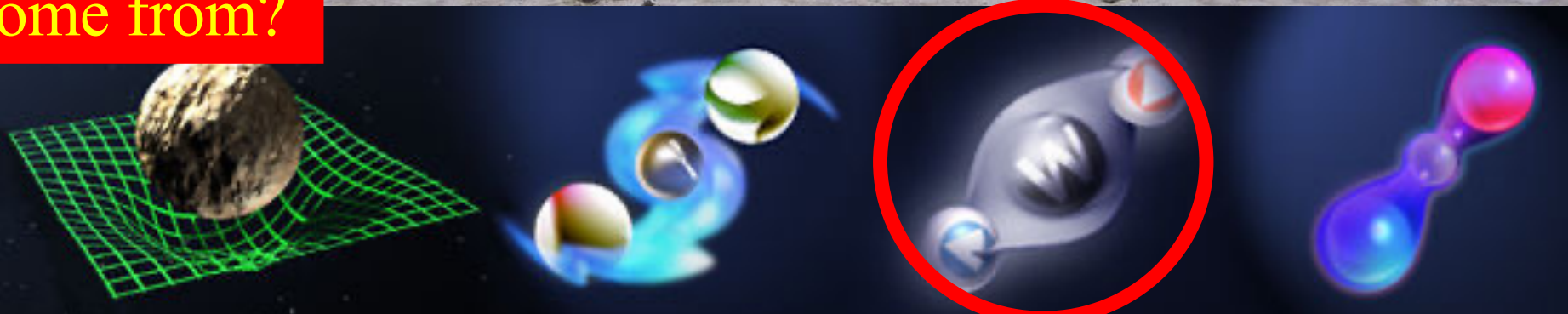
The 'Standard Model'

The matter particles



Where does mass come from?

The fundamental interactions



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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LONDON

Think of a Snowfield



Skier moves fast:
Like particle without mass
e.g., photon = particle of light



Snowshoer sinks into snow,
moves slower:

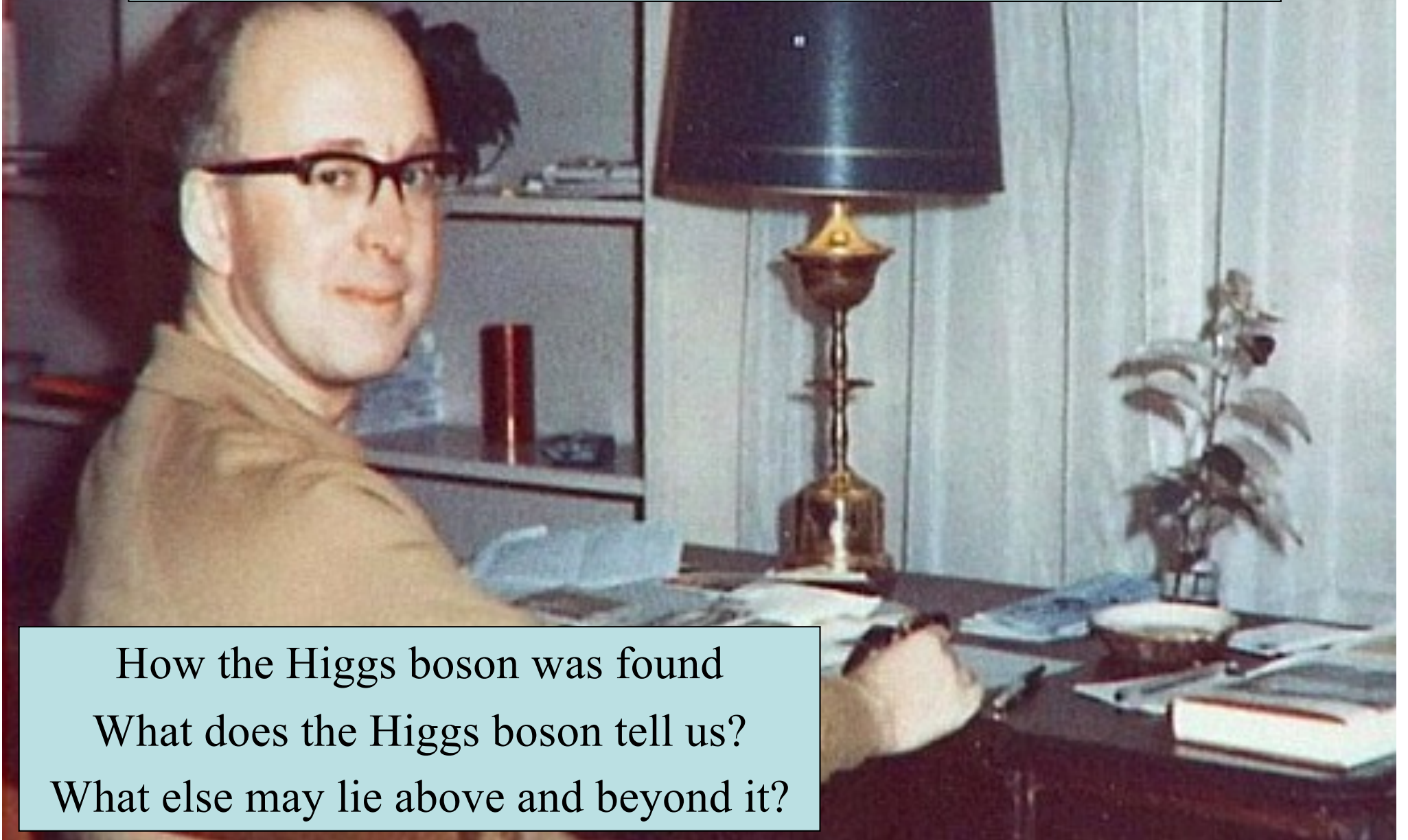
Like particle with mass
e.g., electron

**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?

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.

An aerial photograph of the CERN facility in Switzerland, showing a vast landscape of agricultural fields and some industrial buildings. Overlaid on the image are two large, white, circular lines representing the paths of the Large Hadron Collider. The larger circle is the main ring, and a smaller one is nested inside it. The text 'To answer Gauguin's questions:' is written in a black serif font on a light blue rectangular background at the top of the image.

To answer Gauguin's questions:

The Large Hadron Collider at CERN

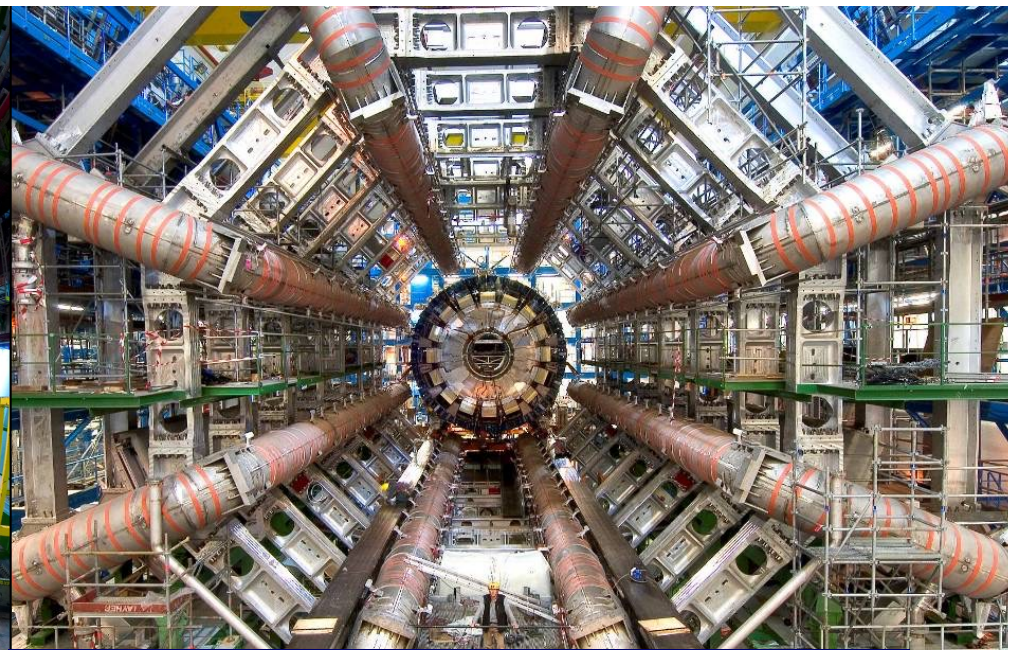
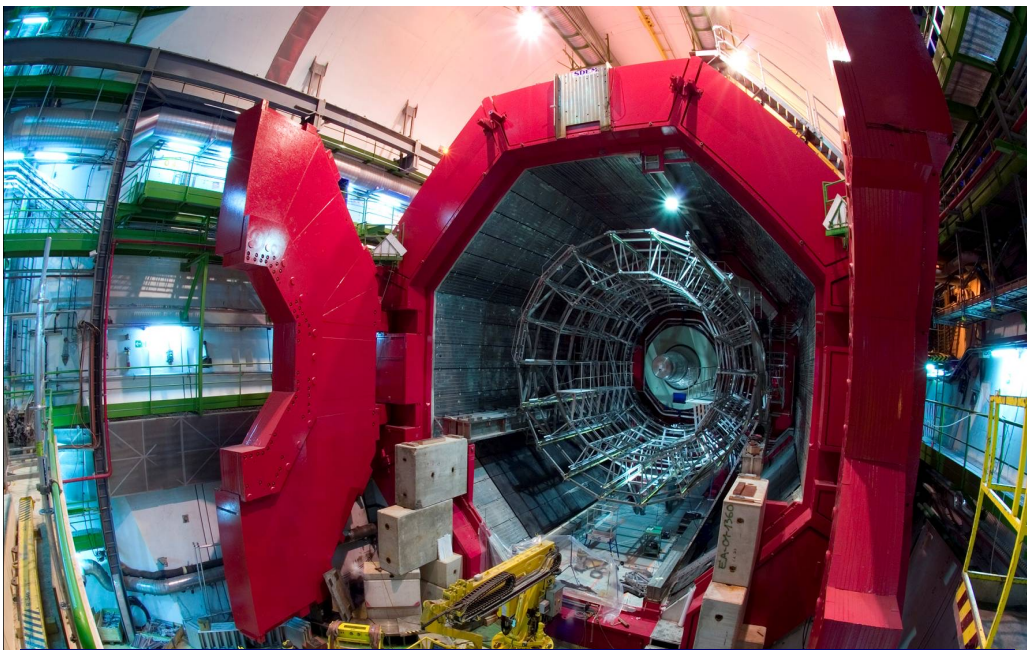
The Large Hadron Collider (LHC)

The image shows the interior of the Large Hadron Collider (LHC) tunnel. The perspective is from a low angle, looking down a long, curved tunnel. On the right side, a series of large, blue, cylindrical superconducting magnets are mounted on a track, receding into the distance. The tunnel walls are metallic and have various pipes and cables attached. The lighting is dim, with some blue lights visible on the ceiling and some warmer lights further down the tunnel.

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

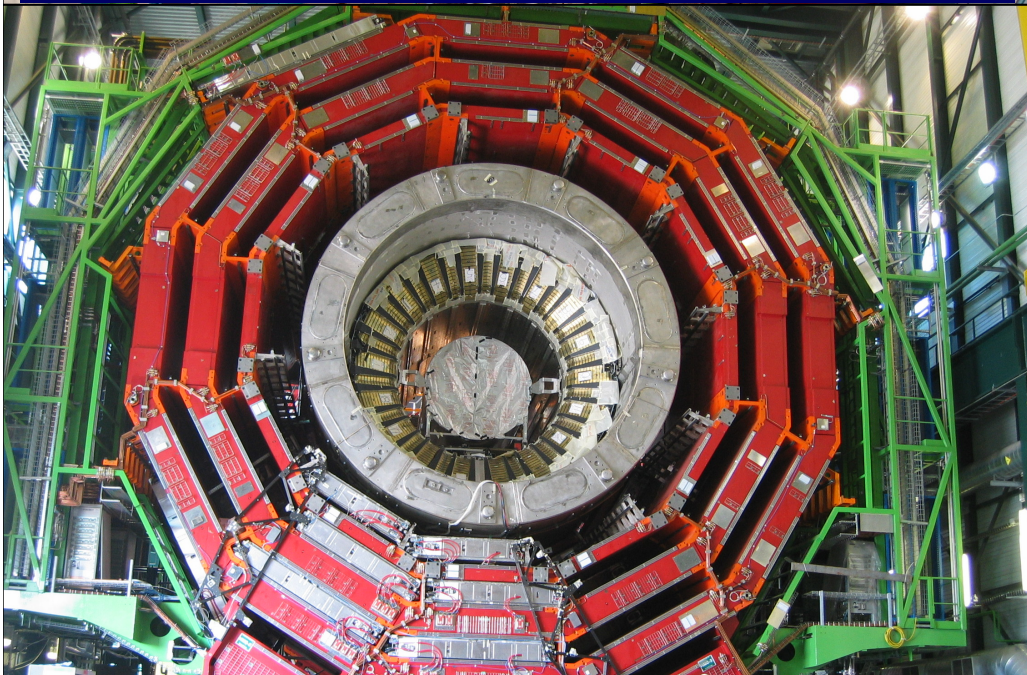
Primary targets:

- 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

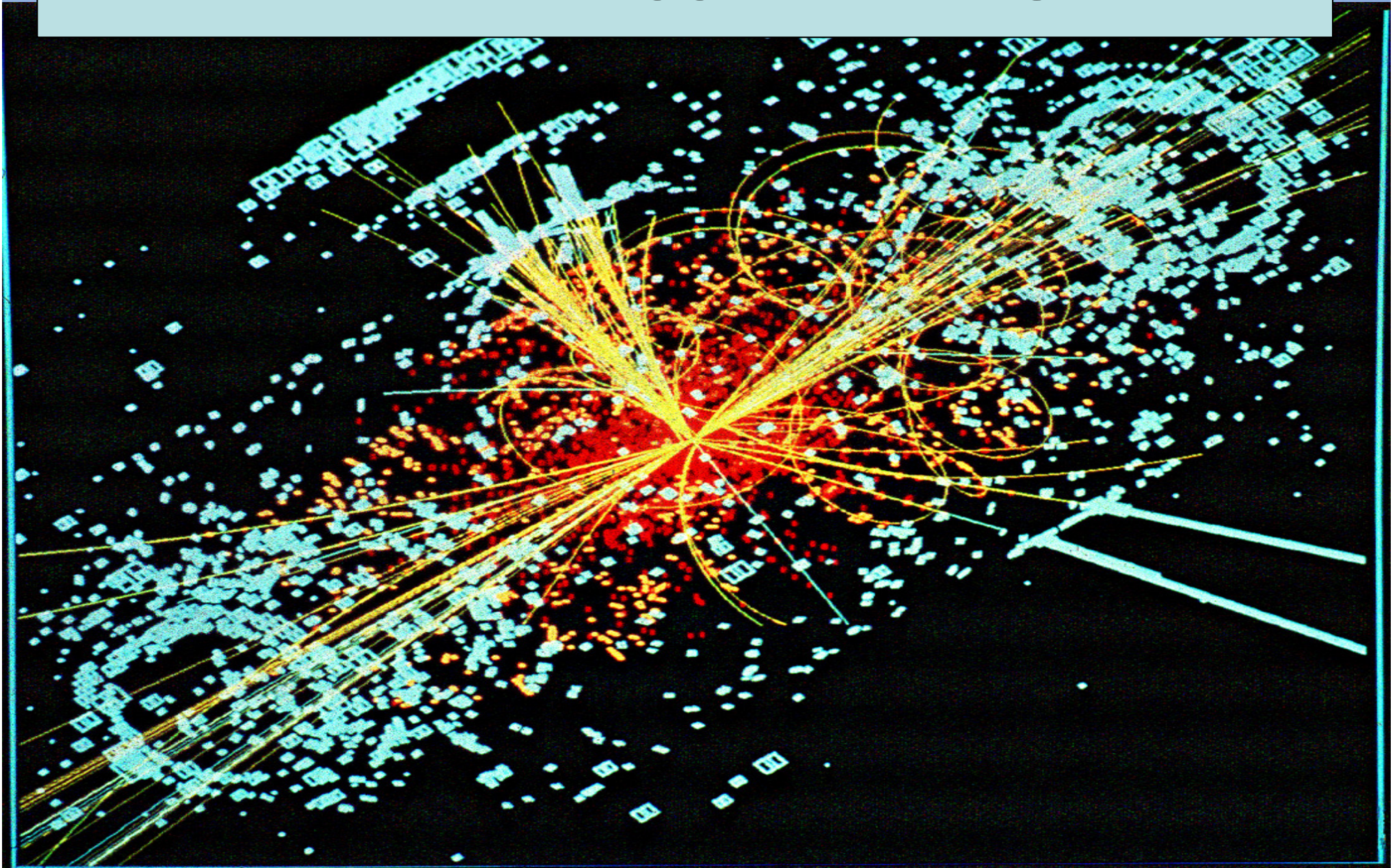
LHCb: Matter-antimatter difference

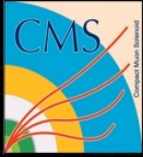
2012: The discovery of the Higgs Boson



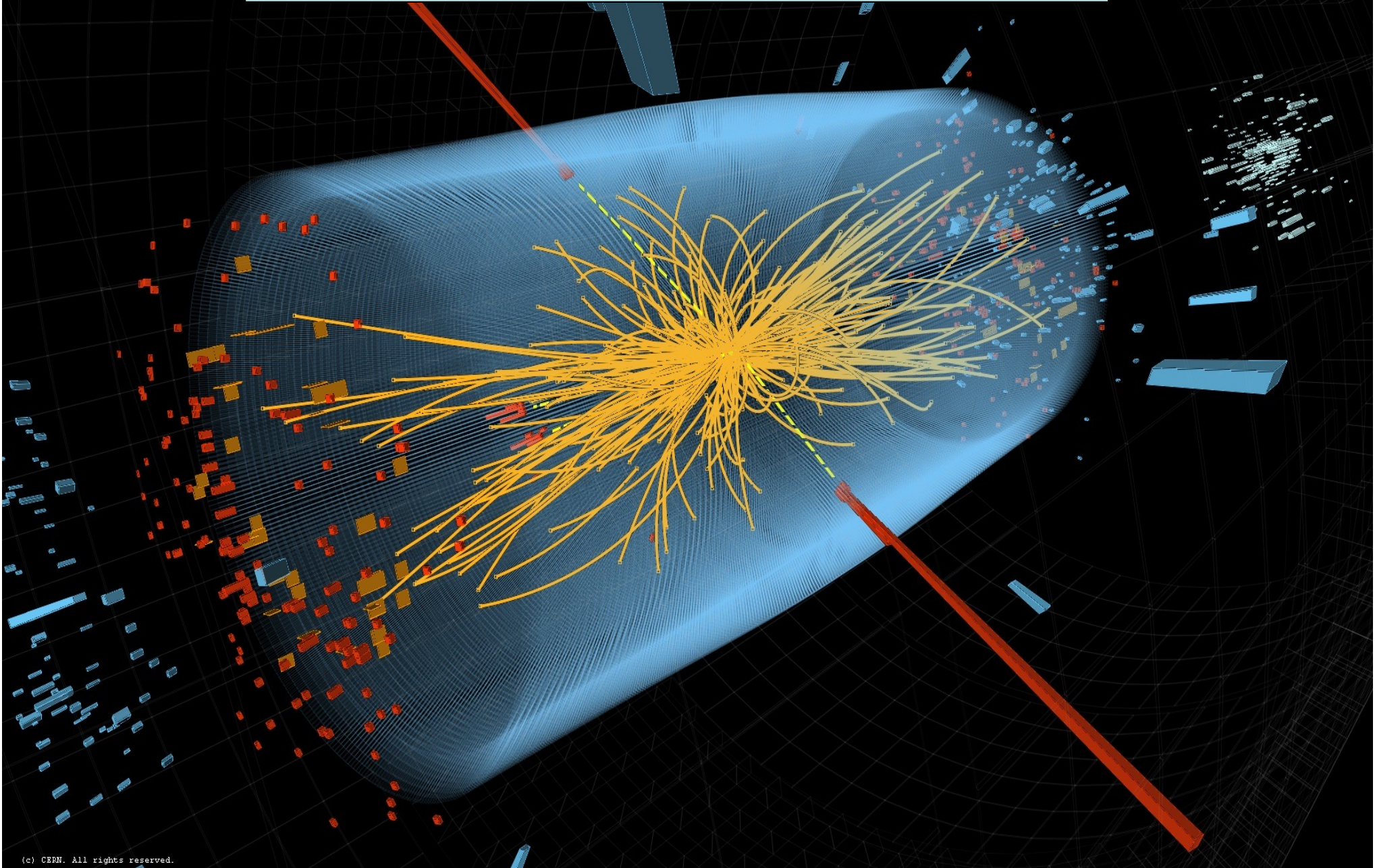
Mass Higgsteria

A Simulated Higgs Event @ LHC

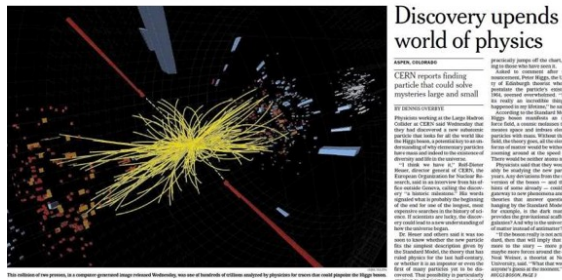




Interesting Events



July 4th 2012
The discovery of a new particle



Discovery upends world of physics
CERN reports finding particle that could solve mysteries large and small

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
Le bon de Higgs, particule manquante pour expliquer l'univers, vient d'être découvert



Le Monde
Les coups de cœur de la rédaction
7.2 milliards de plus dès 2012

The Gazette
EL PAIS
EL PERIÓDICO GLOBAL EN ESPAÑOL

MK
ПОСЛЕДНИЙ КИРПИЧ В СТЕНУ МИРОЗДАНИЯ
«КРЕМЛЕВСКИЕ» САМОЛЕТЫ ПРИШЛОСЬ МЕНЯТЬ НА ПЕРЕПРАВЕ

AD ALGEMEEN DAGBLAD
EINDELIJK GELIJK NA 48 JAAR
Zieke Kaj en zijn moeder toch samen in de VS

Frankfurter Allgemeine
Masse mach's
Große Mehrheit im Europaparlament

CHINADAILY
fallada la partícula clave para a comprensión del universo
Iron Man film company looks to China for screen success

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
L'azienda in ostaggio

gazeta
Czaszkie Higgsa fizycy najpierw wymyśliłi, potem szukali 40 lat
BOSKA MASA

বিশ্বজ্ঞানের 'ঈশ্বর' দর্শন
সত্যেন্দ্রনাথকে বিনয় প্রণাম
'পেয়েছি, যা খুঁজছিলাম'

Higgsdependence Day!



The Particle Higgsaw Puzzle

The image features a 3D-rendered puzzle with a missing piece. The puzzle pieces are a light blue color with a glossy, metallic-like finish. The missing piece is a large, irregular shape in the center, revealing a white surface underneath. The background is a darker blue with a complex, wavy, and somewhat abstract pattern that resembles a topographical map or a fluid flow visualization. The overall lighting is soft, creating subtle highlights and shadows on the puzzle pieces.

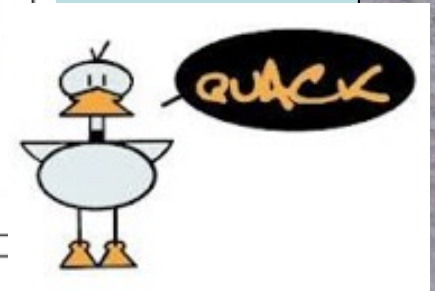
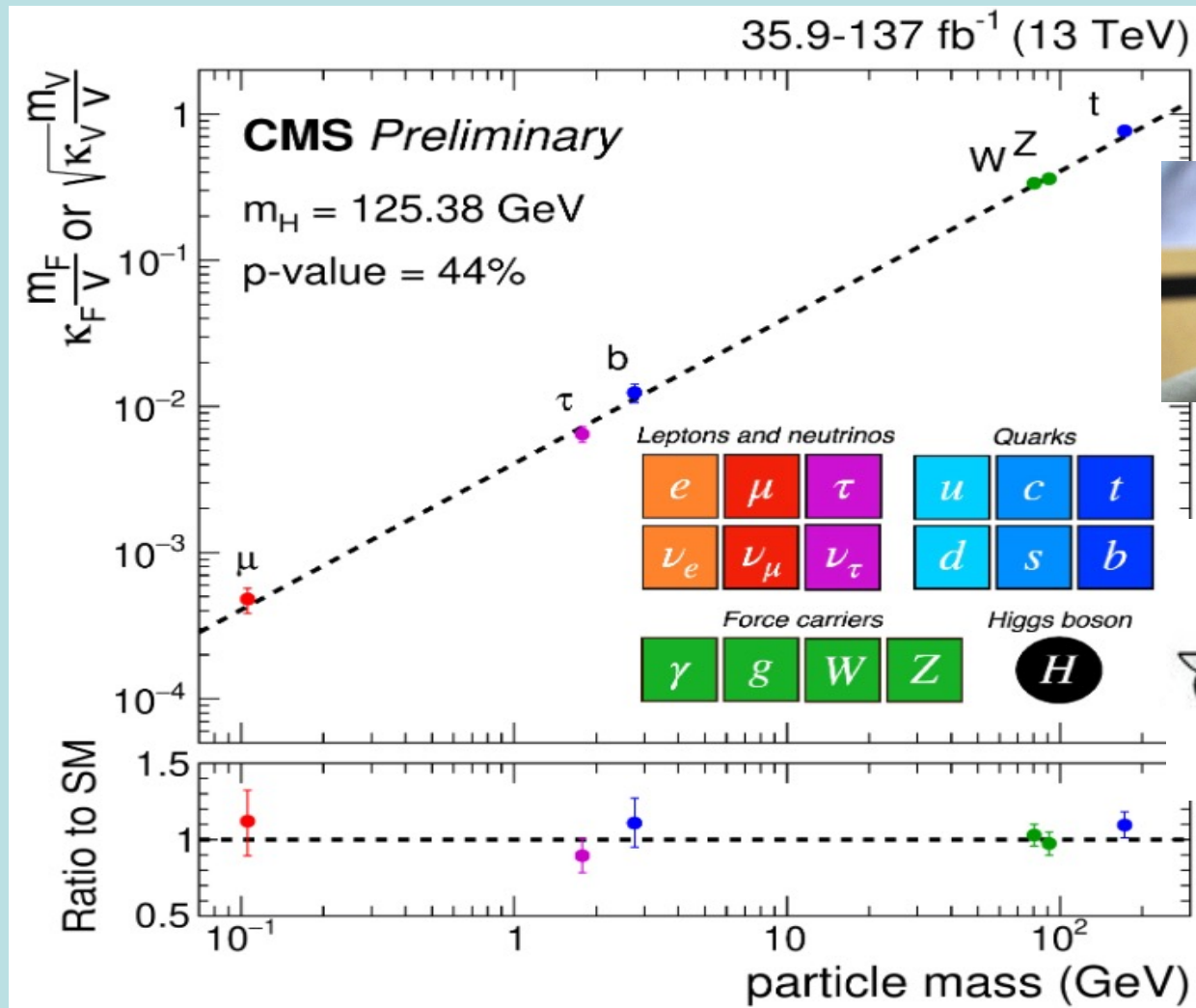
Did the LHC find the missing piece?

Is it the right shape?

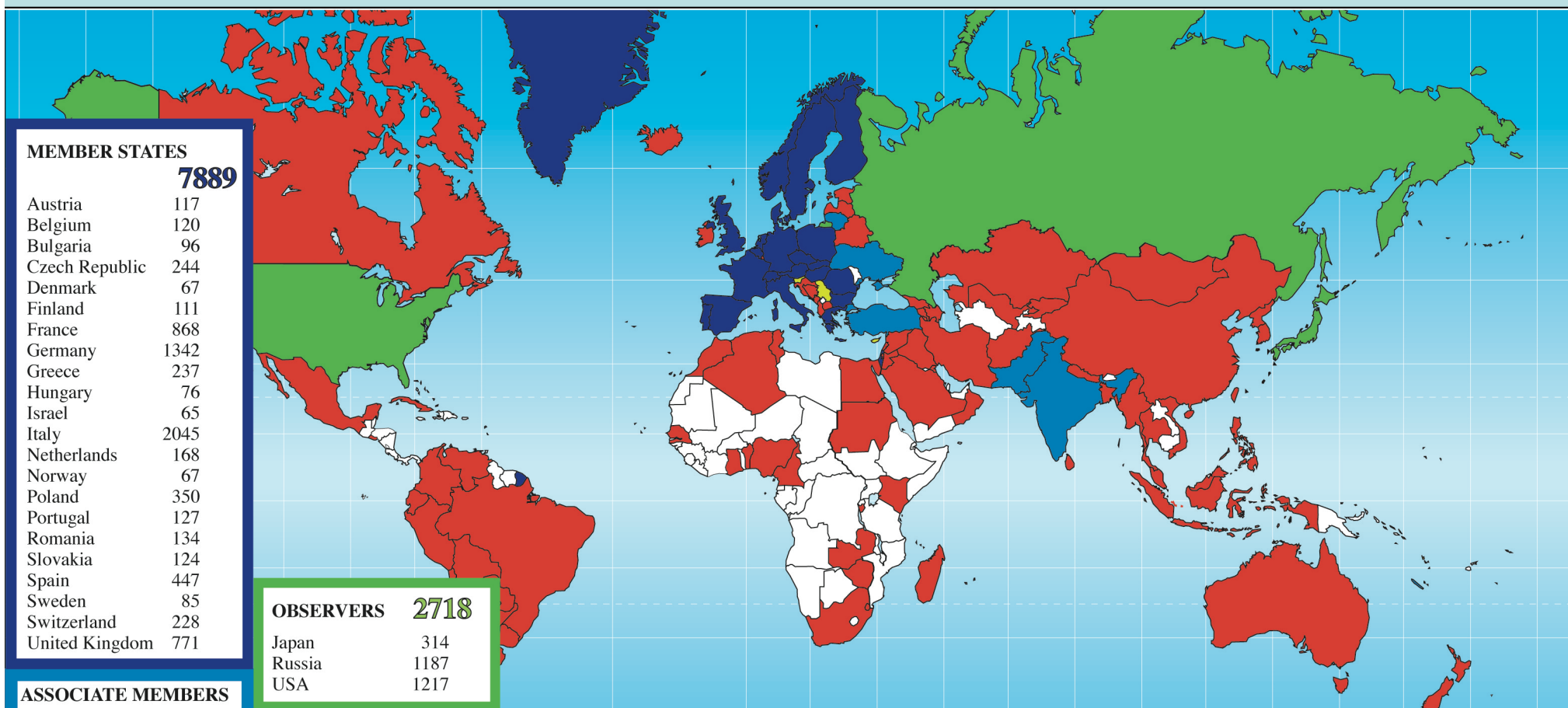
Is it the right size?

It Walks and Quacks like a Higgs

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



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	228
United Kingdom	771

OBSERVERS

2718

Japan	314
Russia	1187
USA	1217

ASSOCIATE MEMBERS

India	357	745
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	Burundi	1	Estonia	15	Korea Rep.	185	Morocco	20	Saudi Arabia	2	Tunisia	5
Argentina	27	Cameroon	1	Georgia	46	Kyrgyzstan	1	Myanmar	1	Senegal	1	Uruguay	1
Armenia	19	Canada	161	Ghana	1	Latvia	2	Nepal	10	Singapore	4	Uzbekistan	4
Australia	31	Chile	20	Hong Kong	1	Lebanon	23	New Zealand	5	South Africa	56	Venezuela	10
Azerbaijan	10	China	510	Iceland	3	Luxembourg	2	Nigeria	3	Sri Lanka	6	Viet Nam	13
Bangladesh	11	Colombia	45	Indonesia	11	Madagascar	4	North Korea	1	Sudan	1	Zambia	1
Belarus	48	Croatia	41	Iran	51	Malaysia	15	Oman	3	Swaziland	1	Zimbabwe	2
Benin	1	Cuba	12	Iraq	1	Malta	9	Palestine (O.T.)	7	Syria	1		
		Ecuador	6	Ireland	16	Mauritius	1	Paraguay	2	Taiwan	51		
				Jordan	1	Mexico	82	Peru	7				



Russian naval shells reused
in the CMS experiment

Dixit Swedish Academy

Today we believe that “Beyond any reasonable doubt, it is a Higgs boson.” [1]

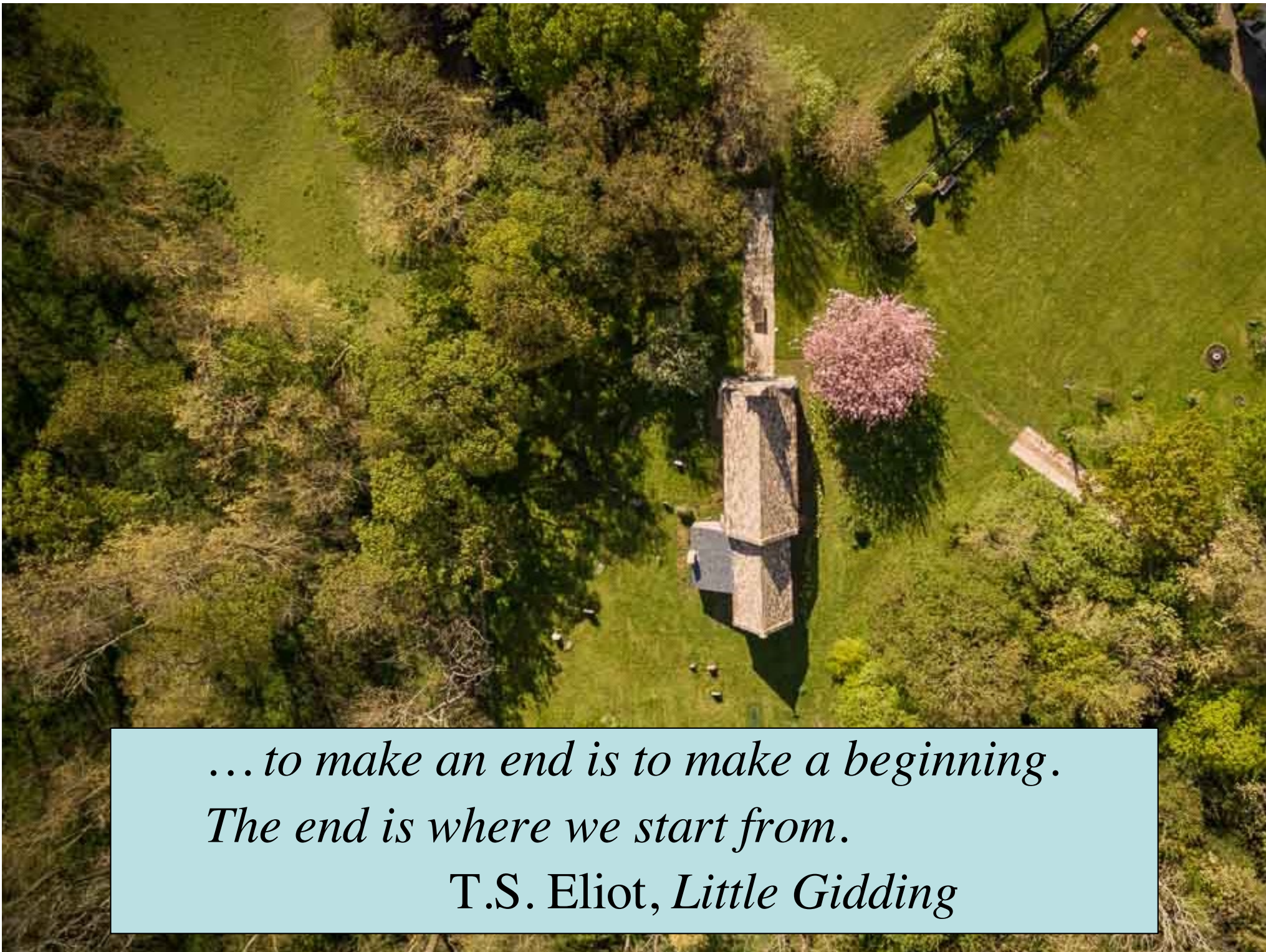
http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/advanced-physicsprize2013.pdf

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

Without Higgs ...

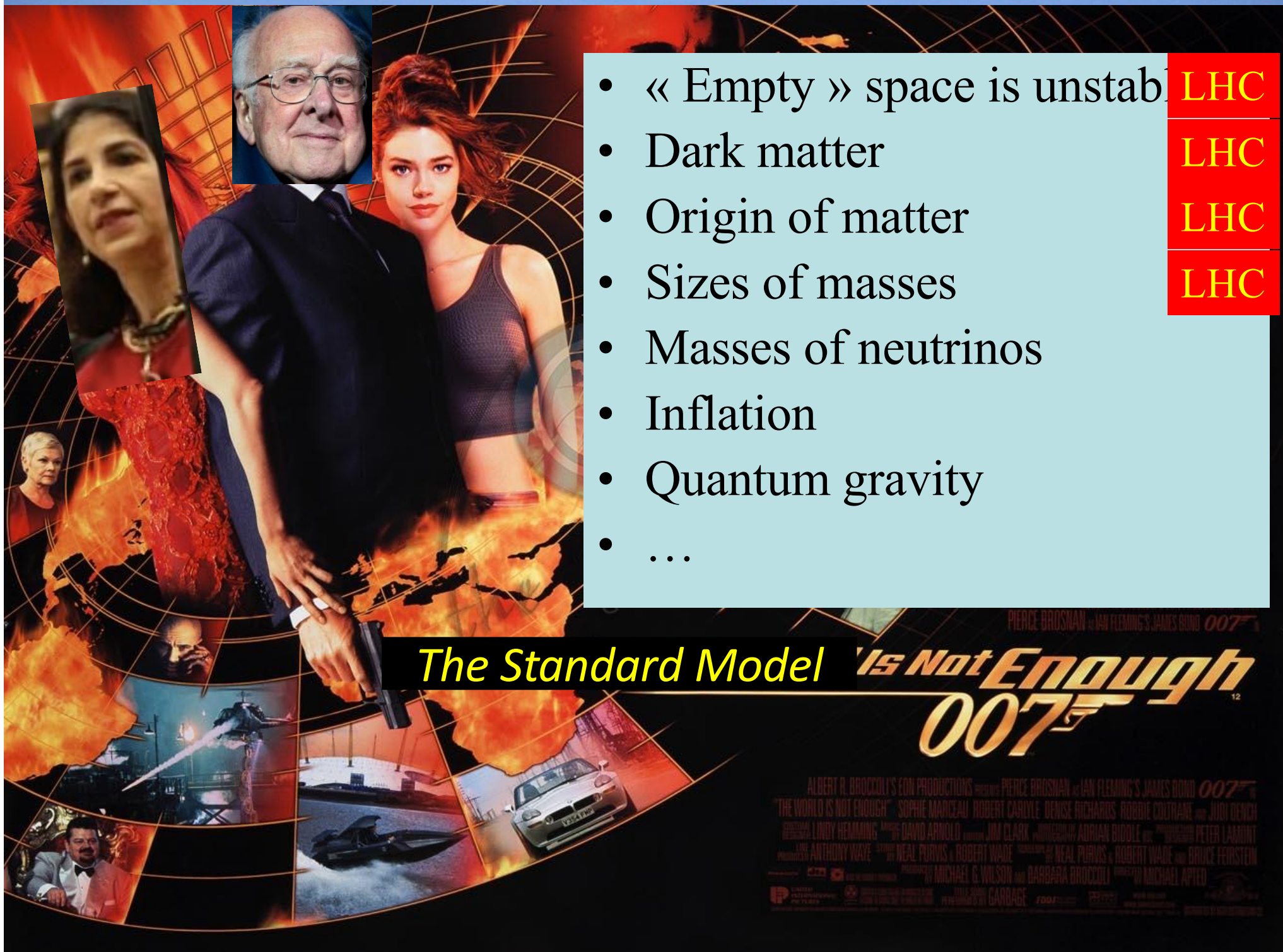
- ... there would be no atoms
 - massless electrons would escape at the speed of light
- ... there would be no heavy nuclei
- ... weak interactions would not be weak
 - Life would be impossible: everything would be radioactive

Its existence is a big deal!



*... to make an end is to make a beginning.
The end is where we start from.*

*T.S. Eliot, *Little Gidding**



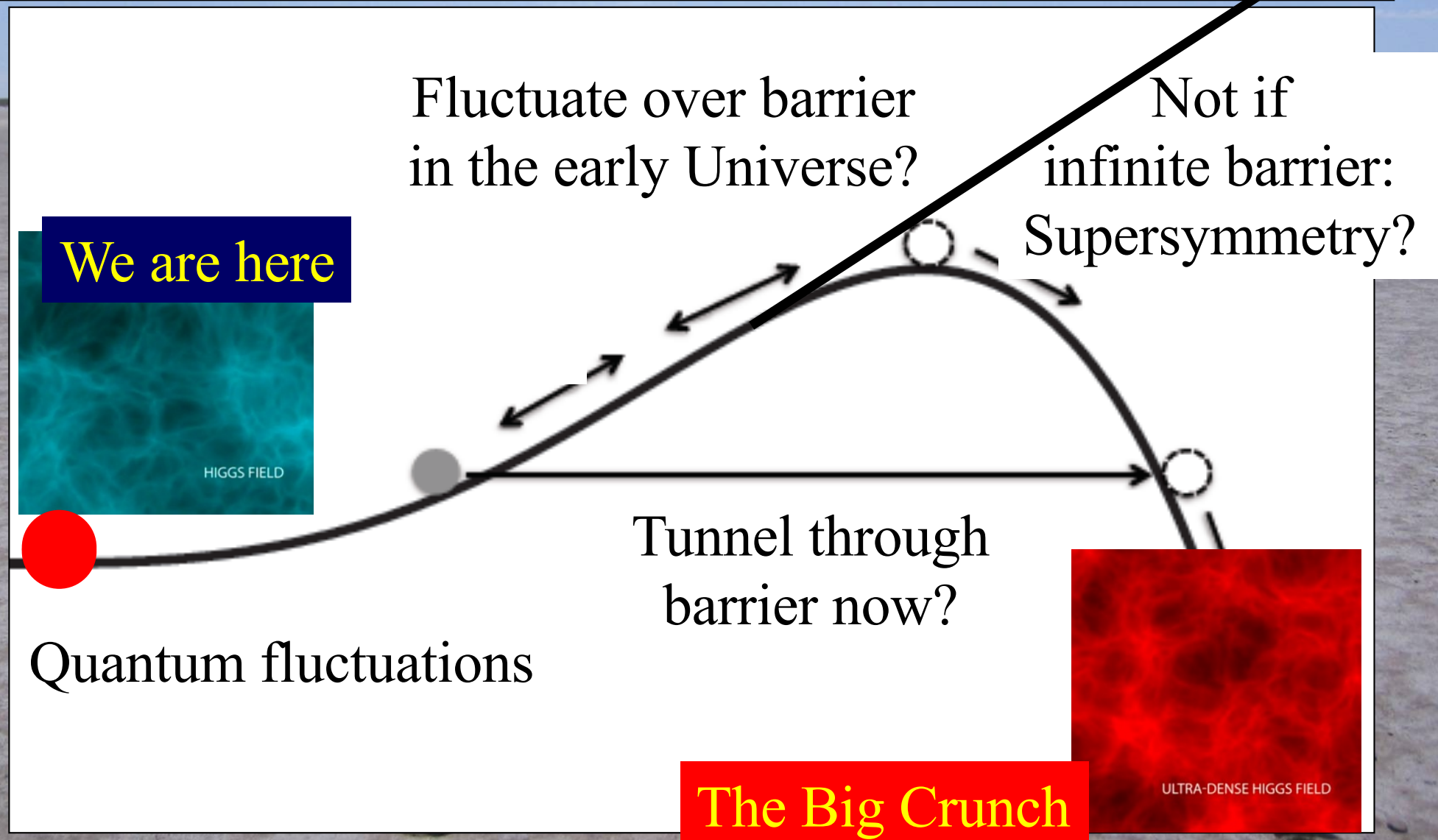
- « Empty » space is unstable
- Dark matter
- Origin of matter
- Sizes of masses
- Masses of neutrinos
- Inflation
- Quantum gravity
- ...

LHC
LHC
LHC
LHC

The Standard Model *Is Not Enough* 007[™]

ALBERT R. BROCCOLLI'S SON PRODUCTIONS PRESENTS PIERCE BRUSNAN in JAMES BOND 007[™] "THE WORLD IS NOT ENOUGH" SOPHIE MARCEAU ROBERT CARVILLE DENISE RICHARDS ROBBIE COLTRANE and JUDI DENCH
MUSIC BY LINDY HEARNEING COSTUME DESIGNER DAVID ARNOLD EDITOR JIM CLARK EXECUTIVE PRODUCERS JONATHAN ADRIAN BRIDLE PRODUCED BY PETER LARSON
WRITTEN BY JAMES ANTHONY WARE DIRECTED BY NEAL PURVIS & ROBERT WARD EXECUTIVE PRODUCERS NEAL PURVIS & ROBERT WARD PRODUCED BY BRUCE FENSTEIN
PRODUCED BY MICHAEL G. WILSON AND BARBARA BROCCOLLI EXECUTIVE PRODUCERS MICHAEL APPEL
CASTING BY JONATHAN CARROLL
COSTUME DESIGNER DAVID ARNOLD
EXECUTIVE PRODUCERS JONATHAN ADRIAN BRIDLE
PRODUCED BY PETER LARSON
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EXECUTIVE PRODUCERS MICHAEL APPEL

Will the Universe Collapse? Should it have Collapsed already?



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

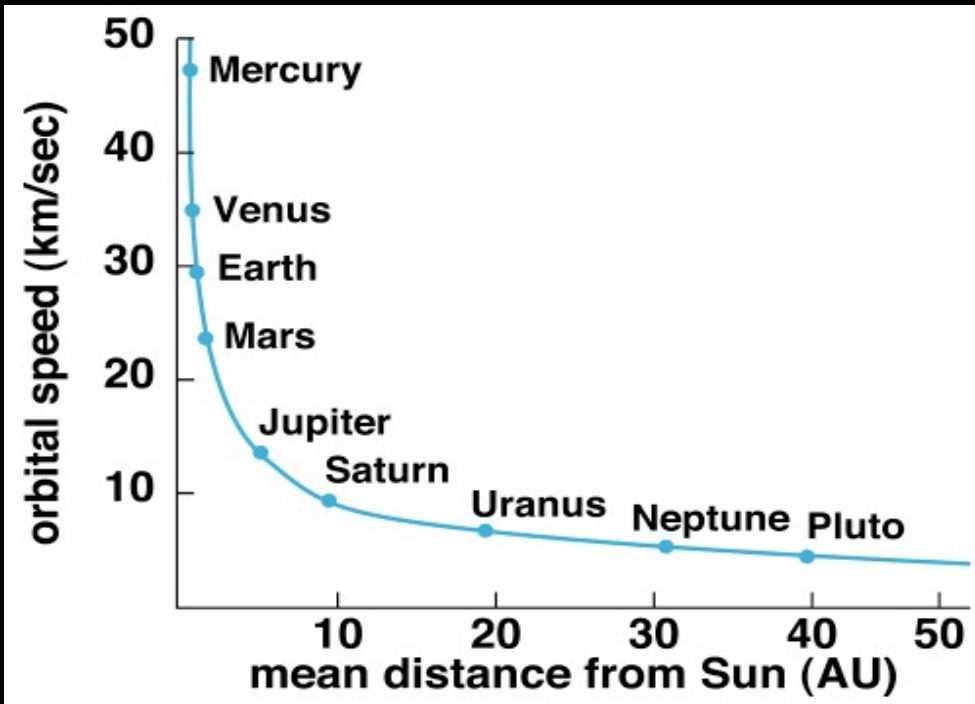
- Measured by Vera Rubin
- The stars also orbit ‘too quickly’
- Her observations also required a stronger gravitational field than provided by the visible matter
- **Further strong evidence for dark matter**



Scanned at the American
Institute of Physics

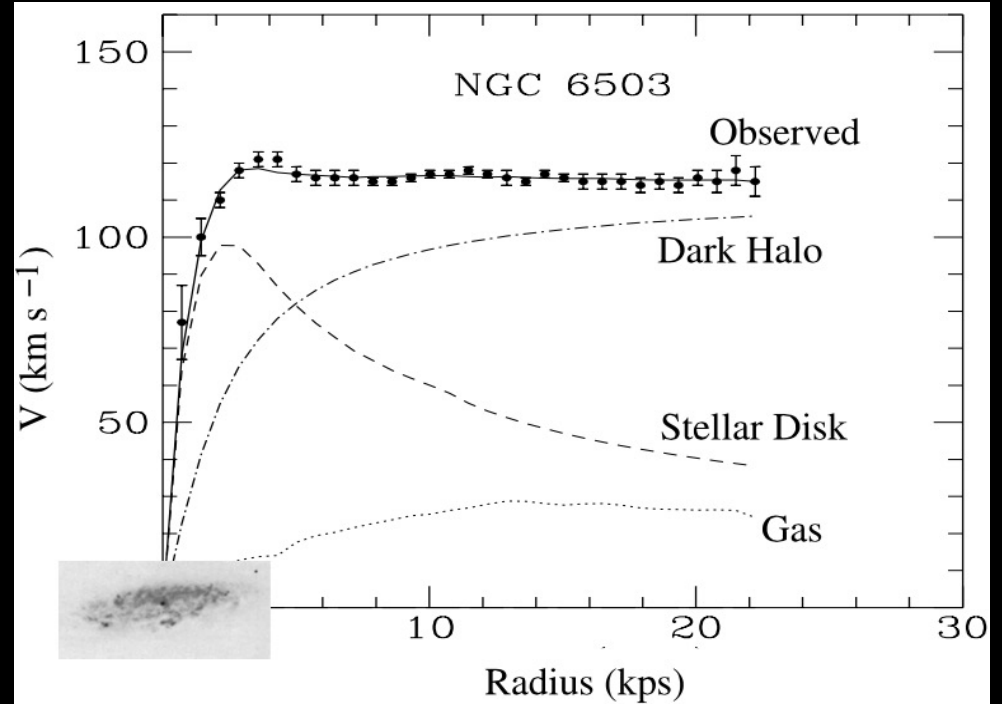
Rotation Curves

- In the Solar System



- The velocities decrease with distance from Sun
- Mass lumped at centre

- In galaxies



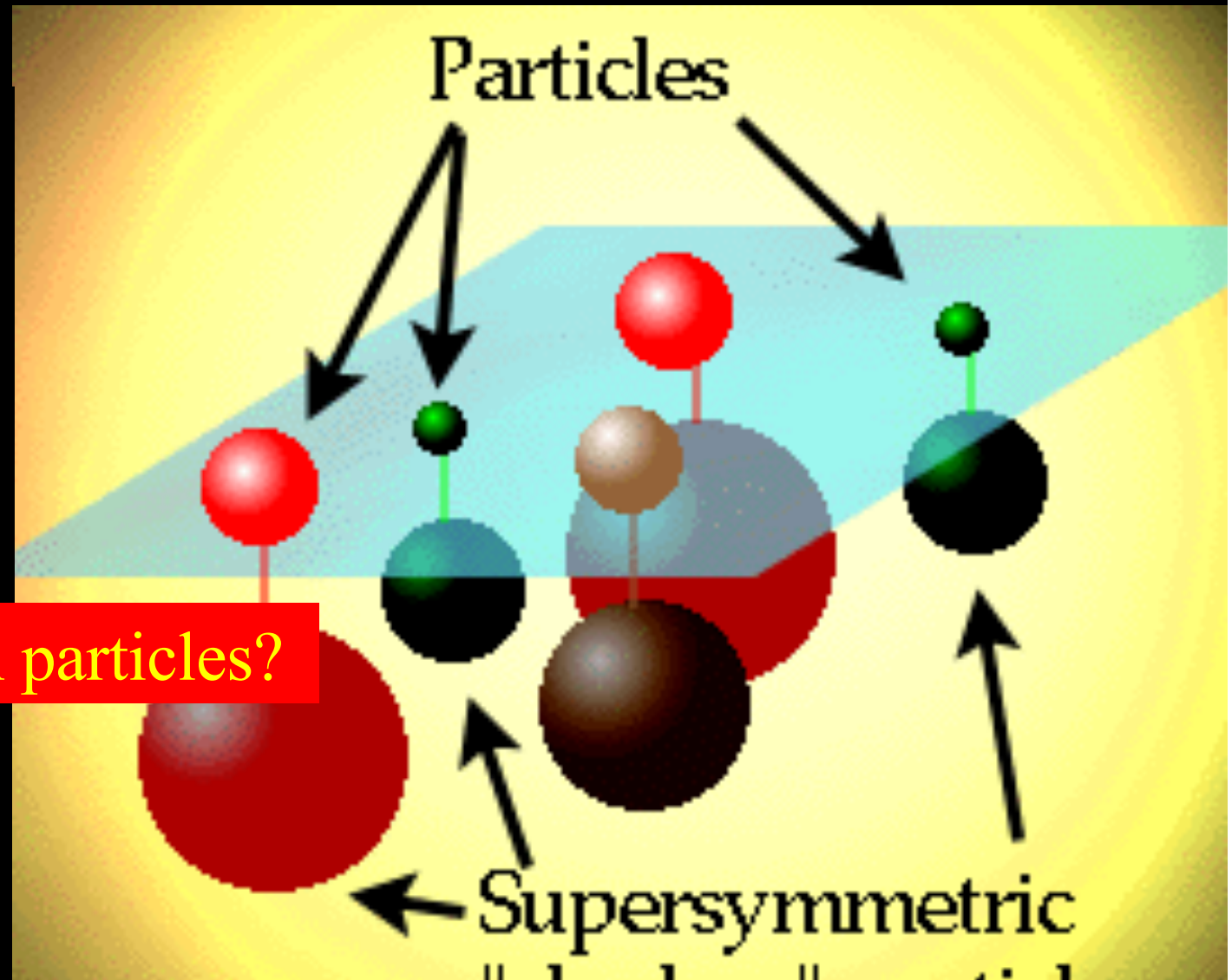
- The velocities do not decrease with distance
- Dark matter spread out

What is the Dark Matter in the Universe?

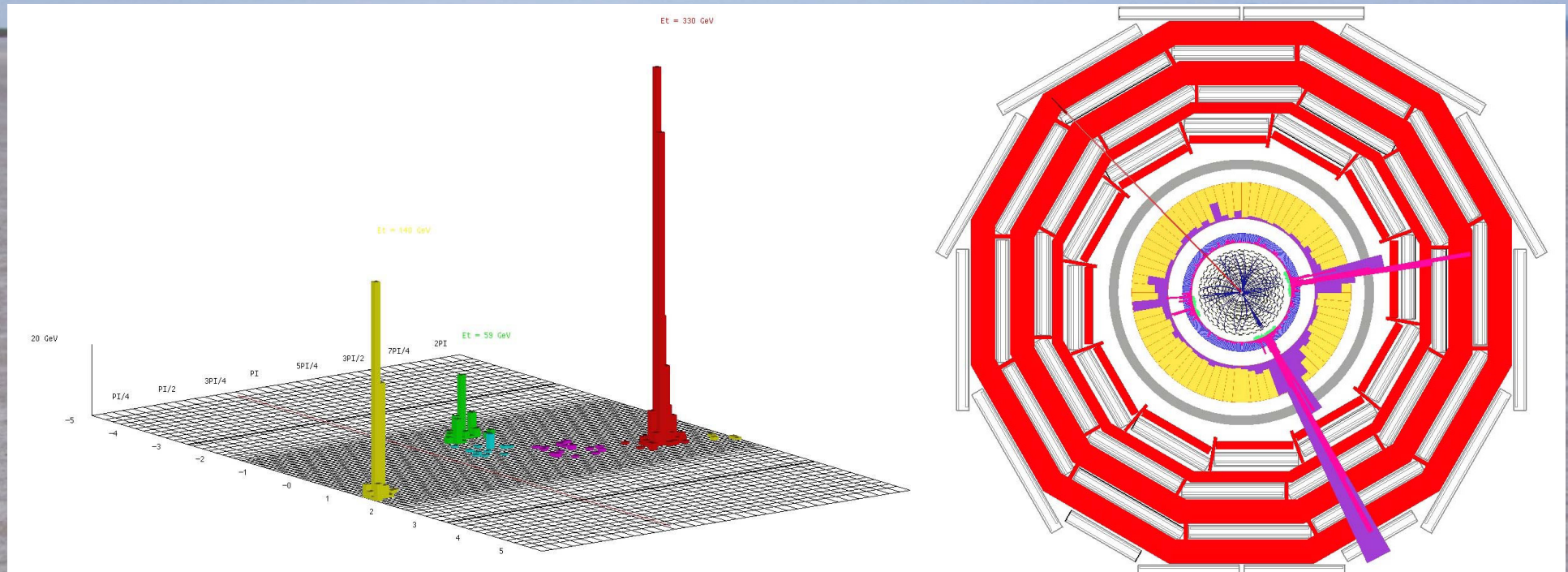
Astronomers say
that most of the
matter in the
Universe is
invisible
Dark Matter

Made of unknown particles?

We are
searching for
them at the

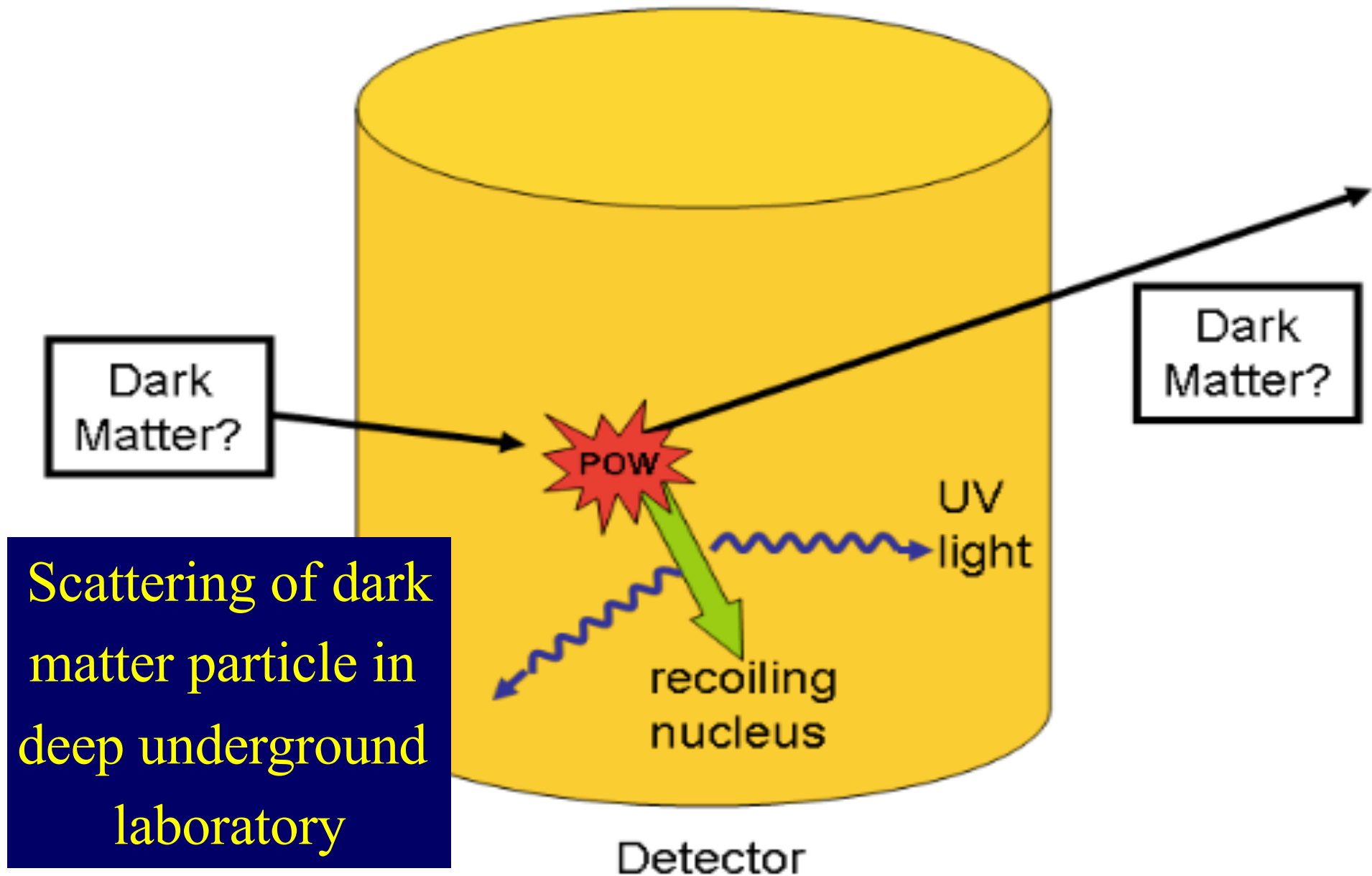


Classic Dark Matter Signature



Missing transverse energy
carried away by dark matter particles

Direct Dark Matter Detection



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

How to Create the Matter in the Universe?

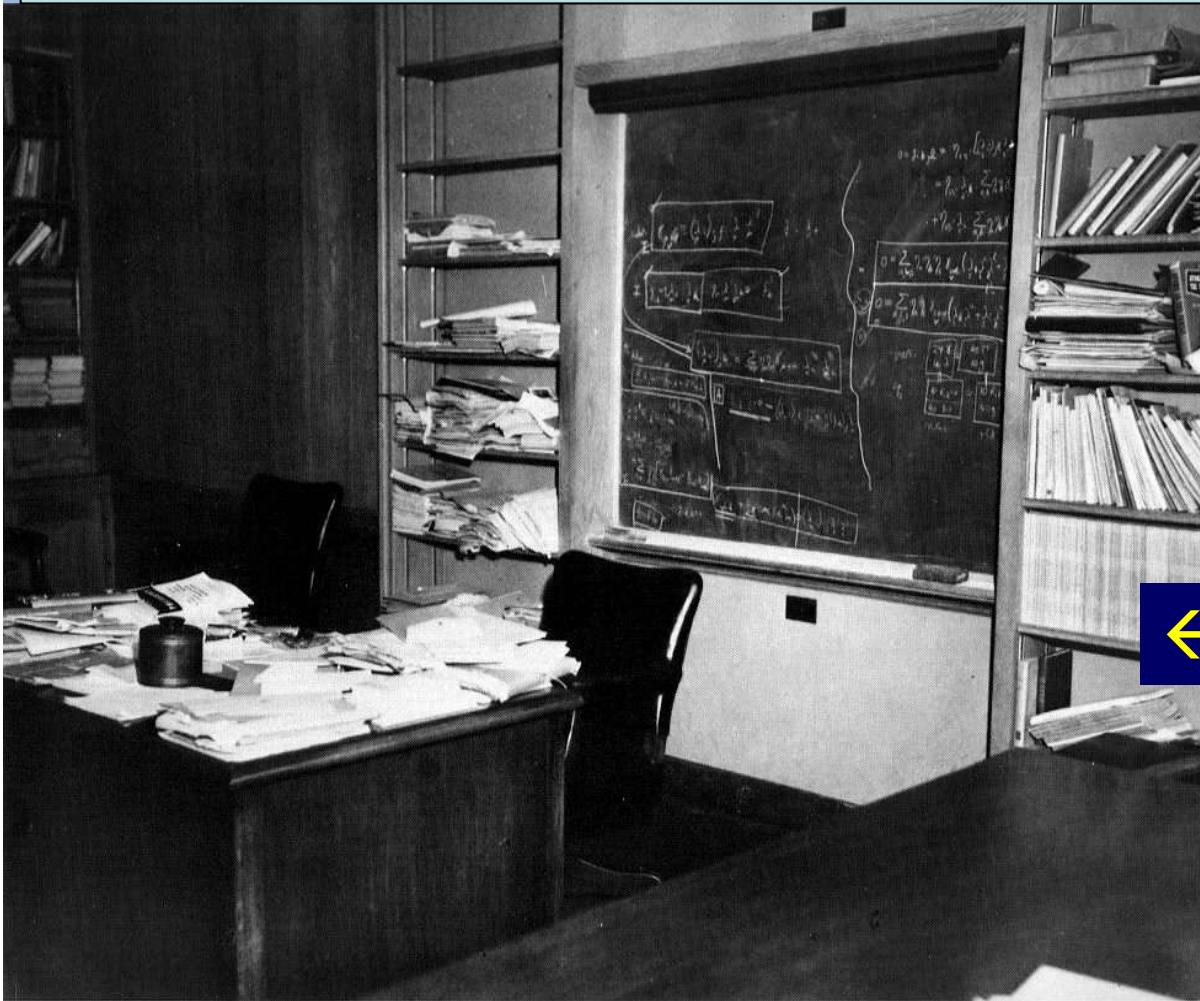
Sakharov

- Need a difference between matter and antimatter observed in the laboratory
- Need interactions able to create matter predicted by theories not yet seen by experiment
- Need the expansion of the Universe a role for the Higgs boson?

Will we be able to calculate using laboratory data?



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



← ... but he never succeeded



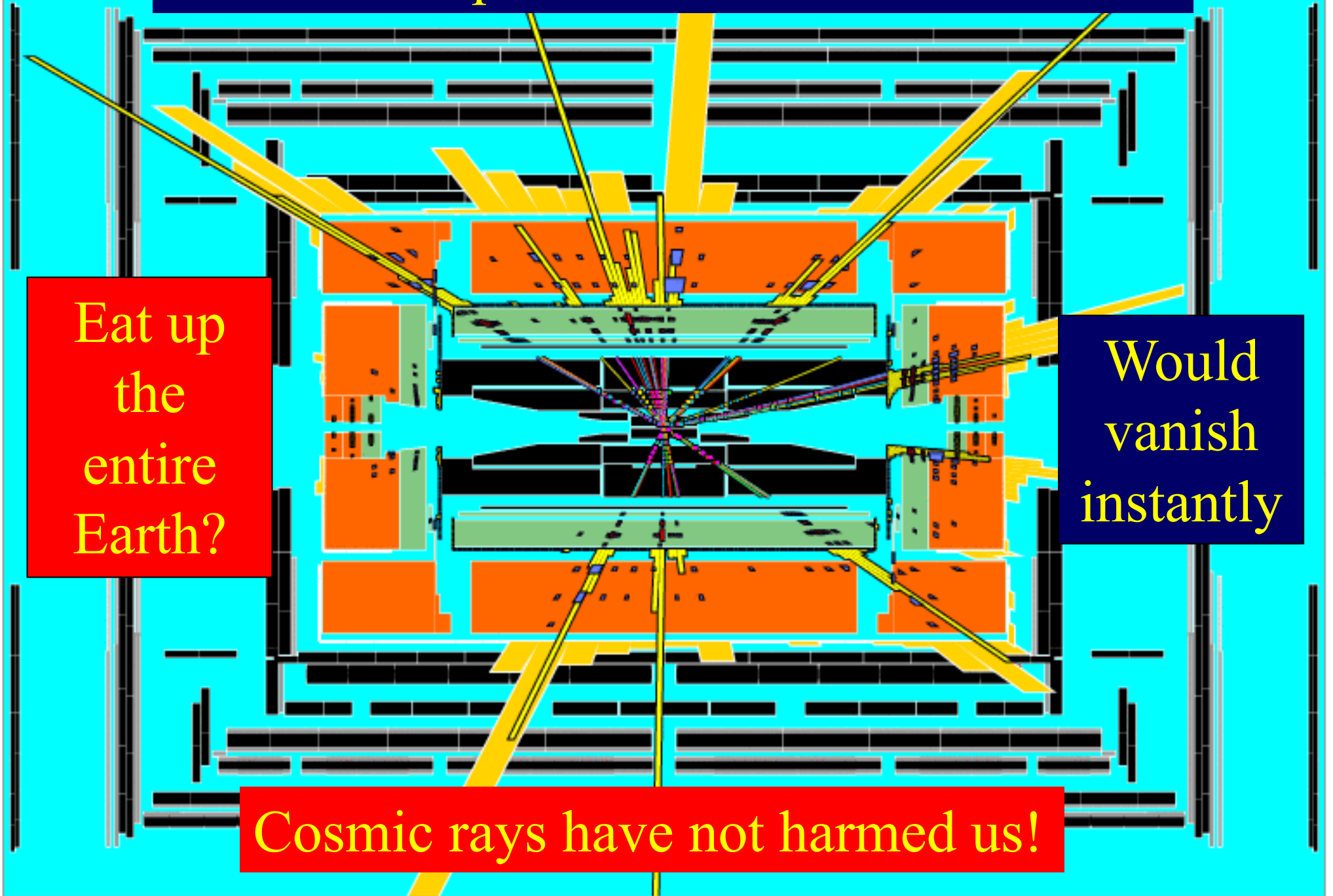
Unification via extra dimensions of space?

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