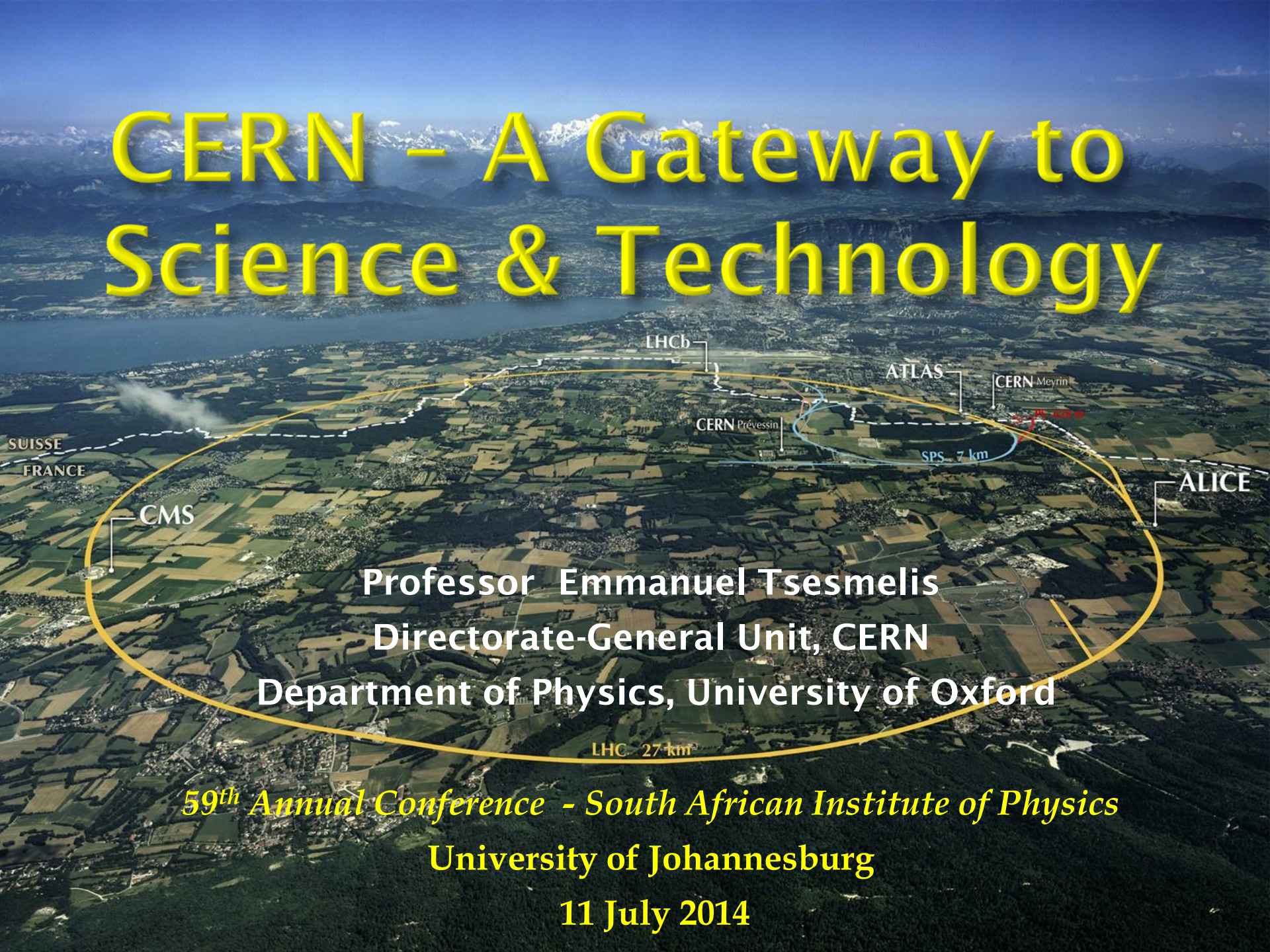
CERN – A Gateway to Science & Technology



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Department of Physics, University of Oxford

59th Annual Conference - South African Institute of Physics

University of Johannesburg

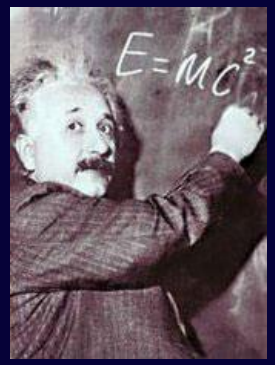
11 July 2014

INTRODUCTION

The Mission of CERN

- *Push back* the frontiers of knowledge

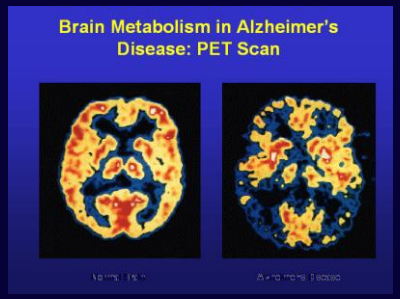
  E.g. the secrets of the Big Bang... what was the matter like within the first moments of the universe's existence?



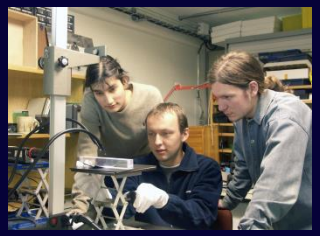
- *Develop* new tech... accelerators an...

  Information technology - the Web and the GRID

  Medicine - diagnosis and therapy

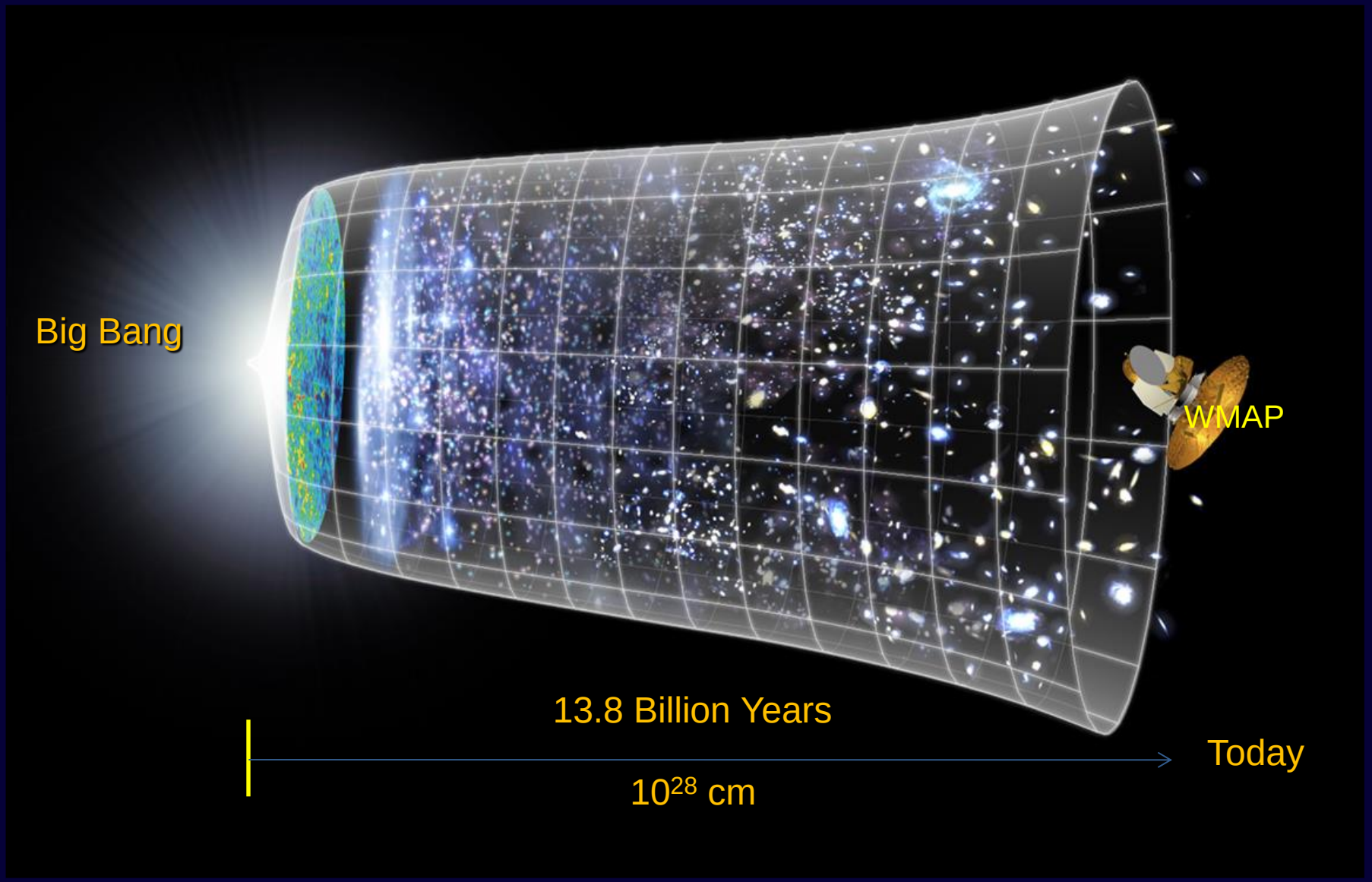


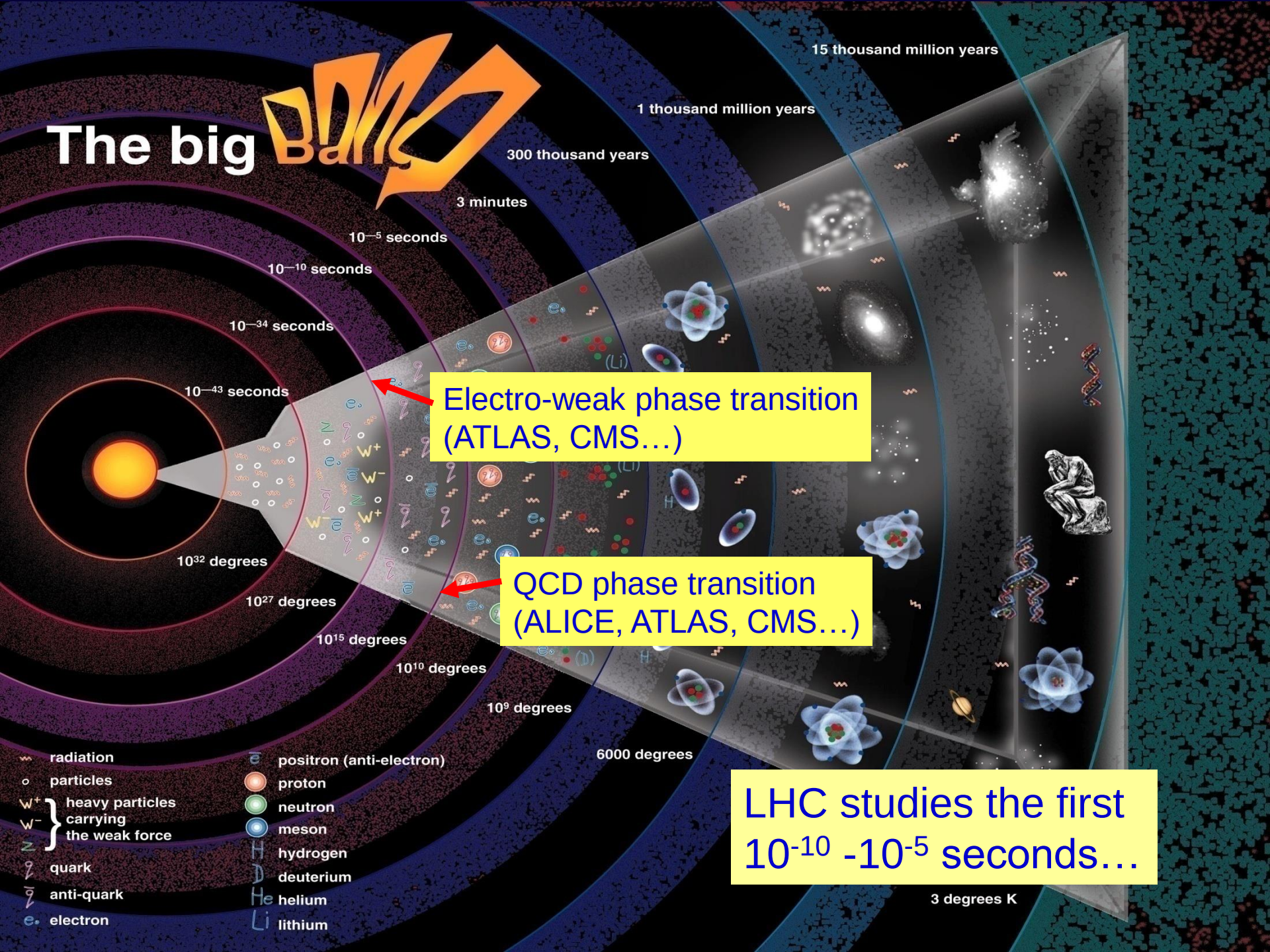
- *Train* scientists and engineers of tomorrow



- *Unite* people from different countries and cultures

Evolution of the Universe




The big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
10⁻⁵ seconds
10⁻¹⁰ seconds
10⁻³⁴ seconds
10⁻⁴³ seconds
10³² degrees
10²⁷ degrees
10¹⁵ degrees
10¹⁰ degrees
10⁹ degrees
6000 degrees
3 degrees K
Electro-weak phase transition (ATLAS, CMS…)
QCD phase transition (ALICE, ATLAS, CMS…)
LHC studies the first 10-10 -10-5 seconds…
radiation
particles
heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium

The Standard Model of Particle Physics

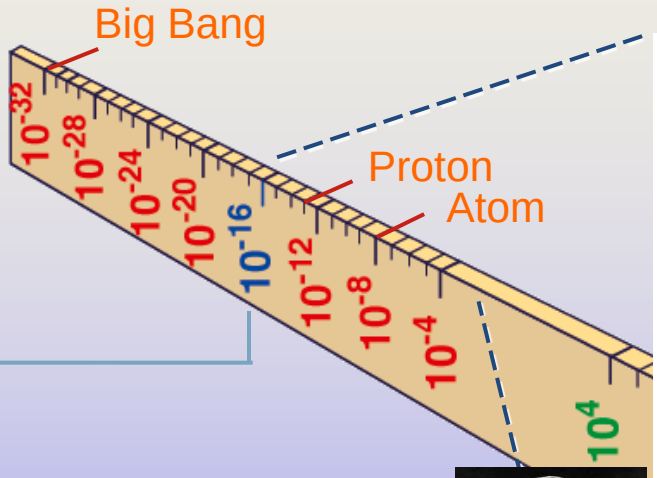
= Cosmic DNA

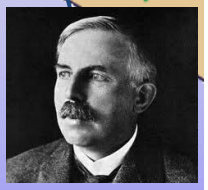
The matter particles

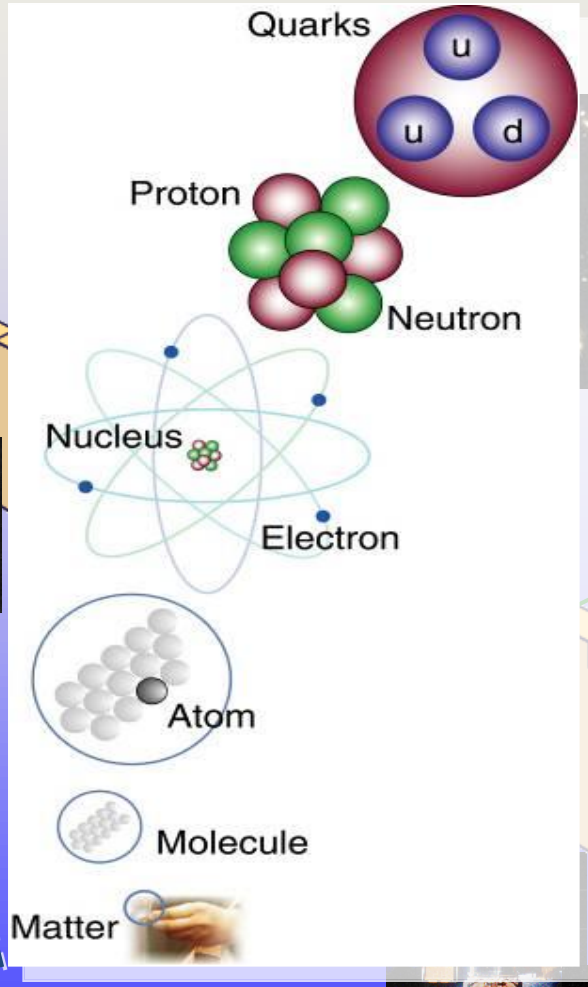
up	down	ν_e - neutrino	electon
charm	strange	ν_μ - neutrino	muon
top	bottom	ν_τ - neutrino	tau

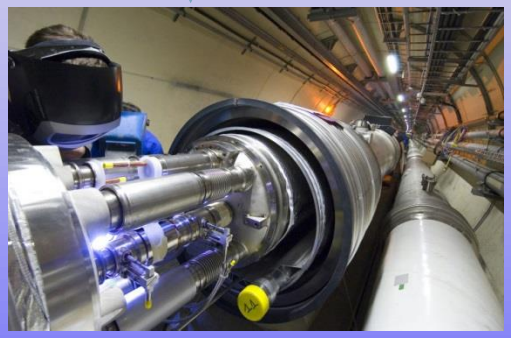
The fundamental interactions

Gravitation electromagnetism weak nuclear force strong nuclear force









LHC

Super-Microscope

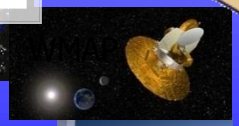
Radius of Galaxies

Universe

10^{24}

10^{28}

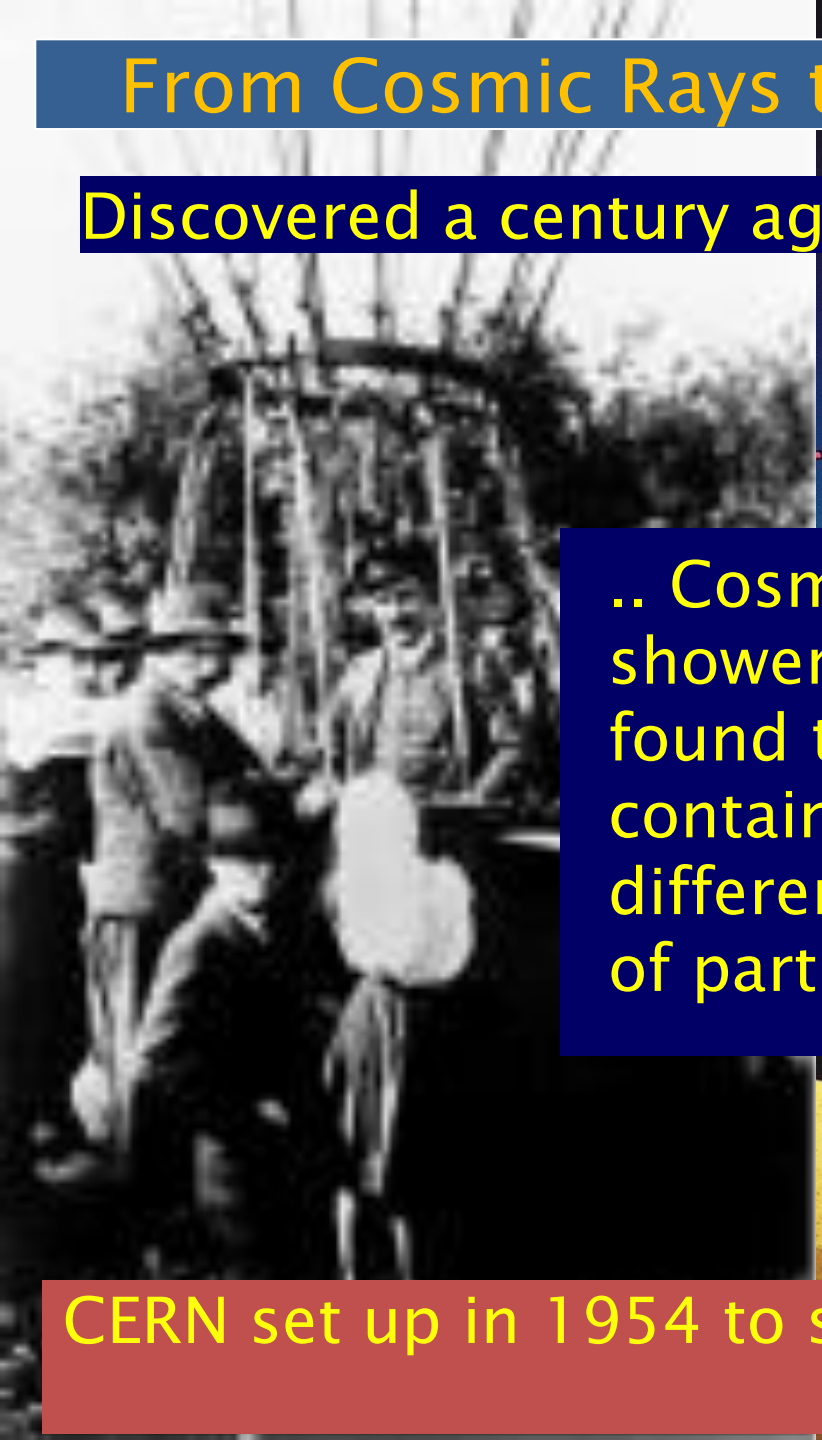
cm

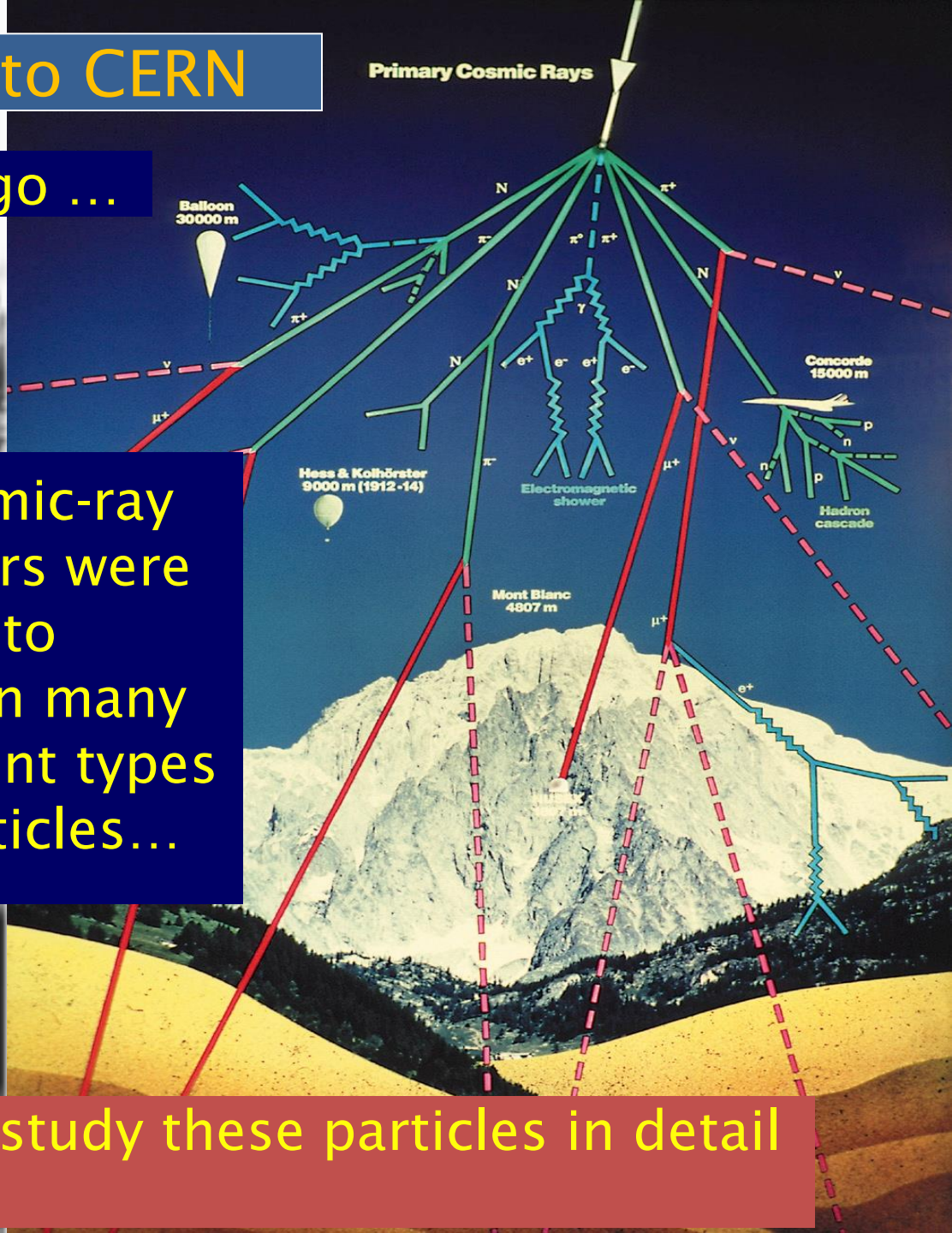


Study physics laws of first moments after Big Bang.
Increasing Symbiosis between Particle Physics, Astrophysics and Cosmology.

From Cosmic Rays to CERN

Discovered a century ago …



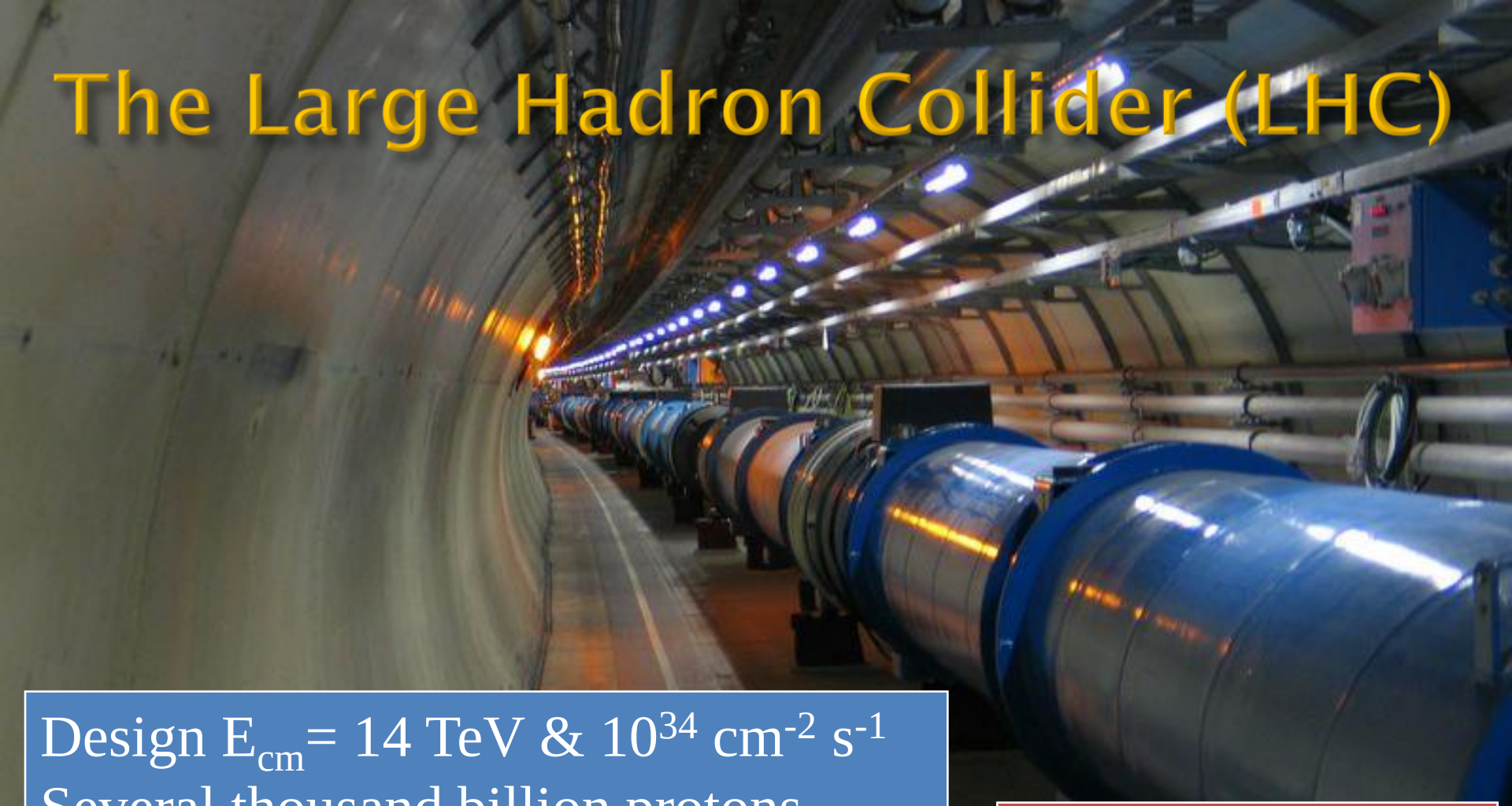


.. Cosmic-ray showers were found to contain many different types of particles…

CERN set up in 1954 to study these particles in detail

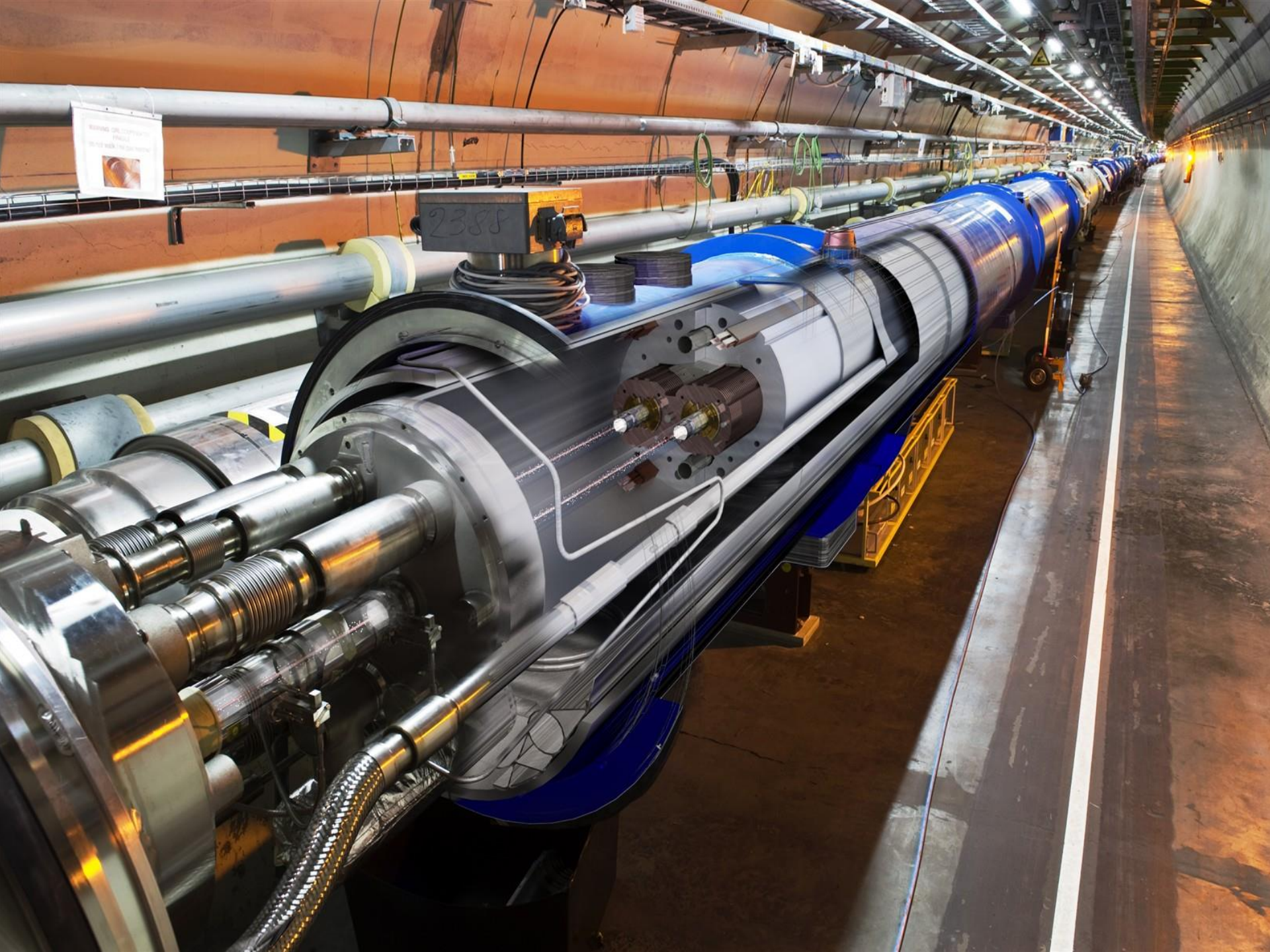
THE LARGE HADRON COLLIDER

The Large Hadron Collider (LHC)



Design E_{cm}= 14 TeV & 10^{34} cm^{-2} s^{-1}
Several thousand billion protons
Each with the energy of a fly (7 TeV)
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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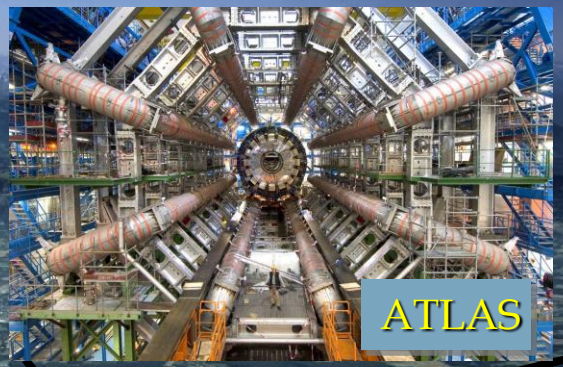
The LHC Arcs

2010: a New Era in Fundamental Science



Exploration of a new energy frontier
in p-p and Pb-Pb collisions

CERN

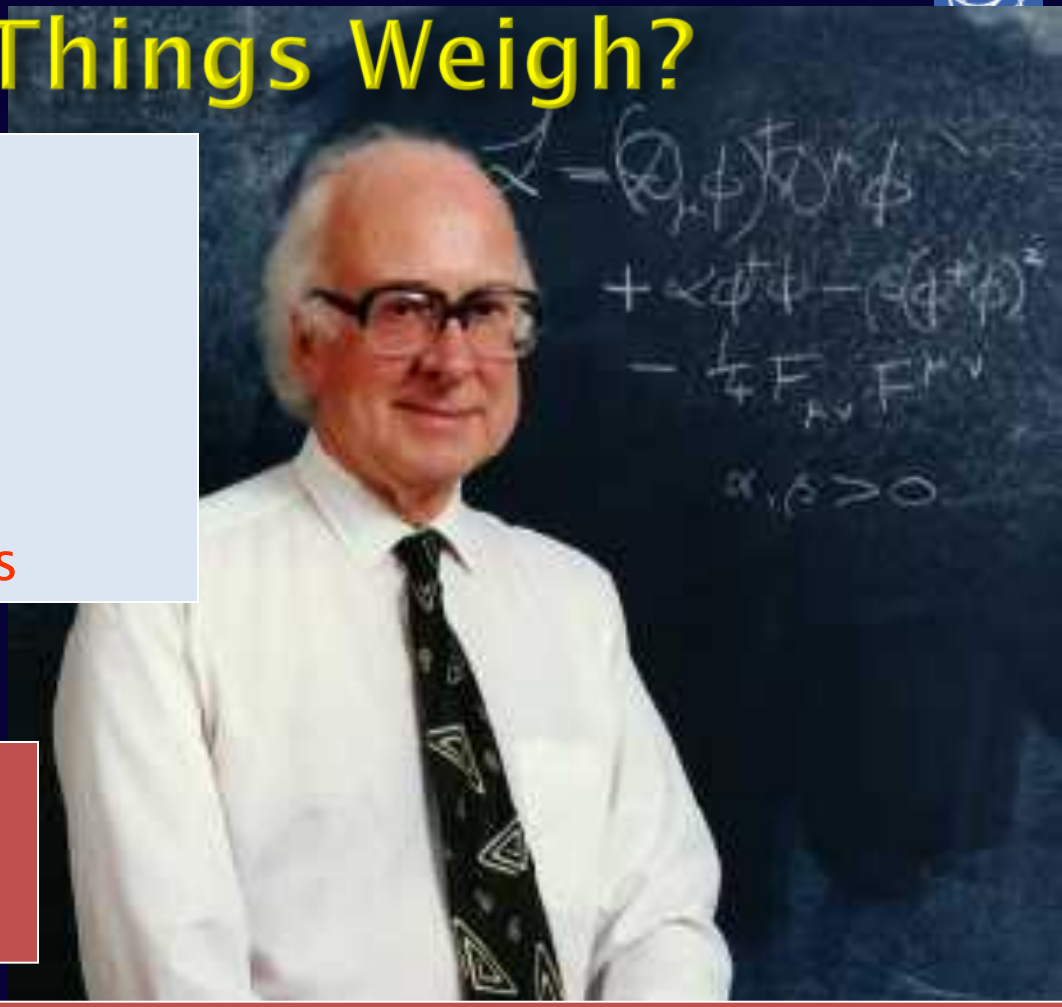
THE PHYSICS AT THE LHC

Why do Things Weigh?

Newton:
Weight proportional to Mass

Einstein:
Energy related to Mass

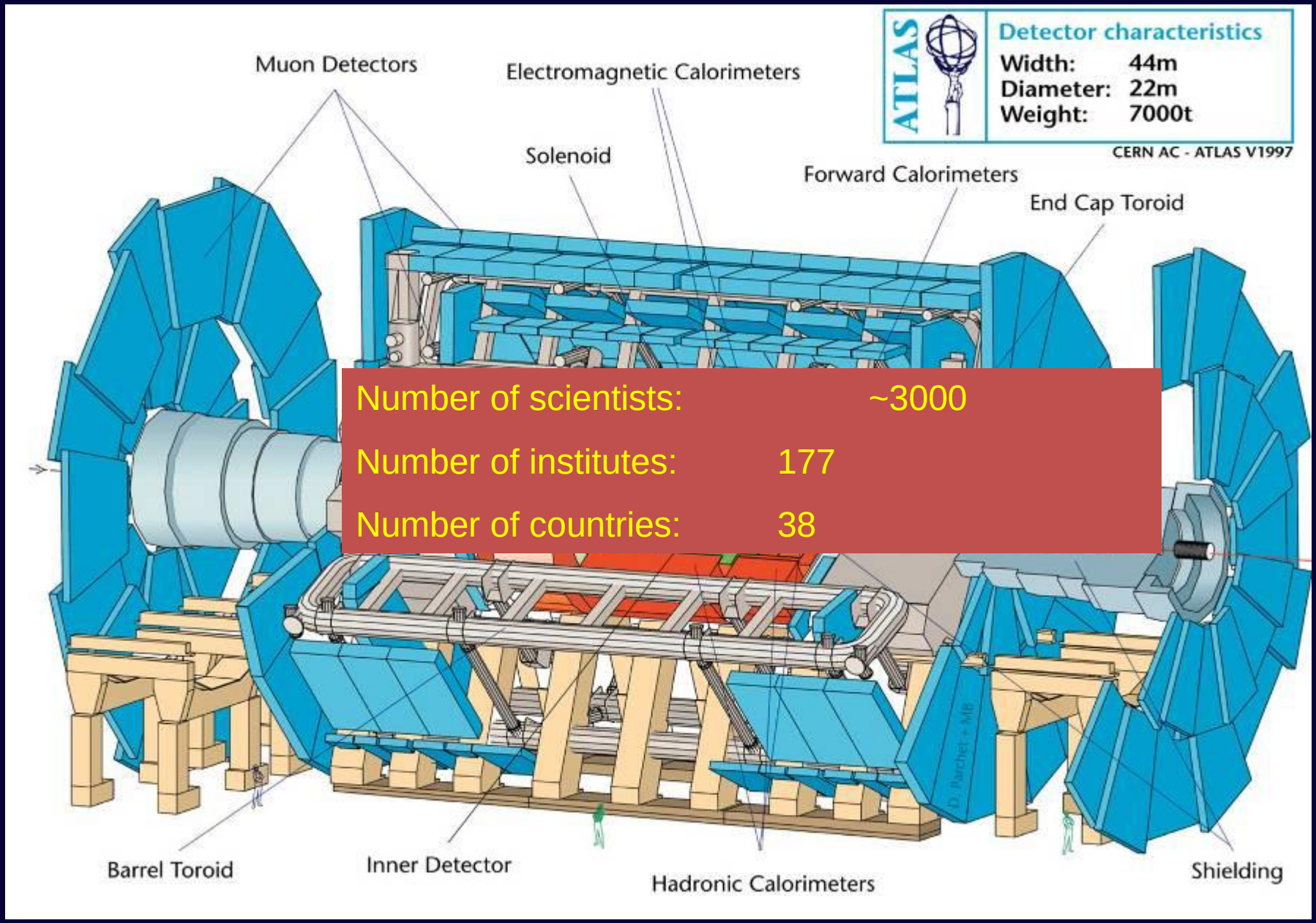
Neither explained origin of Mass



Where do the masses come from?

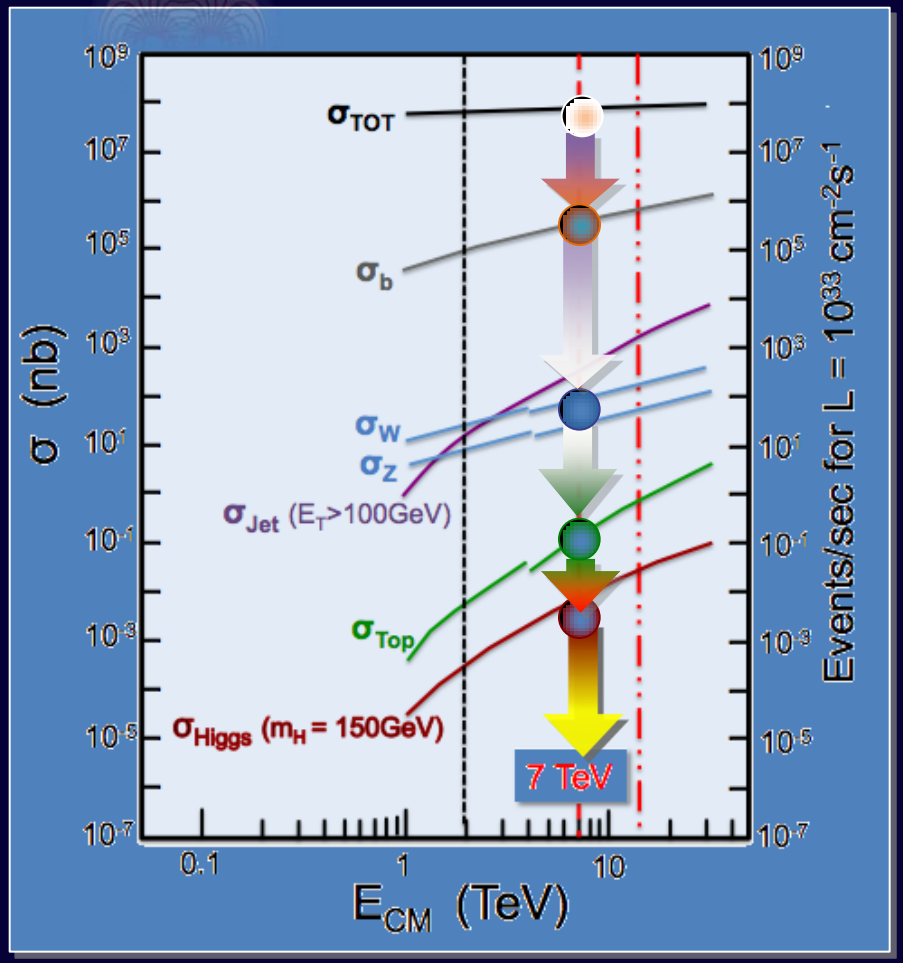
Are masses due to the Brout-Englert-Higgs (BEH) Mechanism & the Higgs boson?
(the physicists' Holy Grail)

The ATLAS Experiment

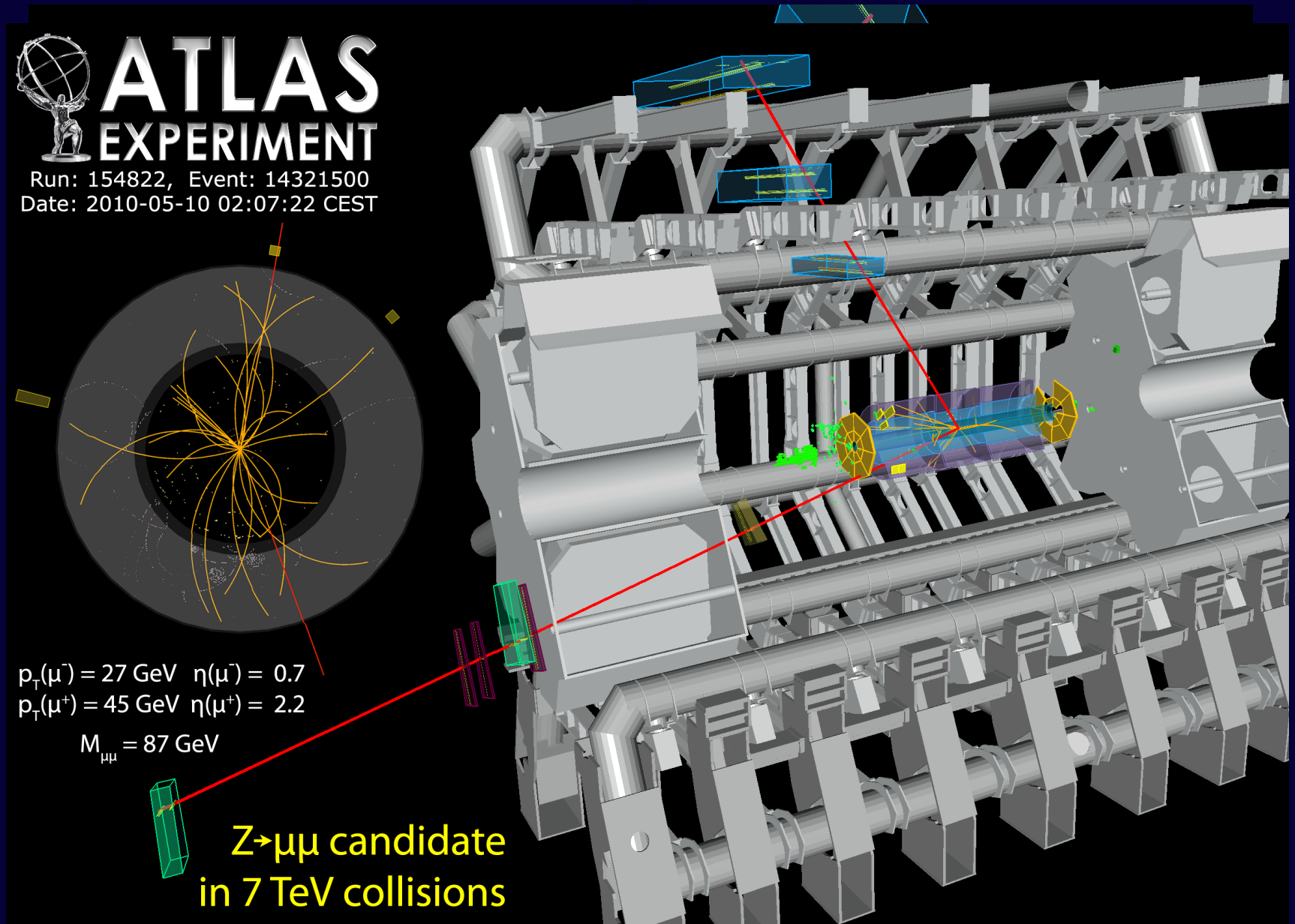


The ATLAS Experiment

Needle in a haystack …

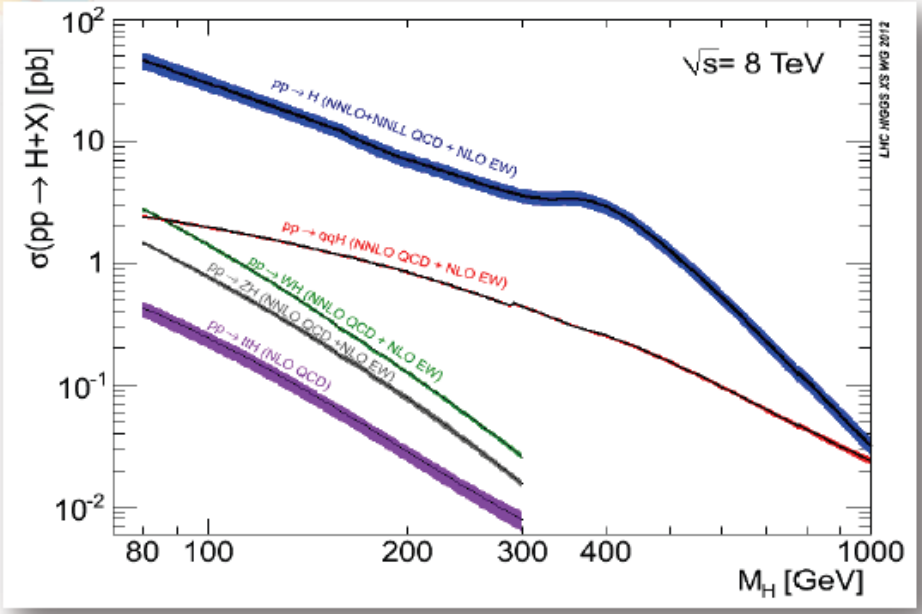


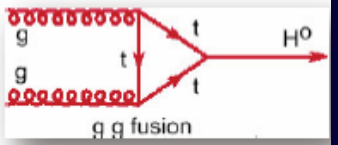
The Story so Far …

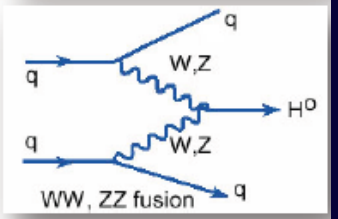


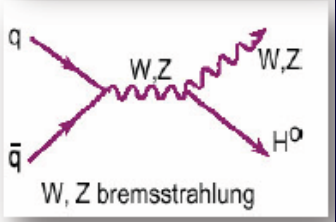
Higgs Boson Production

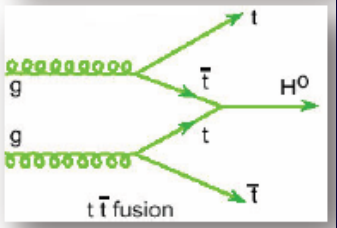
Higgs boson production











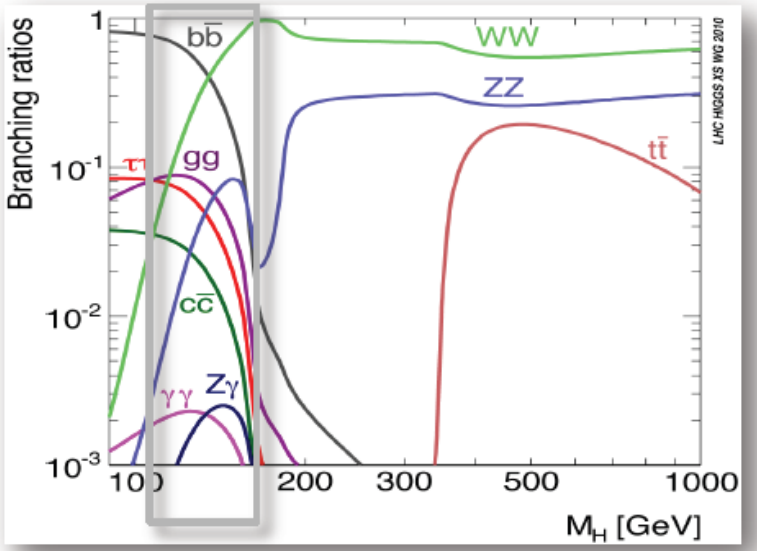
- $\sqrt{s}$=8 TeV: 25-30% higher σ than $\sqrt{s}$=7 TeV at low m_H
- All production modes to be exploited
  - gg VBF VH ttH
  - Latter 3 have smaller cross sections but better S/B in many cases

Higgs Boson Decays

5 decay modes exploited

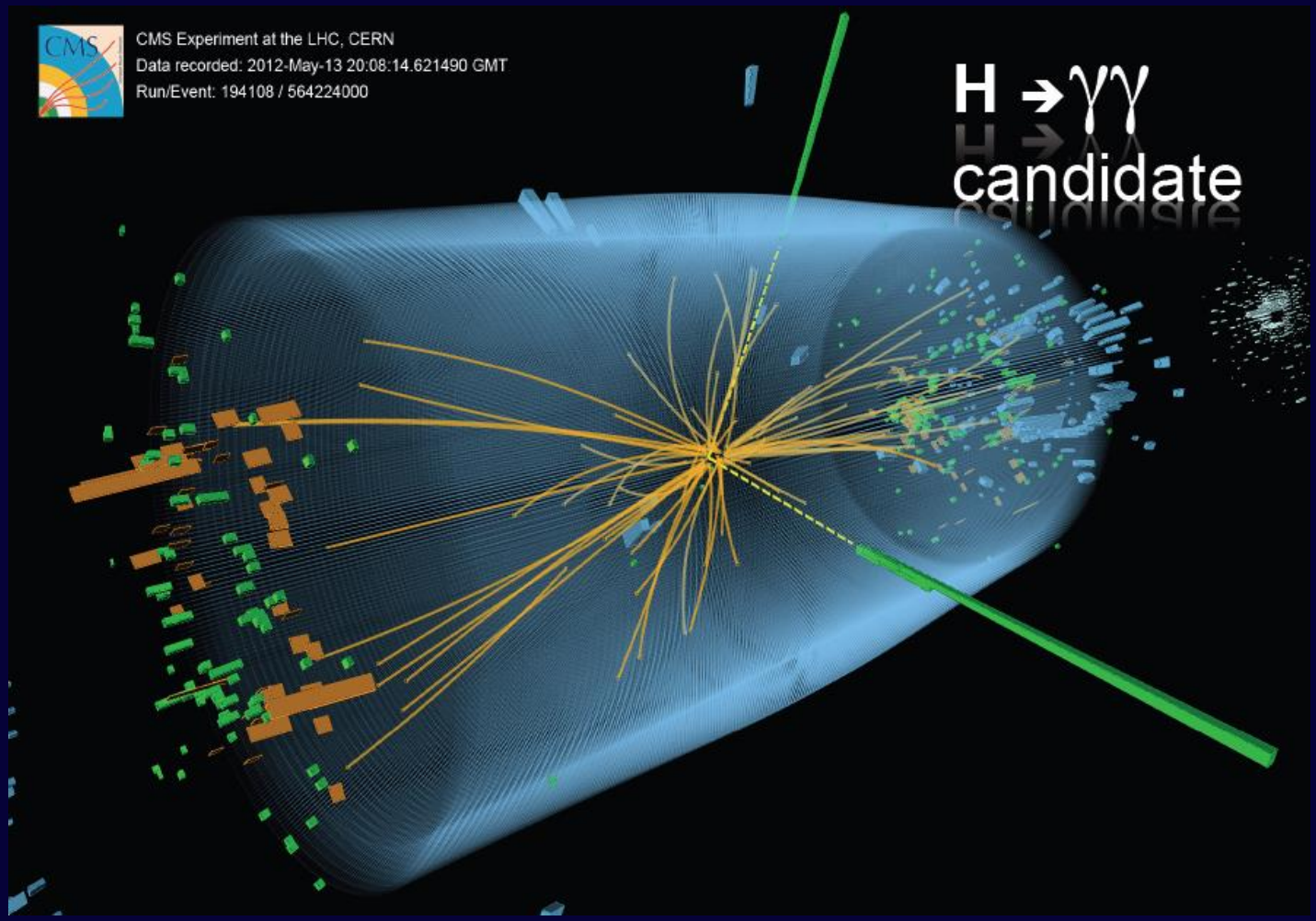
- High mass: WW, ZZ
- Low mass: bb, ττ, WW, ZZ, γγ
- Low mass region is very rich but also very challenging:
  main decay modes (bb, ττ) are hard to identify in the huge background
- Very good mass resolution (1%): H→γγ and H→ZZ→4l

Higgs boson decays

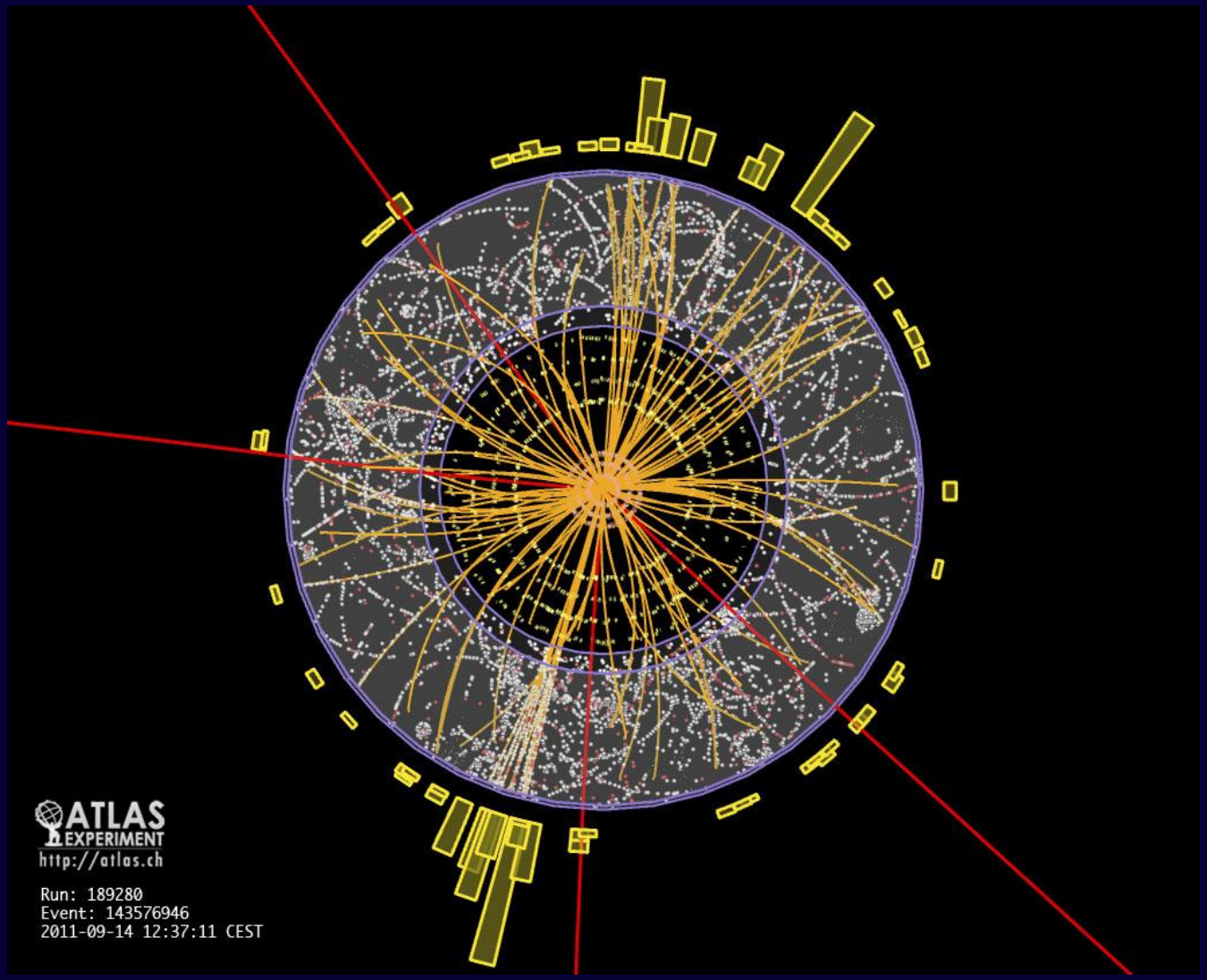


The Higgs is hiding in thousands of trillion interactions...

CMS Higgs Boson Candidate



ATLAS Higgs Boson Candidate



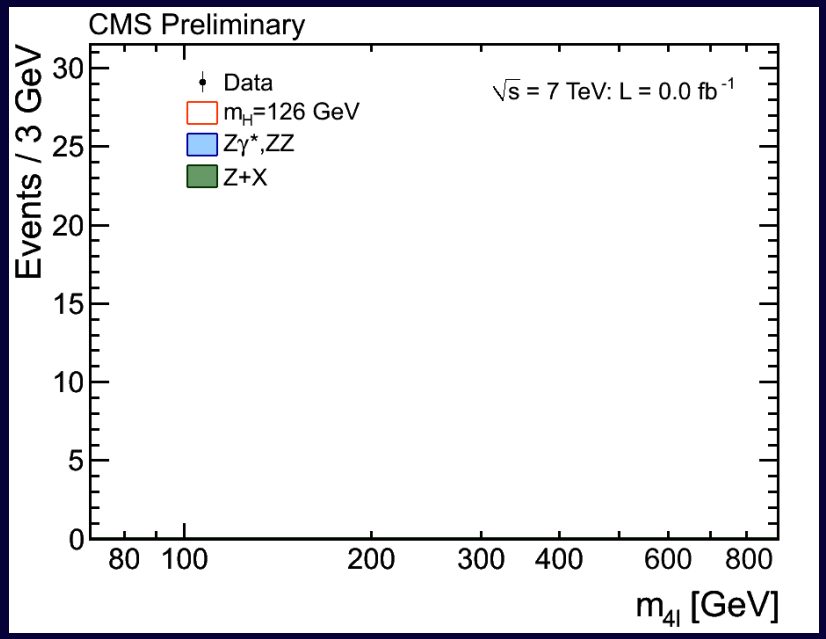
ATLAS event with 4 muons.

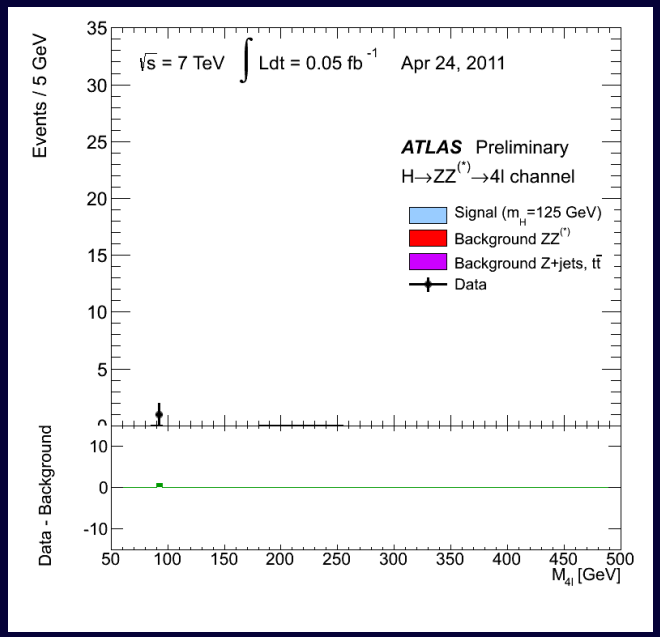
Candidate for
H ➔ Z Z* ➔ 4μ

The Higgs Signal

Accumulation of data

- Gold-plated channel H → ZZ → 4 leptons in CMS and ATLAS





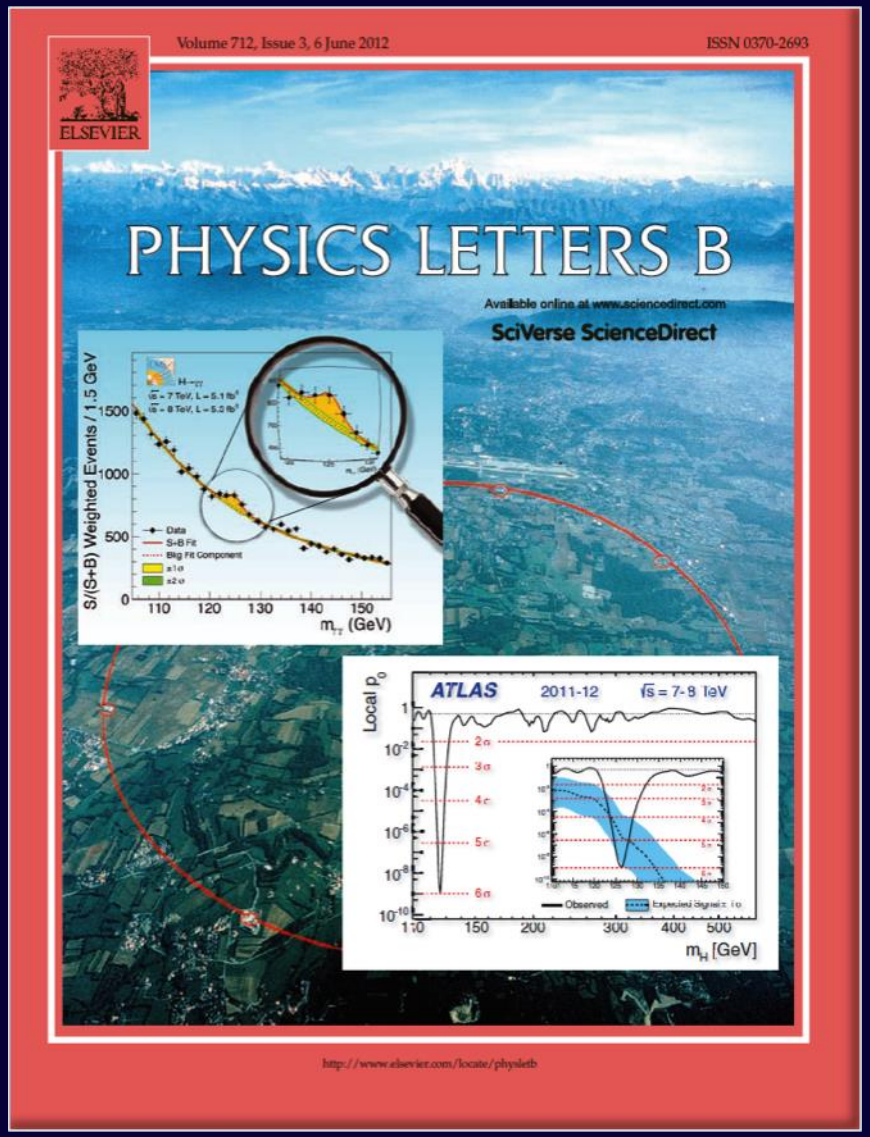
$m_H = 125.8 \pm 0.5 \pm 0.3$ GeV

$m = 0.91^{+0.30}_{-0.24}$

$m_H = 124.3 \pm 0.6 \pm 0.4$ GeV

$m = 1.5 \pm 0.4$ (at 125.5 GeV)

The Highlight of a Remarkable Year 2012



Nobel Prize in Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ***ATLAS and CMS experiments at CERN's Large Hadron Collider****".*

Studying the Higgs boson…

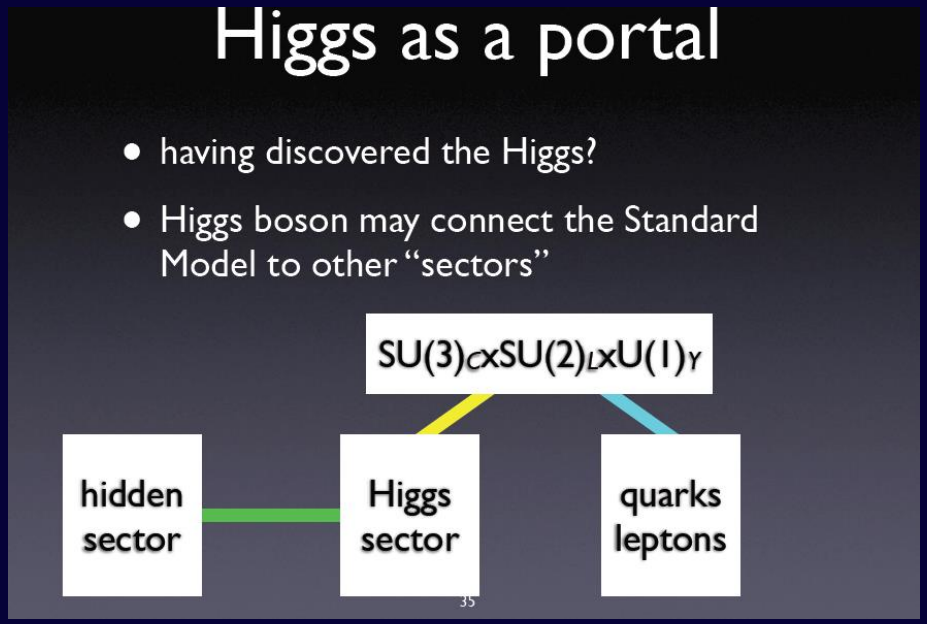
The News Since July 2012

- *The discovery of the new particle has been confirmed with more added collisions in 2012*
- *Signals in the fermion-channels start building up*
- *We tested the spin: it is compatible with a 0^+ state and not with a 0^- or spin 2 states*
- *The mass is measured better with time, now in the range125-126 GeV.*
- *The couplings to Bosons and Fermions are consistent with the SM predictions (but these are not very precise yet; surprises possible…)*

What is Next?

The work is not over yet: Many questions still remain unanswered:

- Is it THE Standard Model Higgs boson or a messenger of New Physics ?
- How can we explain a Higgs mass ~ 126 GeV? What stabilizes the mass?
- What explains the mass pattern of the particles that we observe?
- What is Dark Matter and Dark energy? Supersymmetry at higher masses??
- Where is the antimatter in the Universe? How did it dissapear??



Need for precision measurements with ~100x the present statistics

LHC upgrade ! Experiment upgrades!! (Other machines?)

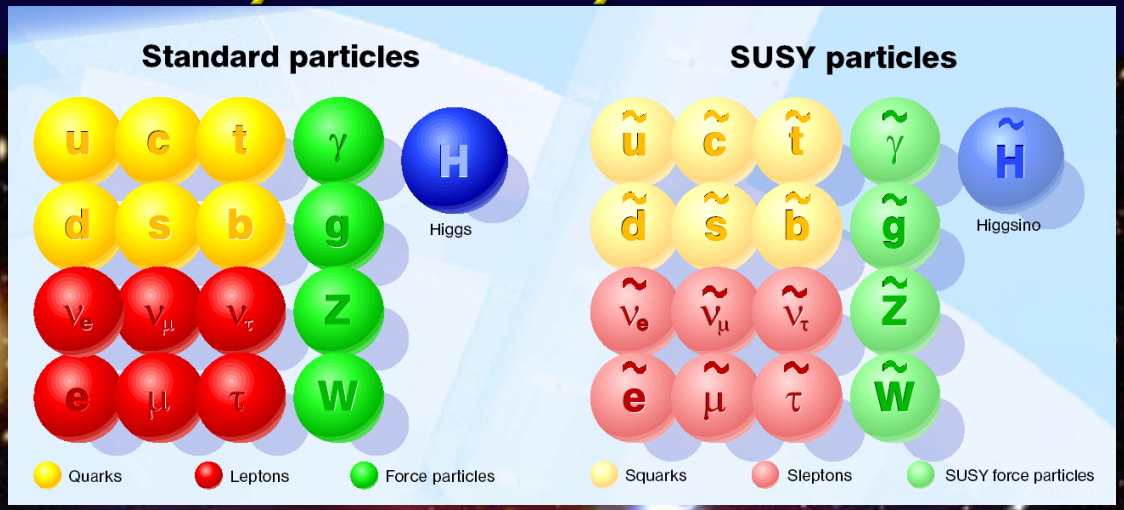
Dark Matter in the Universe

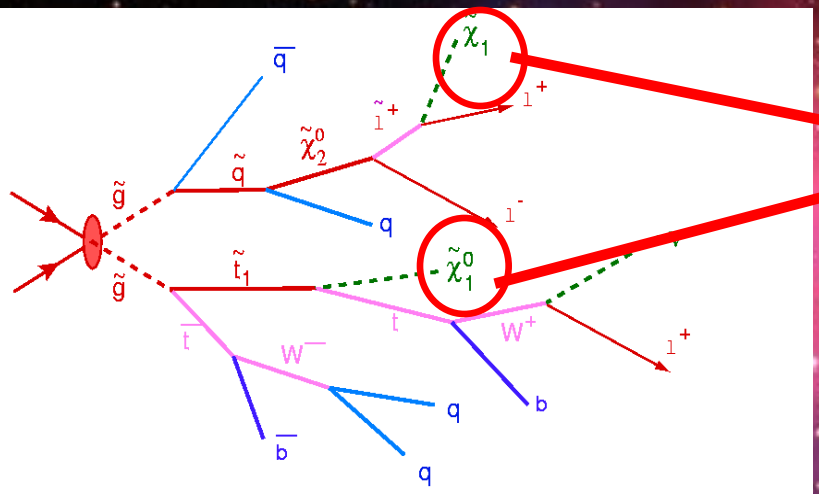
Astronomers say that most of the matter in the Universe is invisible
Dark Matter

'Supersymmetric' particles ?

We shall look for them with the LHC

Supersymmetry
A New Symmetry in Nature?

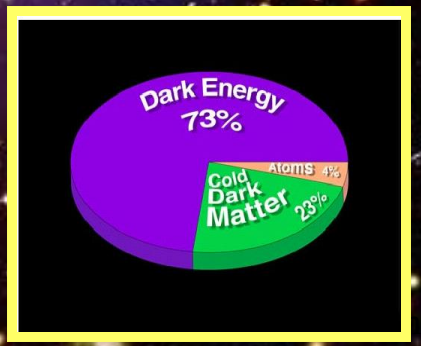




3 isolated leptons
+ 2 b-jets
+ 4 jets
+ E_t^{miss}

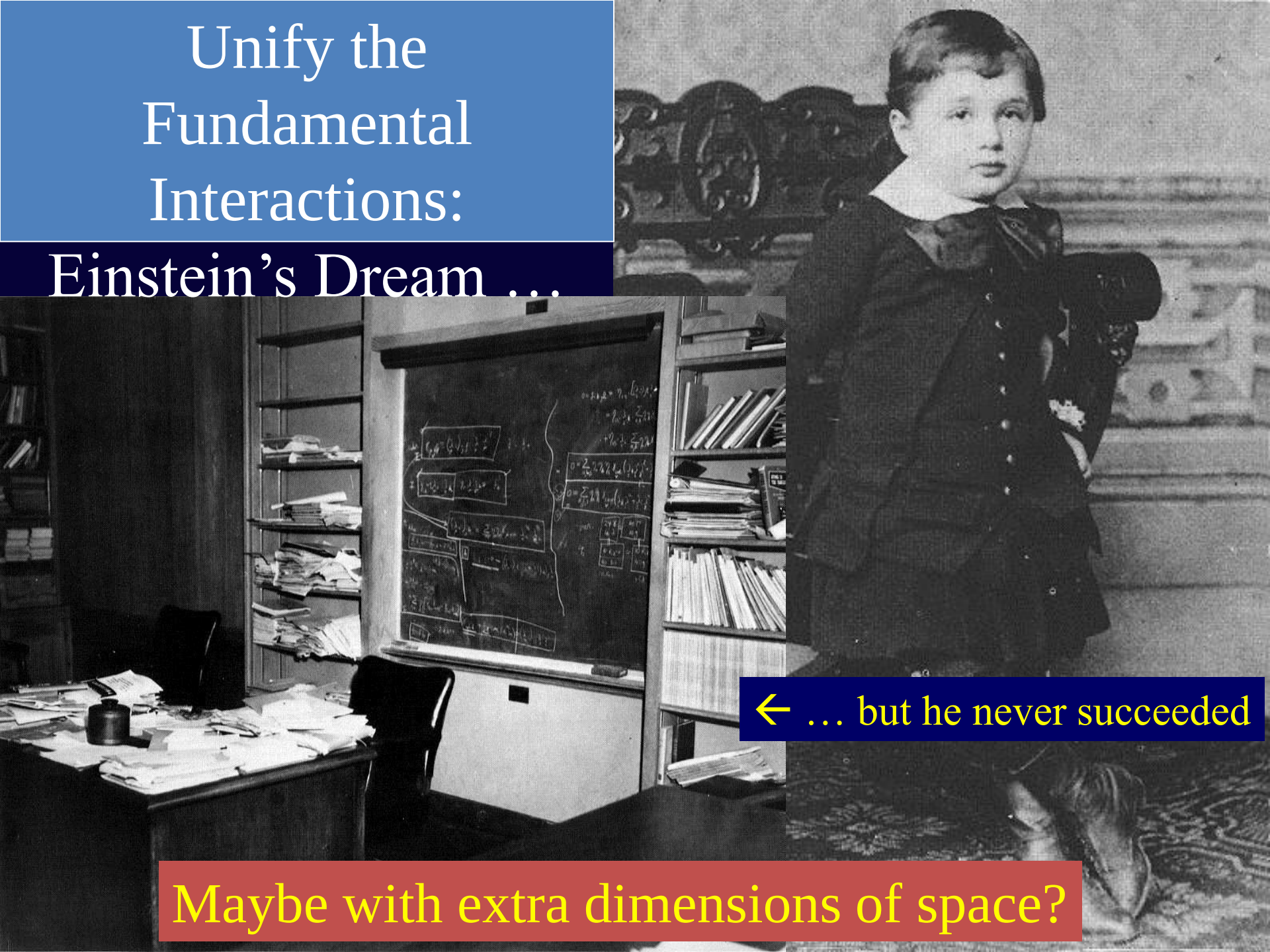
Candidate Particles for Dark Matter
⇒ Produce Dark Matter in the lab

SUSY particle production at the LHC



Unify the Fundamental Interactions:

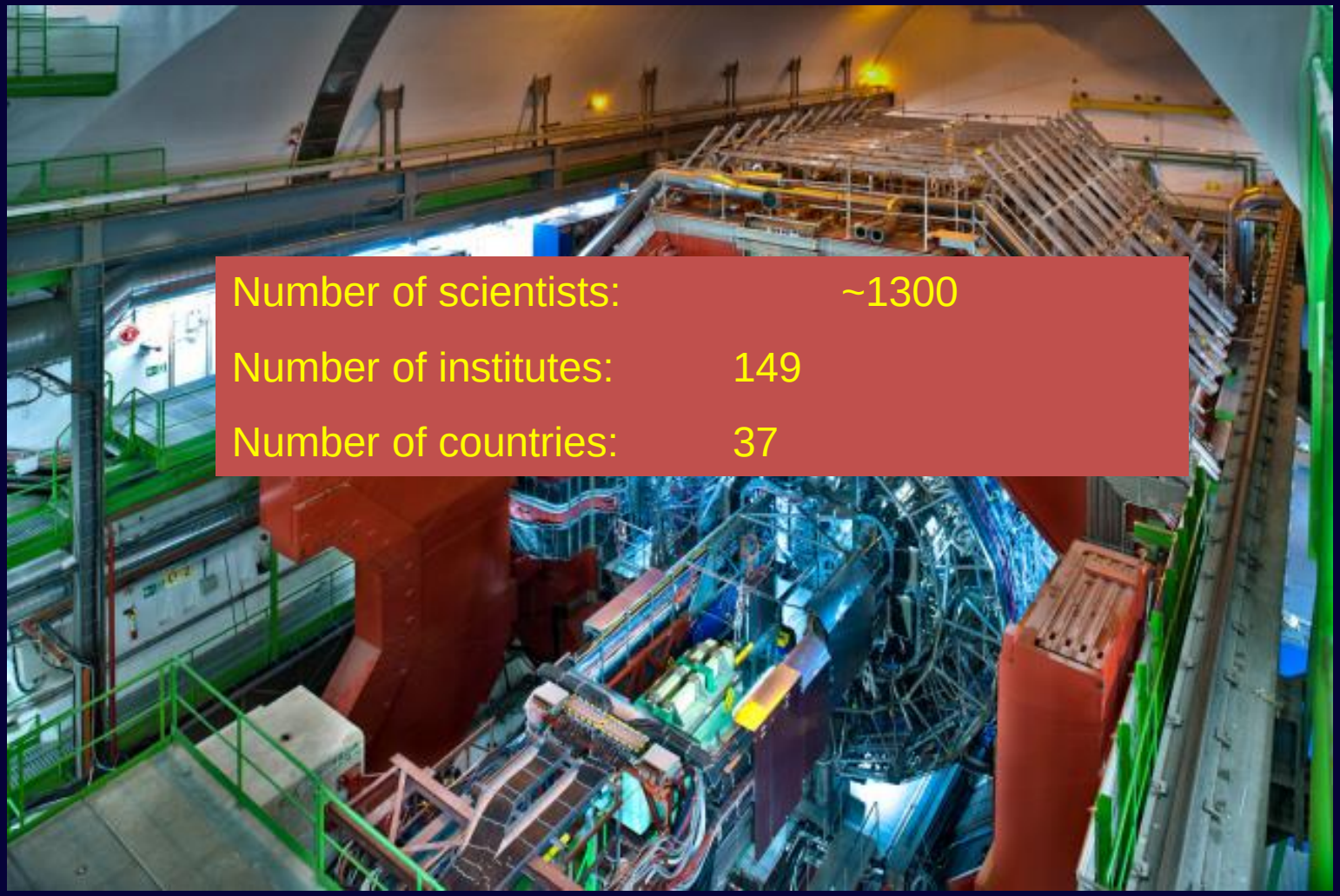
Einstein's Dream …



← … but he never succeeded

Maybe with extra dimensions of space?

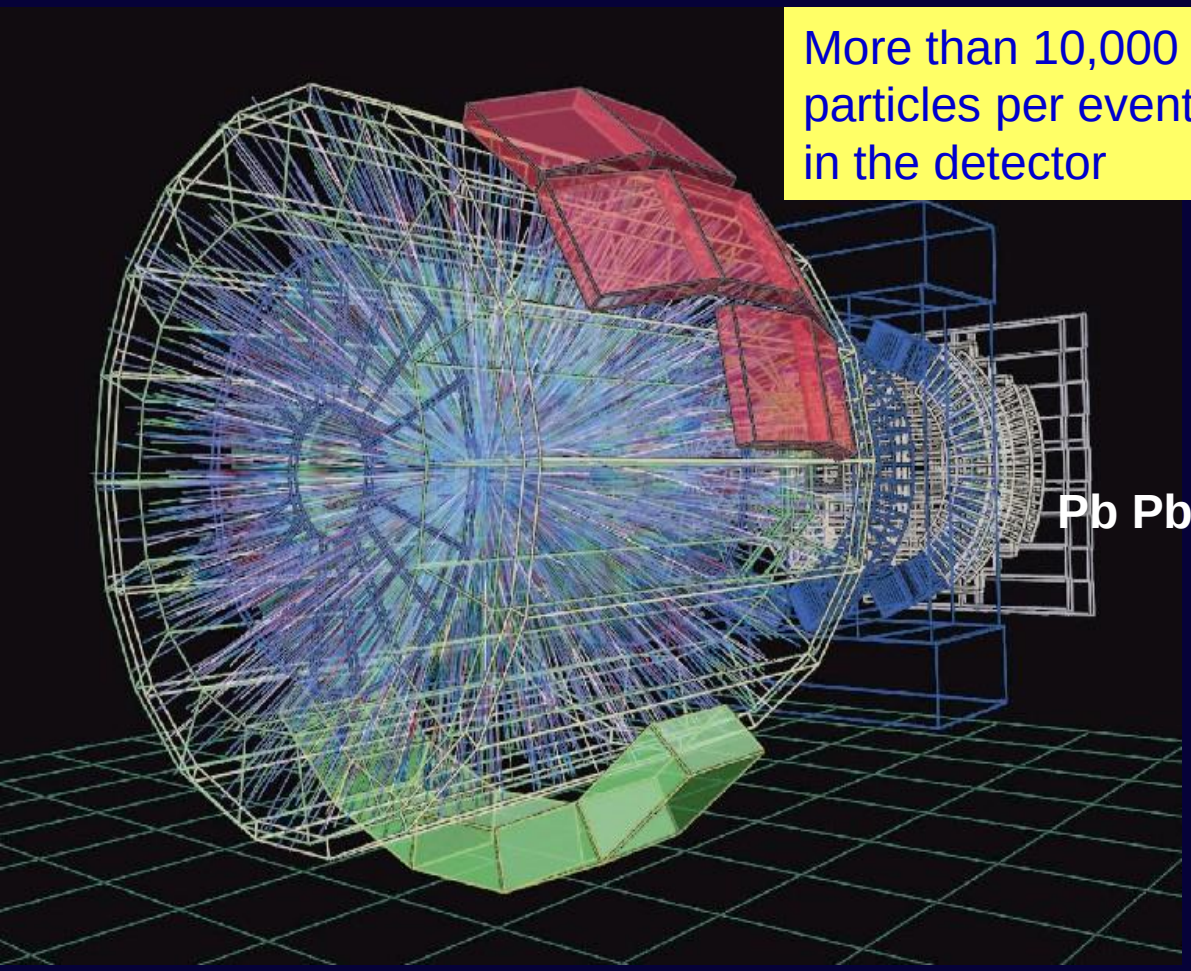
The ALICE Experiment



Number of scientists:	~1300
Number of institutes:	149
Number of countries:	37

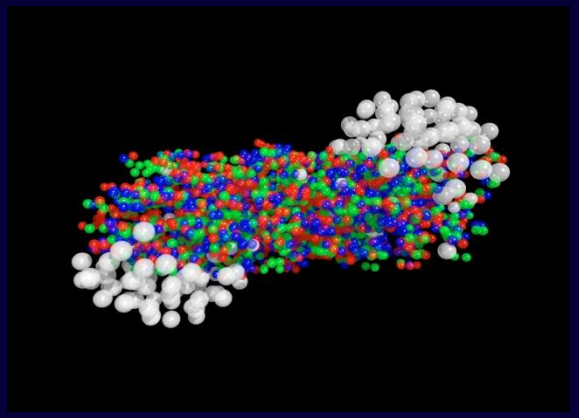
Primordial Plasma

Lead-lead collisions at the LHC study the primordial plasma, a state of matter in the early moments of the Universe



More than 10,000 particles per event in the detector

A lead lead collision simulated in the ALICE detector

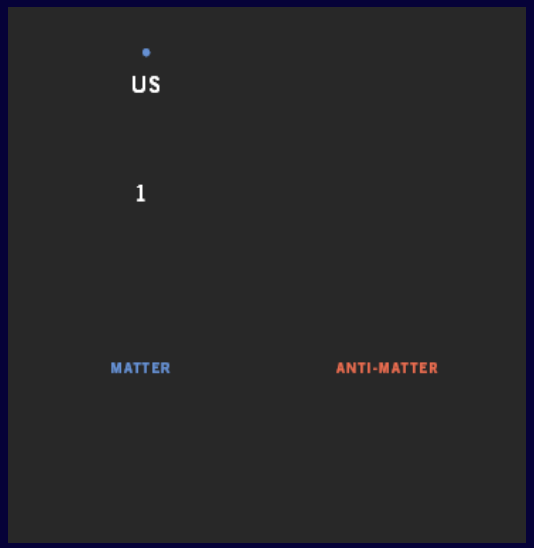


Pb Pb collisions may liberate quarks

Study the phase transition of a state of quark gluon plasma created at the time of the early Universe to the baryonic matter we observe today

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

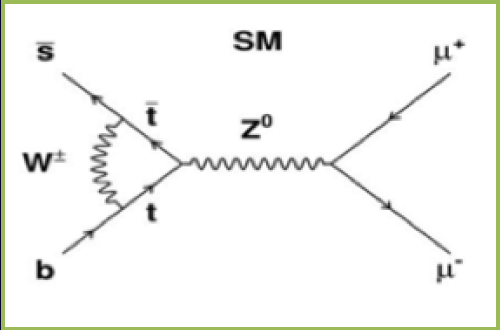


Matter and antimatter not quite equal and opposite: WHY?

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

LHC experiments are searching for answer

Rare Decays: B_s to $\mu\ \mu$ Decays

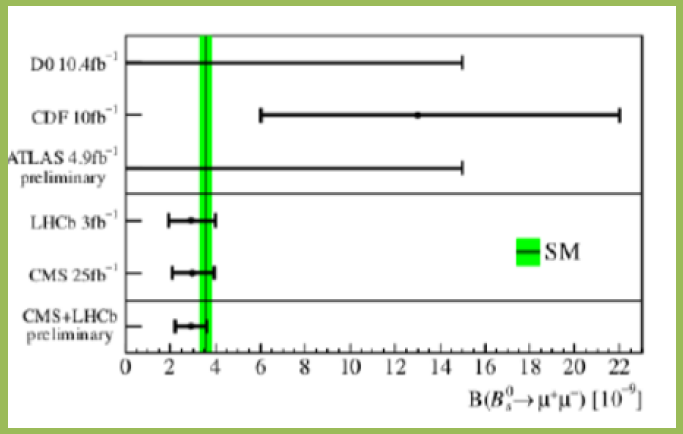


- A B_s particle is a particle consisting of a beauty-quark and strangeness-quark, with a mass of ~ 10 GeV
- Three B_s particles in a billion will decay into two muons. This decay has been chased since 25 years.
- New physics modifies Standard Models predictions

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = 3.56 \pm 0.29 \times 10^{-9}$$

Observation:

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$



Results from LHCb +CMS experiment combined

The Predictable Future: LHC Time-line

2009 — Start of LHC

Run 1: 7 and 8 TeV centre-of-mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, ~25 fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up luminosity to nor… …to 100 fb^{-1}) and centre-of-mass energy (…

2018 — Injector and LHC Phas… …mate luminosity

Run 3: P… …2 x nominal, reaching ~100 fb^{-1} / year acc…

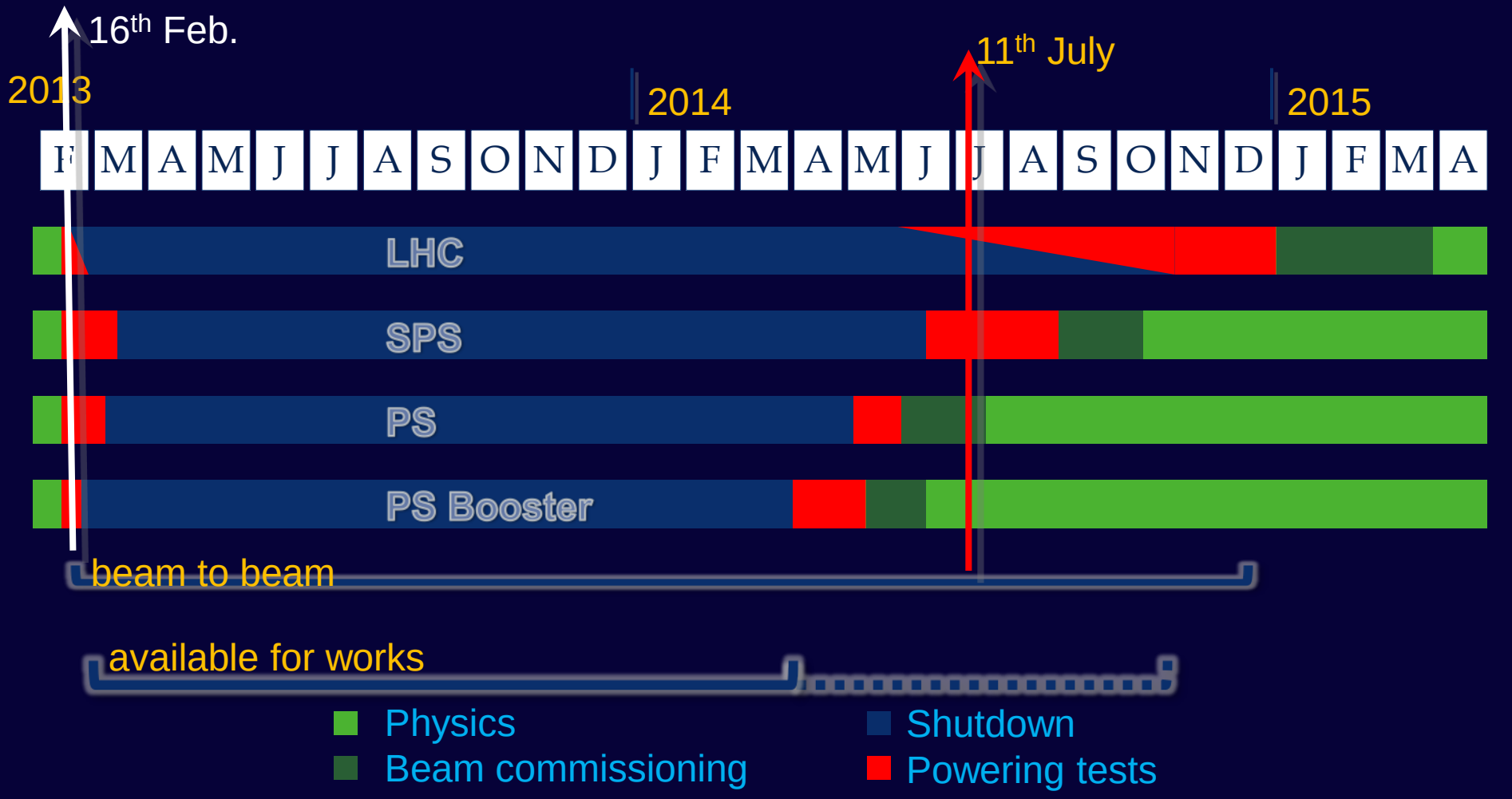
~2023 — Phas… …minosity LHC. New focussing magnets and CRAB… …for very high luminosity with levelling

Run 4: Collect data until > 3000 fb^{-1}

>2030 — HE-LHC?

Study of the properties of the Higgs Boson
and
Physics beyond the Standard Model

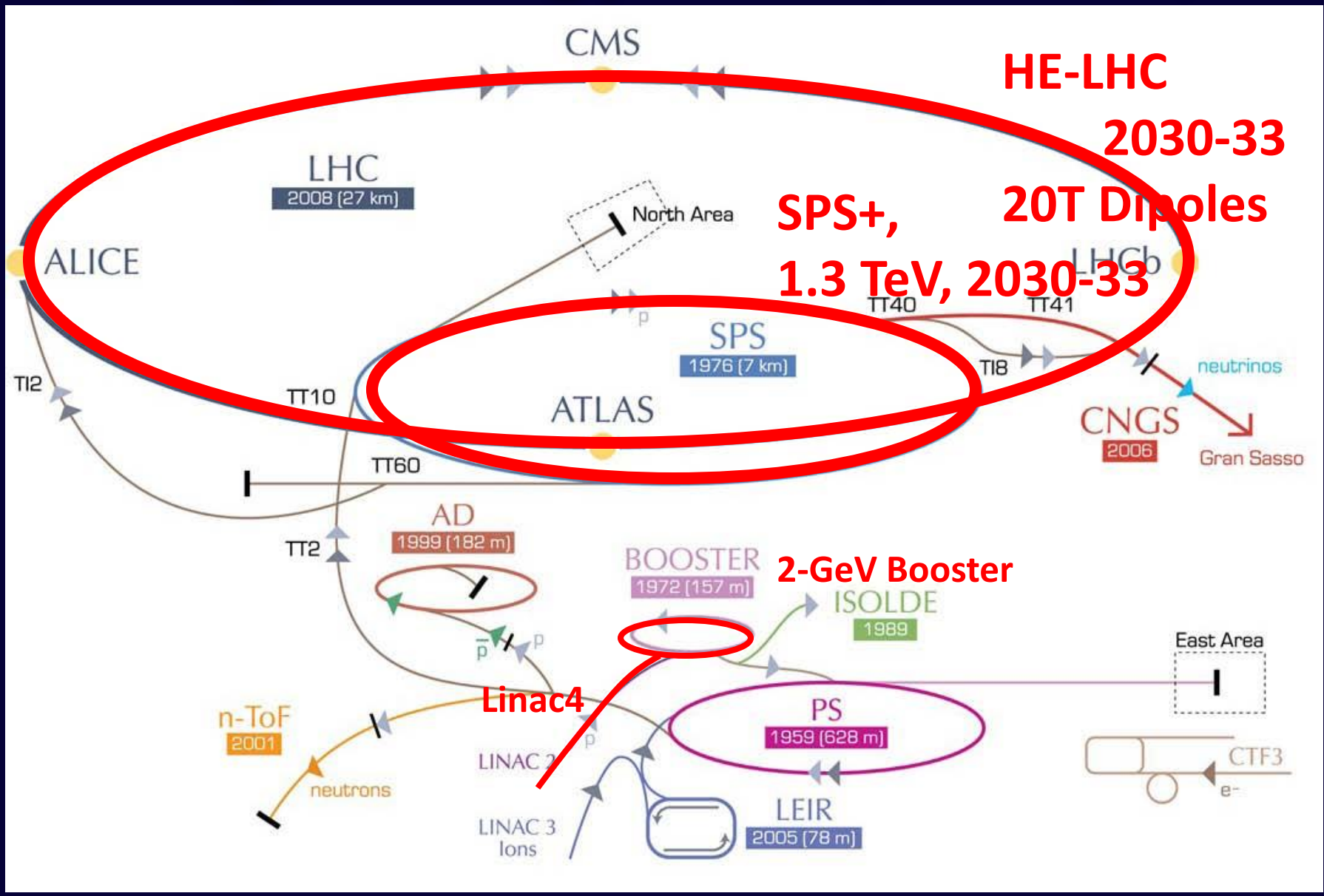
LS1 from Feb. 2013 to Dec. 2014



LHC Schedule beyond LS1

LHC schedule approved by CERN management & LHC experiments
December 2013

High-Energy LHC (HE-LHC)



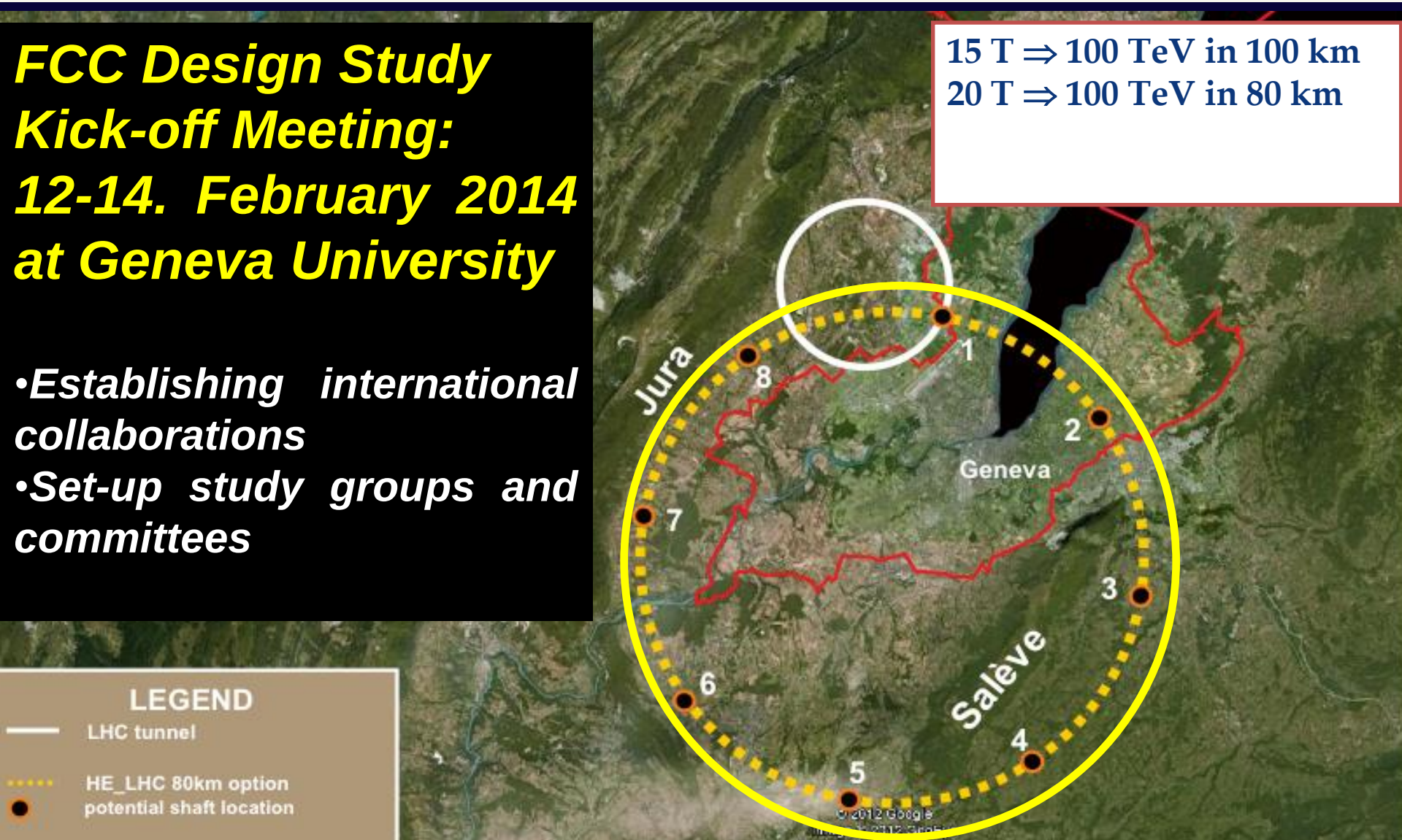
80-100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements

with possibility of e+-e- (TLEP) and p-e (VLHeC)

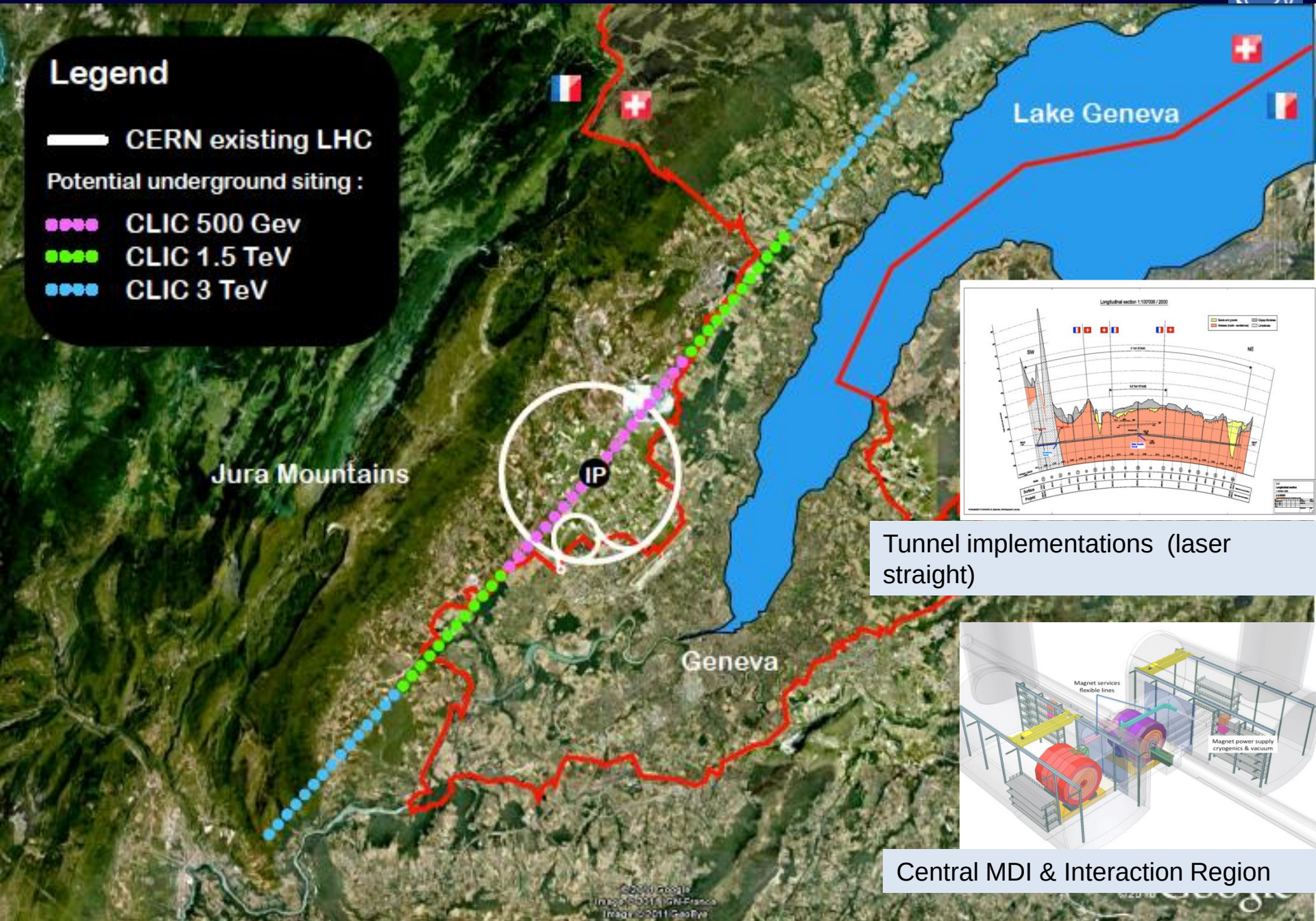
FCC Design Study Kick-off Meeting: 12-14. February 2014 at Geneva University

- ***Establishing international collaborations***
- ***Set-up study groups and committees***

15 T ⇒ 100 TeV in 100 km
20 T ⇒ 100 TeV in 80 km



CLIC near CERN



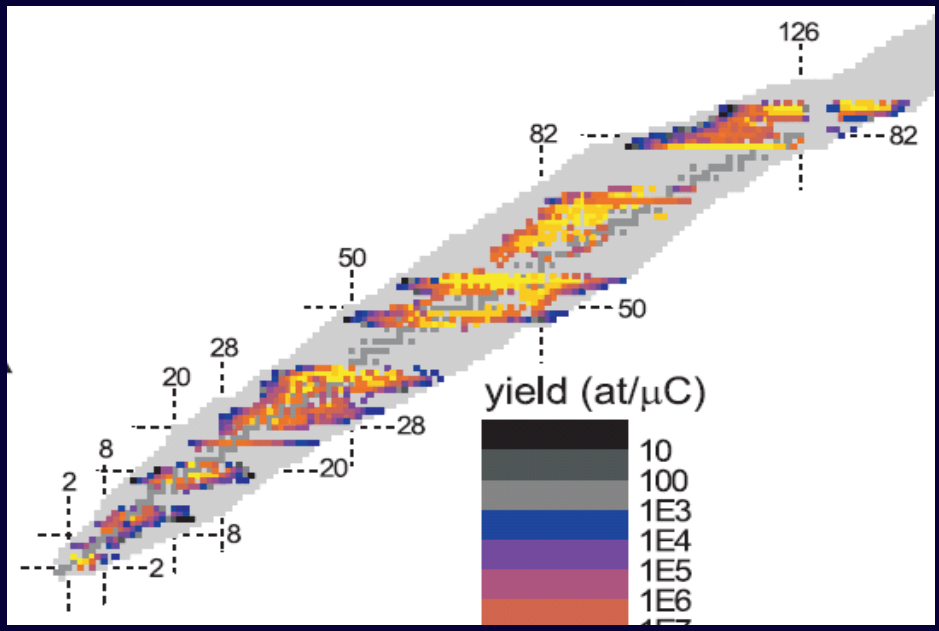
Tunnel implementations (laser straight)

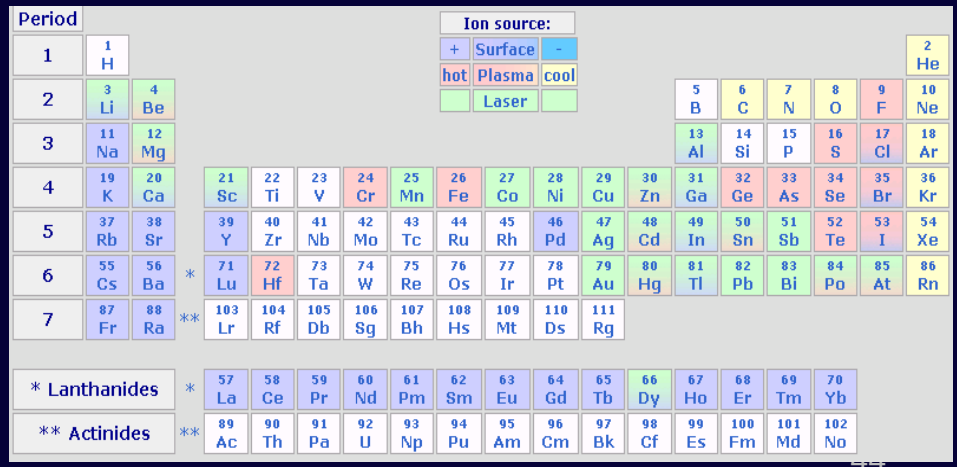
Central MDI & Interaction Region

ISOLDE
Radioactive Ion Beam Facility

- *More than 900 nuclides of over 70 chemical elements delivered to users – by far largest choice among ISOL-type facilities (experience gathered over 40 years).*

- *Experiments range from pure nuclear physics to "applied" research in materials science and medicine.*



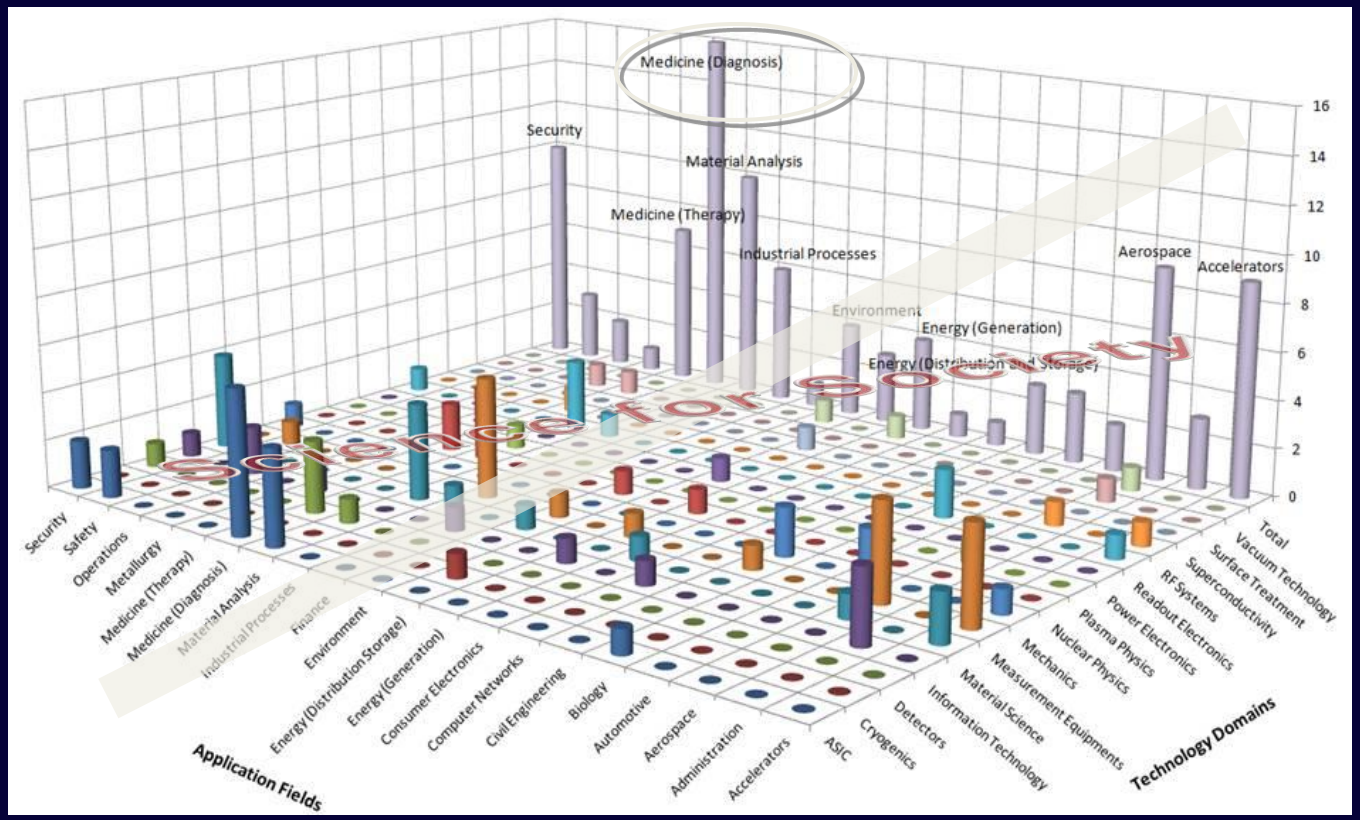


KNOWLEDGE & TECHNOLOGY TRANSFER

Innovation Education
CERN
uniting people
Research

CERN Technologies & Innovation

Cutting edge Research Infrastructures play a key role in a knowledge driven society

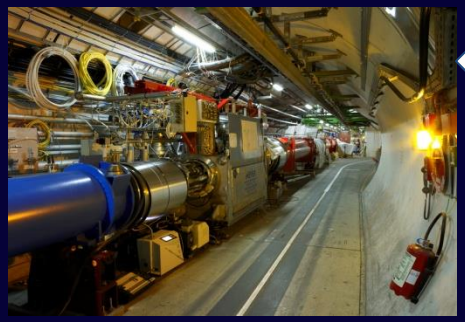


Knowledge is – and will be more and more – the most precious resource for a sustainable development

CERN Technologies and Innovation Example: Medical Applications

Innovation Education CERN uniting people Research

Combining Physics, ICT, Biology and Medicine to fight cancer

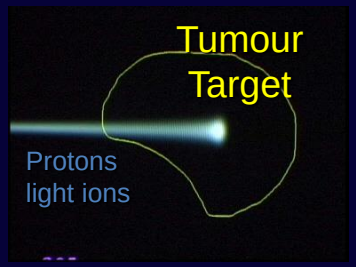


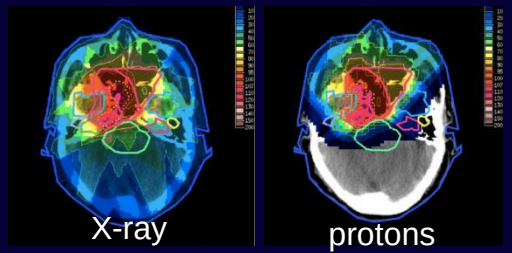
Accelerating particle beams

~30'000 accelerators worldwide

~17'000 used for medicine

Hadron Therapy

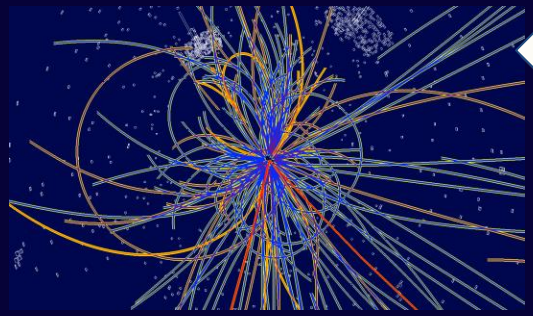




Leadership in Ion Beam Therapy now in Europe and Japan

>70'000 patients treated worldwide (30 facilities)

>21'000 patients treated in Europe (9 facilities)

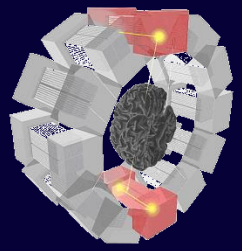


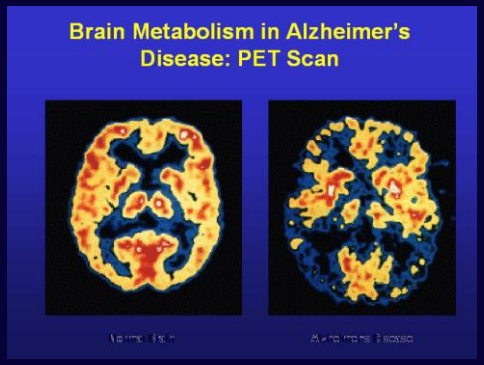
Detecting particles

Imaging

Clinical trial in Portugal for new breast imaging system (ClearPEM)

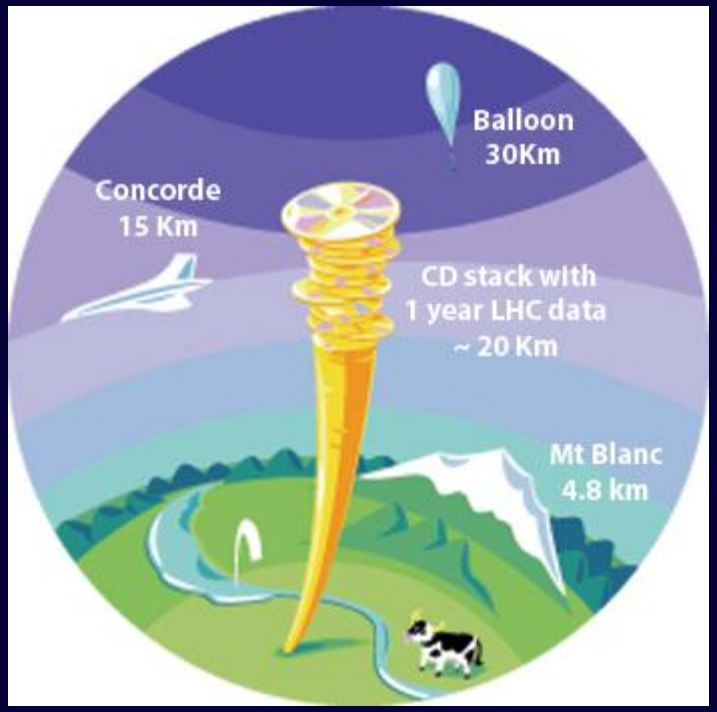
PET Scanner





The LHC Data Challenges

- *Experiments were anticipated to produce about **15 Million Gigabytes** of data each year (~20 million CDs!)*
- *The total volume in eg ATLAS is 5 billion detector events and several billion Monte Carlo events amounting to 100 Million Gigabytes of data in 3 years*
- *LHC data analysis requires a computing power equivalent to **~100,000 of today's fastest PC processors***
- *=> Requires many cooperating computer centres, as CERN can only provide ~20% of the capacity*



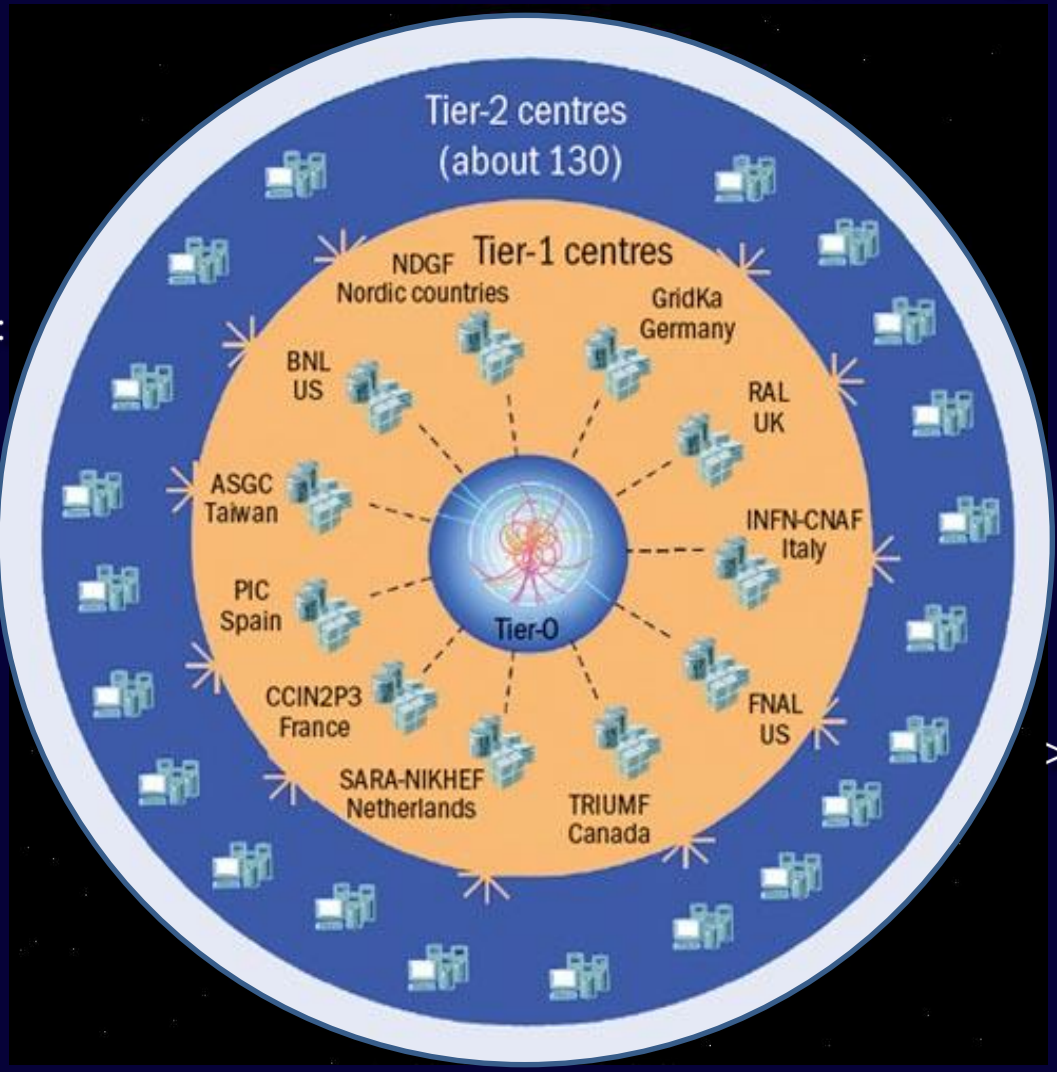
GRID Computing

The Worldwide LHC Computing Grid

Tier-0
(CERN and Hungary):
data recording,
reconstruction and
distribution

Tier-1: permanent
storage, re-
processing,
analysis

Tier-2: Simulation,
end-user analysis



nearly 160 sites,
35 countries

~250'000 cores

173 PB of storage

> 2 million jobs/day

10 Gb links

WLCG:
An International collaboration to distribute and analyse LHC data

Integrates computer centres worldwide that provide computing and storage resources into a single infrastructure accessible by all LHC physicists

CERN Education Activities

Scientists at CERN
Academic Training Programme

NEW:
Asia-Europe-Pacific School of High-Energy Physics
Fukuoka, Oct 2012
India, 2014

Latin American School
Natal, Brazil, 2011
Arequipa, Peru, 2013

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

CERN School of Physics
Hungary, June 2013

Physics Students
Summer Students Programme

CERN Teacher Schools
International and National Programmes

1st African School on Fundamental Physics and its Applications
Stellenbosch, August 2010

CERN Teacher Programme

Teacher Programme Participants 1998 - 2013 (Total: 7087)

MEMBER STATES

Austria	111
Belgium	110
Bulgaria	279
Czech Republic	146
Denmark	83
Finland	472
France	237
Germany	642
Greece	518
Hungary	348
Israel	7
Italy	270
Netherlands	99
Norway	105
Poland	544
Portugal	328
Slovakia	221
Spain	309
Sweden	147
Switzerland	177
United Kingdom	1048

6201

CANDIDATE FOR ACCESSION

Romania	12

ASSOCIATE MEMBER IN THE PRE-STAGE TO MEMBERSHIP

Serbia	14

OBSERVER STATES

India	2
Japan	5
Russia	193
Turkey	3
USA	65

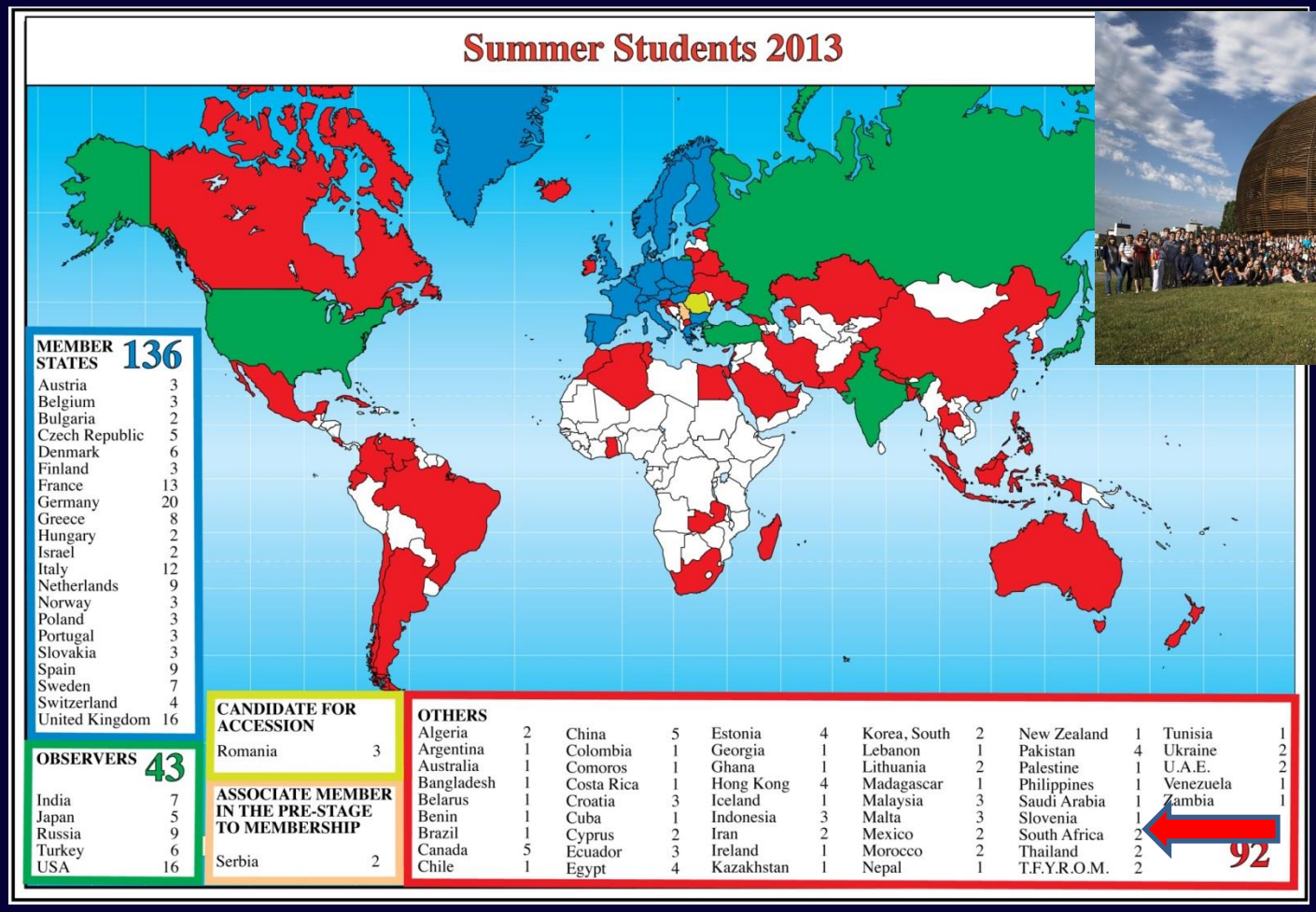
268

OTHERS

Angola	4	China	1	Ireland	5	Morocco	2	Swaziland	1
Australia	5	Croatia	1	Kazakhstan	3	Mozambique	17	Thailand	7
Azerbaijan	1	Cyprus	8	Kenya	4	Qatar	1	T.F.Y.R.O.M.	11
Brazil	114	Dominican Rep.	21	Latvia	1	Rwanda	17	Timor-Leste	7
Burundi	1	Ecuador	2	Lebanon	1	Sao Tome	4	Uganda	3
Cameroon	3	Estonia	46	Madagascar	2	Saudi Arabia	1	Ukraine	77
Canada	3	Georgia	74	Malta	36	Singapore	2	U.A.E.	1
Cape Verde	3	Ghana	6	Mexico	6	Slovenia	21		
Chile	3	Guinea Bissau	1	Mongolia	1	South Africa	6		
		Iran	1	Montenegro	13	South Korea	44		

92

Summer Students 2013



INTERNATIONAL RELATIONS

CERN was founded 1954: 12 European States

"Science for Peace"

Today: 21 Member States

~ 2300 staff
~ 1600 other paid personnel
~ 10500 scientific users

Budget (2014) ~1000 MCHF

Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

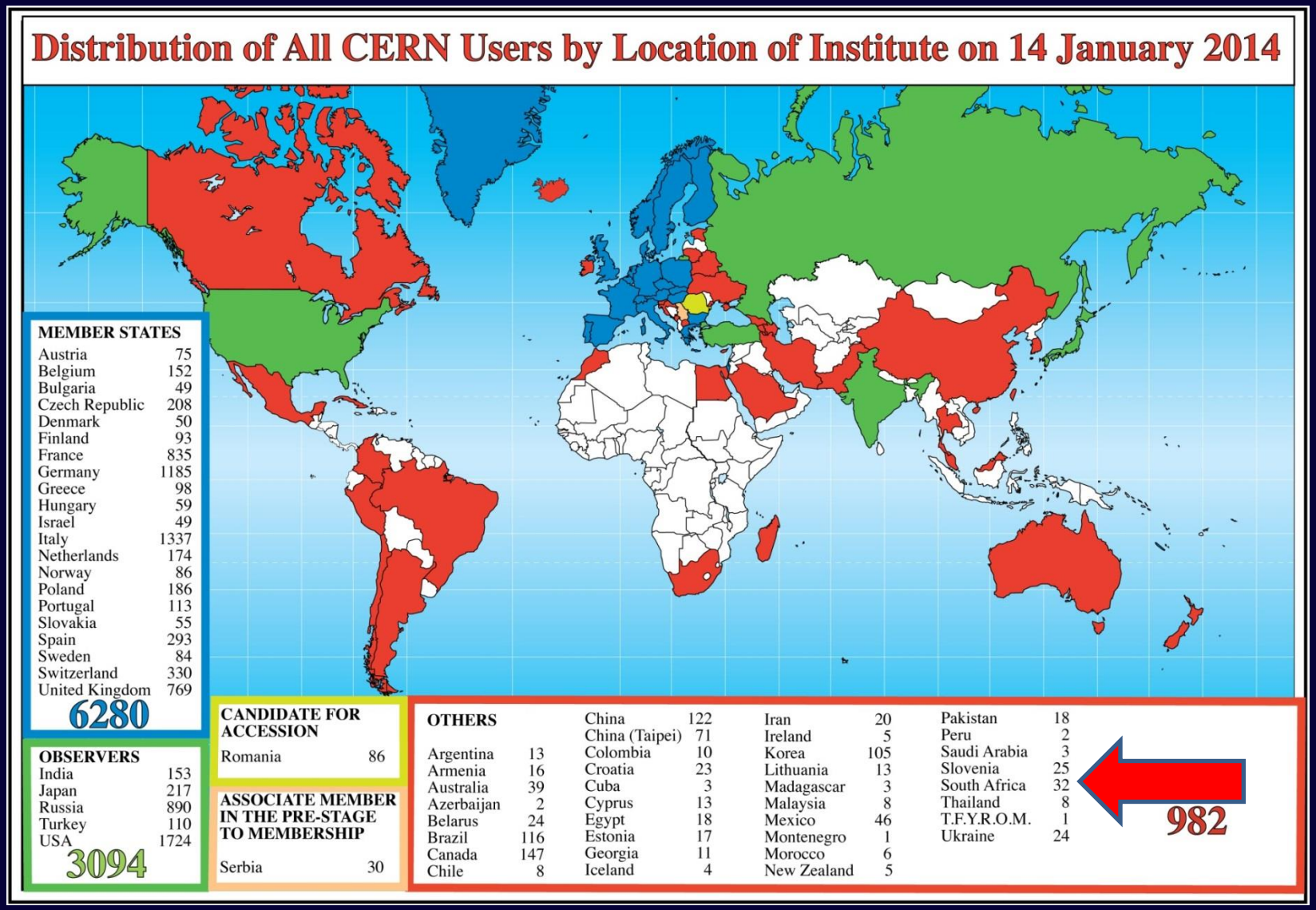
Candidate for Accession: Romania

Associate Member in Pre-Stage to Membership: Serbia

Applicant States for Membership or Associate Membership: Brazil, Croatia, Cyprus, Pakistan, Russia, Slovenia, Turkey, Ukraine

Observers to Council: India, Japan, Russia, Turkey, United States of America; European Commission and UNESCO

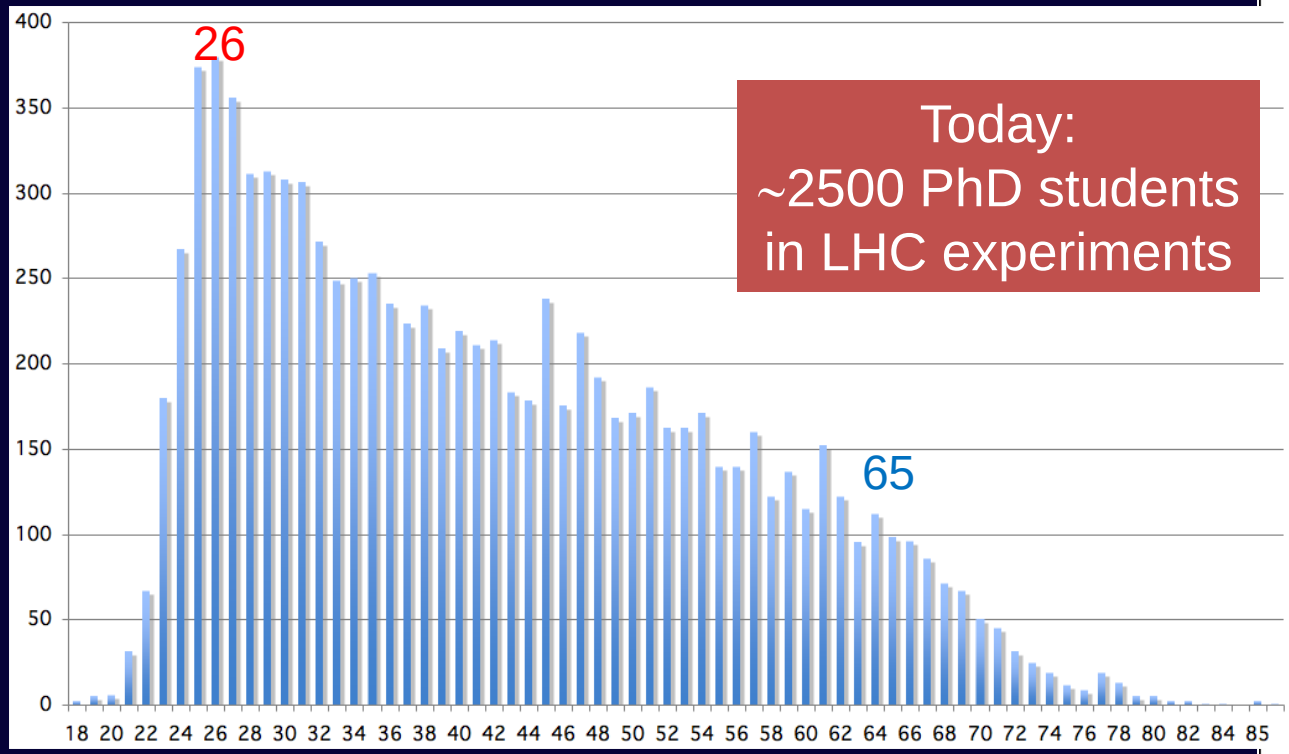
Science is getting more and more global



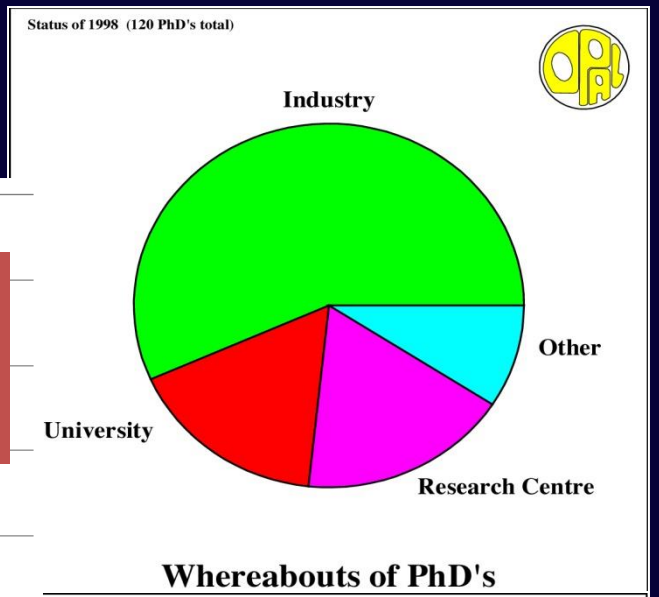
Age Distribution of Scientists

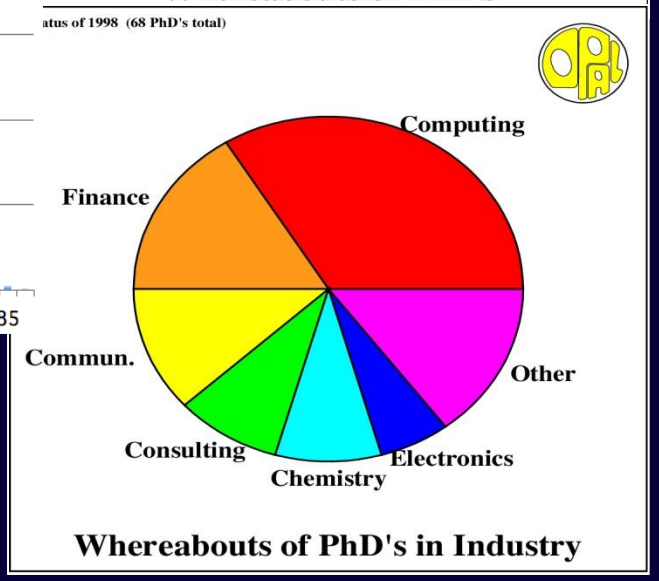
- and where they go afterwards

Survey in March 2009



Today:
~2500 PhD students
in LHC experiments





They do not all stay: where do they go?

South Africa & CERN

- *In the early 1990s, senior physicists in South Africa saw the advantages of collaborating with CERN, particularly for the training of young scientists.*
- *In 1992, South Africa and CERN signed an International Co-operation Agreement concerning the further development of scientific and technical Co-operation in research projects at CERN.*
- *South Africa-CERN Collaboration in place.*

Launch Event of the SA-CERN on 15 Dec 2008

Builds on the long-standing excellent relations

South Africa & CERN

- Initial participation in fixed-target experiments and ISOLDE continues and has evolved.

- November 2001: University of Cape Town & iThemba LABS joined ALICE & recently University of Witwatersrand.
- July 2010: Team from Universities of Johannesburg & Witwatersrand joined ATLAS and subsequently Universities of Cape Town & KwaZulu-Natal.

Minister Pandor at ATLAS

- Collaboration in theoretical physics.

Minister Pandor at ALICE

- CERN – iThemba LABS collaboration on accelerator sector for hadrontherapy.
- Developing computing Grid infrastructure.

CERN – innovate, discover, publish, share

… and bring the world together


60
YEARS/ANS CERN