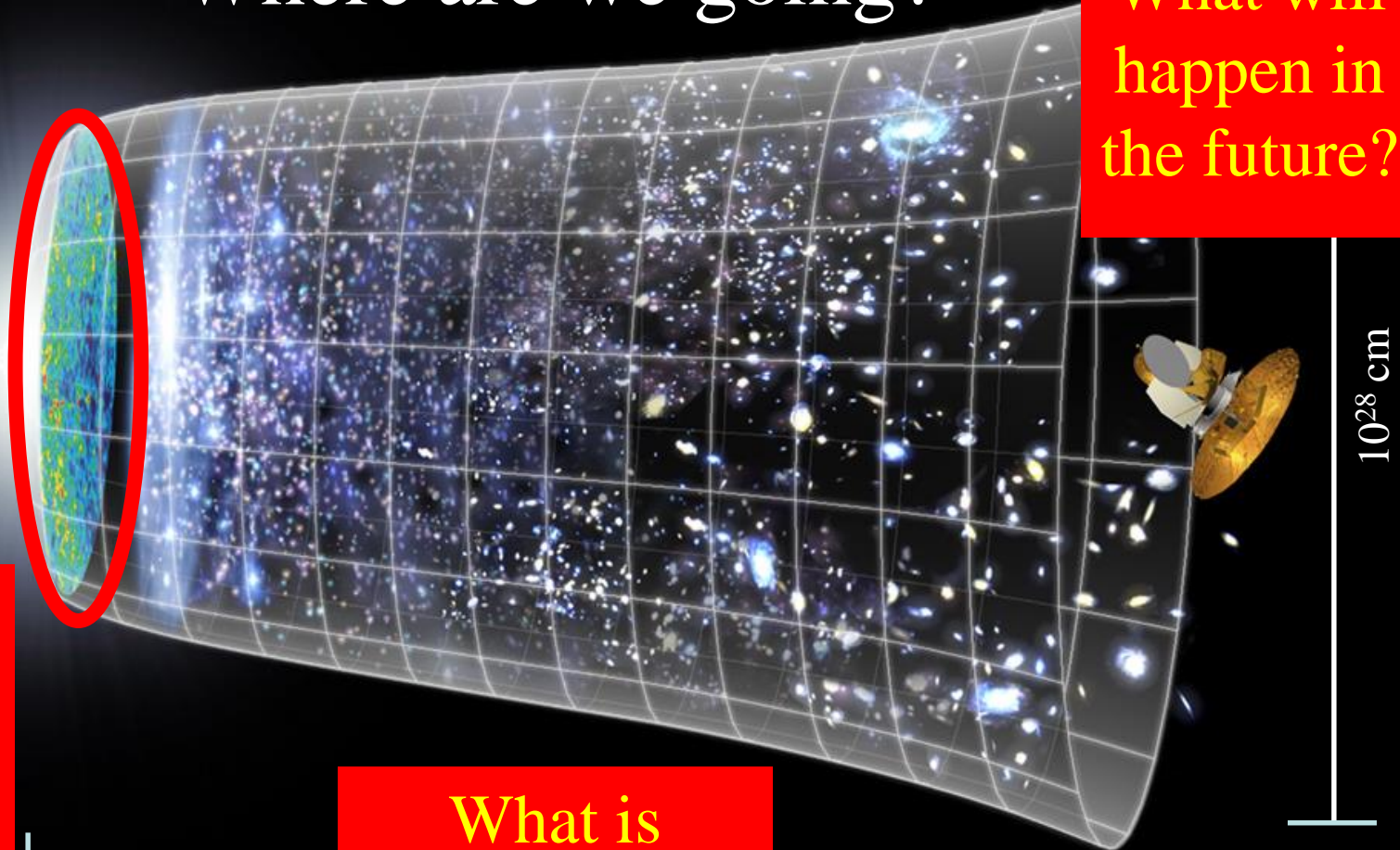


What are we?
Where do we come from?
Where are we going?

What will happen in the future?

Big Bang



What happened then?

What is the universe made of?

Today

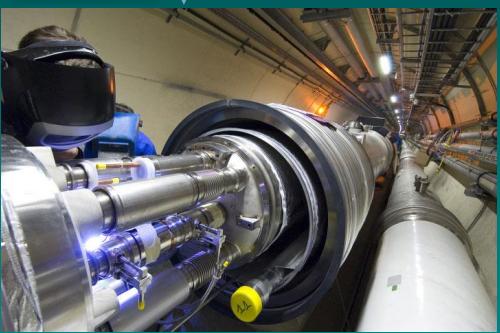
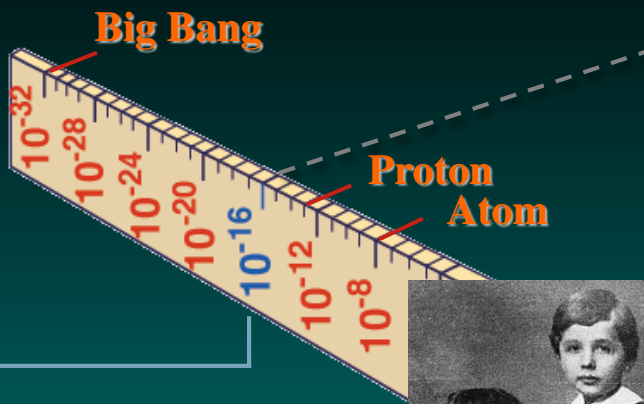
John Ellis

KING'S
College
LONDON

“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?

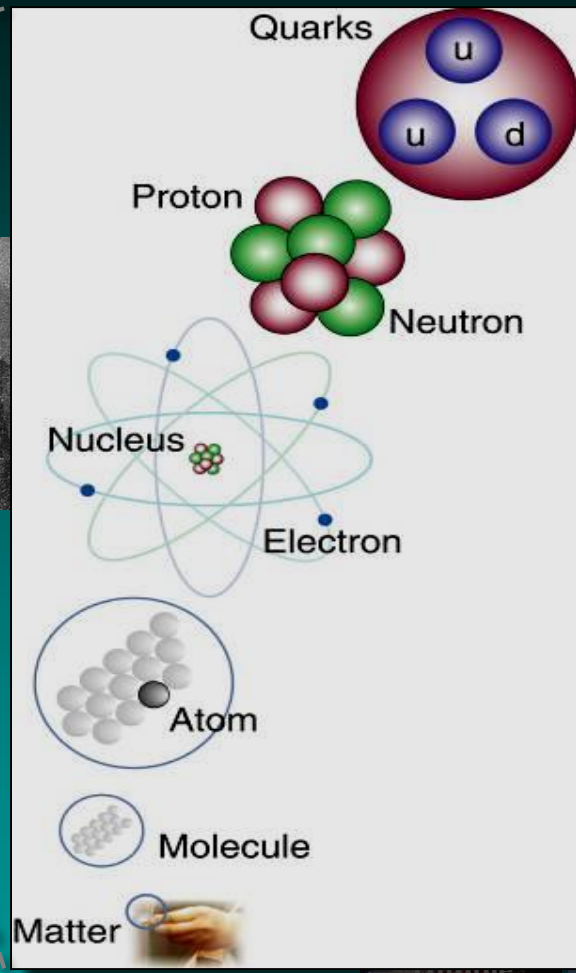


LHC

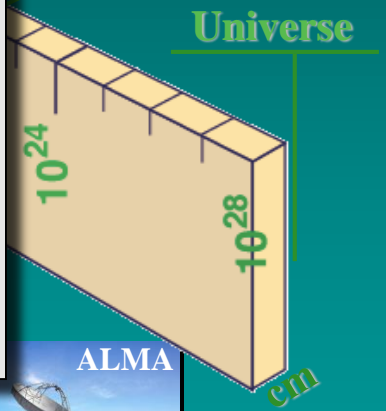
Super-Microscope



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



Radius of Galaxies

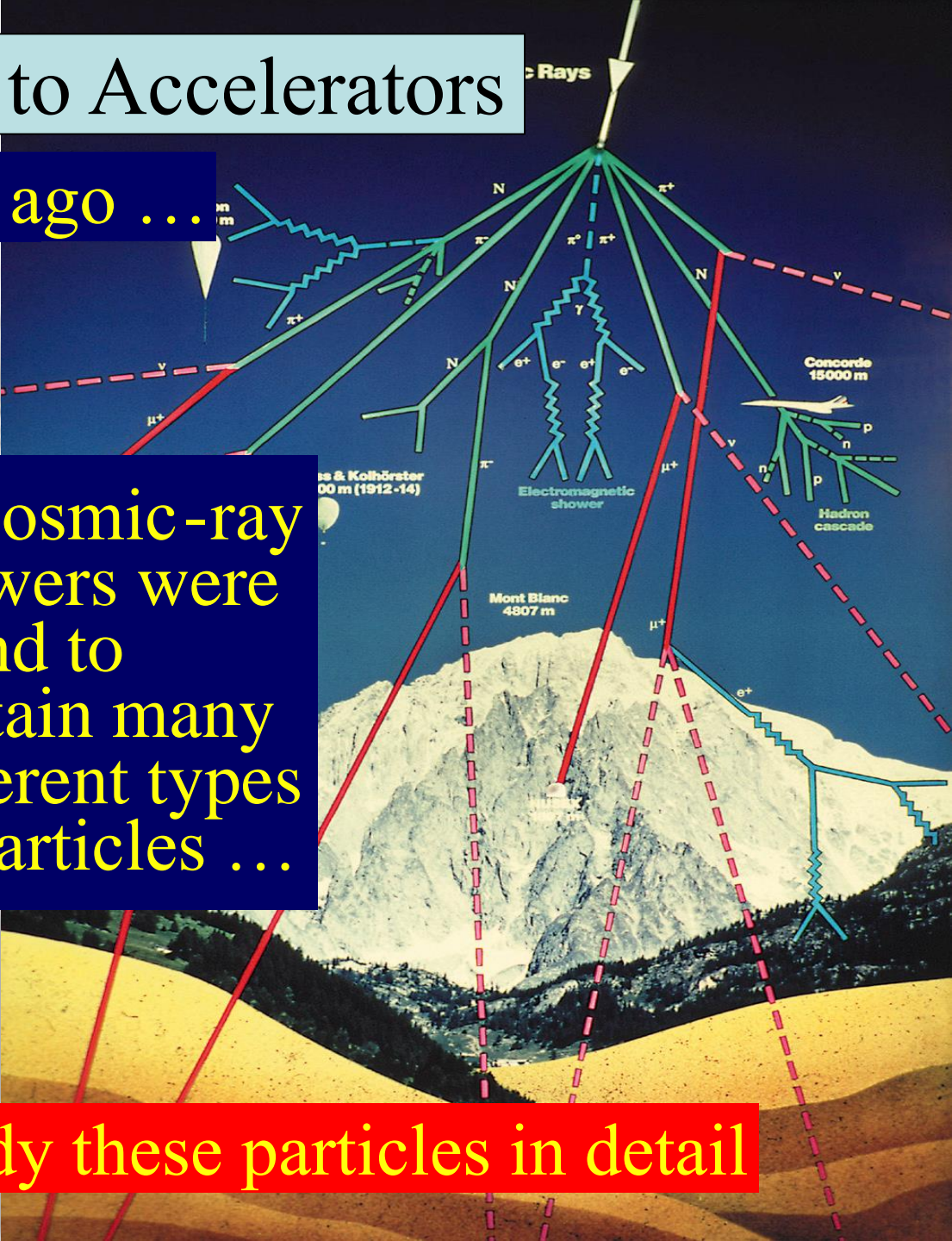


From Cosmic Rays to Accelerators

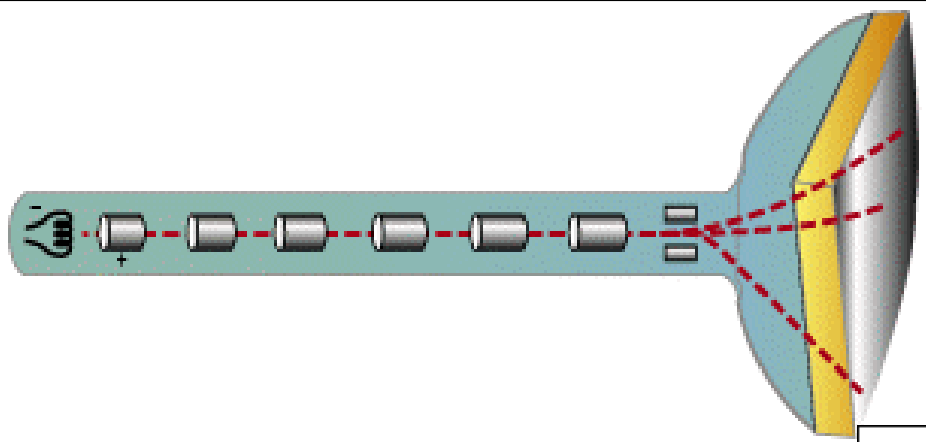
Discovered a century ago ...

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

Accelerators study these particles in detail

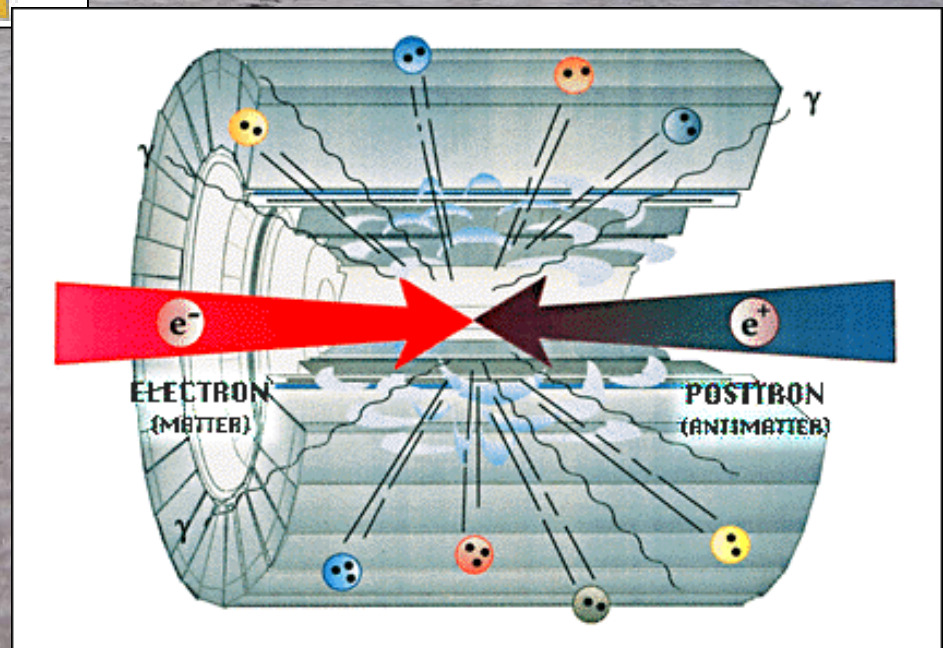


Experiments at Accelerators

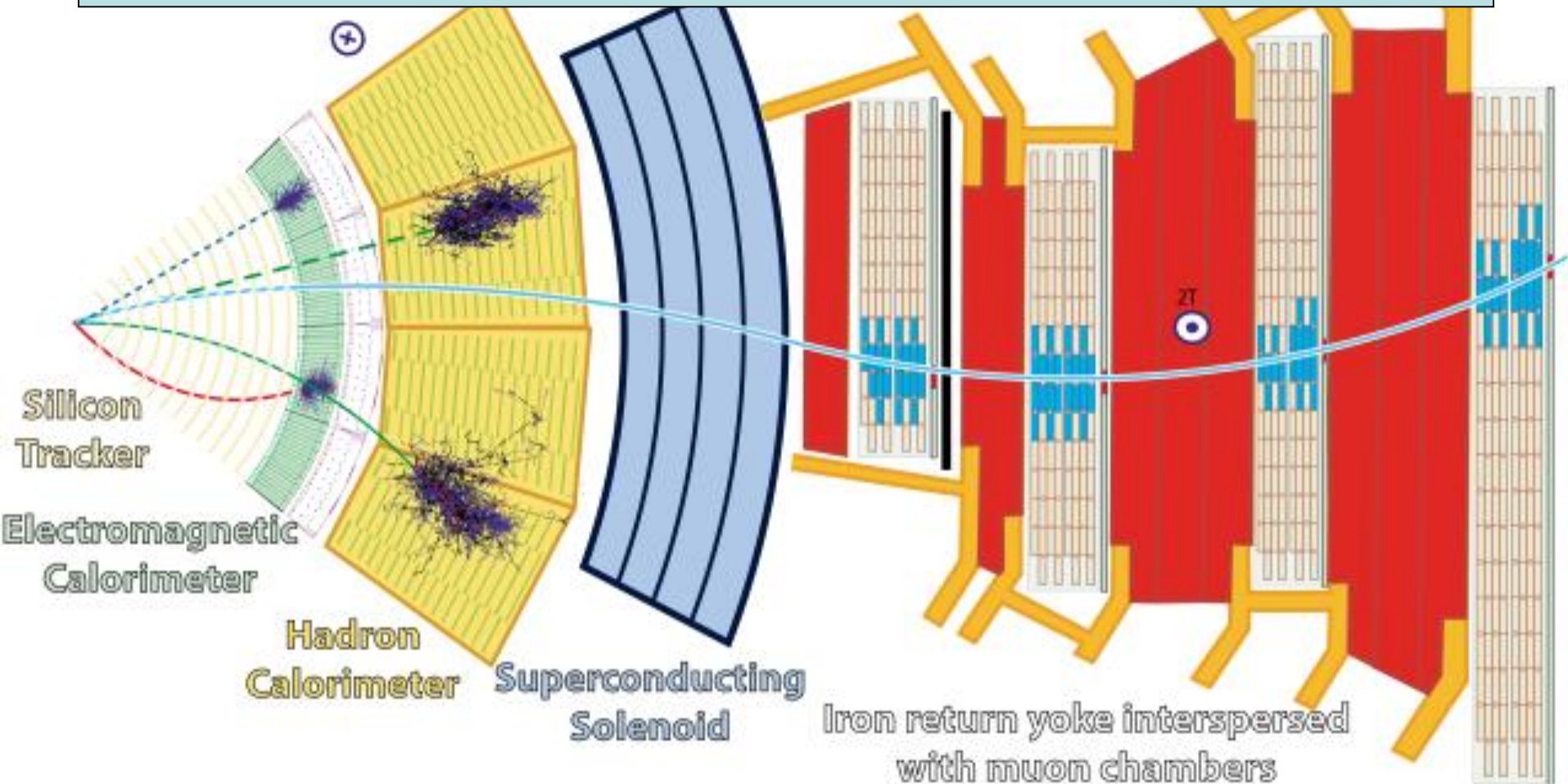


Large accelerators are based on same principles as old TV set
Accelerate and direct particle beams using electric and magnetic fields

Collisions take place inside large detectors that observe and measure the particles produced



A Typical Particle Detector



— Muon

— Electron

— Charged hadron (e.g. pion)

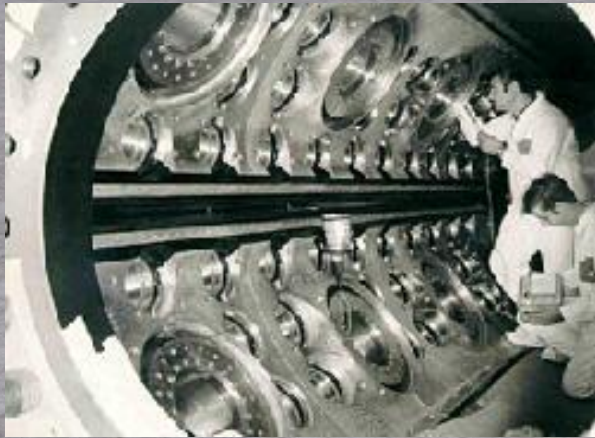
- - - Neutral hadron (e.g. neutron)

- - - Photon

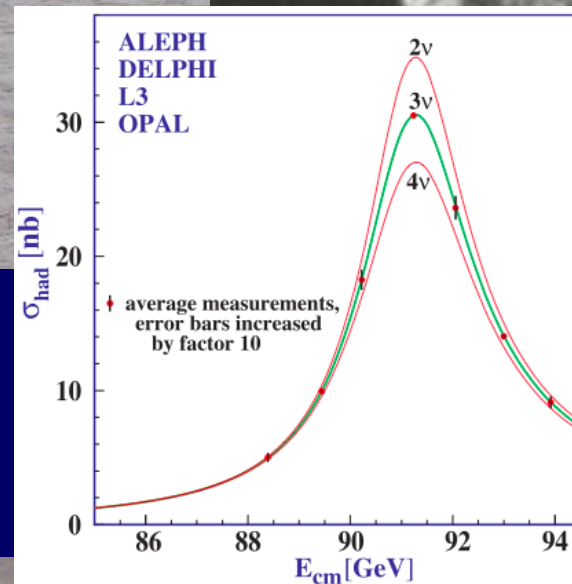
The 'Standard Model' of Particle Physics

Proposed by Abdus Salam,
Glashow and Weinberg

Tested by experiments
at CERN



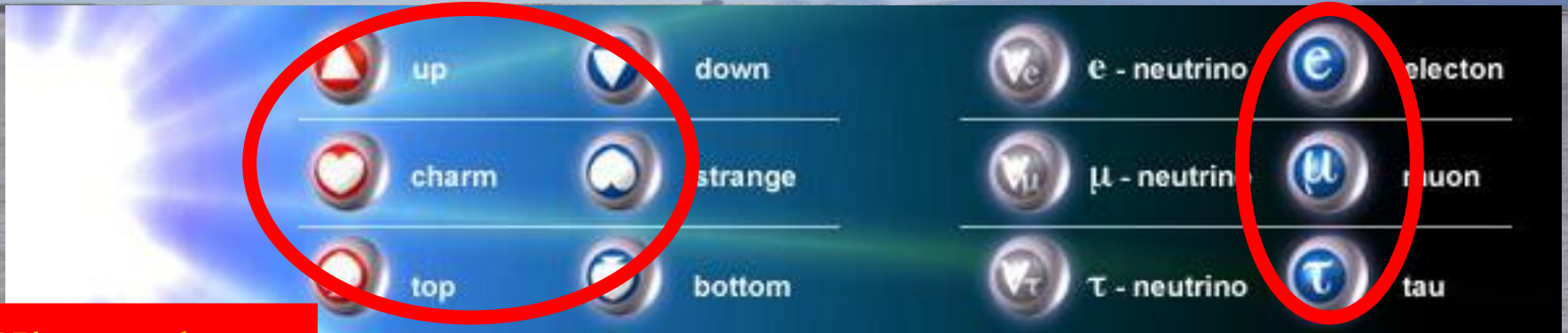
Perfect agreement between
theory and experiments
in all laboratories



The 'Standard Model'

= Cosmic DNA

The matter particles



Where does mass come from?

The fundamental interactions



Gravitation

electromagnetism

weak nuclear force

strong nuclear force

The Man with the Answer



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 found
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.

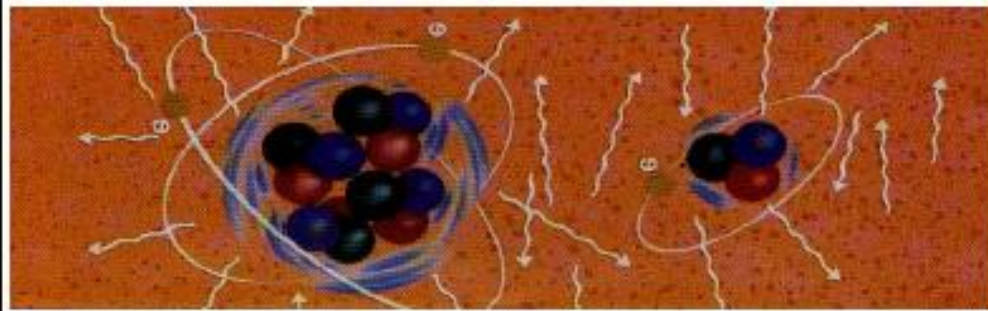
Gauguin's Questions in the Language of Particle Physics

- 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

300,000
years



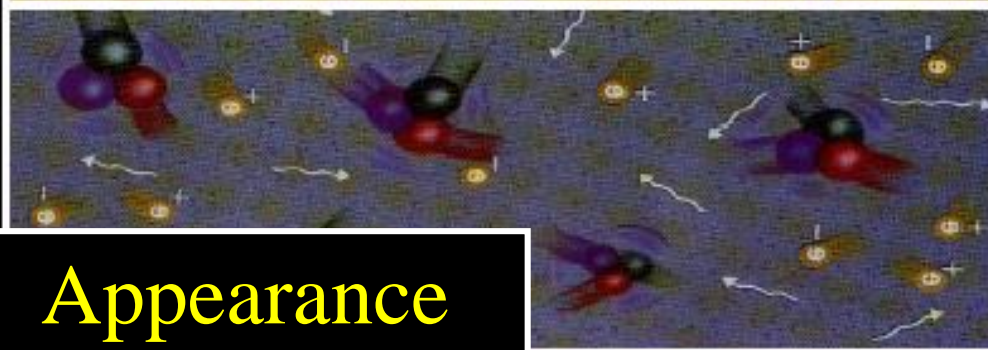
Formation
of atoms

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?



To answer Gauguin's questions:



Large Hadron Collider at CERN

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

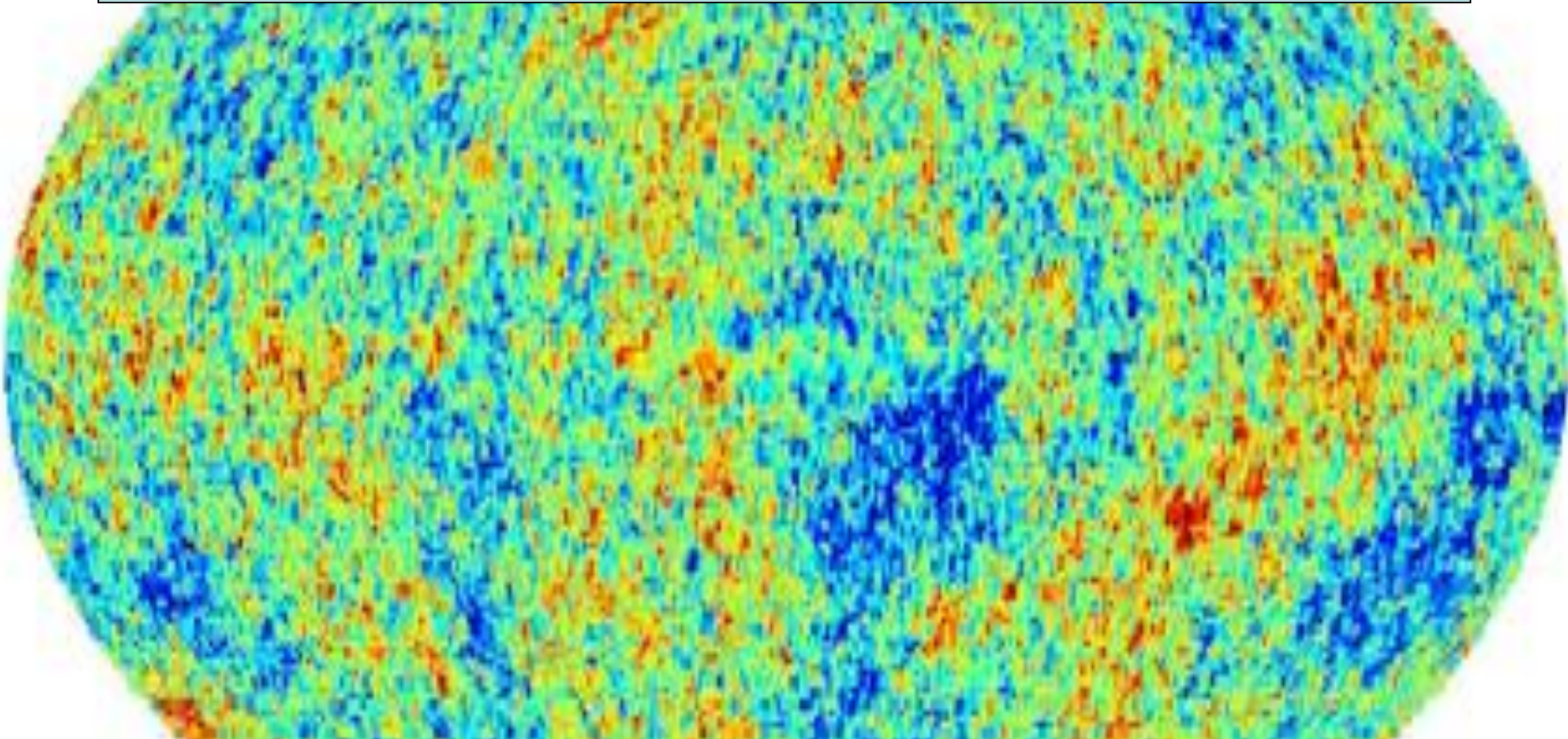
Collisions at 8 TeV in Run 1
13/14 TeV in LHC Run 2:
3 times earlier in the
history of the Universe

The Emptiest Space in the Solar System



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

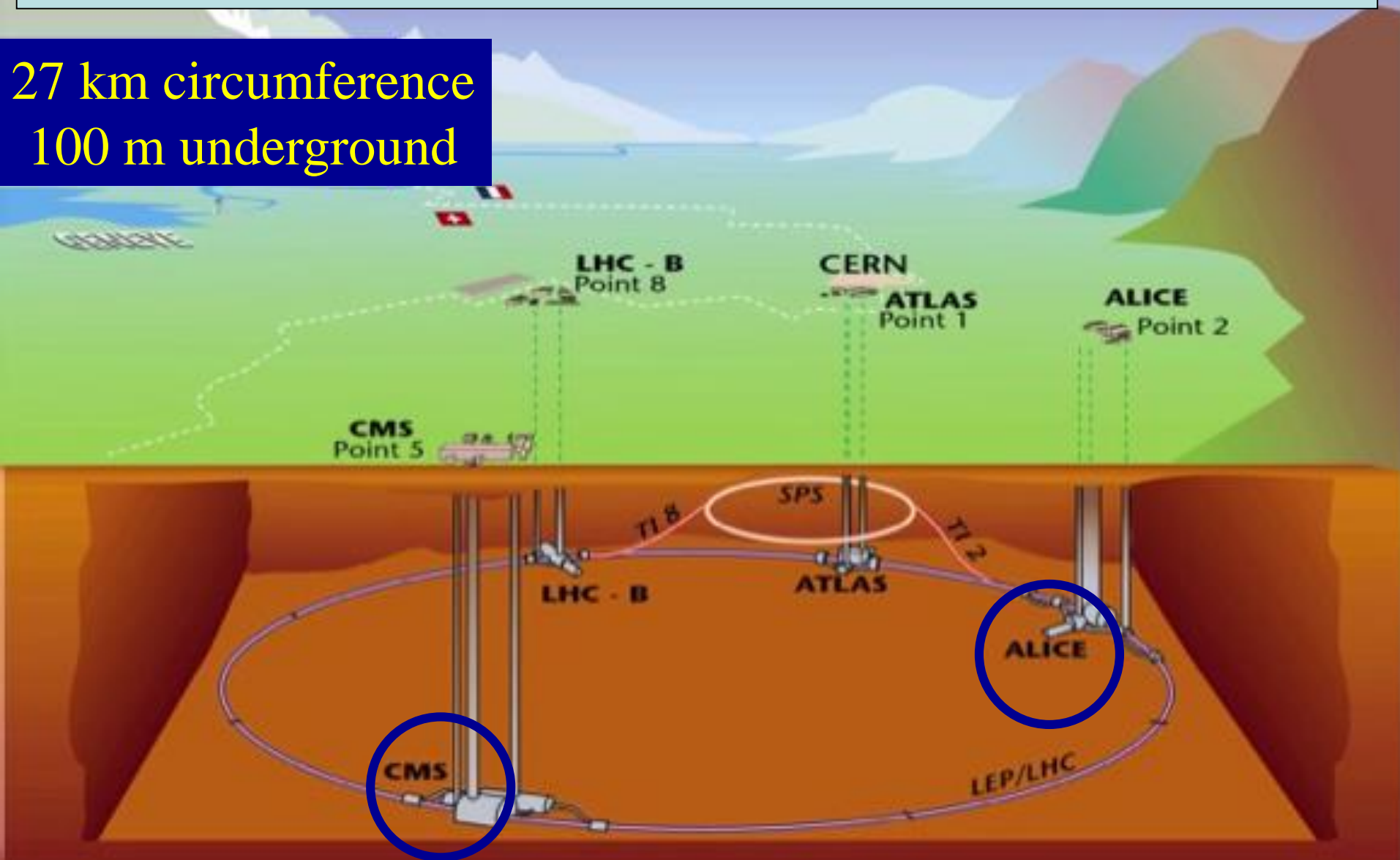
Cooler than Outer Space

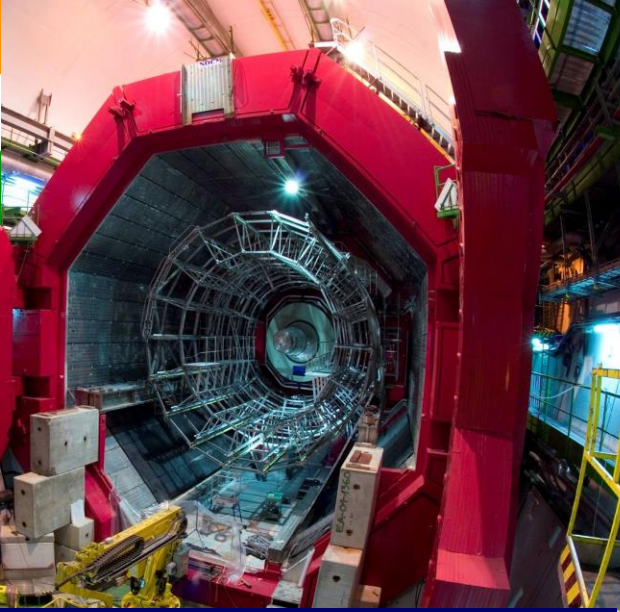


LHC 1.9 degrees above absolute zero = - 271 C
Outer space 2.7 degrees above zero = - 270 C

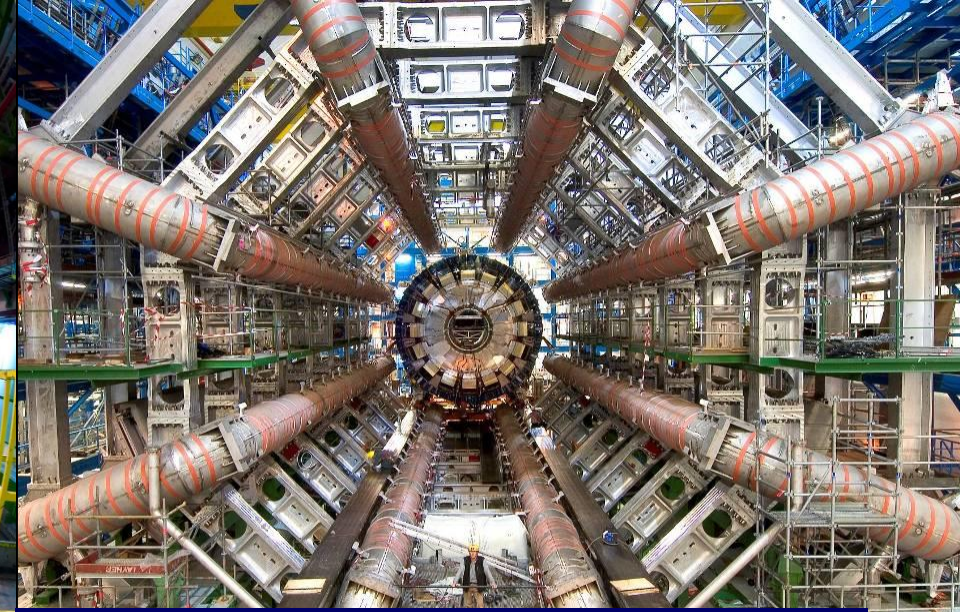
Overall View of the LHC and its Experiments

27 km circumference
100 m underground

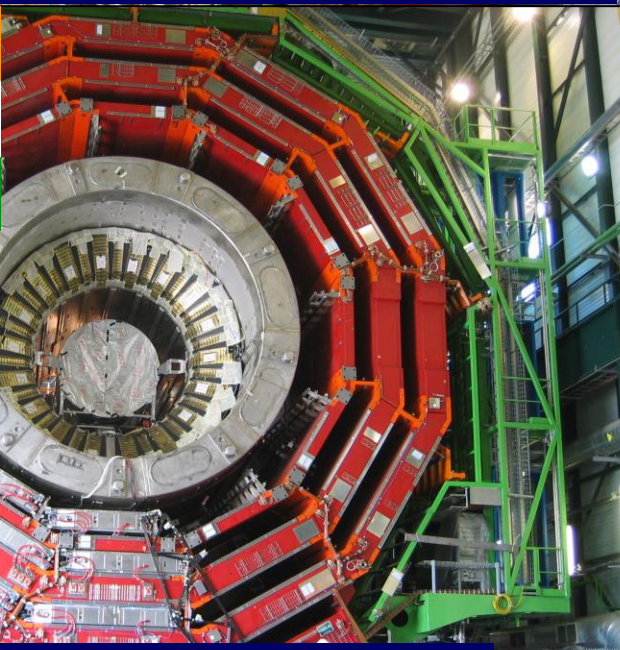




ALICE: Primordial cosmic plasma



ATLAS: Higgs and dark matter

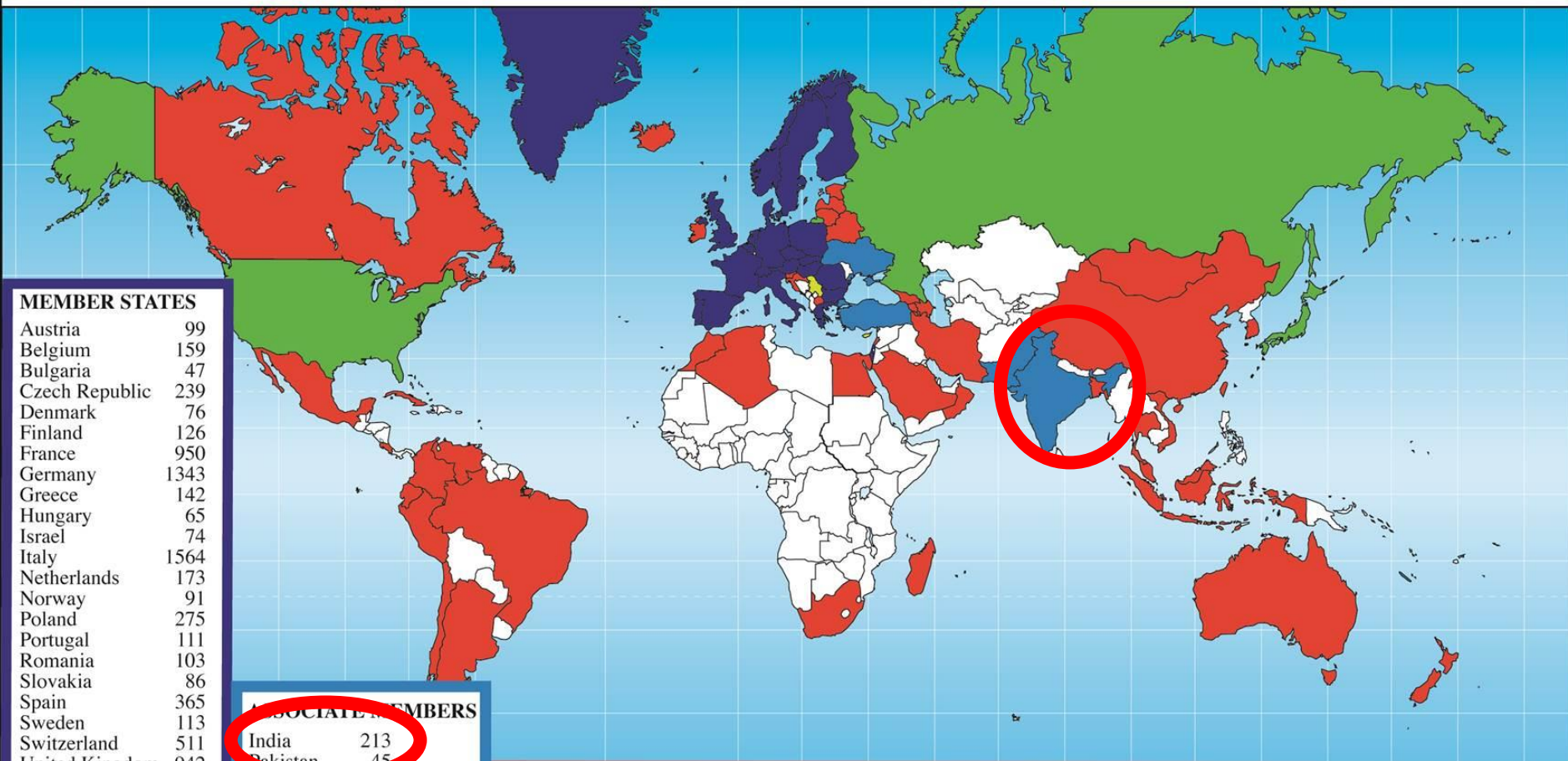


CMS: Higgs and dark matter



LHCb: Matter-antimatter difference

Scientists from around the World



MEMBER STATES

Austria	99
Belgium	159
Bulgaria	47
Czech Republic	239
Denmark	76
Finland	126
France	950
Germany	1343
Greece	142
Hungary	65
Israel	74
Italy	1564
Netherlands	173
Norway	91
Poland	275
Portugal	111
Romania	103
Slovakia	86
Spain	365
Sweden	113
Switzerland	511
United Kingdom	942

7654

ASSOCIATE MEMBERS

India	213
Pakistan	45
Turkey	128
Ukraine	30

416

OBSERVERS

Japan	294
Russia	1046
USA	2018

3358

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP

Cyprus	15
Serbia	35

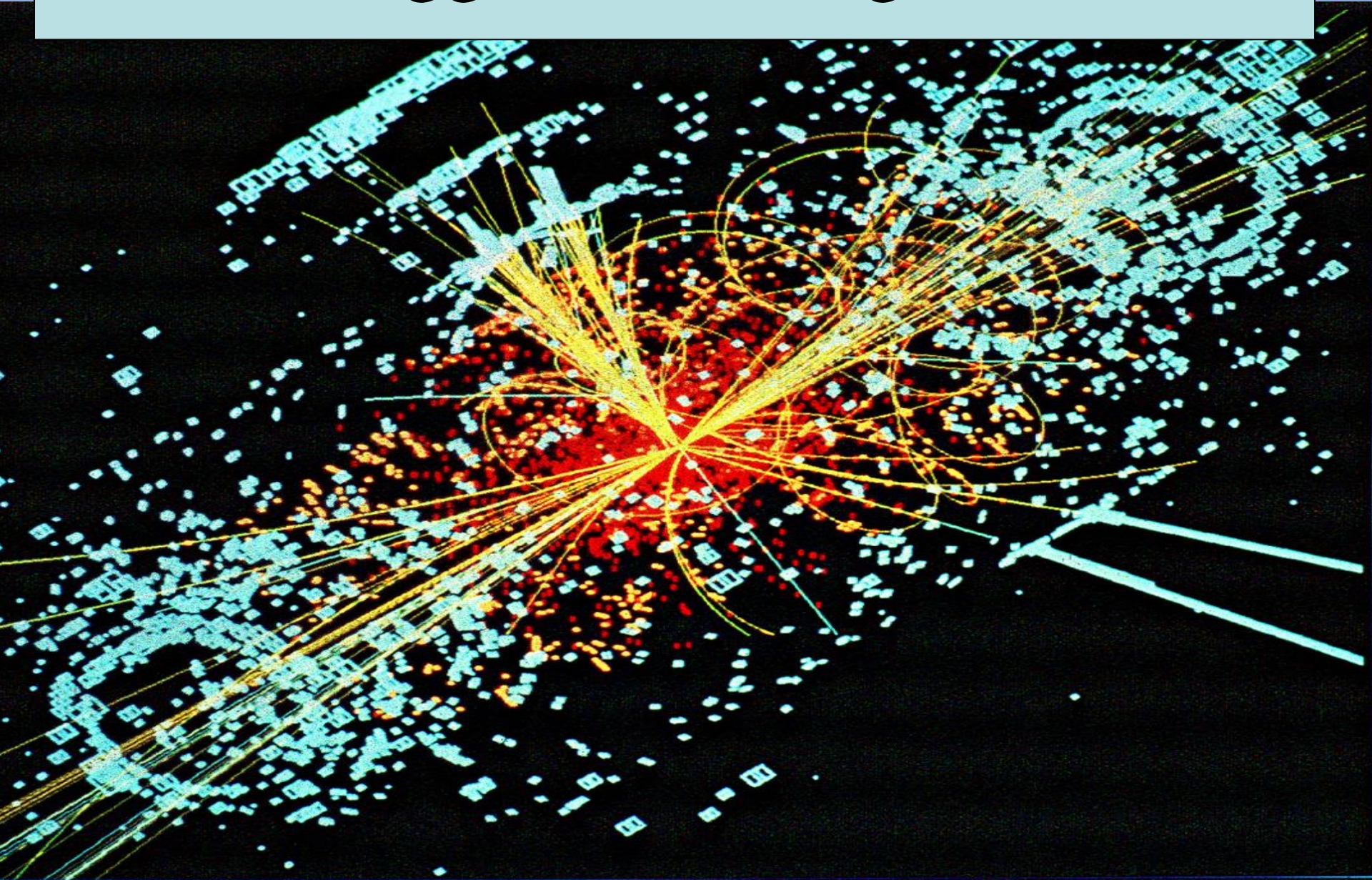
50

OTHERS

Algeria	1	Chile	19	Hong Kong	21	Malaysia	12	Slovenia	22
Argentina	24	China	216	Iceland	5	Malta	9	South Africa	58
Armenia	19	Colombia	21	Indonesia	9	Mexico	60	Taiwan	74
Australia	39	Costa Rica	1	Iran	34	Mongolia	2	Thailand	17
Azerbaijan	3	Croatia	27	Ireland	9	Morocco	10	TFYROM	2
Bangladesh	4	Cuba	3	Korea	163	New Zealand	8	Venezuela	1
Belarus	23	Ecuador	2	Latvia	1	Oman	3	Viet Nam	1
Brazil	136	Egypt	27	Lebanon	3	Peru	3		
Canada	180	Estonia	16	Lithuania	17	Saudi Arabia	1		
		Georgia	26	Madagascar	2	Singapore	4		

1338

What a Higgs Boson might look like

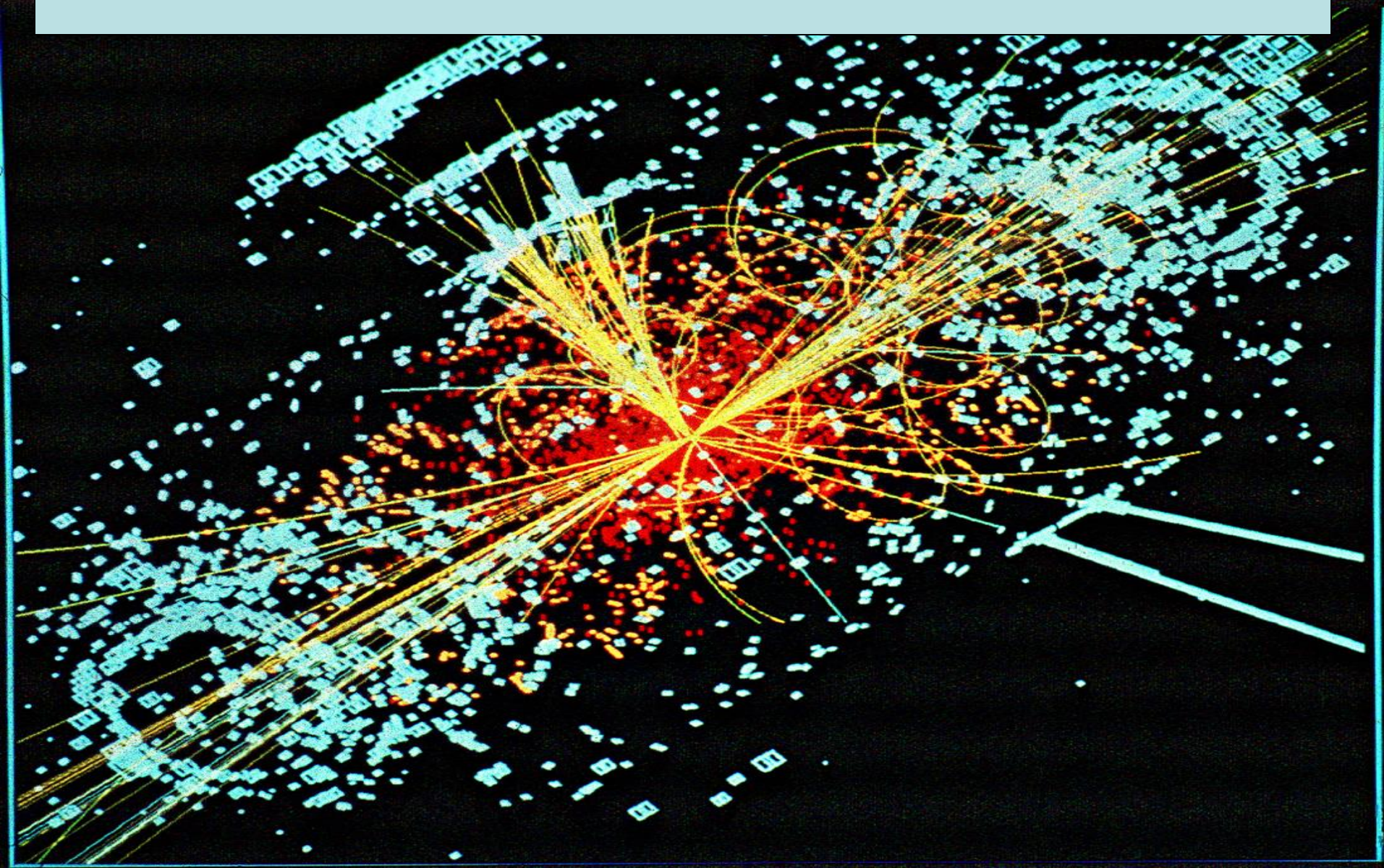


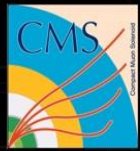
The Discovery of the Higgs Boson



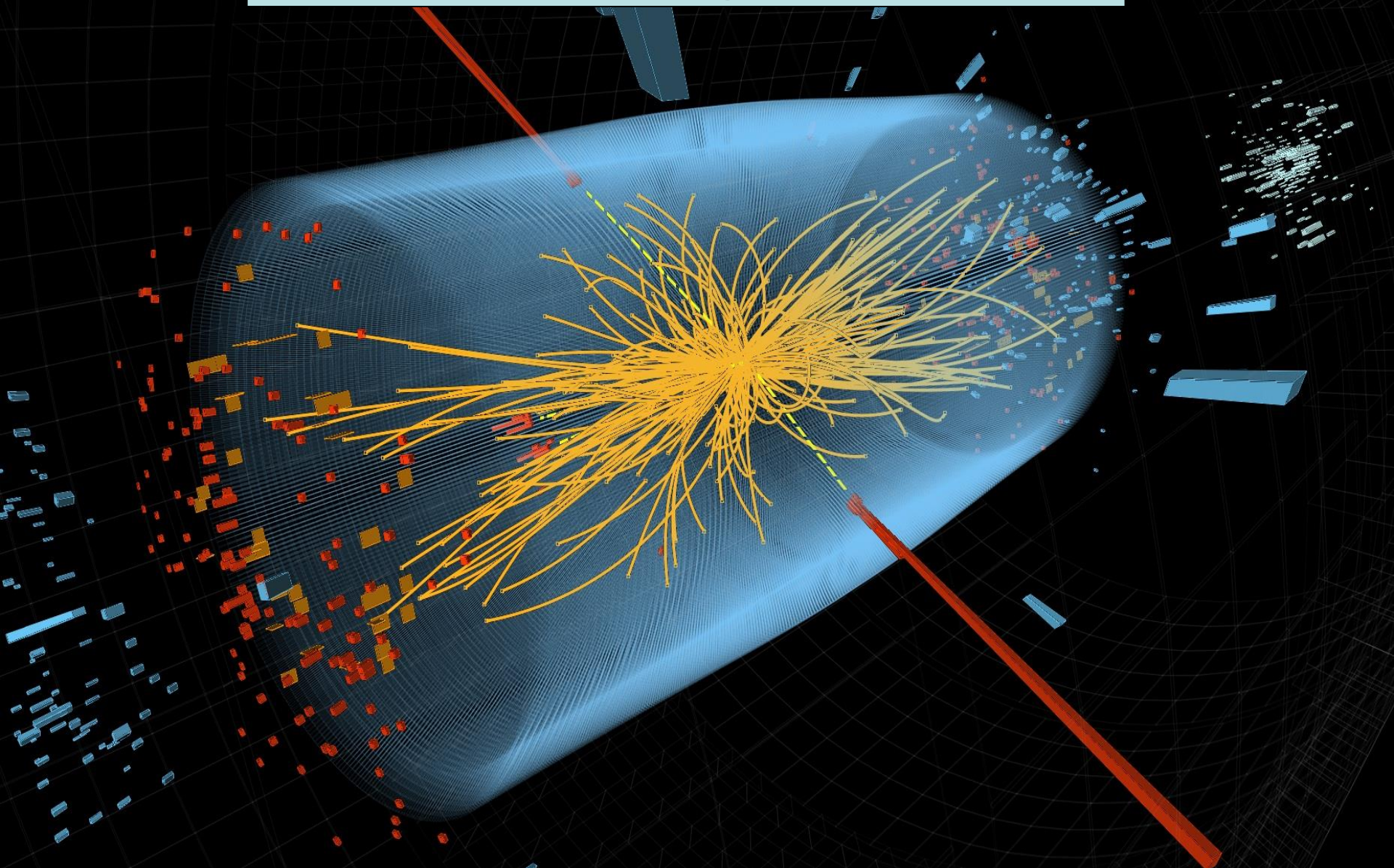
Mass Higgsteria

A Simulated Higgs Event @ LHC

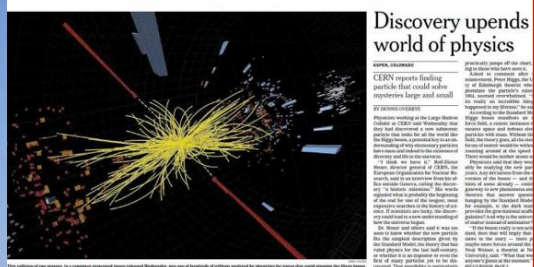




Interesting Events



July 4th 2012 The discovery of a new particle



Discovery upends world of physics

CERN reports finding particle that could solve mysterious large and small...
Physicists have found a new particle, one that could solve some of the most mysterious puzzles in physics. The discovery, announced Thursday by the European Organization for Nuclear Research (CERN), is a major breakthrough in particle physics.



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 boson de Higgs, particule manquante pour expliquer l'univers, vient d'être découvert
Les physiciens du CERN de Genève ont prouvé l'existence d'une particule...



The Gazette
EL PAIS
falloa la partícula clave para a comprensión del universo
La Audiencia Nacional imputa a toda la cúpula de Bankia

MK
ПОСЛЕДНИЙ КИРПИЧ В СТЕНУ МИРОЗДАНИЯ
«КРЕМЛЕВСКИЕ» САМОЛЕТЫ ПРИШЛОСЬ МЕНЯТЬ НА ПЕРЕГРABE
METPO CПУCТAT HA BOДY

AD ALGEMEEN DAGBLAD
EINDELIJK BELIJK NA 48 JAAR
Zieke Kaj en zij moeder toch samen in de VS
Finl Tote het Godelnabme in Karlsruhe

Frankfurter Allgemeine
Masse macht's
Große Mehrheit im...
AD JUSTING ESSEL PRICE BETTER THAN TAKING CAR DONAZA FOR AS E

CHINADAILY
THE TIMES OF INDIA
Big bang moment: Scientists may have found 'God particle'
Adarsh scam: Finally, CBI chargesheets 13
আনন্দবাজার পত্রিকা
বিশ্বজ্ঞানের 'ঈশ্বর' দর্শন

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
CERN scientists hail discovery of Higgs boson

gazeta
Czastke Higgsa fizycy najpierw wymyślili, potem szukali 40 lat
BOSKA MASA

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

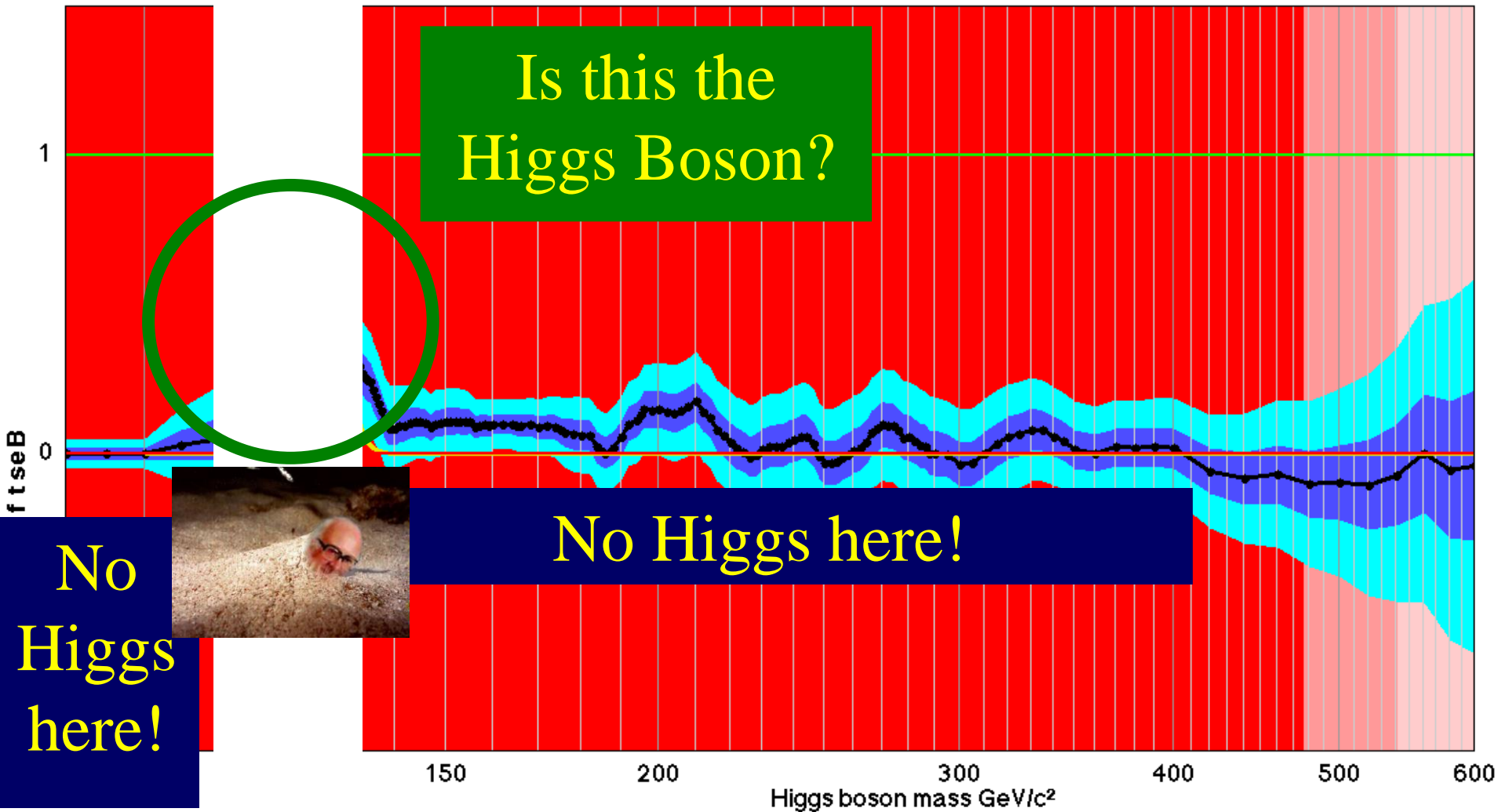
Higgsdependence Day!



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, characteristic of a jigsaw puzzle piece. The lighting is soft, creating subtle shadows and highlights on the edges of the puzzle pieces.

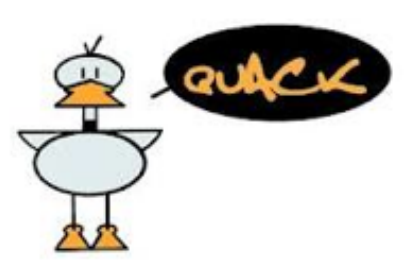
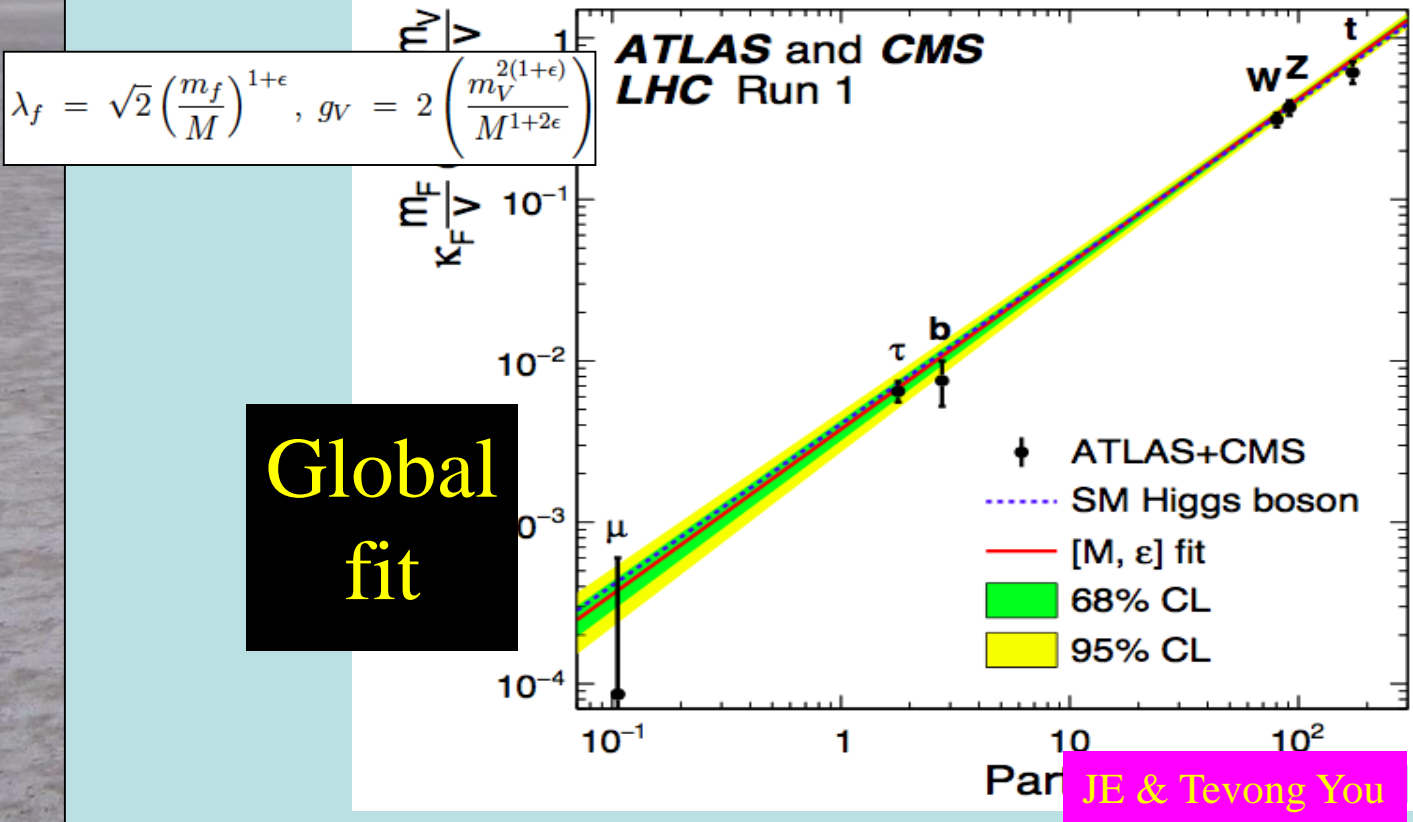
Is LHC finding the missing piece?

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 ?



JE & Tevong You

- Blue** dashed line = Standard Model

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!

Dixit Swedish Academy



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

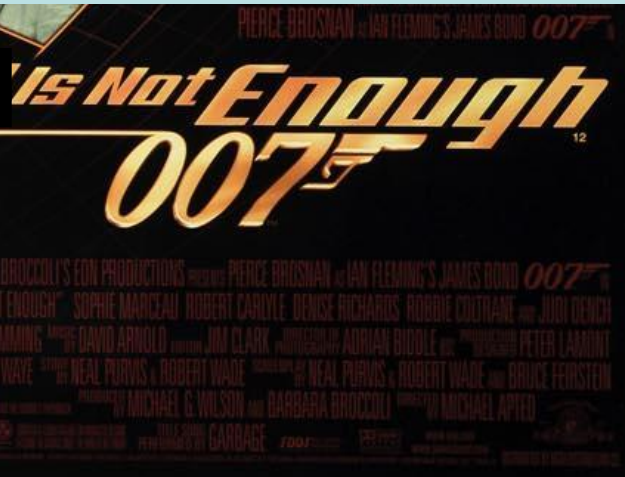
http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/advanced-physicsprize2013.pdf

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



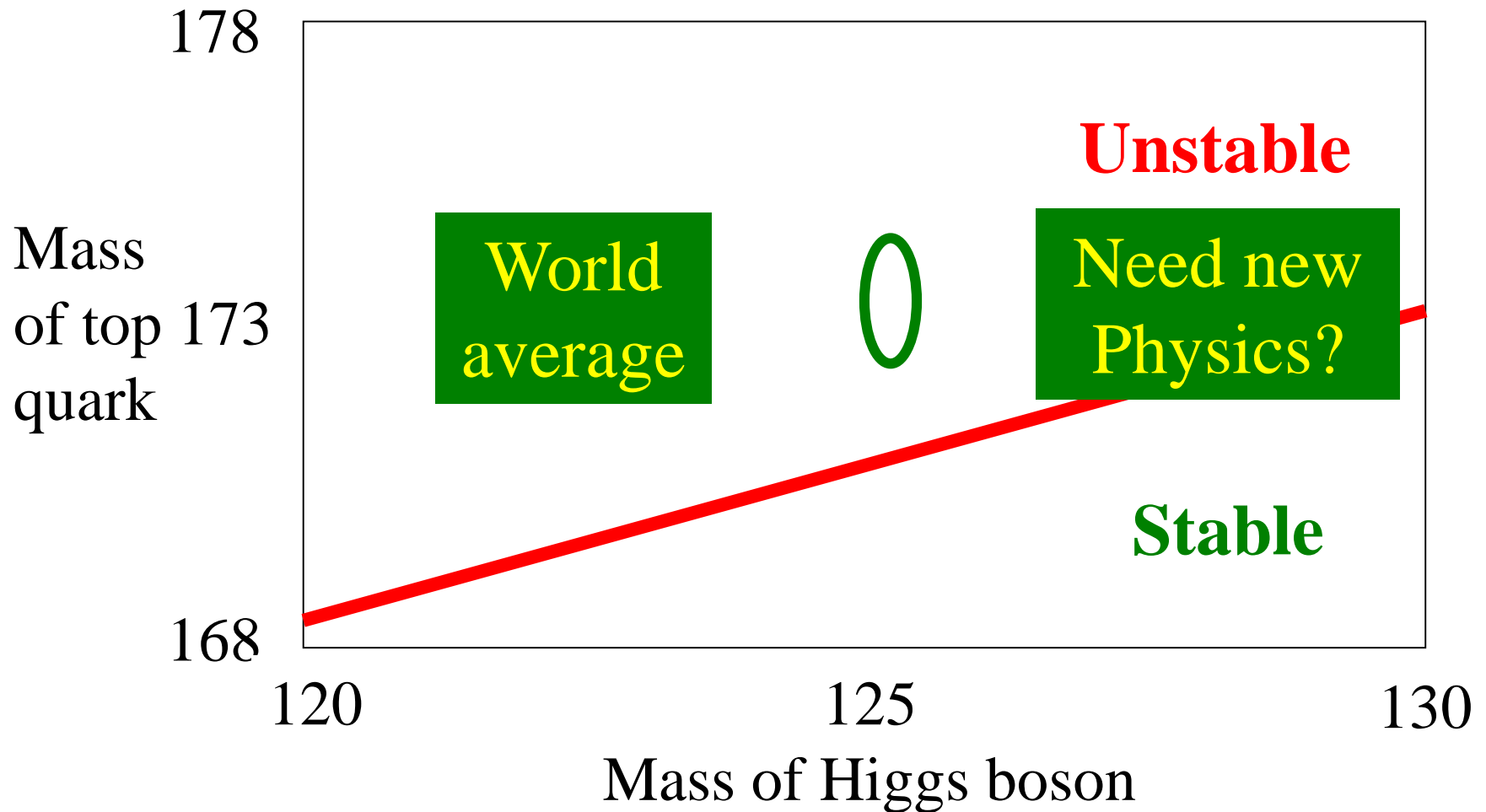
- « Empty » space is unstable **LHC**
- Dark matter **LHC**
- Origin of matter **LHC**
- Sizes of masses **LHC**
- Masses of neutrinos **LHC**
- Inflation **LHC**
- Quantum gravity
- ...

The Standard Model



Is “Empty Space” Unstable?

- Depends on masses of Higgs boson and top quark



Should it have Collapsed already?

Fluctuate over barrier
in the early Universe?

Not if
supersymmetry:
infinite barrier

We are here

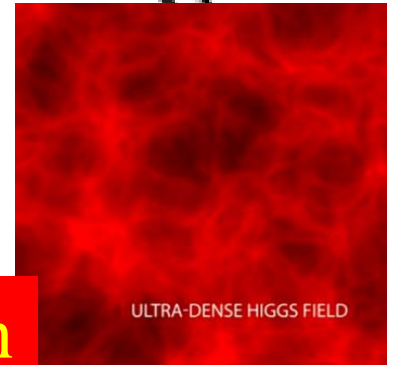


HIGGS FIELD

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?**



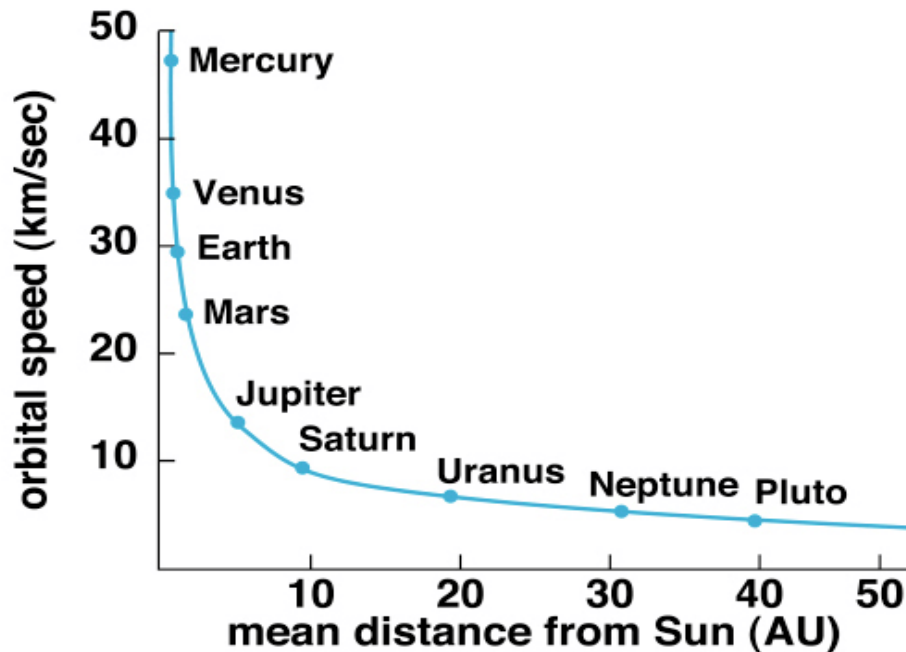
The Rotation Curves of Galaxies

- 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**



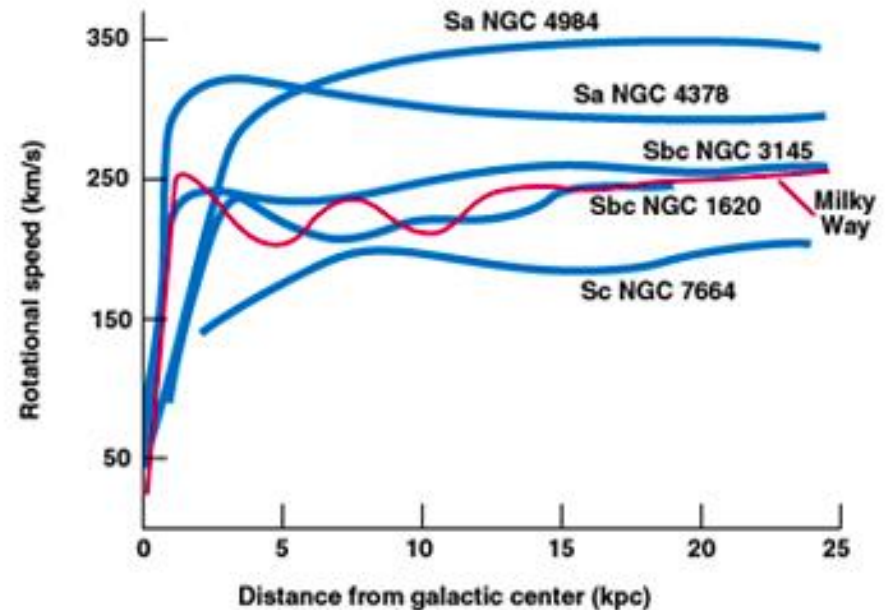
Rotation Curves

- In the Solar System



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

- In galaxies



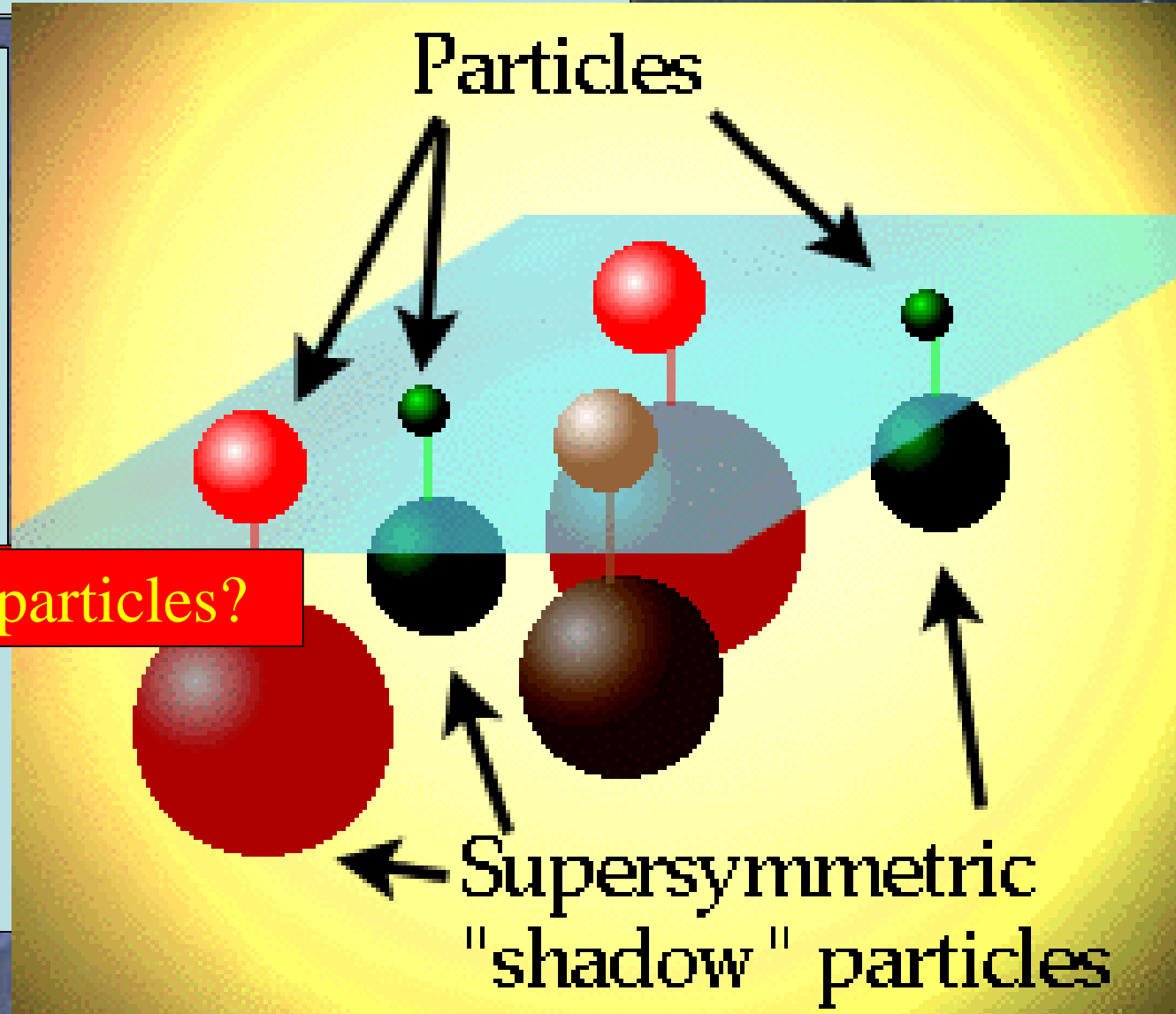
- The velocities do not decrease with distance
- Dark matter spread out

Dark Matter in the Universe

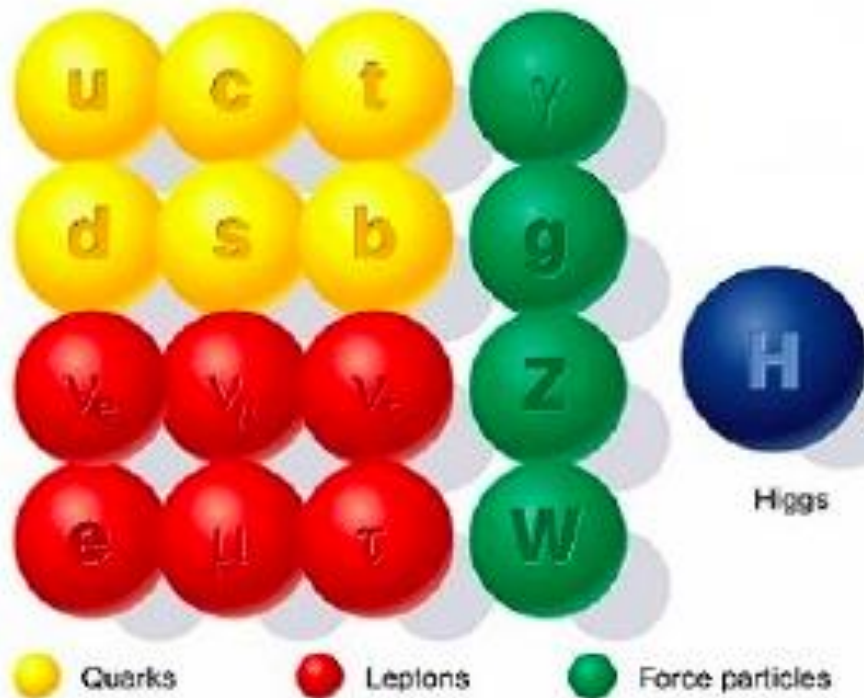
Astronomers say that most of the matter in the Universe is invisible Dark Matter

Supersymmetric particles?

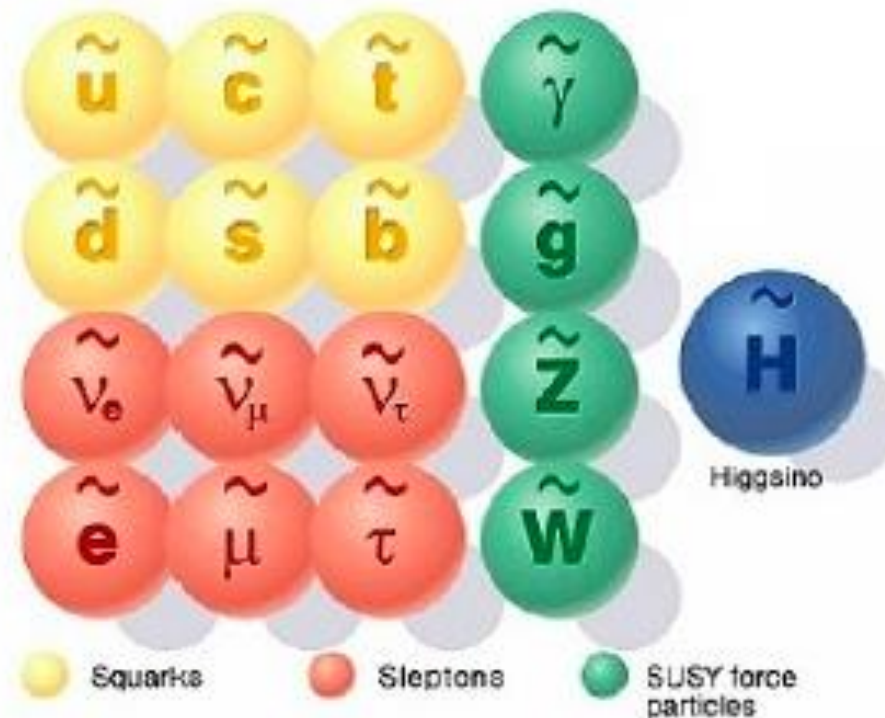
Searching for them at the LHC



Minimal Supersymmetric Extension of the Standard Model



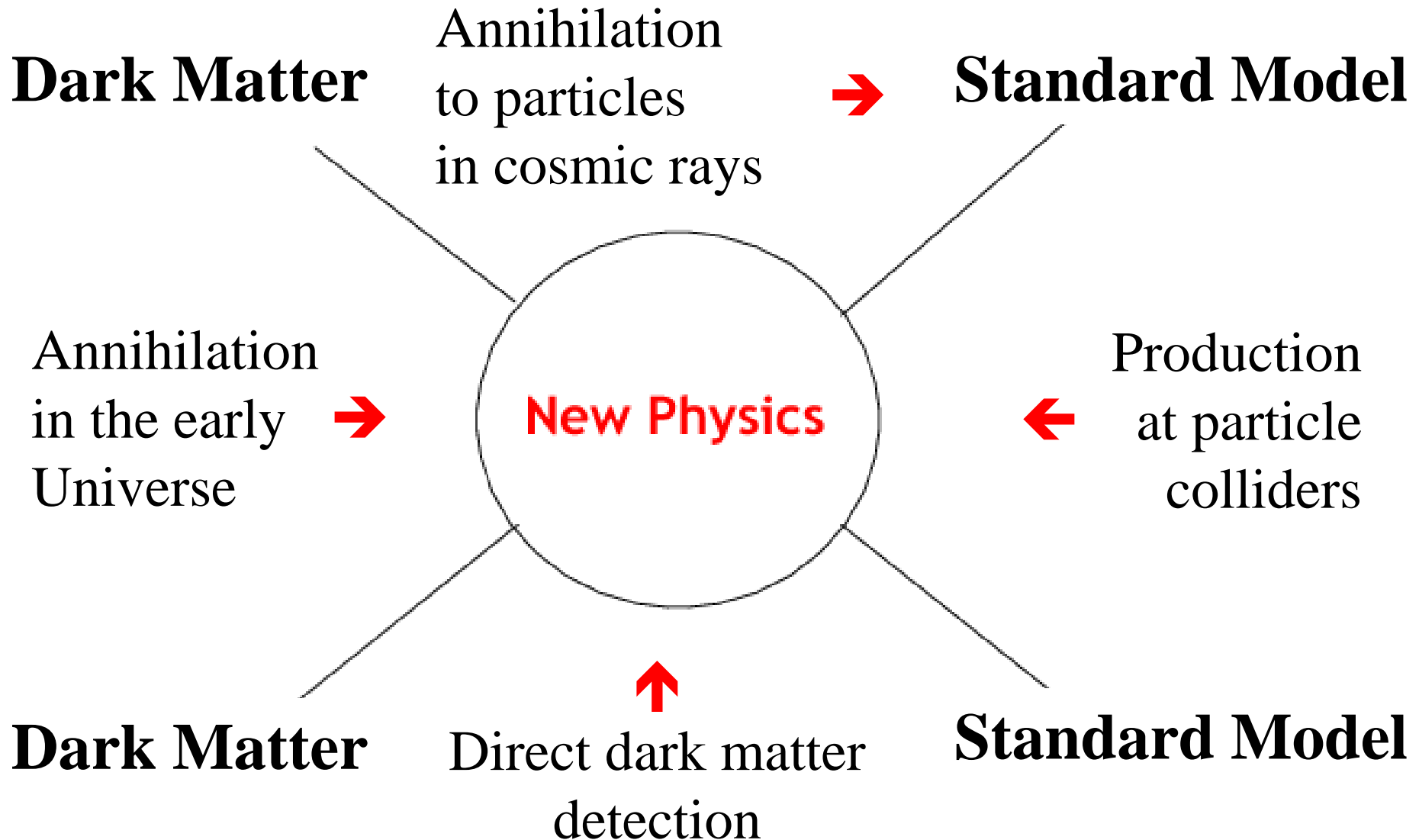
Standard particles



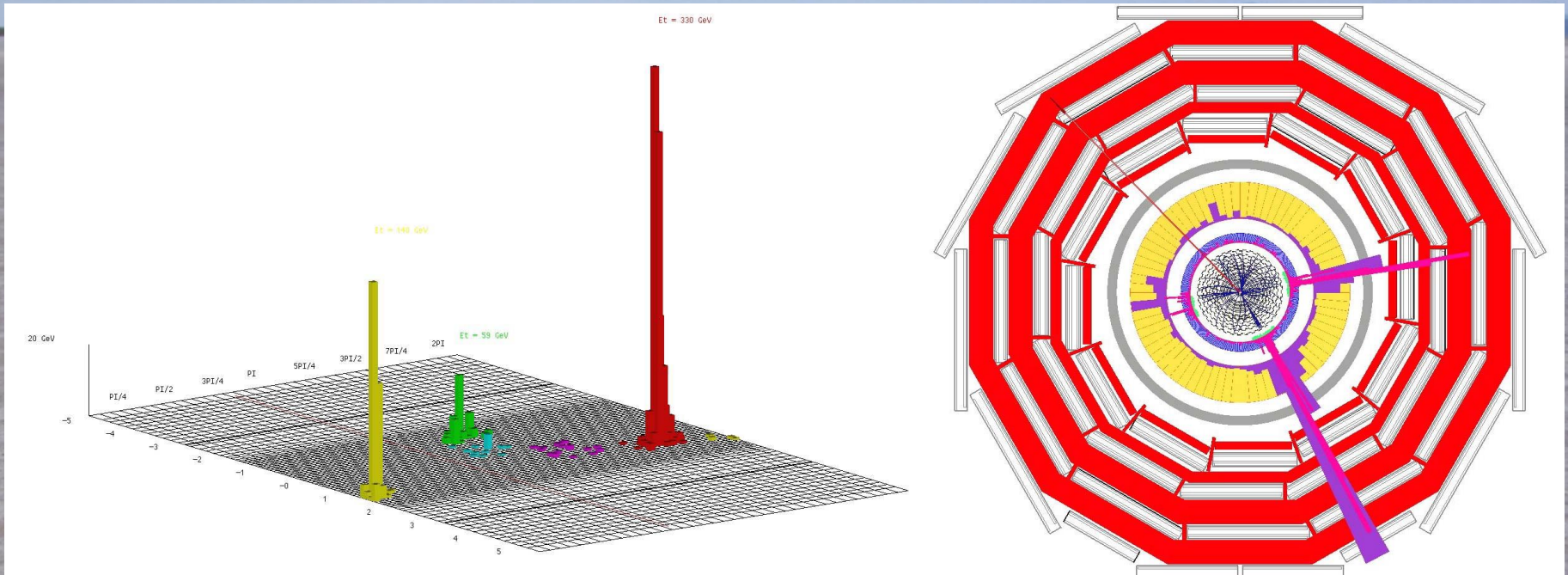
SUSY particles

Would help fix sizes of particle masses

Searches for Dark Matter



Search for Dark Matter at the LHC

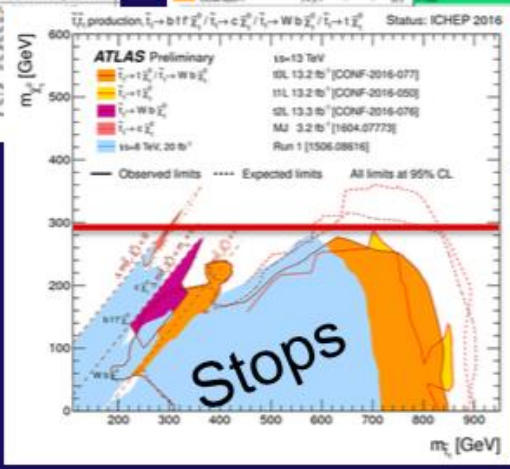
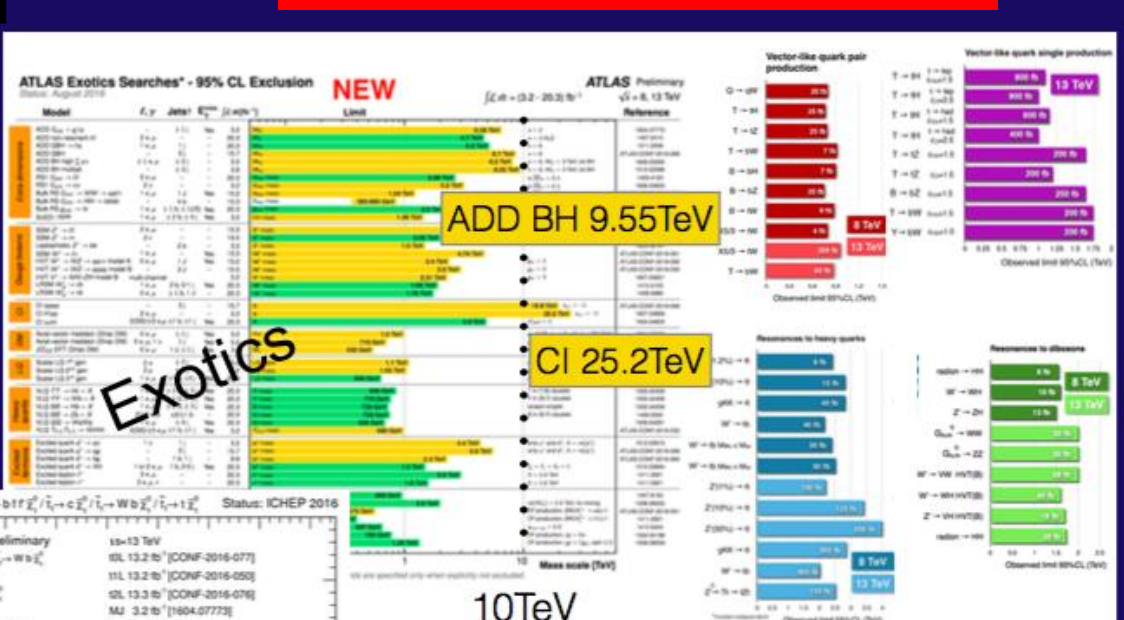


Missing transverse energy
carried away by dark matter particles

Nothing (yet) at the LHC

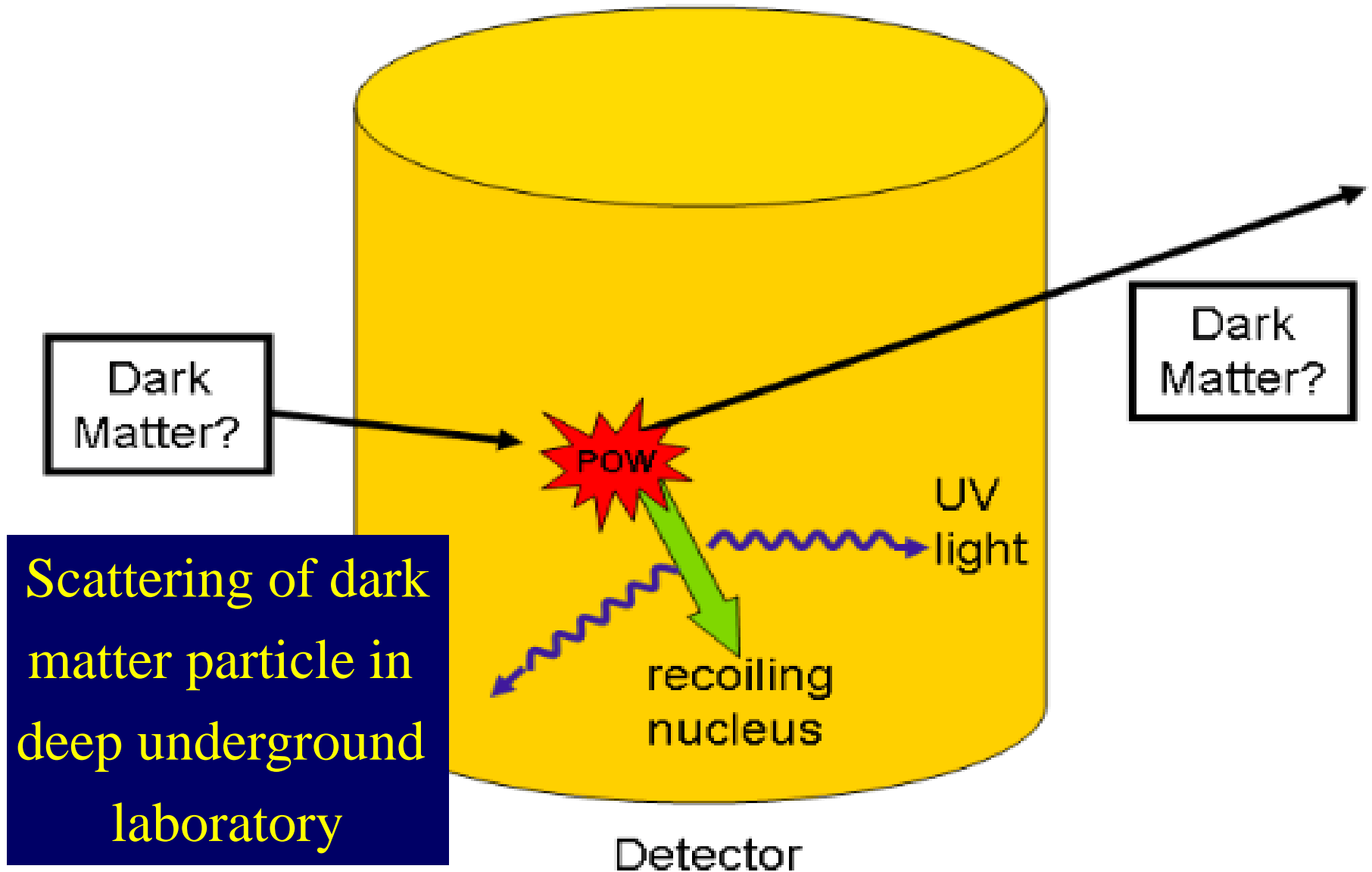
No supersymmetry

Nothing else, either



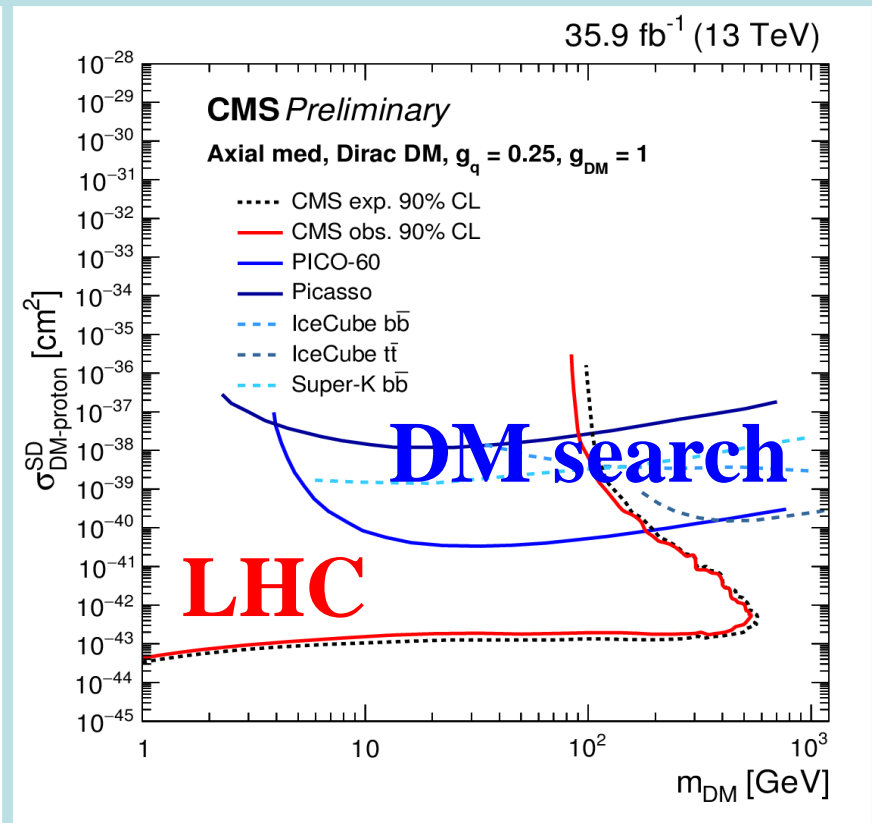
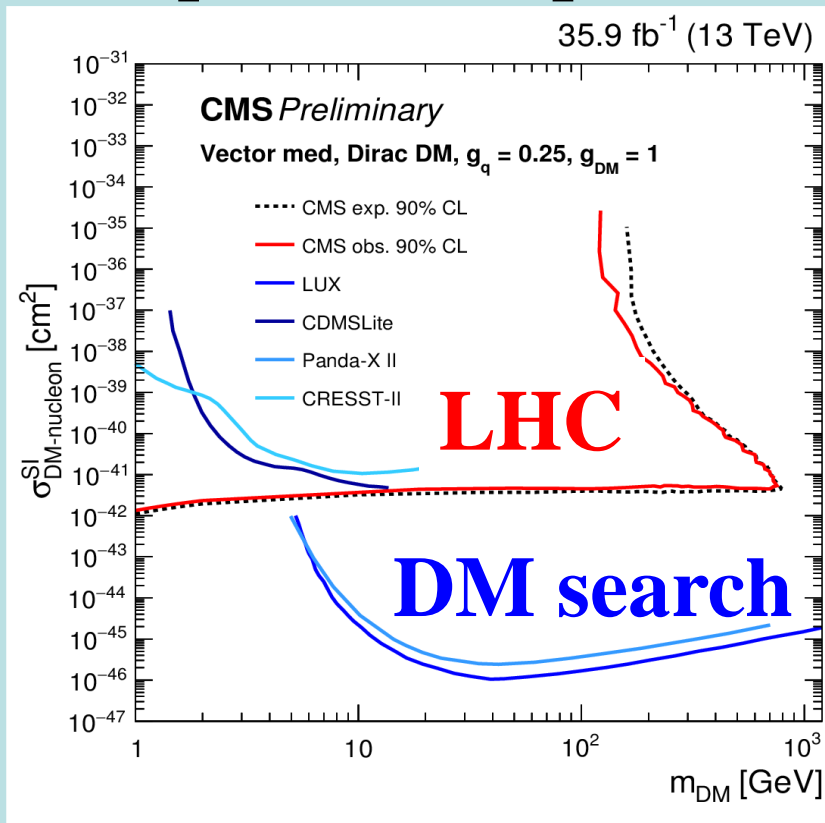
How else to search for Dark Matter?

Direct Dark Matter Detection



LHC vs Dark Matter Searches

- Compilation of present sensitivities



- Complementarity between LHC and direct searches

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?

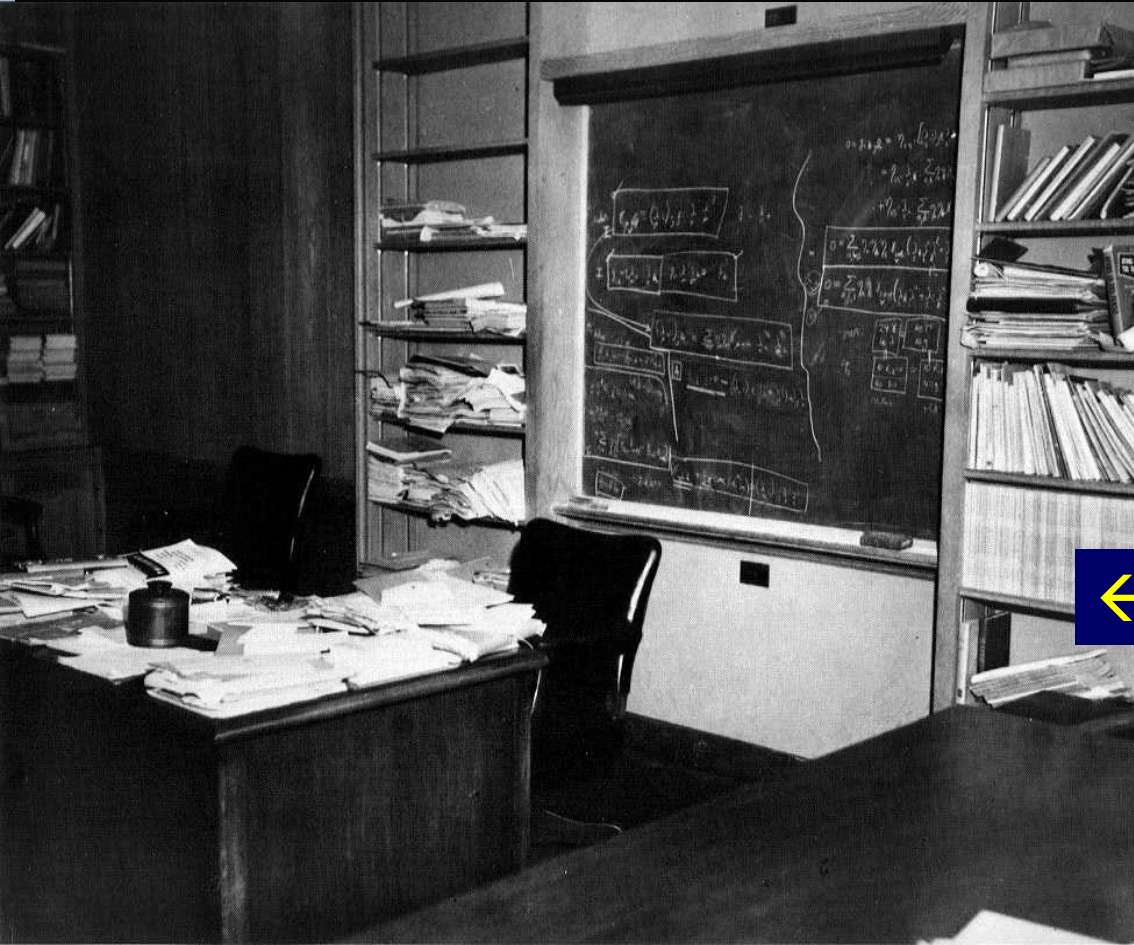
Sakharov

- 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



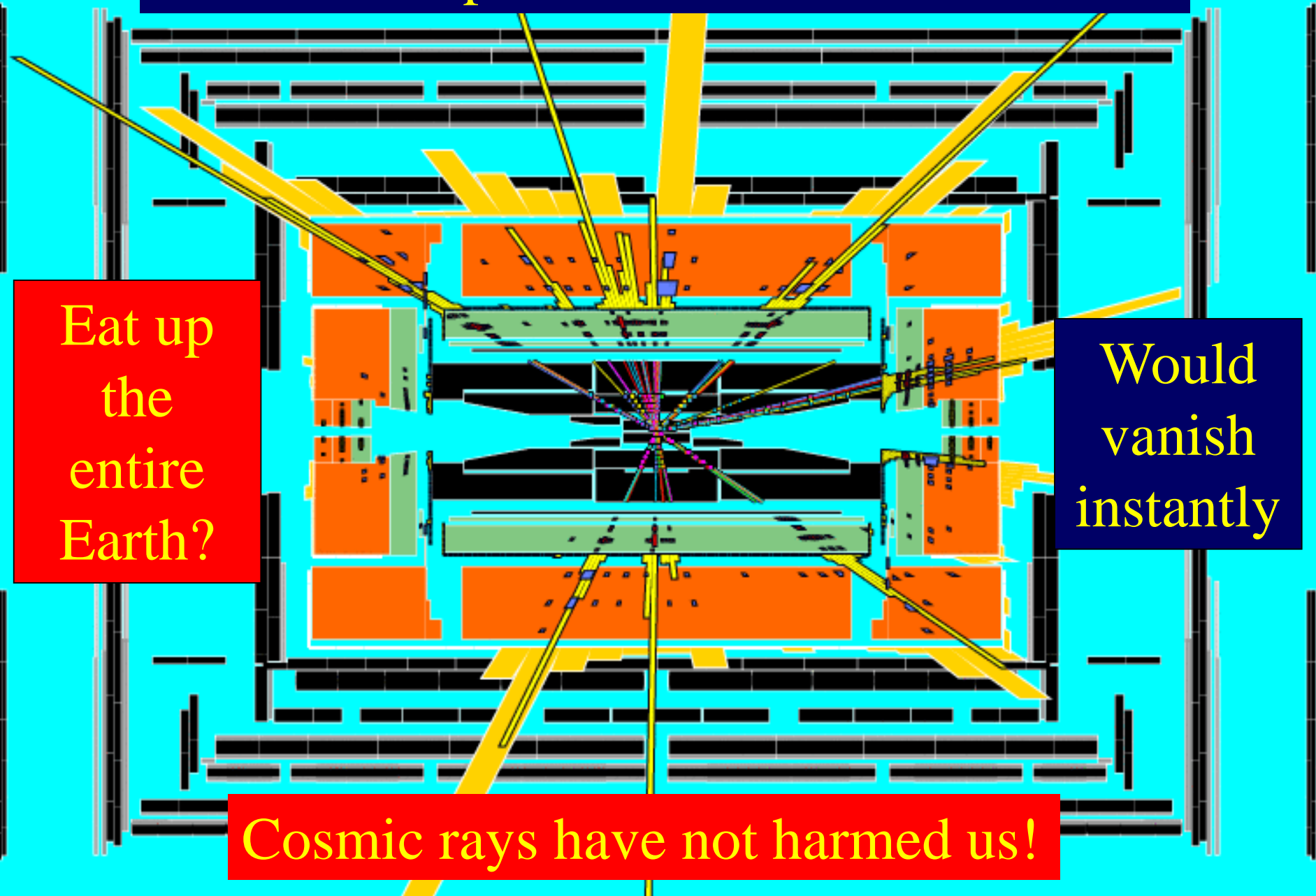
Unification via extra dimensions of space?

Will LHC experiments create black holes?

Eat up
the
entire
Earth?

Would
vanish
instantly

Cosmic rays have not harmed us!



Standard Model Particles: Years from Proposal to Discovery

Electron

Photon

Muon

Electron neutrino

Muon neutrino

Down

Strange

Up

Charm

Tau

Bottom

Gluon

W boson

Z boson

Top

Tau neutrino

HIGGS BOSON

Lovers of physics
Beyond the SM:
be patient!



Summary

Visible matter



Standard Model

**Dark Side
of the
Universe**