

Gauguin's Questions in Physics

*John ELLIS,
CERN, Geneva, Switzerland*

Where do we come from?

What are we?

Where are we going?



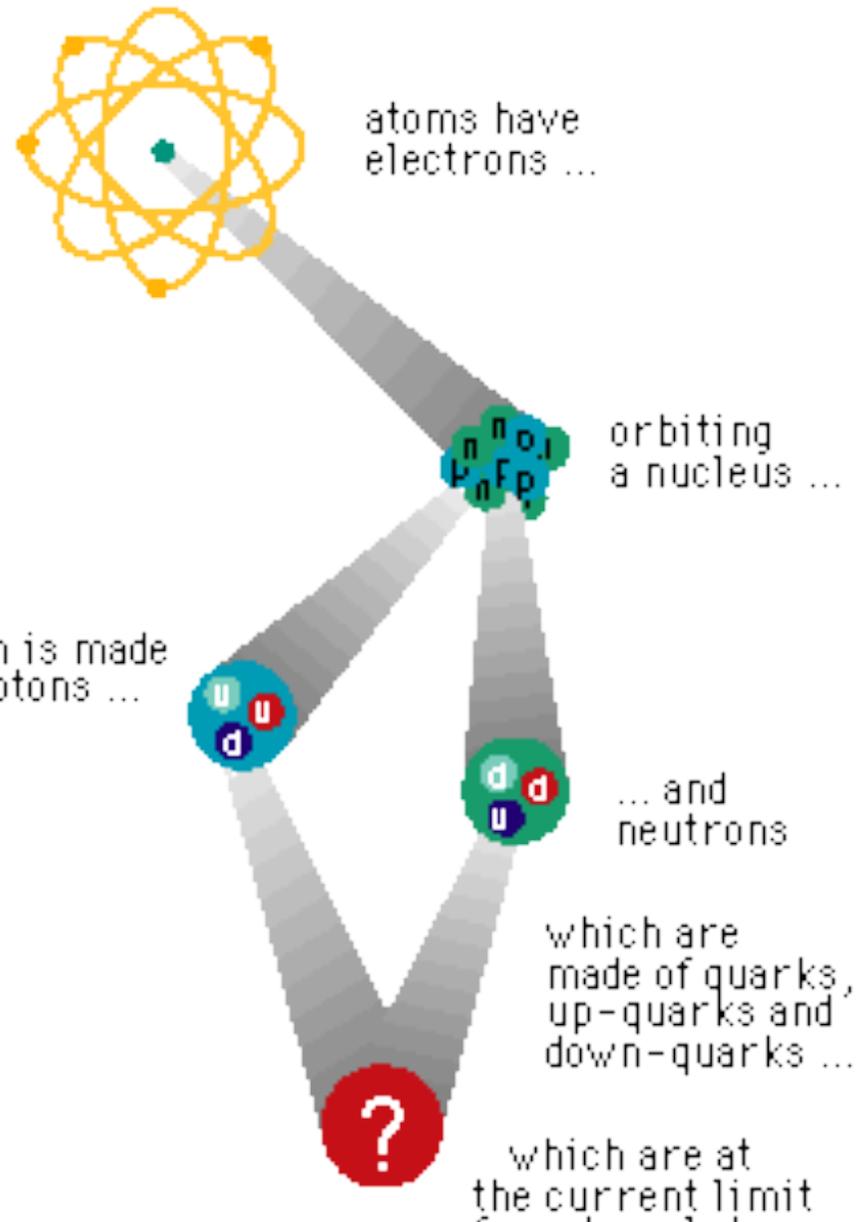
The aim of particle physics, CERN & the LHC:
What is the Universe made of?

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



All matter is made of the same constituents

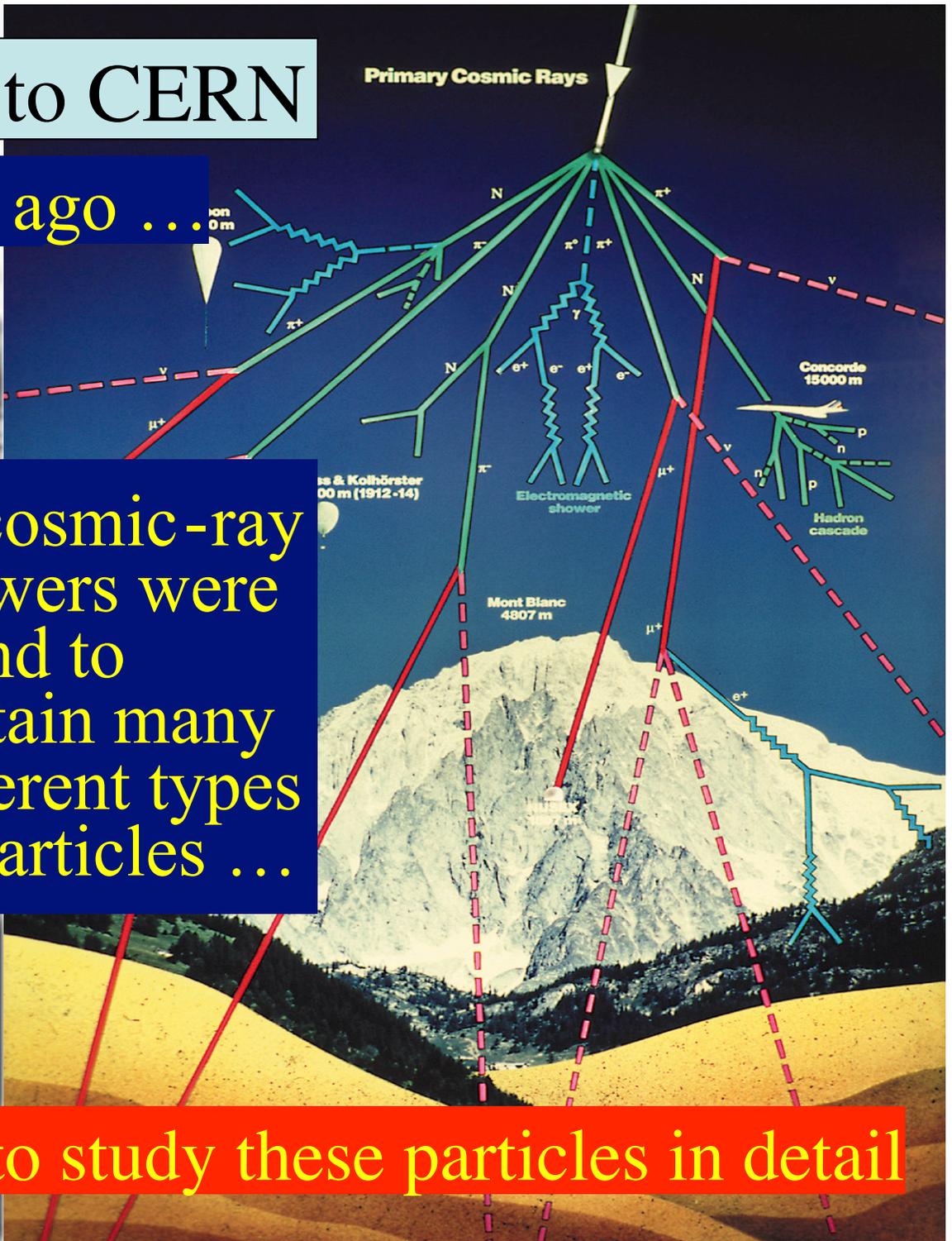
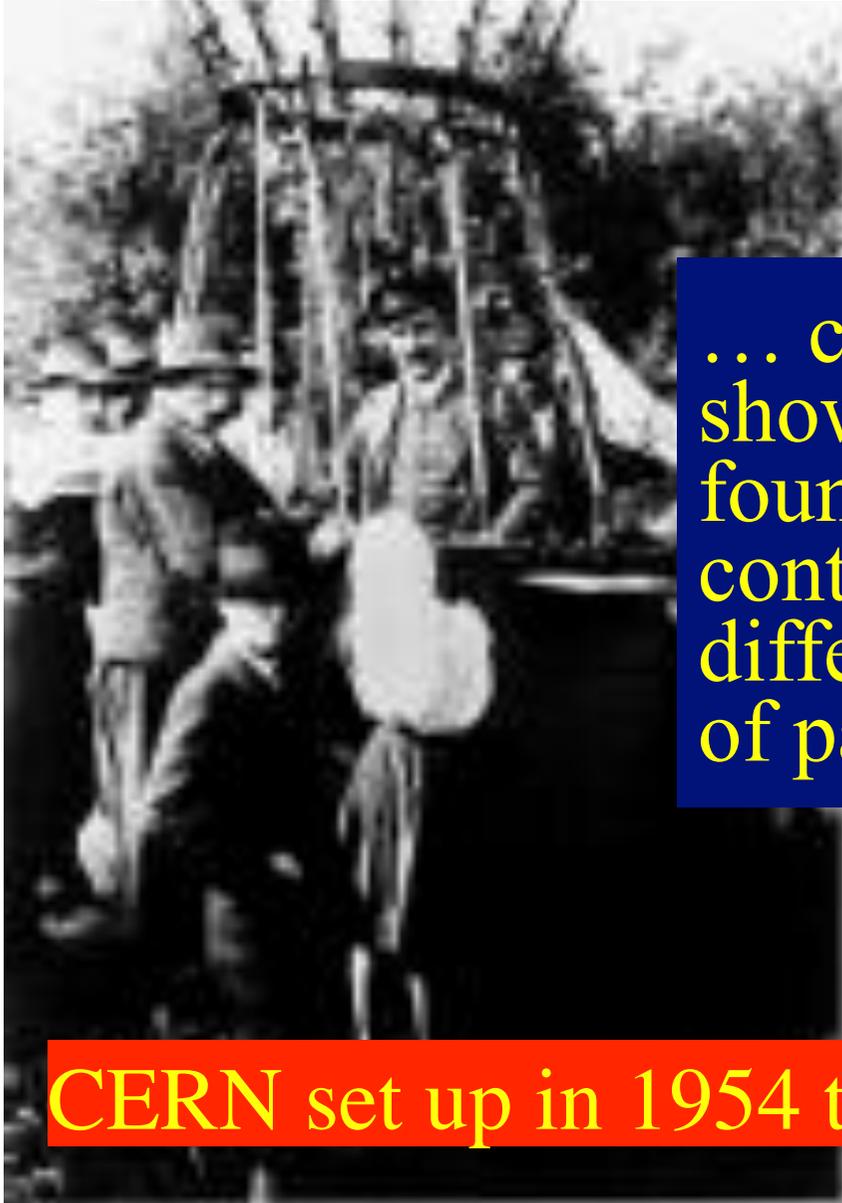
What are they?
What forces between them?

From Cosmic Rays to CERN

Discovered a century ago ...

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

CERN set up in 1954 to study these particles in detail



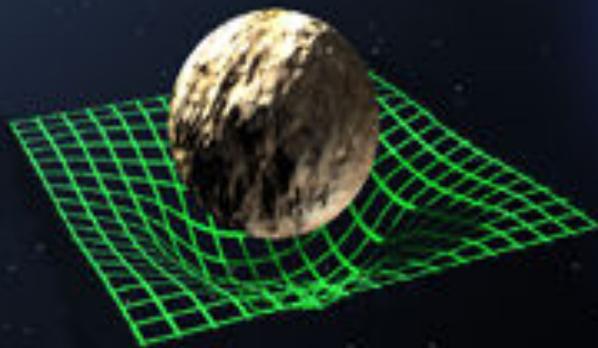
The 'Standard Model'

= Cosmic DNA

The matter particles



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)



Think of a Snowfield



Skier moves fast:

Like particle without mass
e.g., photon = particle of light



Snowshoer sinks into snow,
moves slower:



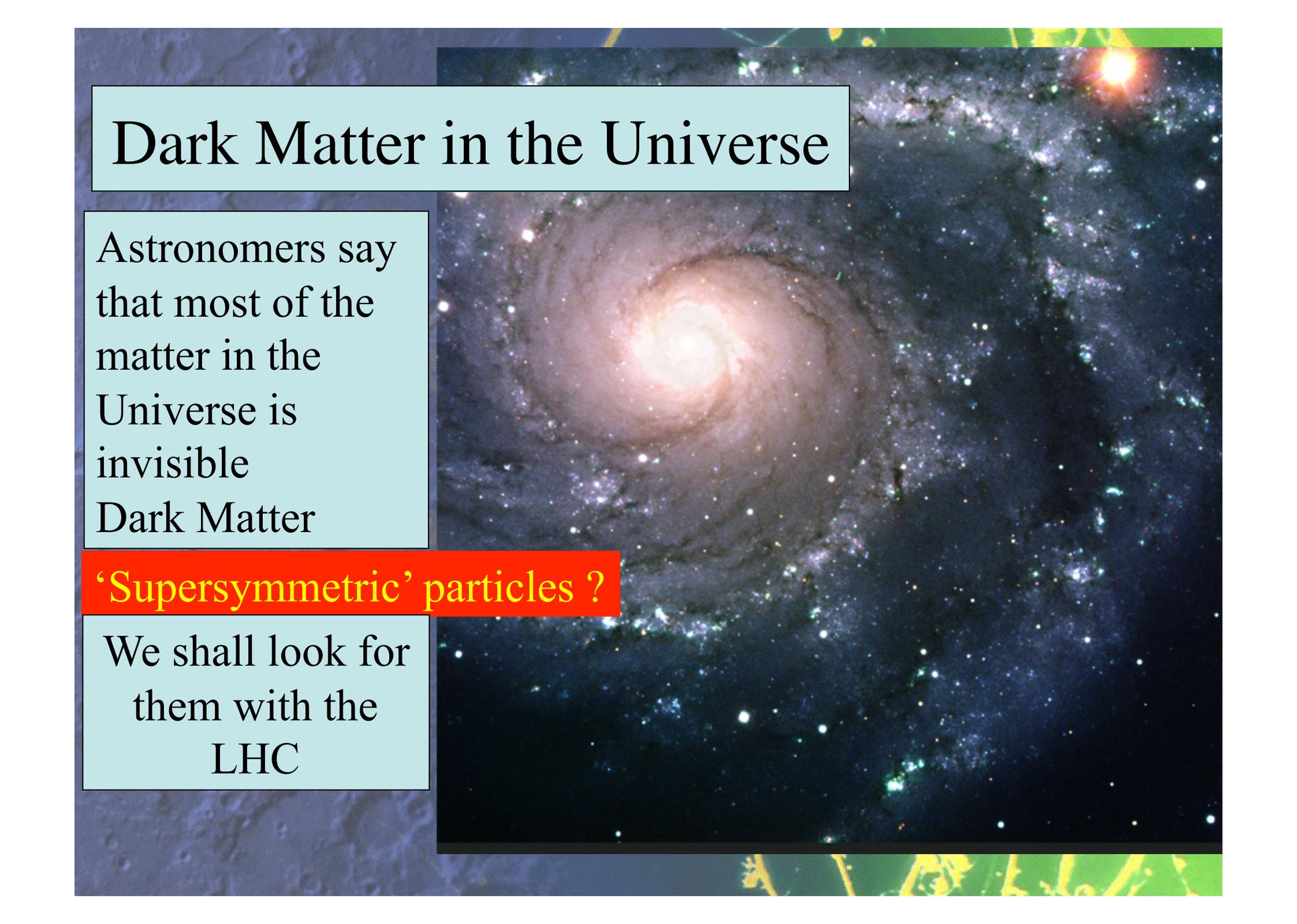
Like particle with mass
e.g., electron

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

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



Dark Matter in the Universe

The background of the slide is a composite image. On the left, there is a close-up of a spiral galaxy with a bright central core and several distinct spiral arms. On the right, there is a field of stars, with a prominent bright orange star in the upper right corner. The overall color palette is dark, with blues, purples, and oranges.

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

‘Supersymmetric’ particles ?

We shall look for
them with the
LHC

Supersymmetry?

- Would unify matter particles and force particles
- Related particles spinning at different rates

0 - 1/2 - 1 - 3/2 - 2

Higgs - Electron - Photon - Gravitino - Graviton

(Every particle is a 'ballet dancer')

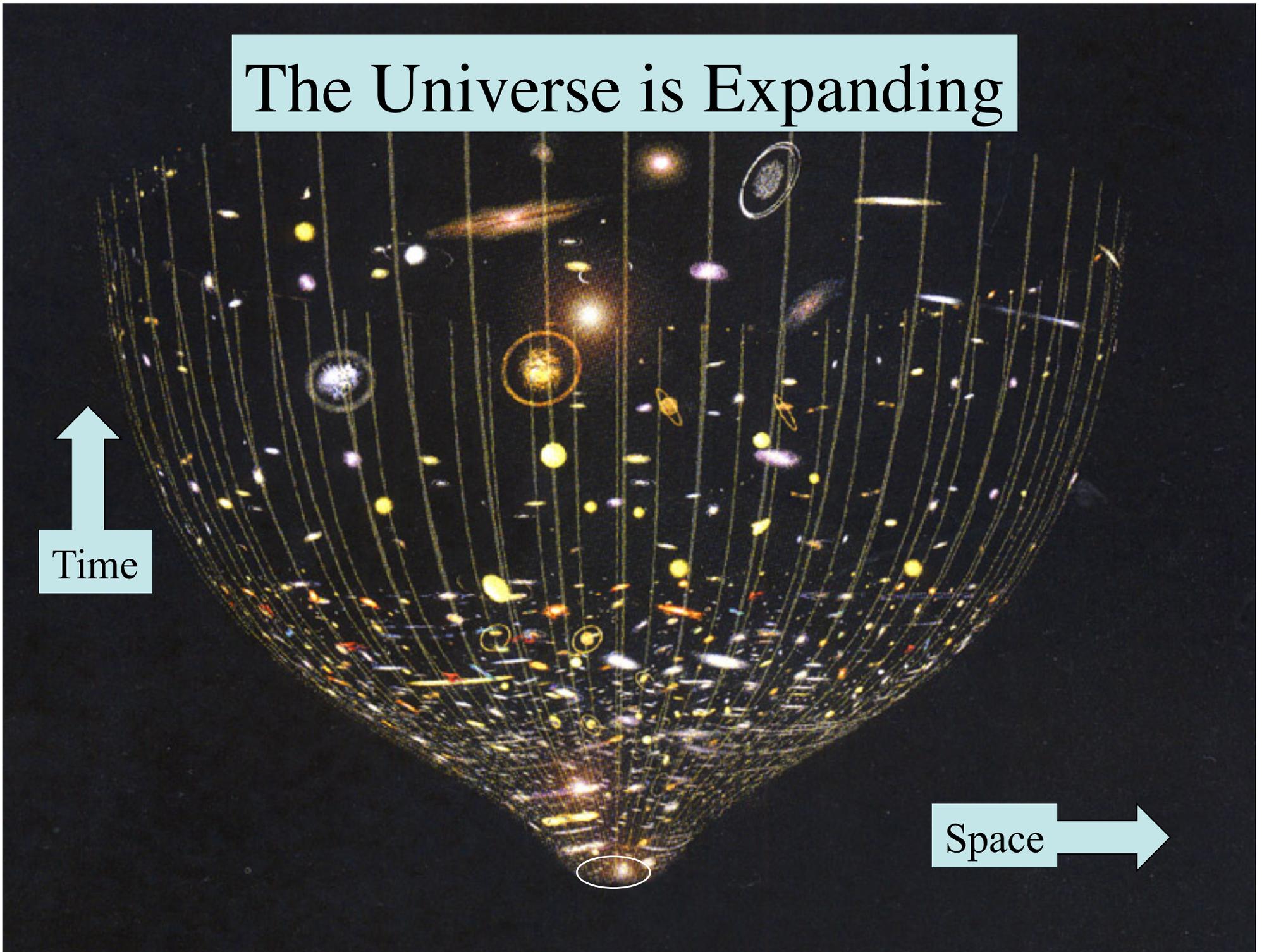
- Would help fix particle masses
- Would help unify forces
- Predicts light Higgs boson
- **Could provide dark matter for the astrophysicists and cosmologists**



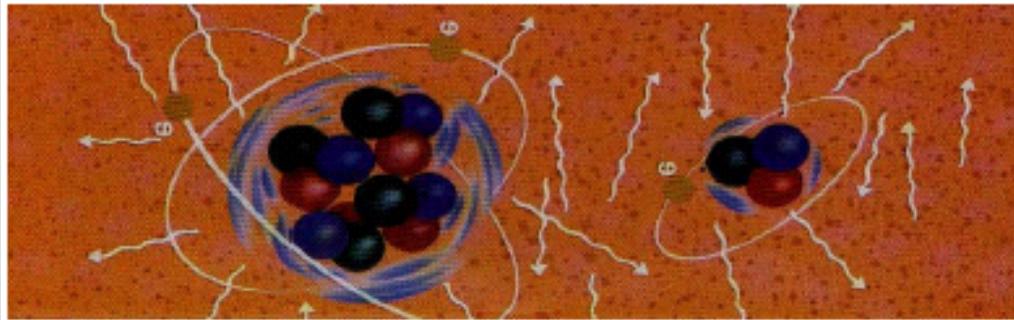
The Universe is Expanding

↑
Time

→
Space



300,000
years



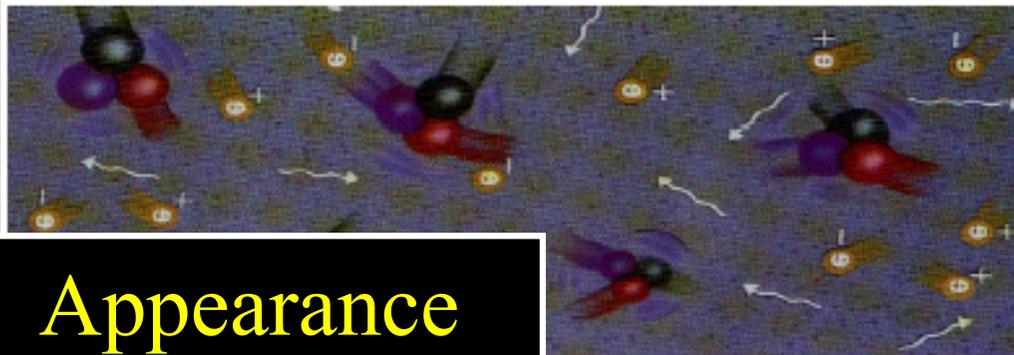
Formation
of atoms

3
minutes



Formation
of nuclei

1 micro-
second



Formation
of protons
& neutrons

1 pico-
second

Appearance
of dark matter?



Appearance
of mass?

BANG!

Where does the Matter come from?

Dirac predicted the existence of antimatter:
same mass
opposite internal properties:
electric charge, ...

Discovered in cosmic rays
Studied using accelerators



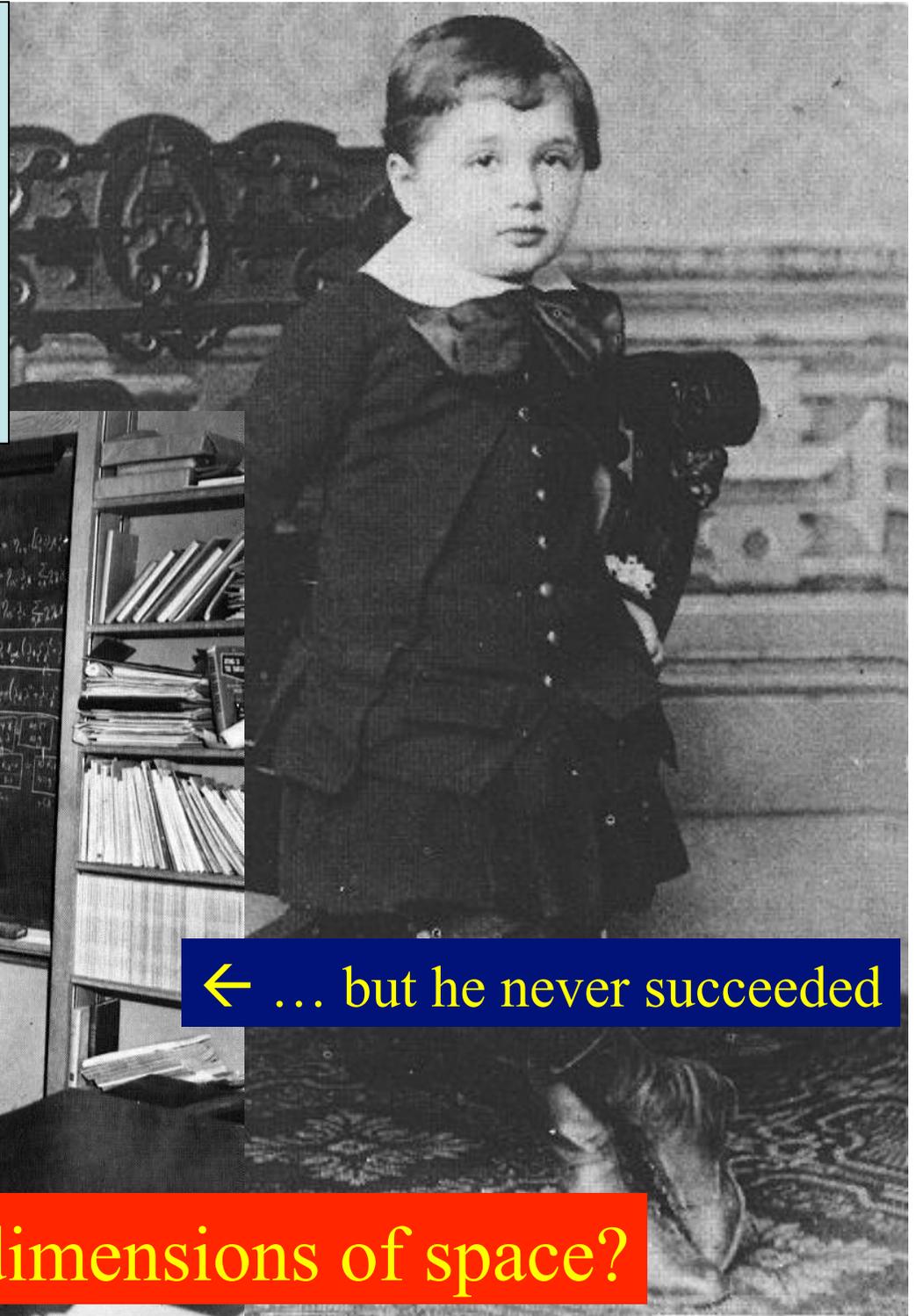
Matter and antimatter not quite equal and opposite: WHY?

2008 Nobel Physics Prize: Kobayashi & Maskawa

Is this why the Universe contains mainly matter, not antimatter?

LHC experiments will look for answer

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



← ... but he never succeeded

Maybe with extra dimensions of space?

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

F.A.Q.s

ABOUT THE

HADRON COLLIDER



Q: How does the Hadron Collider work?

A: You didn't even understand eleventh-grade math, so why are you asking?



Q: What would happen if I went inside it?

A: Just. Don't.



Q: How many miles of pipes and whatnot are in it?

A: A bajillion.

Q: How much did it cost?

A: Forty squillion.



Q: What does this thing do?

A: Don't touch that.

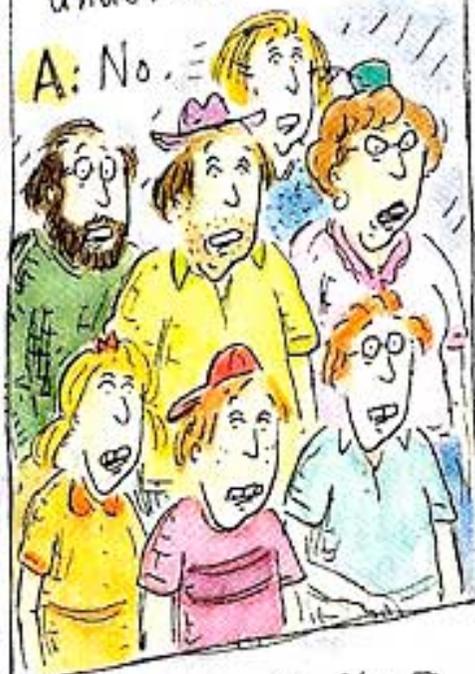


Q: What would happen if you, like, put a cat inside it?

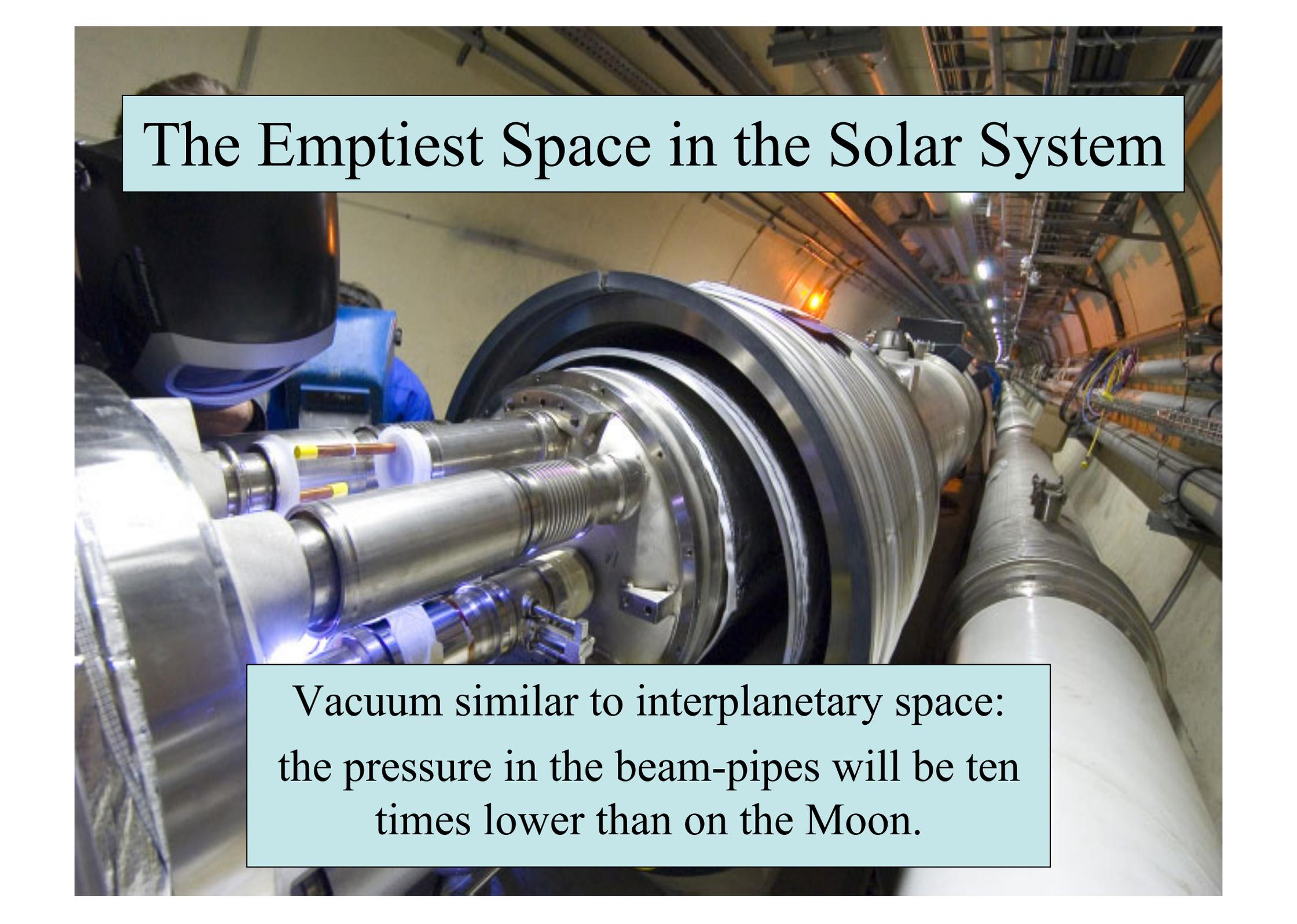
A: I don't know.

Q: If I concentrate ultra-hard, will I ever be able to understand it?

A: No.

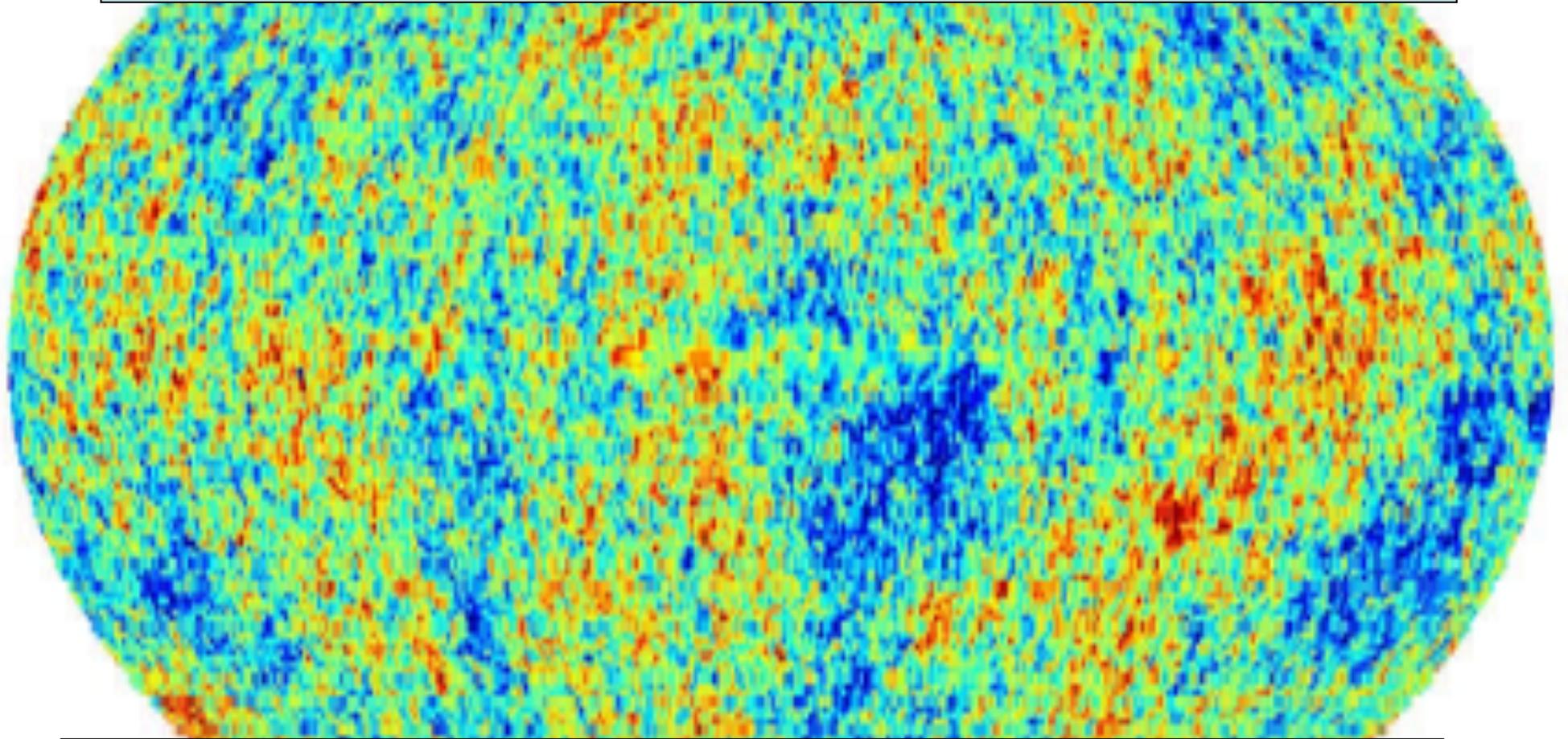


The Emptiest Space in the Solar System



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

Colder than Outer Space

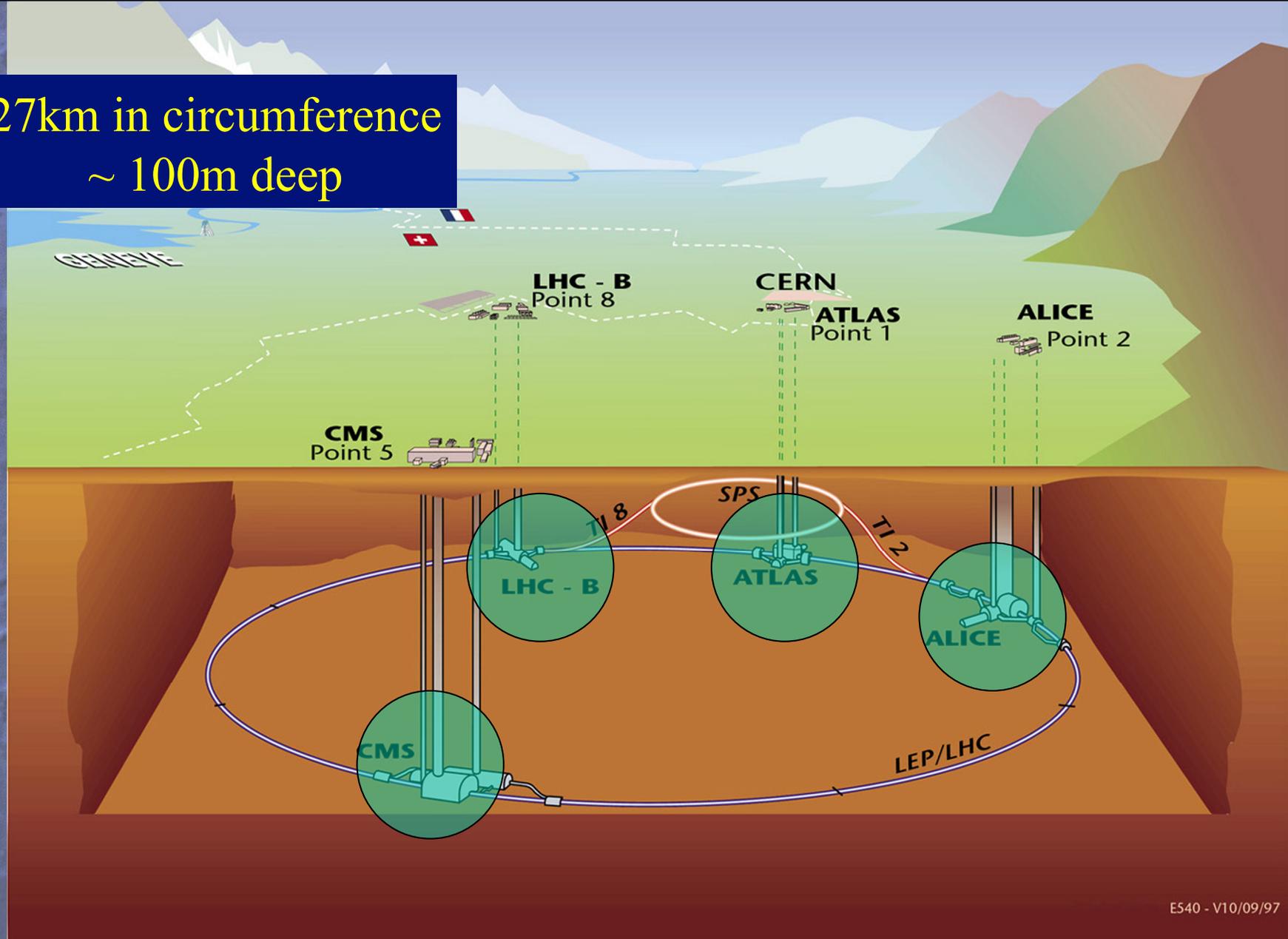


LHC 1.9 degrees above absolute zero = - 271 C

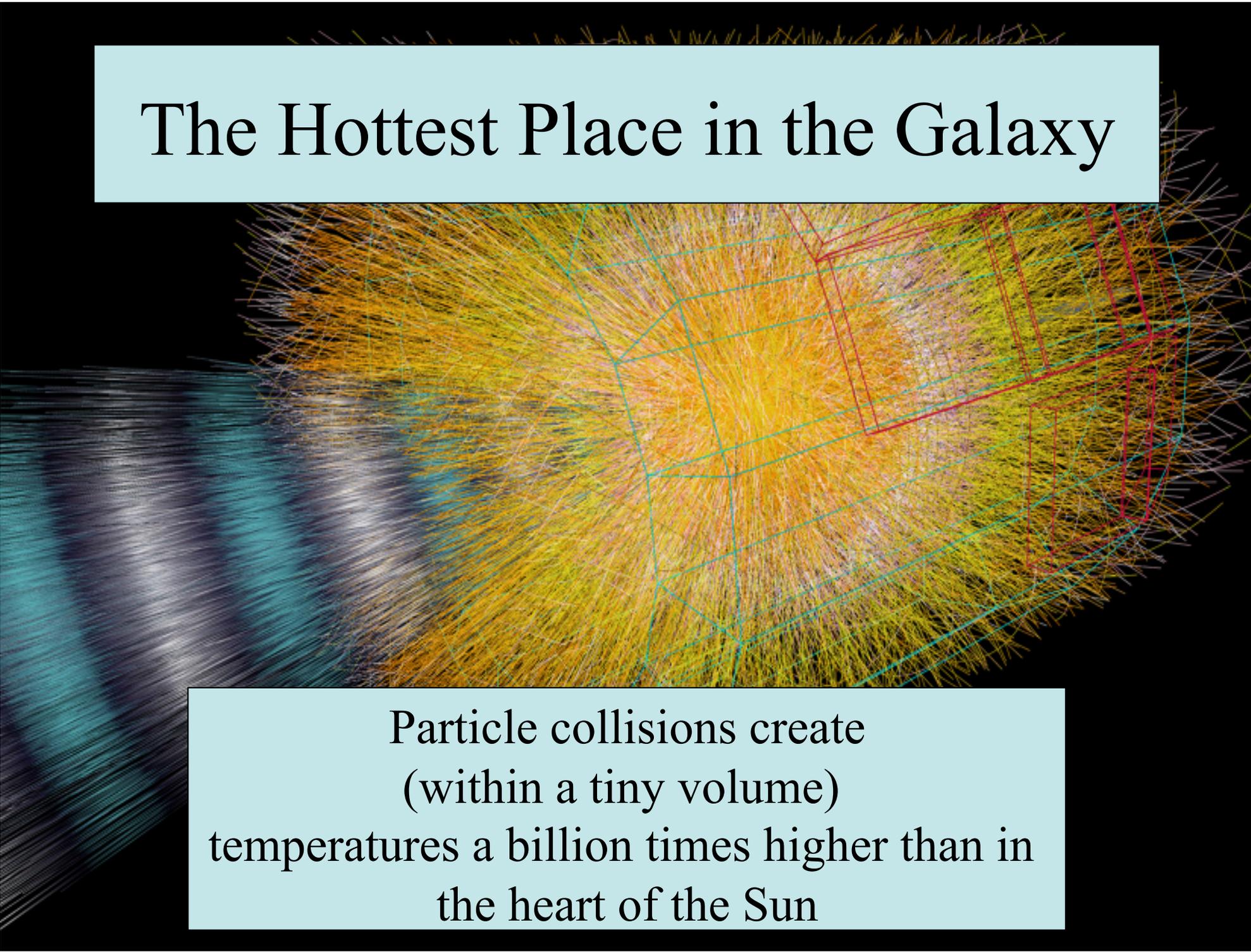
Outer space 2.7 degrees above zero = - 270 C

General View of LHC & its Experiments

27km in circumference
~ 100m deep

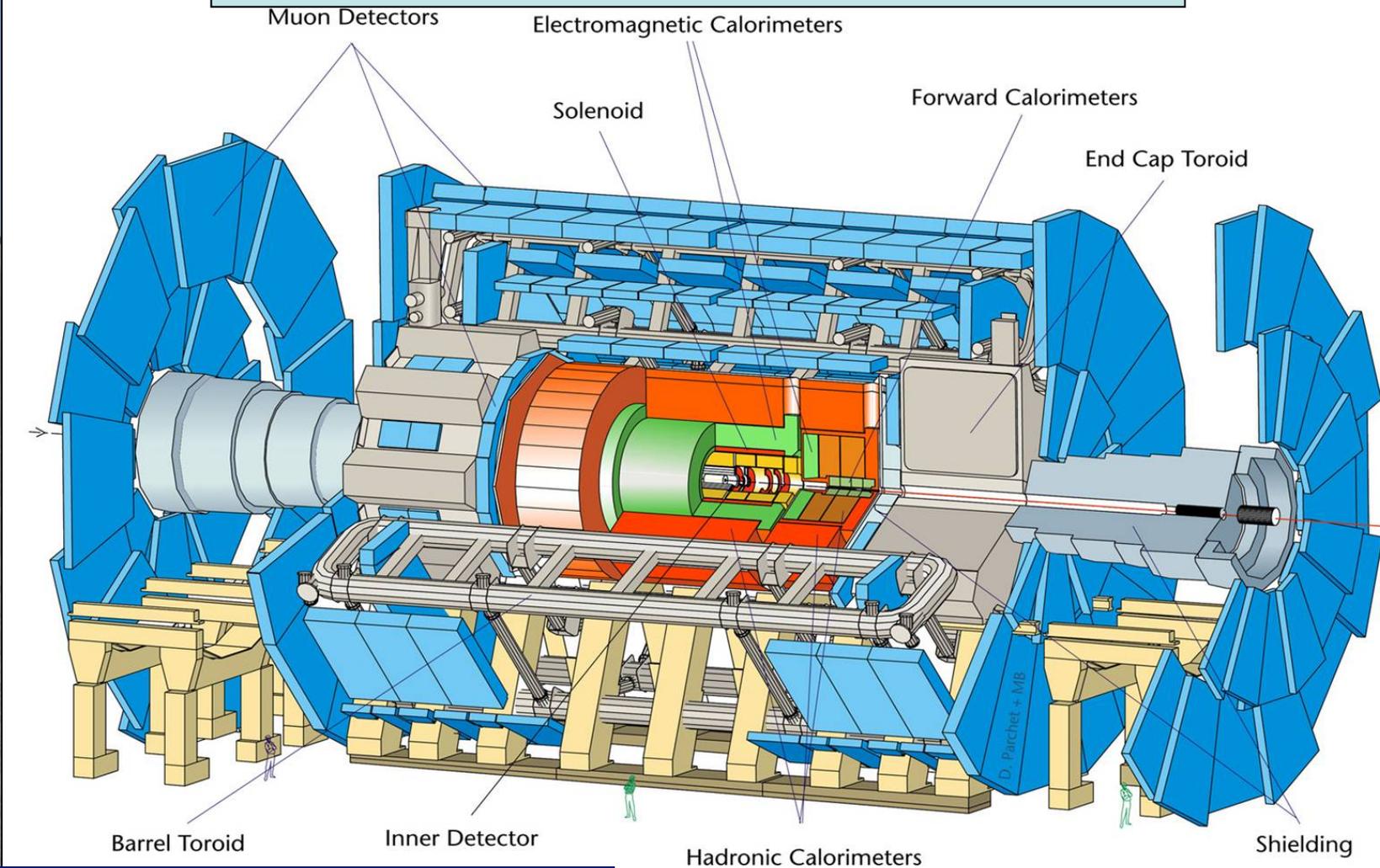


The Hottest Place in the Galaxy



Particle collisions create
(within a tiny volume)
temperatures a billion times higher than in
the heart of the Sun

The ATLAS Detector



Diameter 25 m
Total length 46 m
Overall weight 7000 tons

Over 2000 scientists and engineers
Nearly 40 countries
More components than a moon rocket

A Global Adventure: over 10000 Scientists from Around the World

Passport nationality

MEMBER STATES 6405

AUSTRIA	111
BELGIUM	102
BULGARIA	85
CZECH REPUBLIC	180
DENMARK	69
FINLAND	104
FRANCE	809
GERMANY	1113
GREECE	159
HUNGARY	64
ITALY	1681
NETHERLANDS	171
NORWAY	75
POLAND	241
PORTUGAL	141
SLOVAKIA	85
SPAIN	333
SWEDEN	72
SWITZERLAND	211
UNITED KINGDOM	599

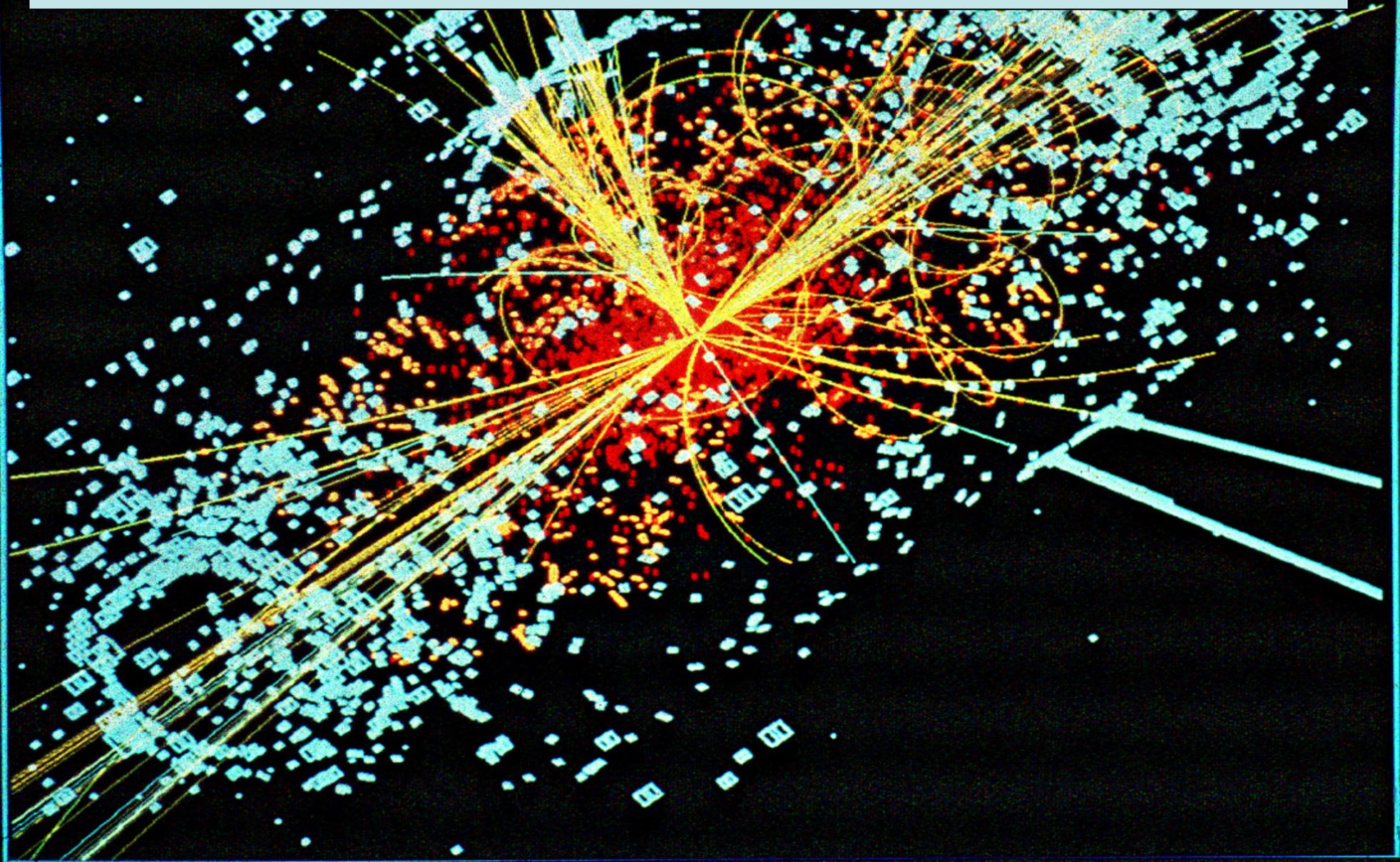
OBSERVER STATES 2530

INDIA	191
ISRAEL	48
JAPAN	209
RUSSIA	983
TURKEY	103
USA	996

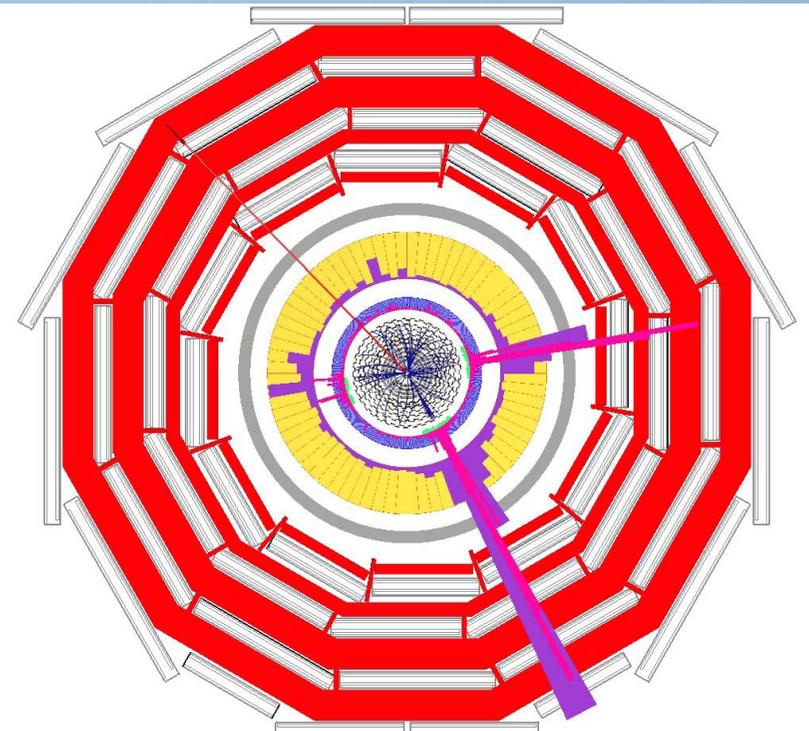
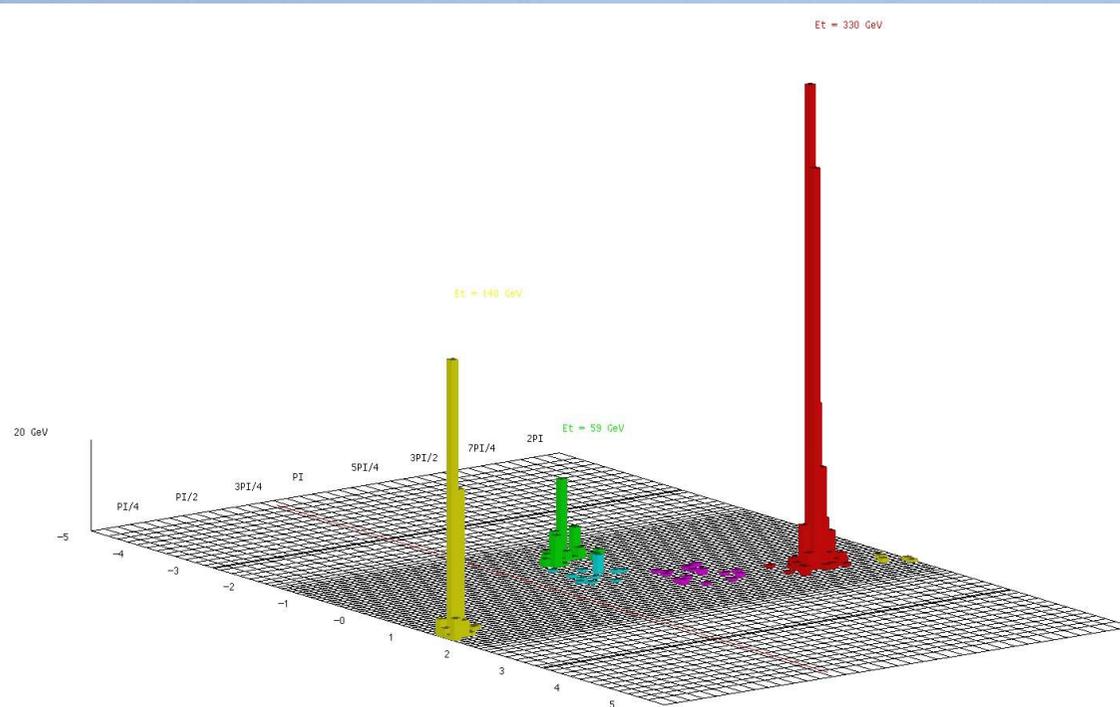
OTHERS 1280

BRAZIL	79	ESTONIA	12	KOREA REP.	86	MONGOLIA	1	SINGAPORE	3
CANADA	151	ETHIOPIA	1	KYRGYZSTAN	1	MOROCCO	17	SLOVENIA	26
CHILE	3	GEORGIA	35	LEBANON	8	NEPAL	3	SOUTH AFRICA	10
CHINA	203	GIBRALTAR	2	LITHUANIA	14	NEW ZEALAND	8	SRI LANKA	6
CHINA (TAIPEI)	38	HONG KONG	2	LUXEMBOURG	4	PAKISTAN	41	SYRIA	2
COLOMBIA	25	ICELAND	1	LIBYA	1	PALESTINE (O.T.)	2	TANZANIA	1
COSTA RICA	1	INDONESIA	2	MADAGASCAR	3	PERU	2	THAILAND	3
CROATIA	21	IRAN	21	MACEDONIA F.Y.R.	1	QATAR	1	TUNISIA	6
CUBA	4	IRAQ	1	MALAYSIA	8	ROMANIA	100	UKRAINE	46
CYPRUS	13	IRELAND	23	MALTA	2	SAN MARINO	1	UZBEKISTAN	2
ECUADOR	2	JORDAN	3	MAURITIUS	1	SAUDI ARABIA	3	VENEZUELA	7
EGYPT	7	KENYA	1	MEXICO	49	SENEGAL	1	VIET NAM	8
EL SALVADOR	1	KOREA, D.P.R.	3	MOLDOVA	2	SERBIA	36		

A Simulated Higgs Event



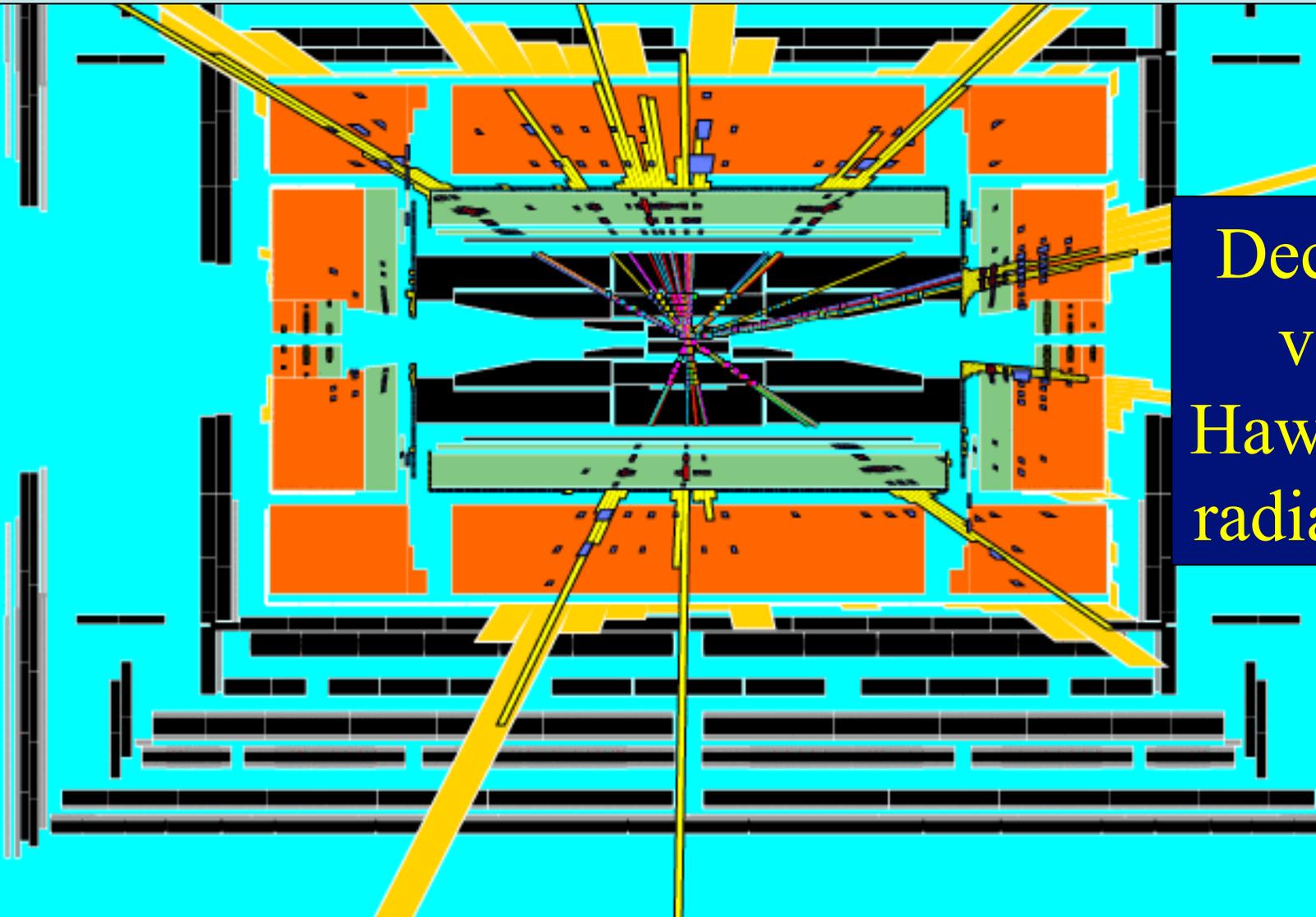
Looking for Dark Matter



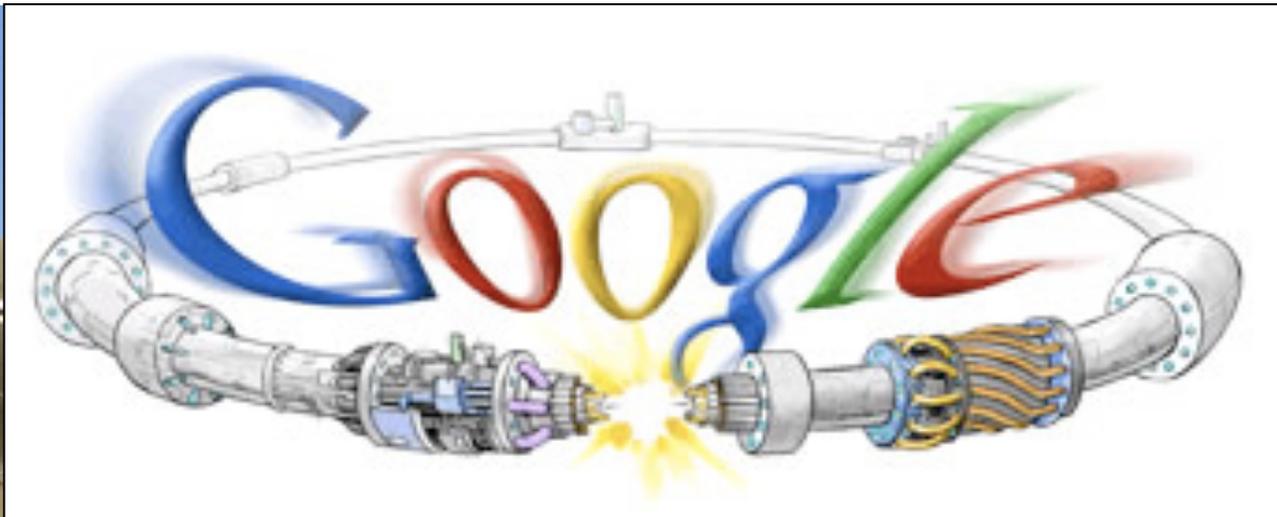
Missing energy
taken away by dark matter particles

And if gravity becomes strong at the TeV scale ...

Black Hole Production at LHC?



Decays
via
Hawking
radiation



A billion people watched on TV

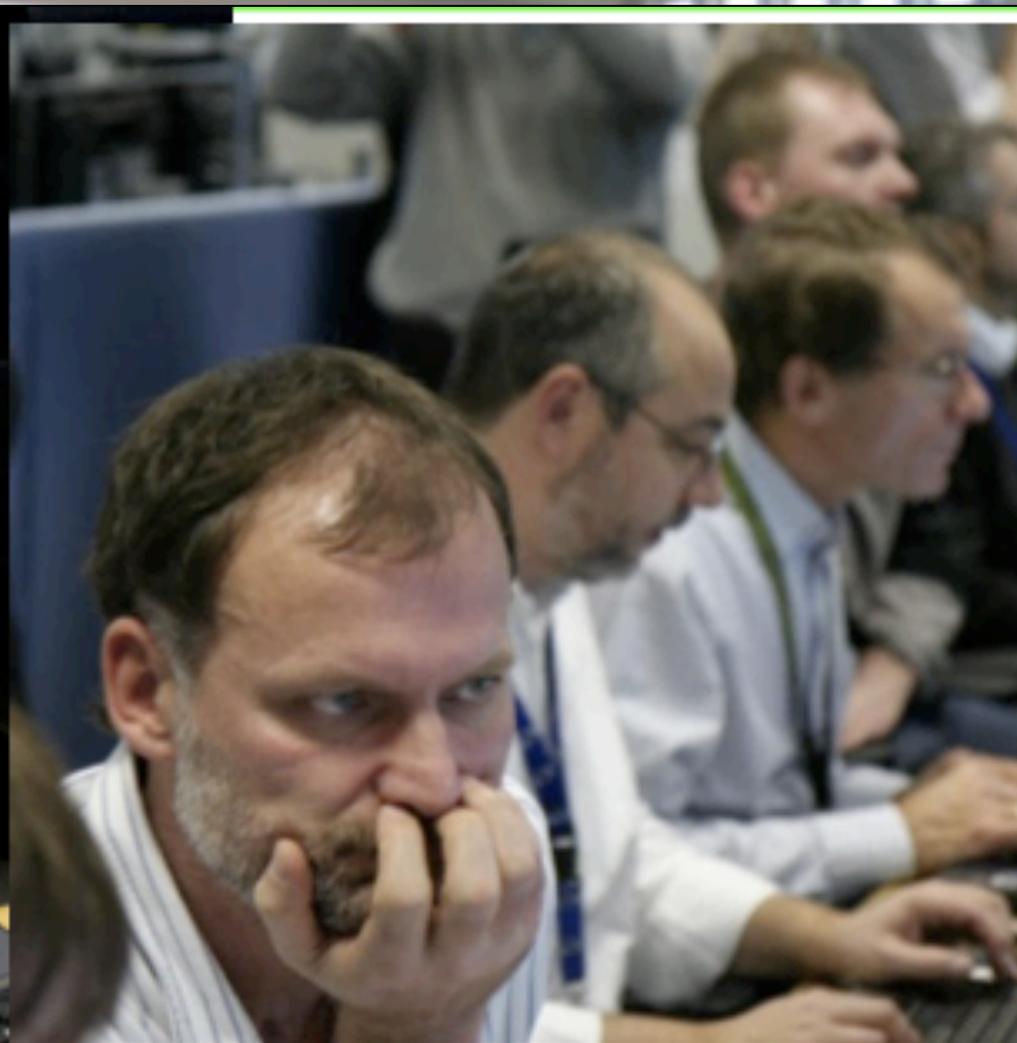
The LHC Enters Popular Culture



Concentration, Anxiety ...



..after concentrated preparations..



... and tense anticipation

in the ALICE Control Room

Nov. 20th 2009: Jubilation



First High-Energy LHC Collision

Collision Event at
7 TeV



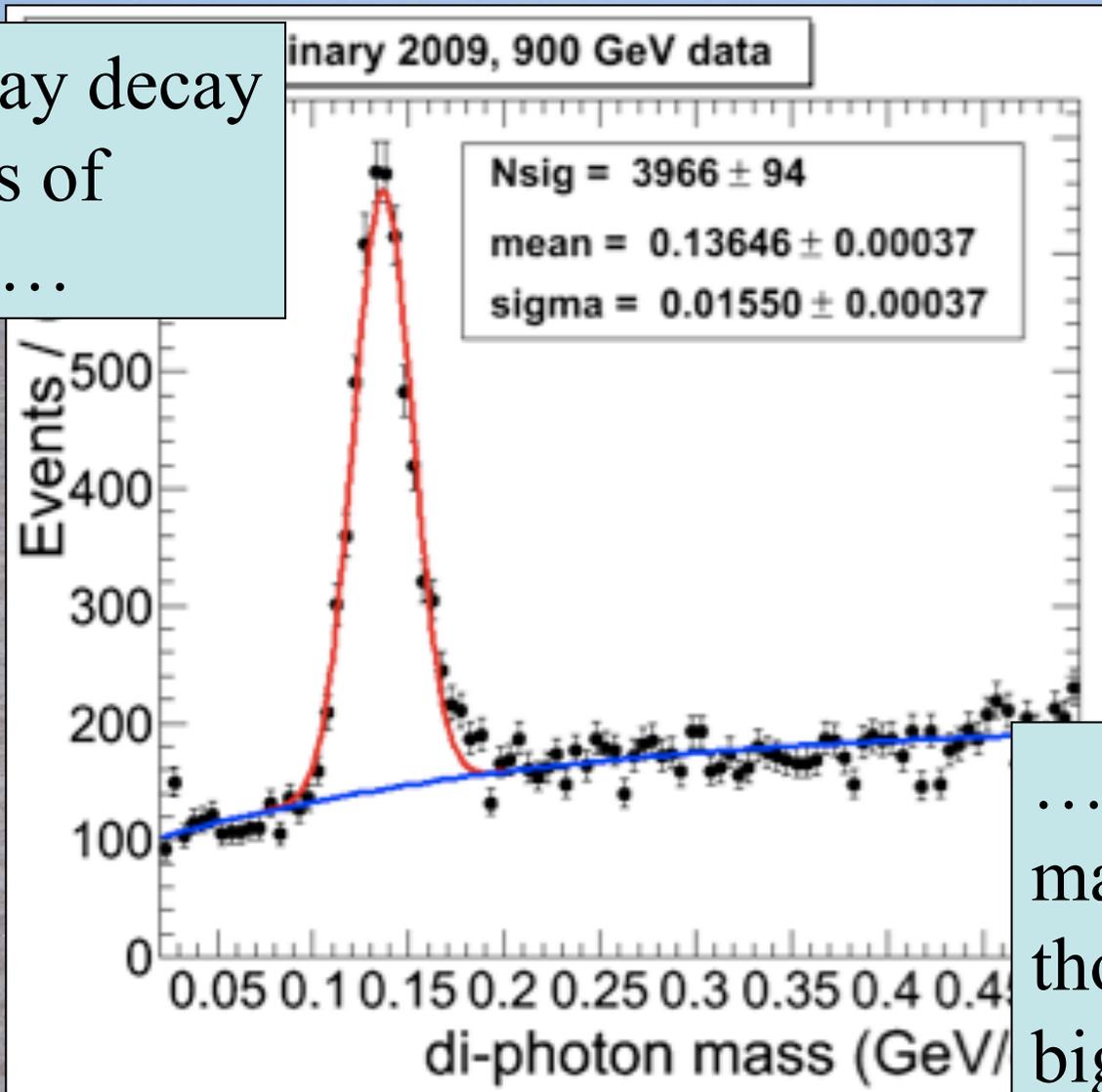
2010-03-30, 12:58 CEST
Run 152166, Event 316199

<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>



No Higgs yet!

Higgs may decay into pairs of photons ...



... but the Higgs mass is about a thousand times bigger!

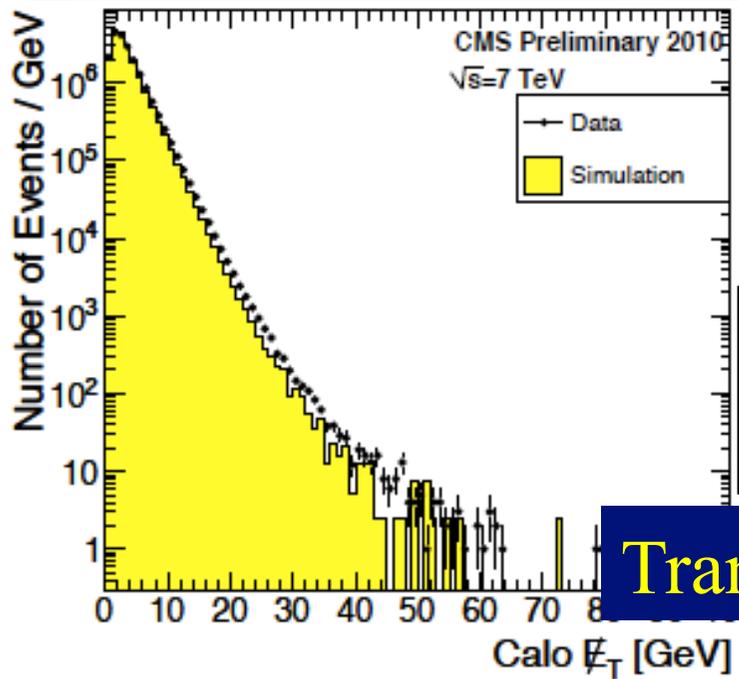
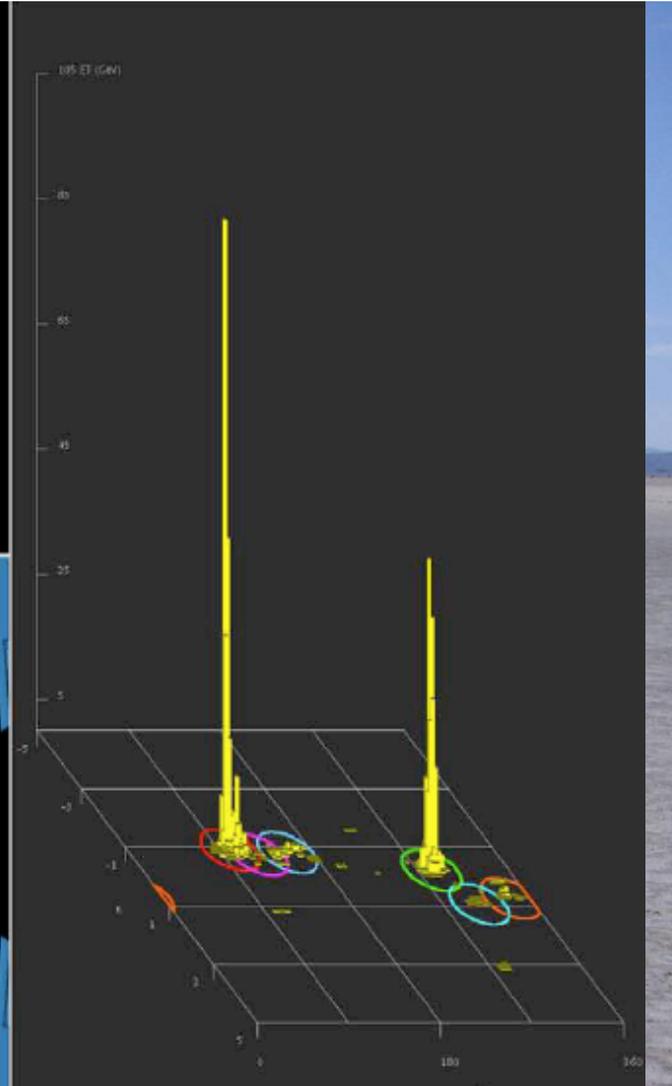


ATLAS EXPERIMENT

Run Number: 152166, Event Number: 810258

Date: 2010-03-30 14:56:29 CEST

Di-jet Event at 7 TeV



No Supersymmetry yet!

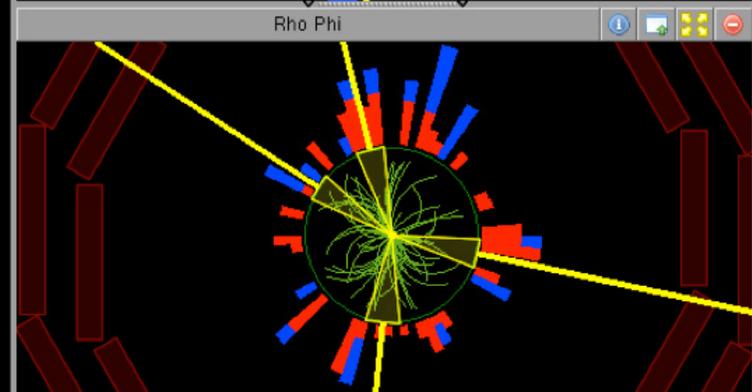
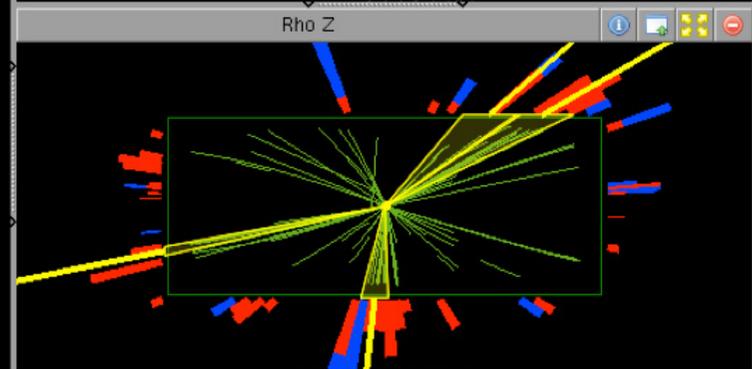
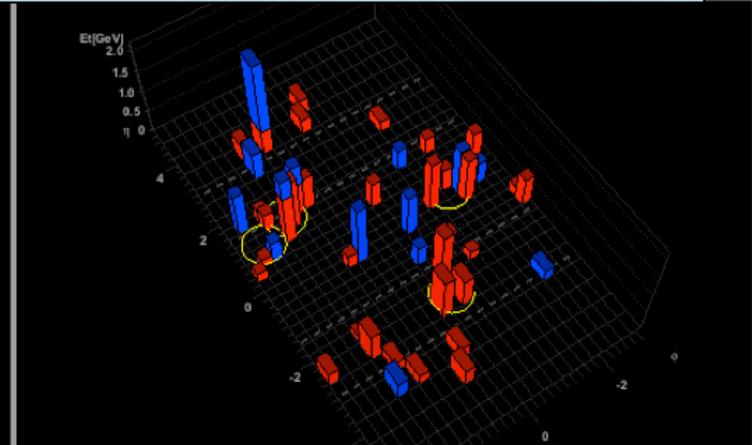
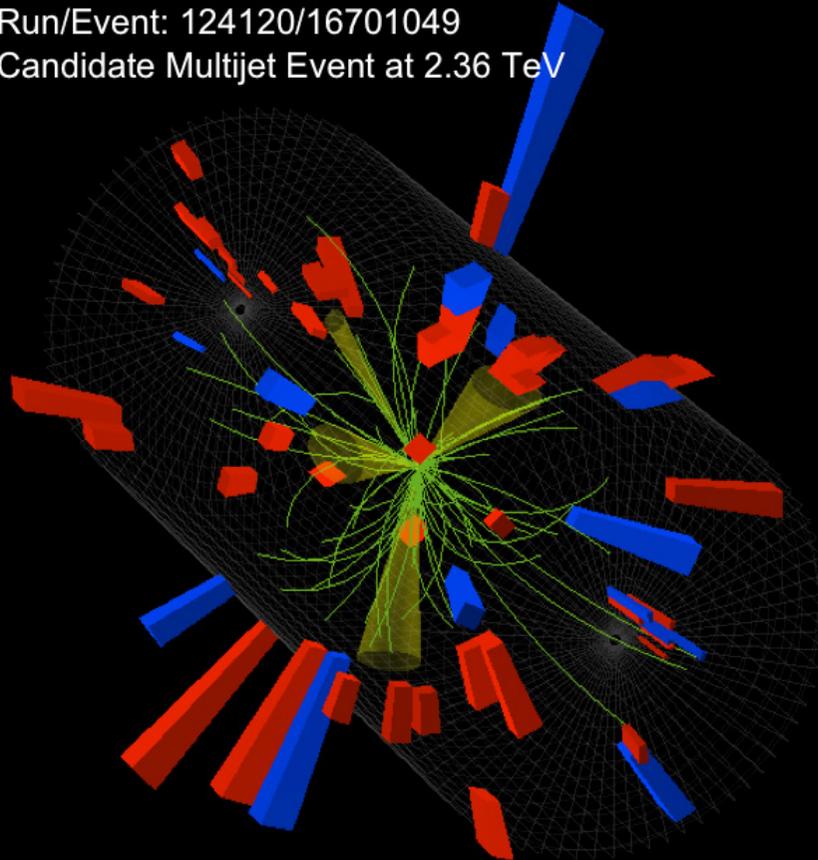
Transverse momentum balanced, so far ...

No Black Holes yet!

CMS 4-Jet Event @ 2.36 TeV



CMS Experiment at the LHC, CERN
Date Recorded: 2009-12-14 05:41 CET
Run/Event: 124120/16701049
Candidate Multijet Event at 2.36 TeV

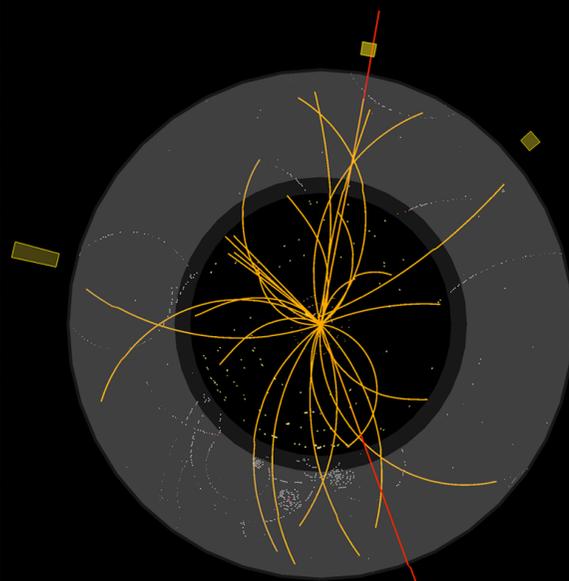


The Story so Far ...



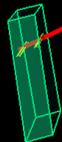
ATLAS
EXPERIMENT

Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST

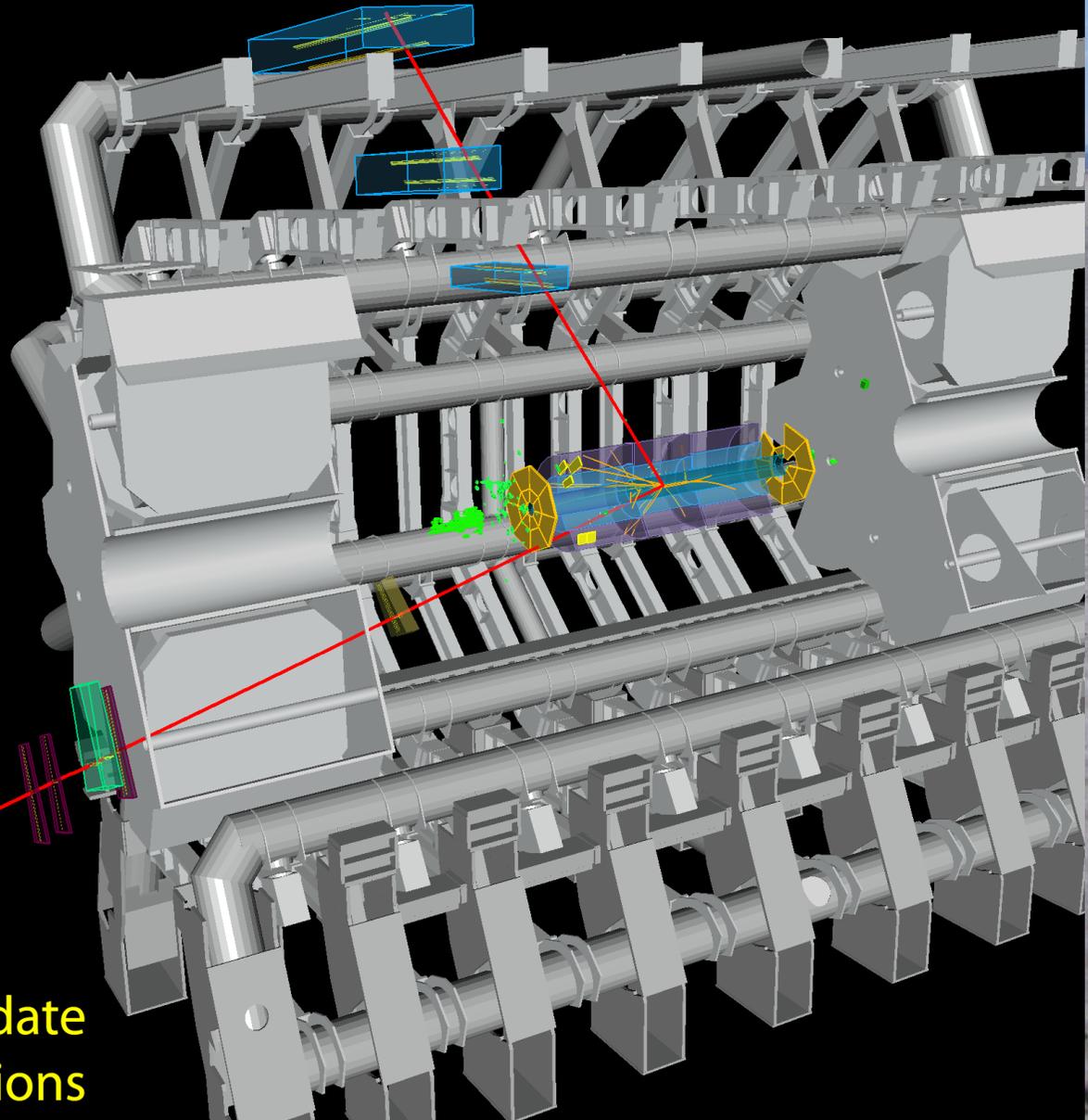


$$p_T(\mu^-) = 27 \text{ GeV} \quad \eta(\mu^-) = 0.7$$
$$p_T(\mu^+) = 45 \text{ GeV} \quad \eta(\mu^+) = 2.2$$

$$M_{\mu\mu} = 87 \text{ GeV}$$



**Z $\rightarrow\mu\mu$ candidate
in 7 TeV collisions**



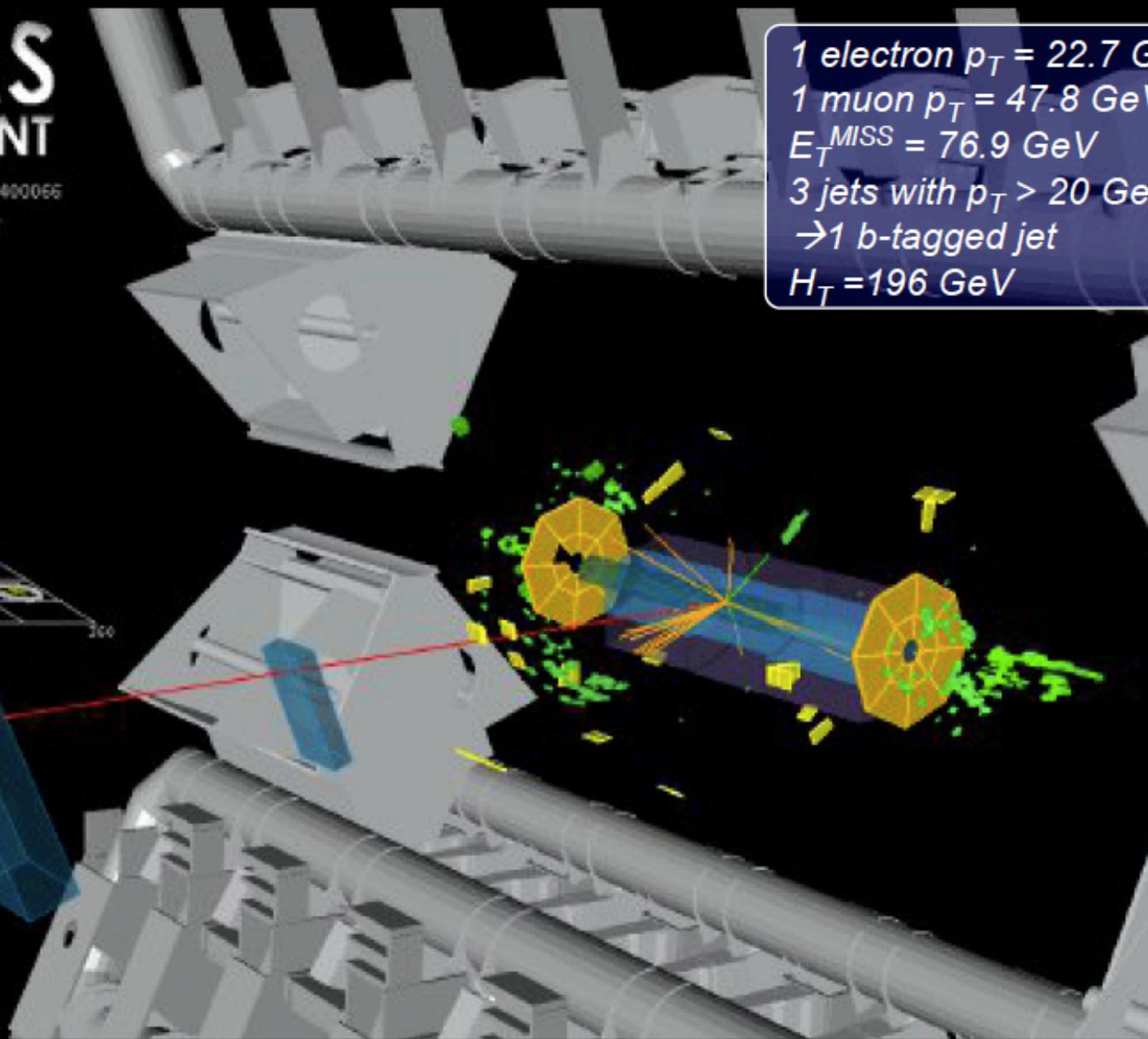
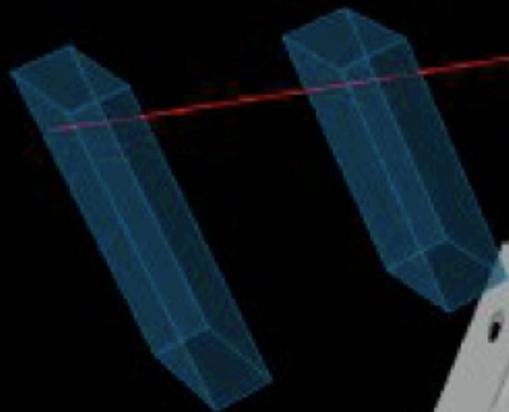
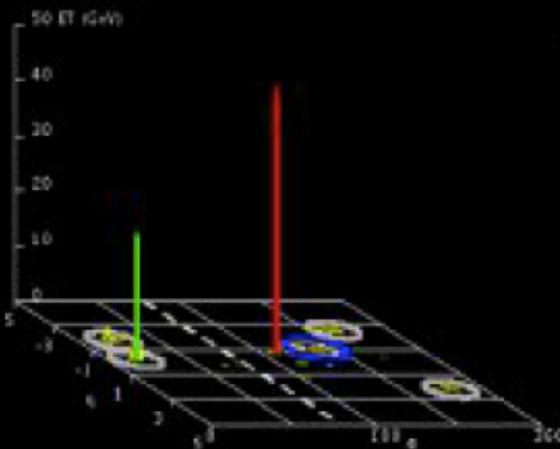
Top Pair Candidate in ATLAS

 **ATLAS**
EXPERIMENT

Run Number: 158582, Event Number: 27400066

Date: 2010-07-05 07:53:15 CEST

1 electron $p_T = 22.7$ GeV
1 muon $p_T = 47.8$ GeV
 $E_T^{MISS} = 76.9$ GeV
3 jets with $p_T > 20$ GeV
→ 1 b-tagged jet
 $H_T = 196$ GeV



CERN's Basic Missions

- **Scientific research**
& discovery!
- **Technological innovation**
Spin-offs & industrial collaboration
- **Advanced training**
Many aspects of human resource development
- **International collaboration**
Member and non-member states

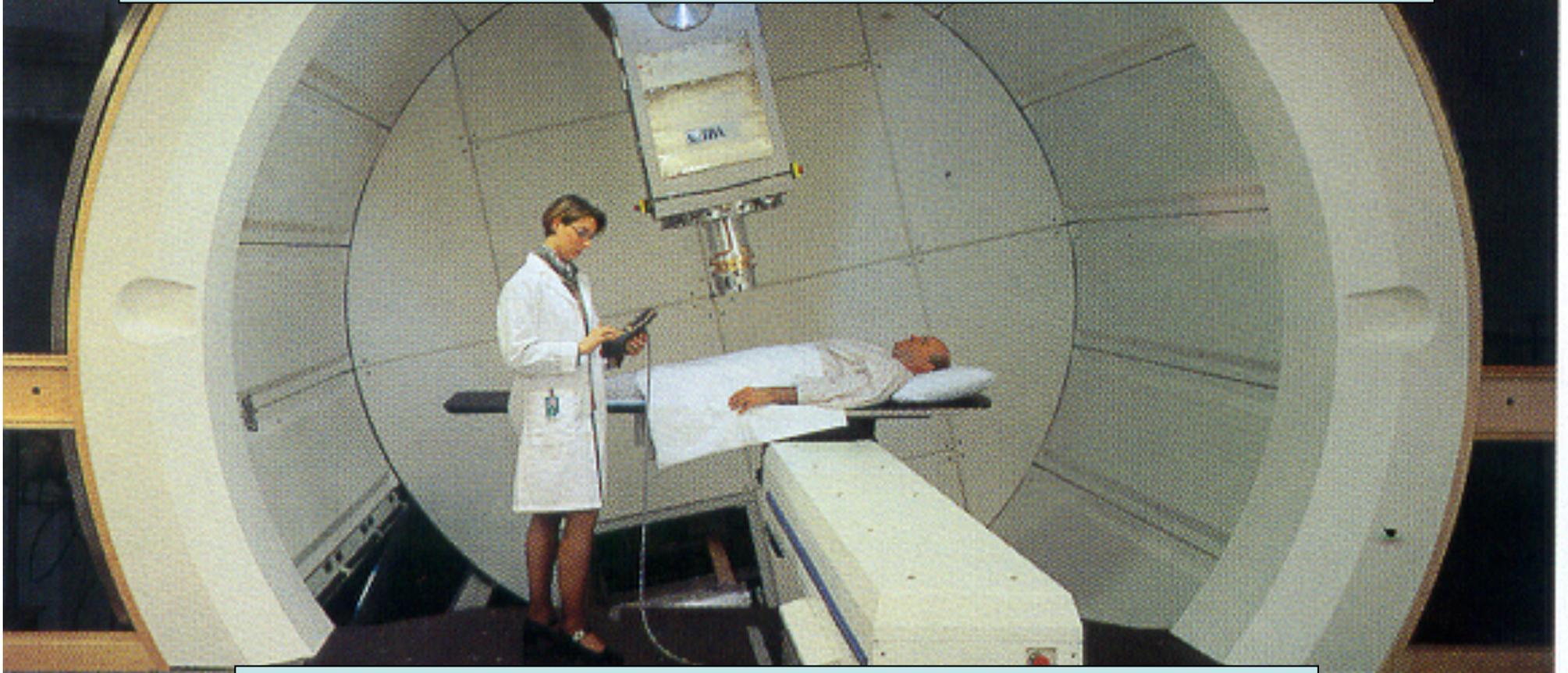
A photograph of Tim Berners-Lee speaking at a conference. He is wearing a light blue shirt and a patterned tie. He has his hands raised and is looking upwards with an expressive face. In the background, a banner is visible with the text "et, WWW, ha" and "26 June 1998".

CERN: where the World-Wide Web was born

Tim Berners-Lee

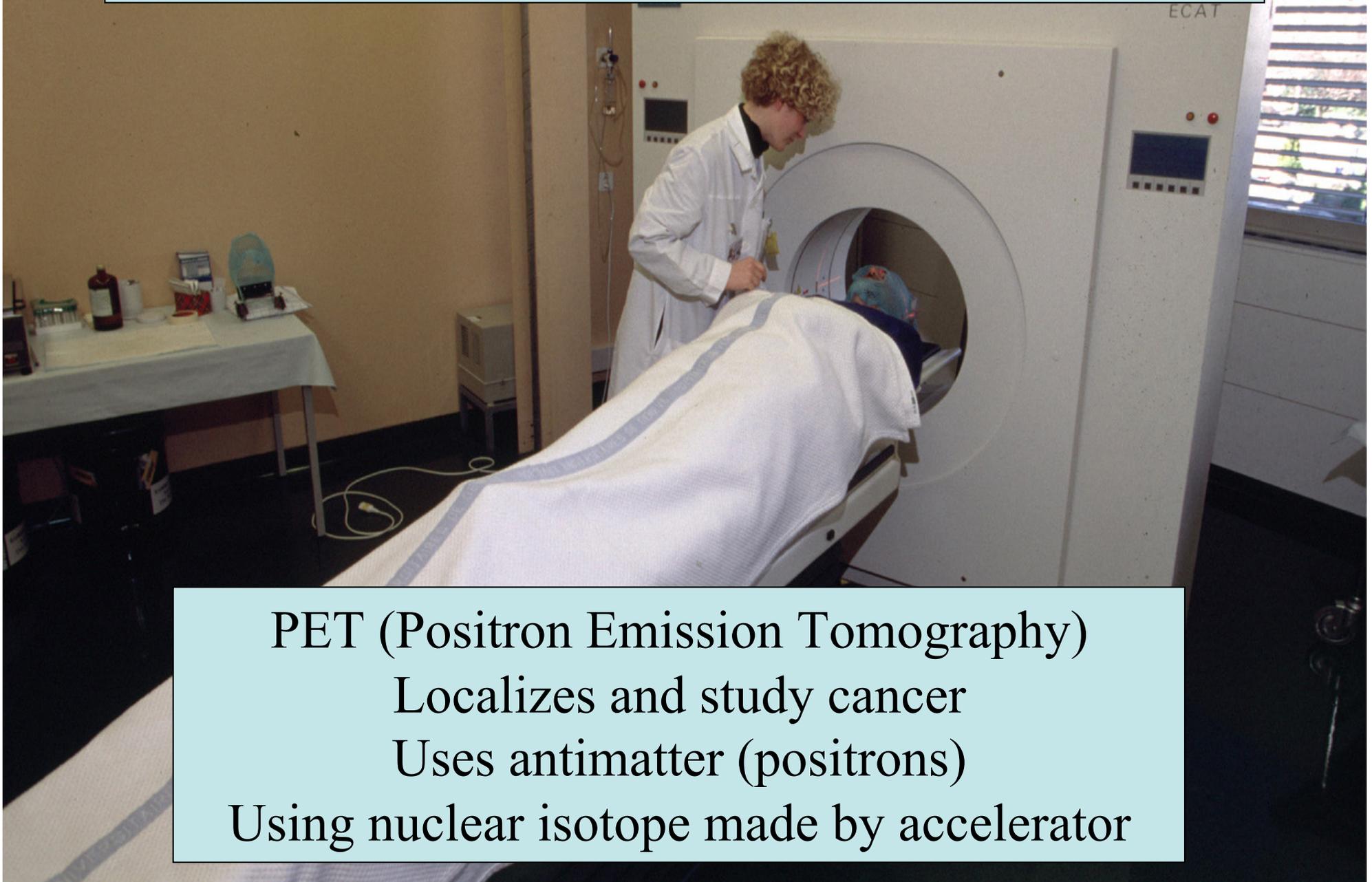
Invented to enable physicists around world to share data

Accelerators are Us



Over 20000 accelerators in the World
Over half are used for medicine
Protons for therapy

Detectors are Us



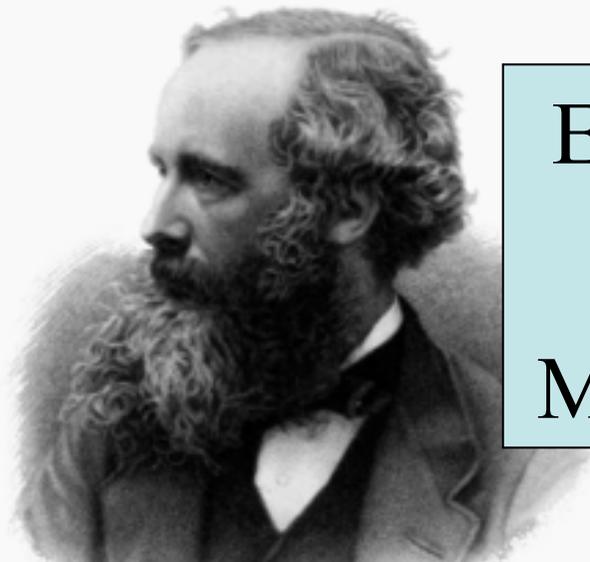
PET (Positron Emission Tomography)

Localizes and study cancer

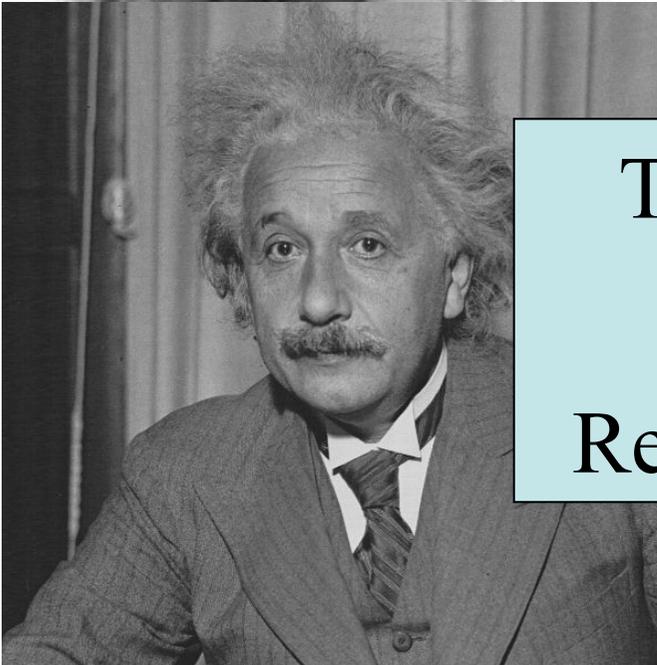
Uses antimatter (positrons)

Using nuclear isotope made by accelerator

Innovation is based on Fundamental Science



Electricity
and
Magnetism



Theory
of
Relativity



CERN as Capacity-Builder

Visits

Accelerator School

Doctoral Students

Language Training

Exhibitions

Academic Training

Physics School

Communications Training

Apprentices

CERN-Latin America School

Technical Training

Computing School

Teachers programmes

Technical Students

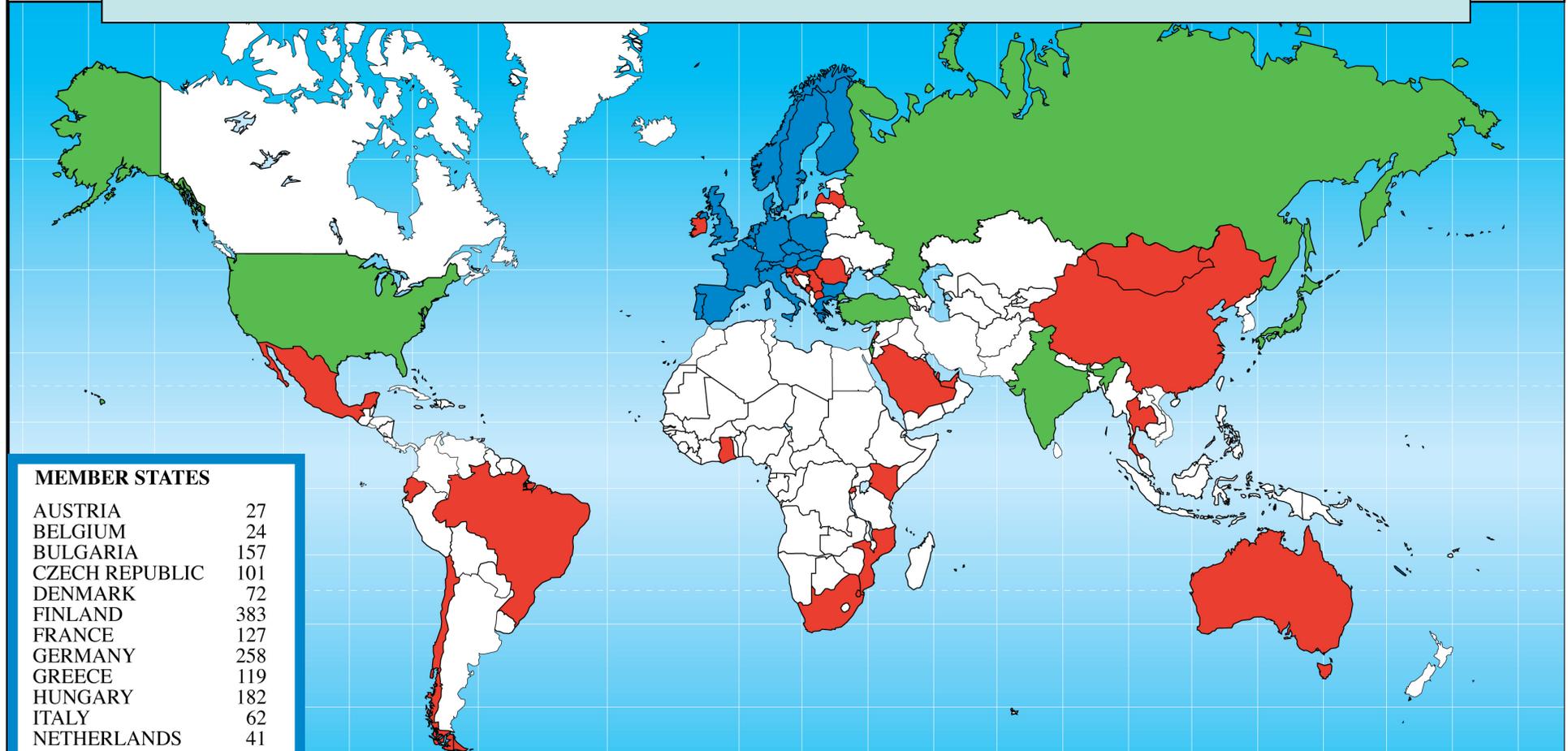
Summer Students

Research Fellows

Management Training



Teachers from around the World



MEMBER STATES

AUSTRIA	27
BELGIUM	24
BULGARIA	157
CZECH REPUBLIC	101
DENMARK	72
FINLAND	383
FRANCE	127
GERMANY	258
GREECE	119
HUNGARY	182
ITALY	62
NETHERLANDS	41
NORWAY	48
POLAND	460
PORTUGAL	167
SLOVAKIA	189
SPAIN	168
SWEDEN	79
SWITZERLAND	12
UNITED KINGDOM	567

3243

OBSERVER STATES

INDIA	2
ISRAEL	1
JAPAN	2
RUSSIA	48
TURKEY	2
USA	51

106

OTHERS

AUSTRALIA	1	IRELAND	3	MONTENEGRO	13	SLOVENIA	21
AZERBAIJAN	1	KENYA	1	MOZAMBIQUE	5	SOUTH AFRICA	6
BRAZIL	12	LATVIA	1	QATAR	1	SWAZILAND	1
CHILE	3	LEBANON	1	ROMANIA	7	THAILAND	2
CHINA	1	MACEDONIA	11	RWANDA	7	U.A.E.	1
CROATIA	1	MALTA	36	SAUDI ARABIA	1		
ECUADOR	1	MEXICO	5	SERBIA	10		
GHANA	2	MONGOLIA	1	SINGAPORE	2		

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2010 Summer Students from around the World

MEMBER & OBSERVER STATES

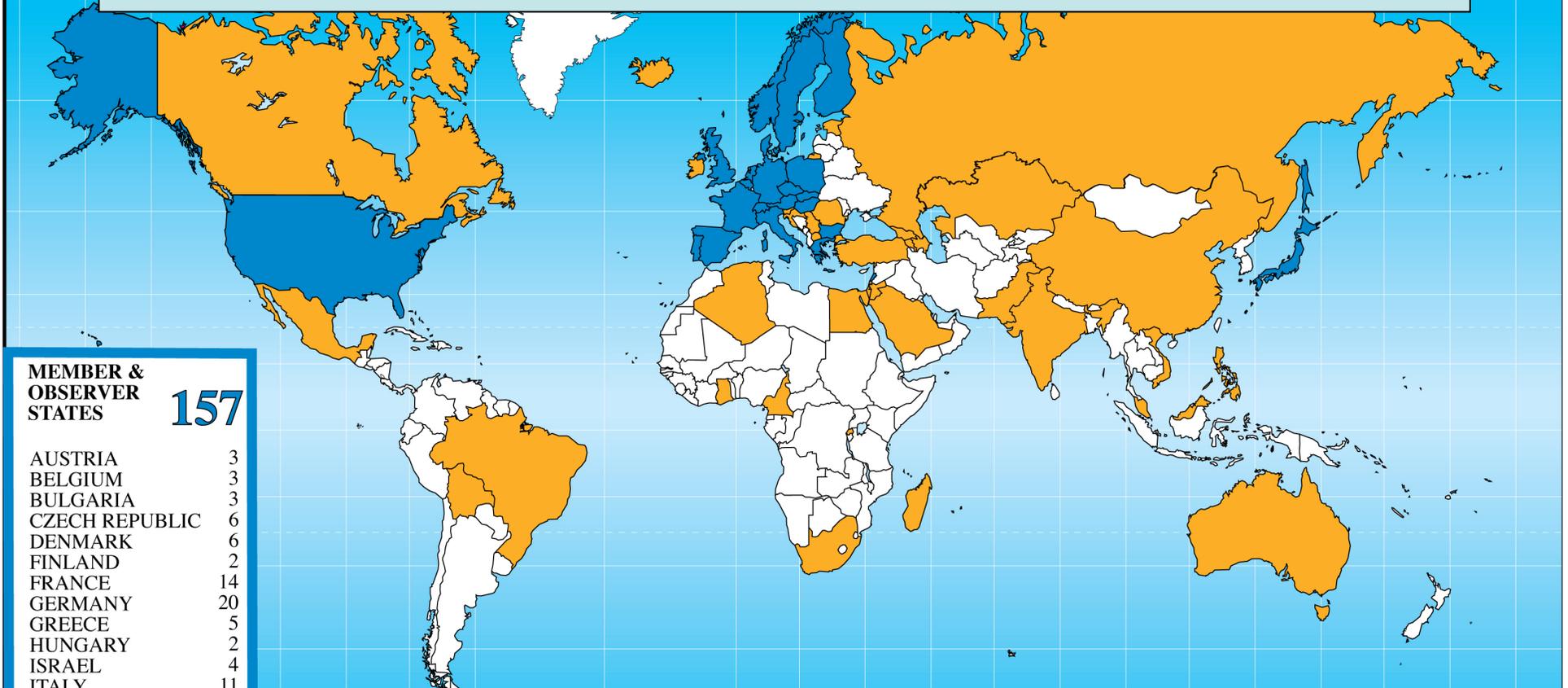
157

AUSTRIA	3
BELGIUM	3
BULGARIA	3
CZECH REPUBLIC	6
DENMARK	6
FINLAND	2
FRANCE	14
GERMANY	20
GREECE	5
HUNGARY	2
ISRAEL	4
ITALY	11
JAPAN	5
NETHERLANDS	9
NORWAY	3
POLAND	5
PORTUGAL	3
SLOVAKIA	2
SPAIN	9
SWEDEN	7
SWITZERLAND	3
UNITED KINGDOM	15
USA	17

NON-MEMBER STATES

ALGERIA	2	CAMEROON	1	INDIA	8	MALTA	3	SERBIA	1
ARMENIA	2	CANADA	5	IRELAND	1	MEXICO	2	SINGAPORE	1
AUSTRALIA	2	CHINA	2	JORDAN	1	PAKISTAN	6	SLOVENIA	1
AZERBAIJAN	1	CROATIA	4	KAZAKHSTAN	1	PHILIPPINES	1	SOUTH AFRICA	1
BOLIVIA	1	EGYPT	1	LEBANON	1	ROMANIA	1	SOUTH KOREA	1
BOSNIA & HERZEGOVINA	2	ESTONIA	2	MACEDONIA	2	RUSSIA	9	THAILAND	2
BRAZIL	2	GHANA	1	MADAGASCAR	2	RWANDA	1	TURKEY	10
		GIBRALTA	1	MALAYSIA	1	SAUDI ARABIA	2	VIETNAM	4
		ICELAND	1						

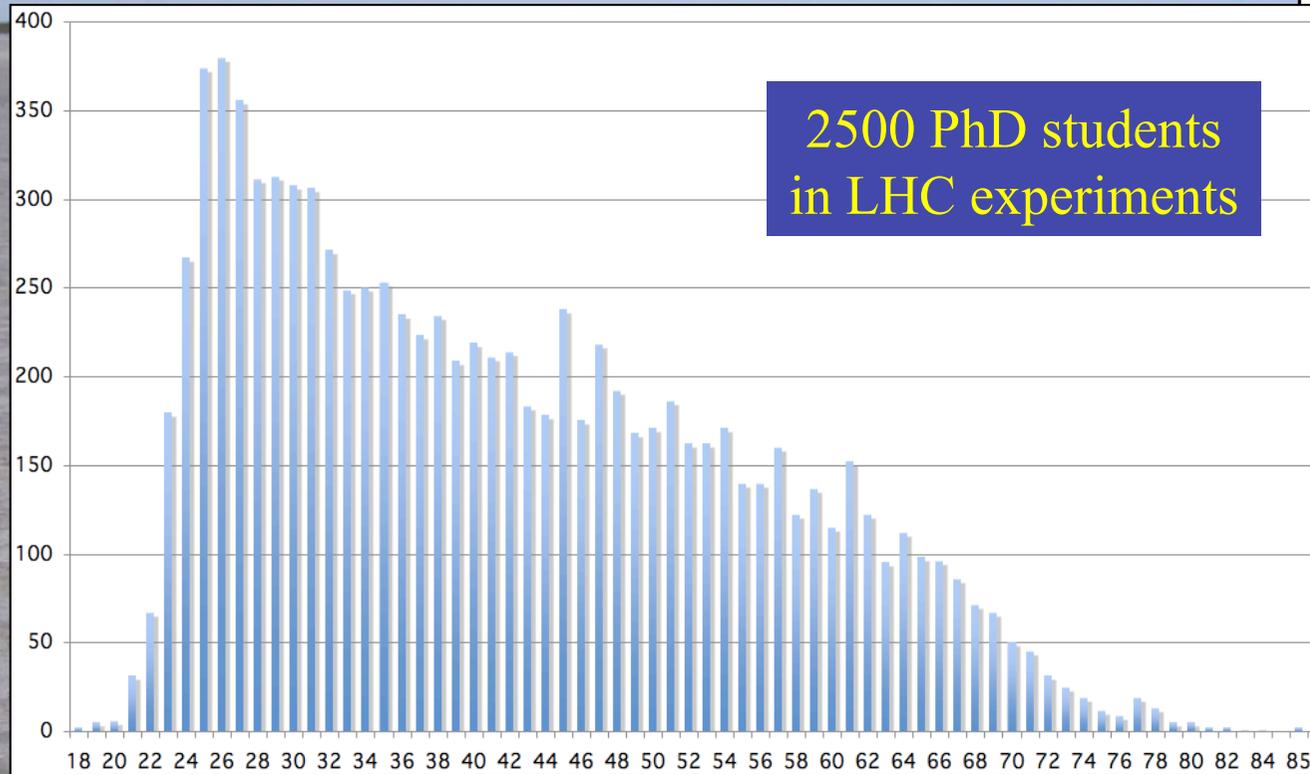
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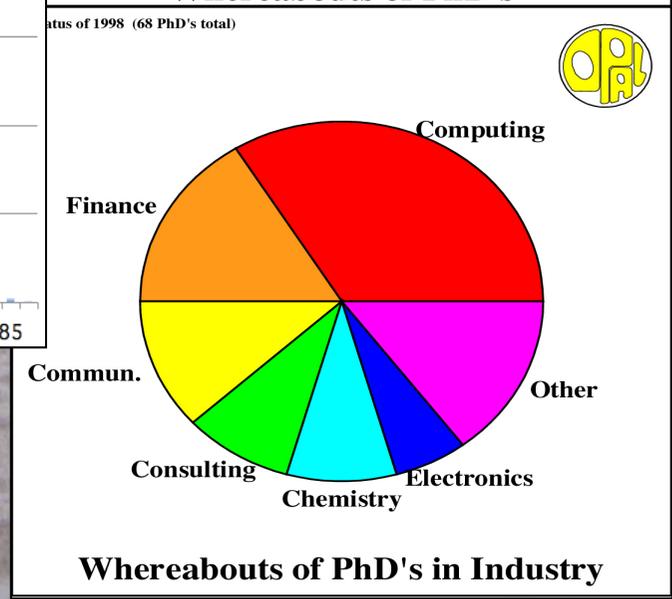
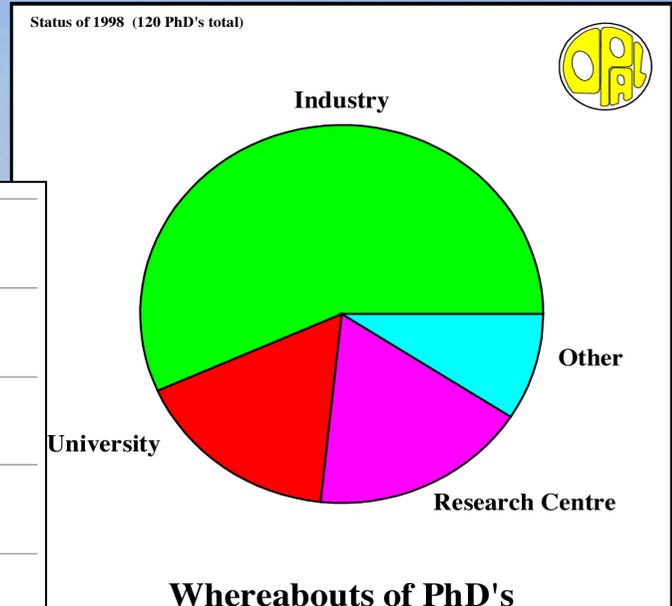
Age Distribution of Scientists

- and where they go afterwards

Survey in March 2009



They do not all stay: where do they go?

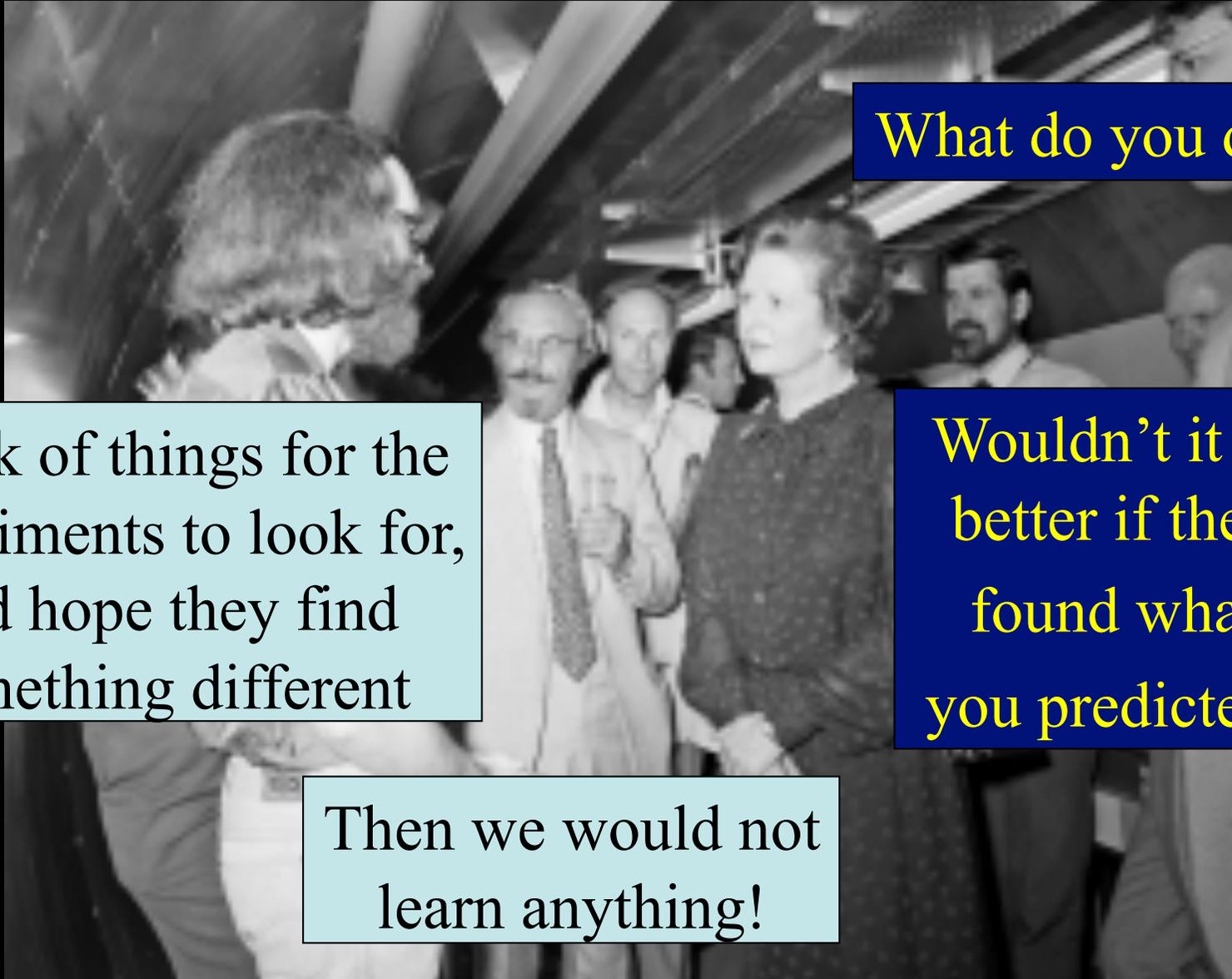


The LHC is not only the World's
most powerful microscope,
but also a telescope



Looking towards
the beginning of time

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!