Experimentele Technieken

in de Hoge Energie Fysica en verdere toepassingen

Deel 1: Inleiding

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CERN, Geneva, Switzerland
Universiteit Antwerpen
UC Davis, California

Kursus inhoud

- Inleiding tot experimenten in de Hoge Energie Fysica
- Voorbereiding op de Large Hadron Collider (LHC).
- Instrumentatie
  - Deeltjes doorheen materie
  - Detector principes
  - Recente ontwikkelingen
- Detail studie van detektoren voor de LHC (CMS, ATLAS, ALICE, LHCb…). Detektor uitdagingen
- Detail studie van andere detektoren (Cosmic rays, lineaire versneller, experimenten voor kosmologie, gravitatiegolven, andere gebieden (geneeskunde…))

Kursus inhoud

- Inleiding, tot het CMS experiment
- Daarna gespecializeerde detectoren
- Dan neemt prof D'Hondt over met trigger, DAQ, ….
- Geen examen maar permanente evaluatie
- Opdrachten (1 per persoon). Voorbeelden
  - Deeltjes door materie
  - Detectoren in detail (vanuit leerboeken)
  - CMS Subdetectoren in detail (Tracker, ECAL, HCAL, muons,…)
  - Andere experimenten (WMAP, Auger, Gravitatie experimenten, LHC experimenten)..
  - Echte experimentele papers (van CMS)
    - Start met projecten na de les volgende week

Timeline & Projects

- Report (5-10 pages) + Presentation of ~ 15 minutes
- When (some time December or January)?
- ⇒ Agenda

Friday Sept 28- 9:00-12:00 Les 1 (De Roeck) - UA
Friday Oct 12 - 9:00-12:00 Les 2
Friday Oct 19 – 9:00-12:00 Les 3 ?
Friday Nov 9 - 9:00-12:00 Les 4
Friday Nov 16 – 9:00-12:00 Reserve
Friday Nov 23 – 9:00-12:00 Les 1 (D'Hondt) - VUB
Friday Nov 30 - 9:00-12:00 Les 2
Friday Dec 7 - 9:00-12:00 Les 3
Friday Dec 21 - 9:00-12:00 Examen (De Roeck) - UA

Projects

- Simple Projects (*)
  - Derive the Bethe Bloch Formula (Grupen)
  - Cherenkov light radiation (Grupen)
- Other key experiments (**)
  - The Auger cosmic ray experiment. Ultra High Cosmic Rays
  - The WMAP experiment (satellite, dark matter/dark energy)
  - The Planck experiment (satellite, dark mater dark energy)
  - Ligo: gravitational waves / laser interferometry
  - The MOEDAL experiment at CERN (monopole search)
  - Neutrino experiments (eg OPERA)
- Detection techniques (**)
  - General: EM shower calorimeters (Grupen)
  - Hadronic shower calorimeters (Grupen)
  - Compensating calormeters (Wigmans lectures)
  - Dual readout calorimeters (Wigmans lectures)
  - Silicon detectors (Kleinknecht)
  - MSGC gas detectors
- Difficult projects (***)
  - CMS papers with real data (calibration, alignment, efficiency of CMS detector)

Last Year: Strange Neutrinos

Faster than the speed of light?

Measure:
-Starting time
-Arrival time
-Distance

Neutrinos arrive 60 nsecs to early

Finally it was a loose cable…

Why the LHC

The LHC is the most complex,
most challenging and at the same time one of the most anticipated scientific instruments so far built by mankind:

The Large Hadron Collider (LHC), built at CERN, Switzerland

- What Is CERN?
- What is the Large Hadron Collider?
- What are the challenges of the collider and experiments?
- What is the science of the Large Hadron Collider?

CERN
The European Laboratory for Particle Physics

CERN is the European Organization for Nuclear Research, the world's largest Particle Physics Centre, near Geneva, Switzerland
It is now commonly referred to as European Laboratory for Particle Physics
It was founded in 1954 and has 20 member states + several observer states
CERN employes >3000 people + hosts 9000 visitors from >500 universities.
Annual budget ~ 1100 MCHF/year (2010)

CERN: the place where the World Wide Web was born

The 20 CERN Member States

US is an observer state... US contributed to the LHC.

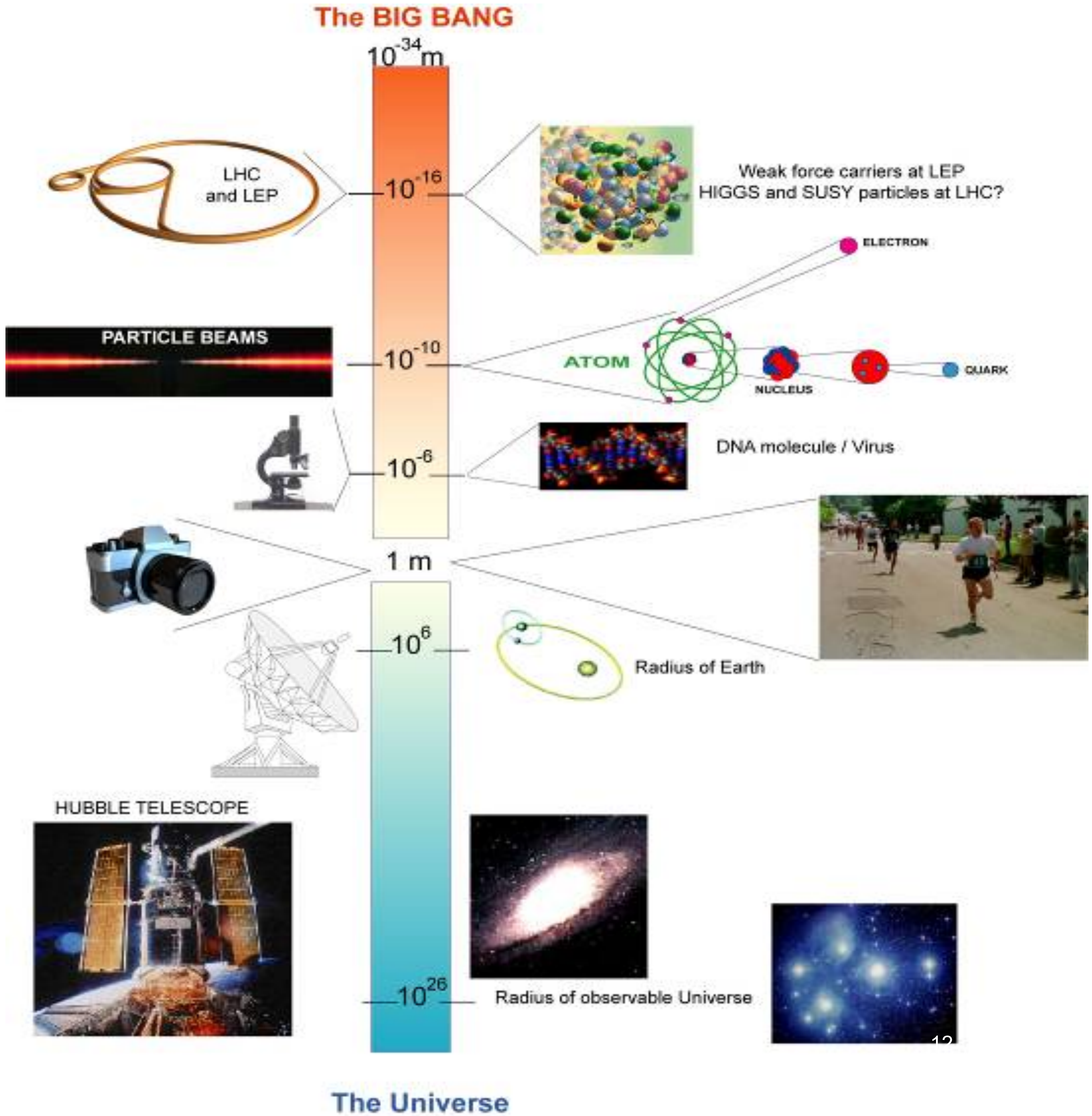
CERN
Provides
Particle Beams
&
Research Infrastructure

Why do we need particle accelerators?


What is the world made of?
What holds the world together?
Where did we come from?

Different types of tools and equipment are needed to observe different sizes of object

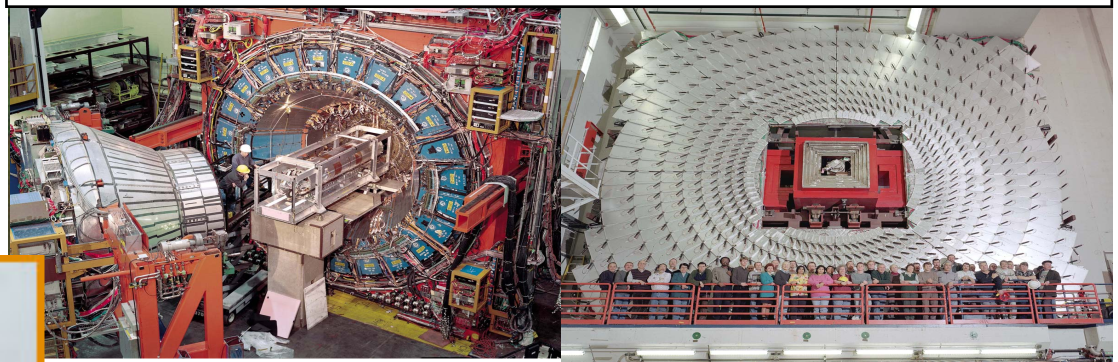
Only particle accelerators can explore the tiniest objects in the Universe



Many generations of accelerators created
with higher and higher energy given to the beam particle

Ernest Lawrence
(1901 - 1958)

CDF ~1500 Scientists DZero



Tevatron at Fermilab
$\times 10^4$ bigger, $\times 10^6$ higher energy

Accelerators are Powerful Microscopes

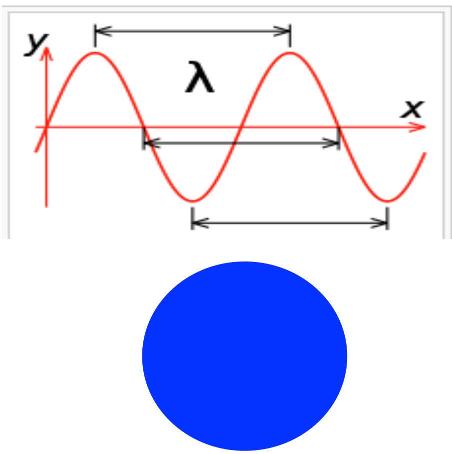
They make high energy particle beams that allow us to see small things.

$$\lambda = \frac{h}{p}$$

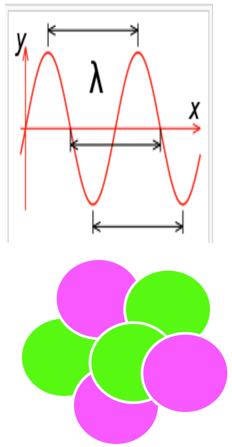
Planck constant

wavelength

momentum ~ energy



seen by low energy beam of particles (poorer resolution)



seen by high energy beam of particles (better resolution)

We can create particles from energy

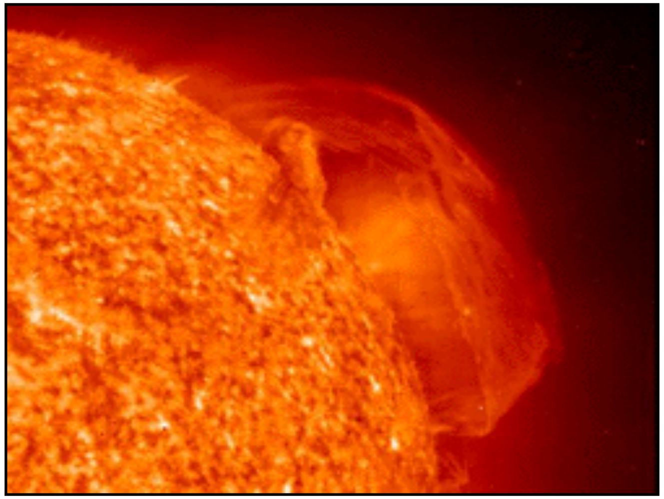
Two beams of protons collide and generate, in a very tiny space, temperatures over a billion times higher than those prevailing at the center of the Sun.

The Fundamental Forces of Nature

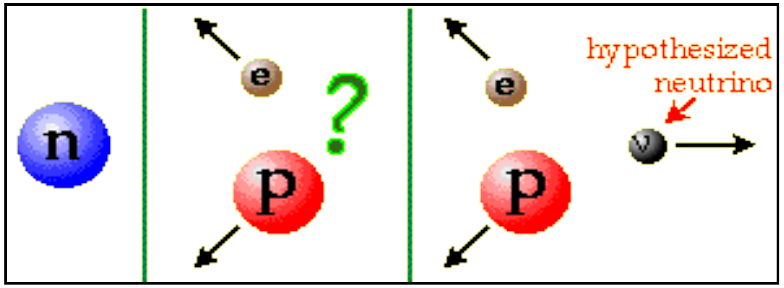
Electromagnetism:
gives light, radio, holds atoms together

Strong Nuclear Force:
holds nuclei together

Weak Nuclear Force:
gives radioactivity



together they make the Sun shine



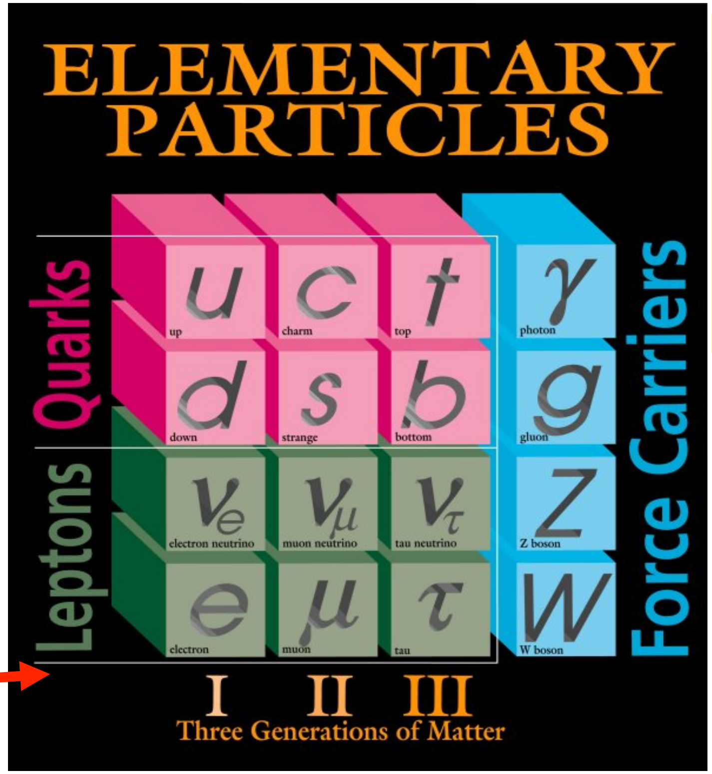
Gravity:
holds planets and stars together

The Standard Model in Particle Physics

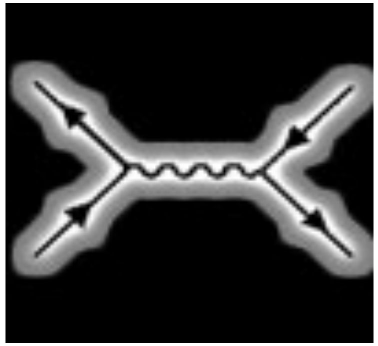
But not all questions solved:

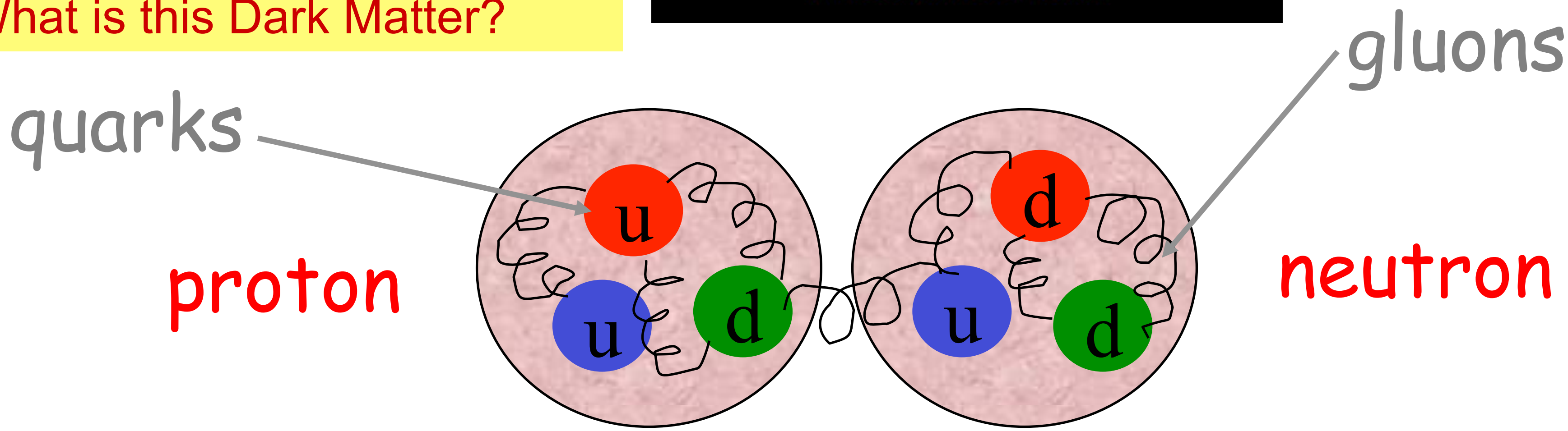
Why is the top quark much more heavy than the quarks
⇒Mass(top) = gold nucleus
What is the origin of mass?

Astrophysics/cosmological measurements show that most matter in the universe is NOT in this table
What is this Dark Matter?

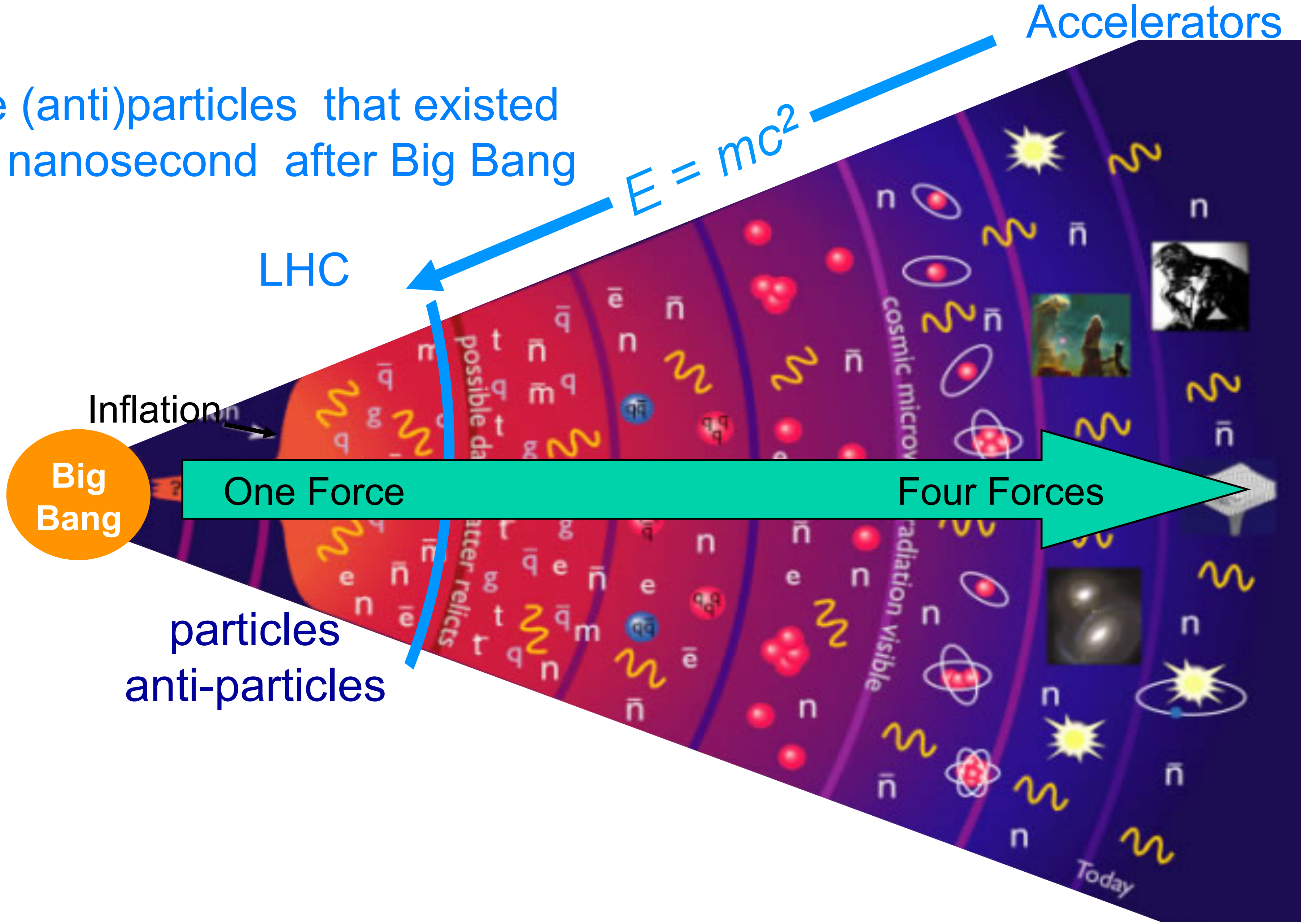


Four known forces
•Gravity
•Electro-magnetisme
•Strong nuclear force
•Weak force





Create (anti)particles that existed ~0.001 nanosecond after Big Bang



Create (anti)particles that existed
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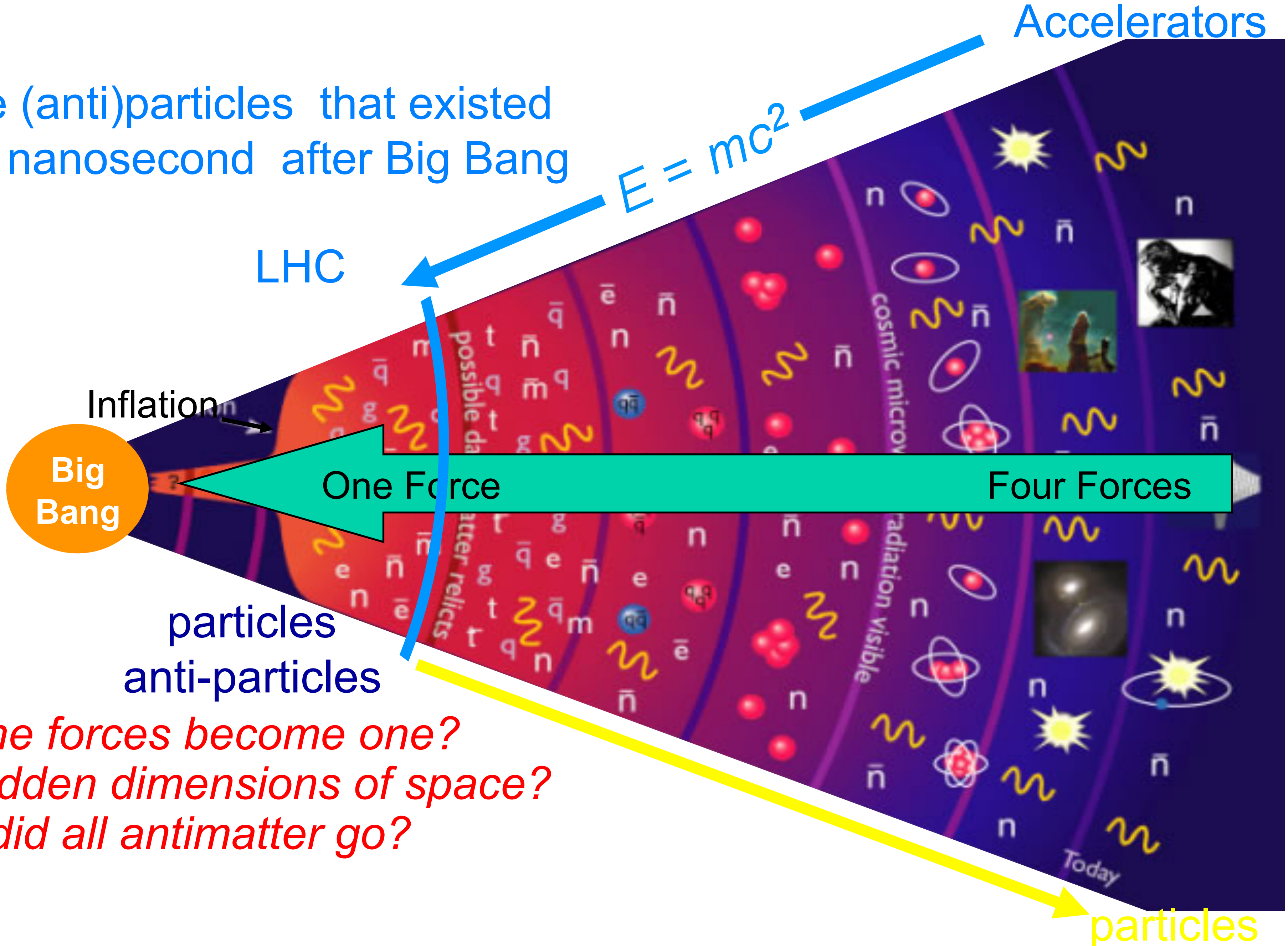


Do all the forces become one?
Extra hidden dimensions of space?
Where did all antimatter go?

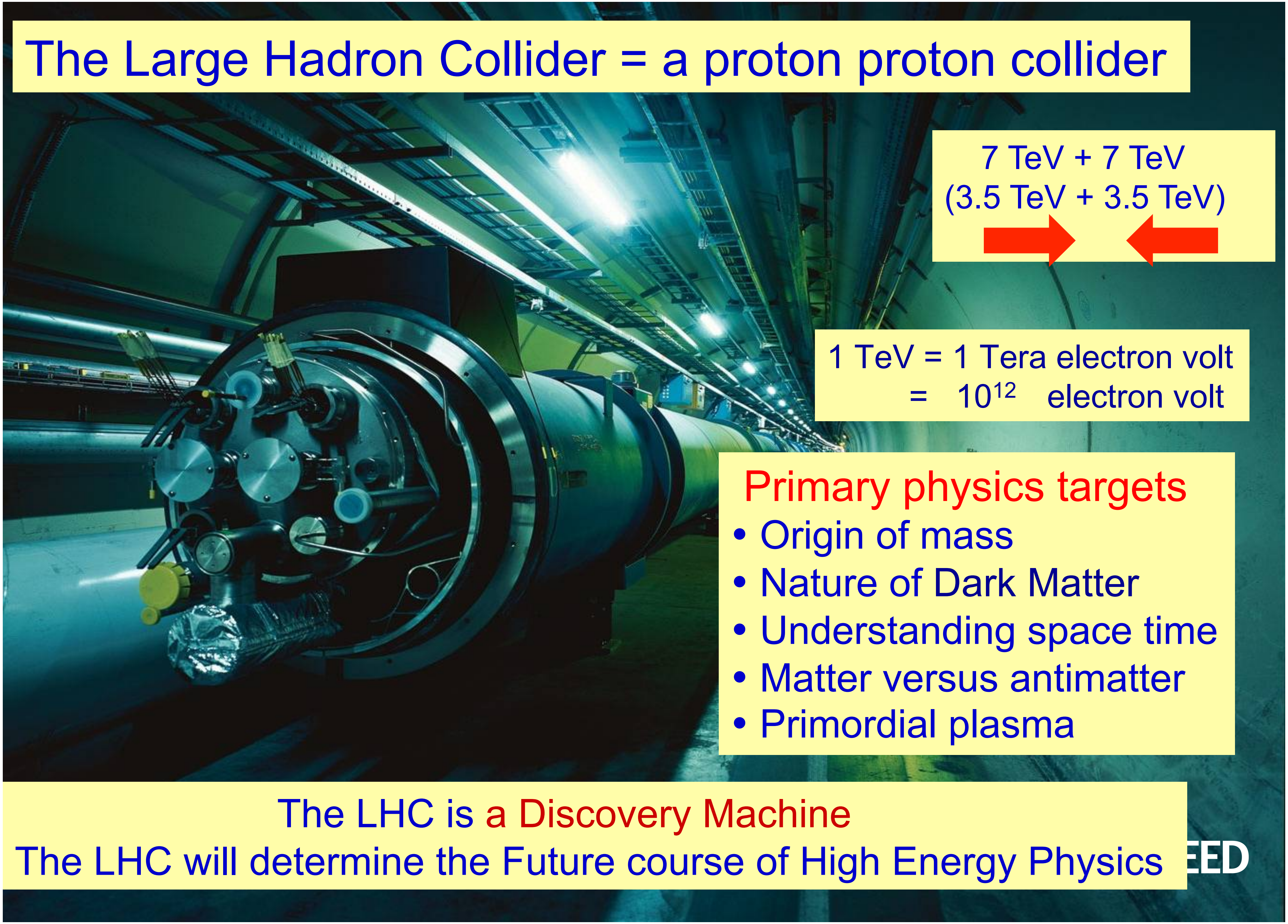
1. Are there undiscovered principles of nature: New symmetries, new physical laws?
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter? How can we make it in the laboratory?
7. What are neutrinos telling us?
8. How did the universe come to be?
9. What happened to the antimatter?
10. What is mass?

"Quantum Universe" and "Discovering the Quantum Universe"

Evolved Thinker

Discoveries and breakthroughs will likely come from Energy Frontier Accelerators at the Terascale.

The Large Hadron Collider = a proton proton collider



7 TeV + 7 TeV
(3.5 TeV + 3.5 TeV)

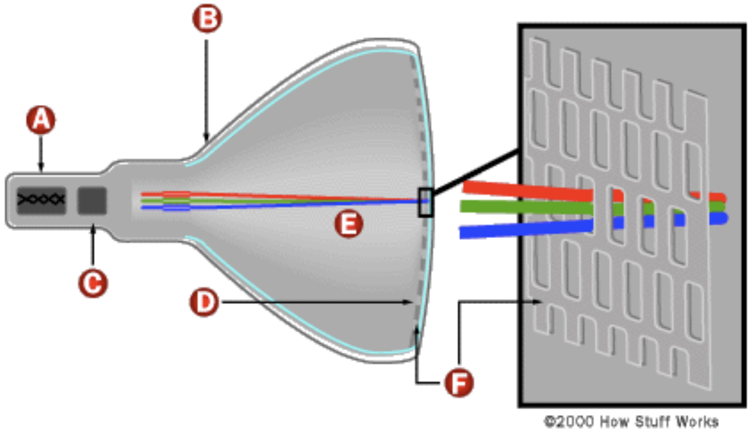
1 TeV = 1 Tera electron volt
= 10^{12} electron volt

Primary physics targets

- Origin of mass
- Nature of Dark Matter
- Understanding space time
- Matter versus antimatter
- Primordial plasma

The LHC is a Discovery Machine
The LHC will determine the Future course of High Energy Physics

Accelerators for Charged Particles



A Cathode
B Conductive coating
C Anode
D Phosphor-coated screen
E Electron beams
F Shadow mask

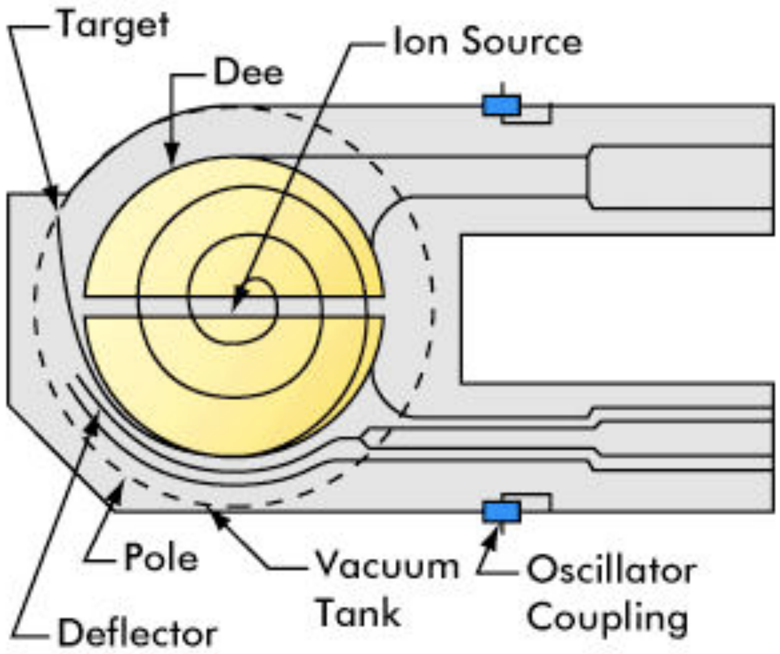
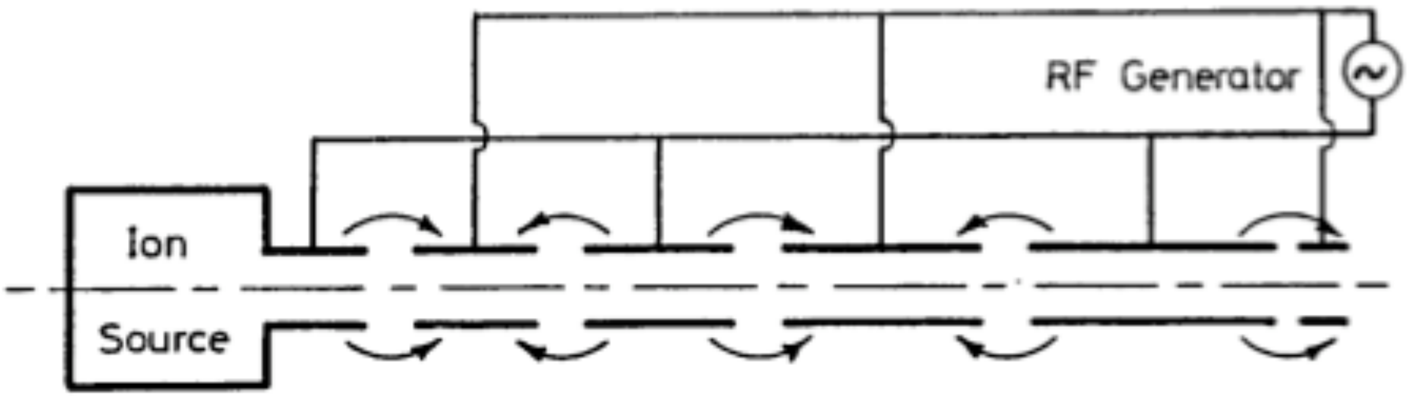


Photo courtesy SLAC

Schematic diagram of a cyclotron



Recent High Energy Colliders

Highest energies can be reached with proton colliders

Machine	Year	Beams	Energy ($\sqrt{s}$)	Luminosity
SPPS (CERN)	1981	pp	630-900 GeV	$6.10^{30}cm^{-2}s^{-1}$
Tevatron (FNAL)	1987	pp	1800-2000 GeV	10^{31}-$10^{32}cm^{-2}s^{-1}$
SLC (SLAC)	1989	e^+e^-	90 GeV	$10^{30}cm^{-2}s^{-1}$
LEP (CERN)	1989	e^+e^-	90-200 GeV	10^{31}-$10^{32}cm^{-2}s^{-1}$
HERA (DESY)	1992	ep	300 GeV	10^{31}-$10^{32}cm^{-2}s^{-1}$
RHIC (BNL)	2000	pp / AA	200-500 GeV	$10^{32}cm^{-2}s^{-1}$
LHC (CERN)	2009	pp (AA)	7-14 TeV	10^{33}-$10^{34}cm^{-2}s^{-1}$

Luminosity = number of events/cross section/sec

- Limits on circular machines
  - Proton colliders: Dipole magnet strength →superconducting magnets
  - Electron colliders: Synchrotron radiation/RF power

Accelerators: developed in physics labs are used in hospitals for HADRON Therapy

Around 9000 of the 17000 accelerators operating in the world today are used for medicine

The LHC: >20 Years Already!

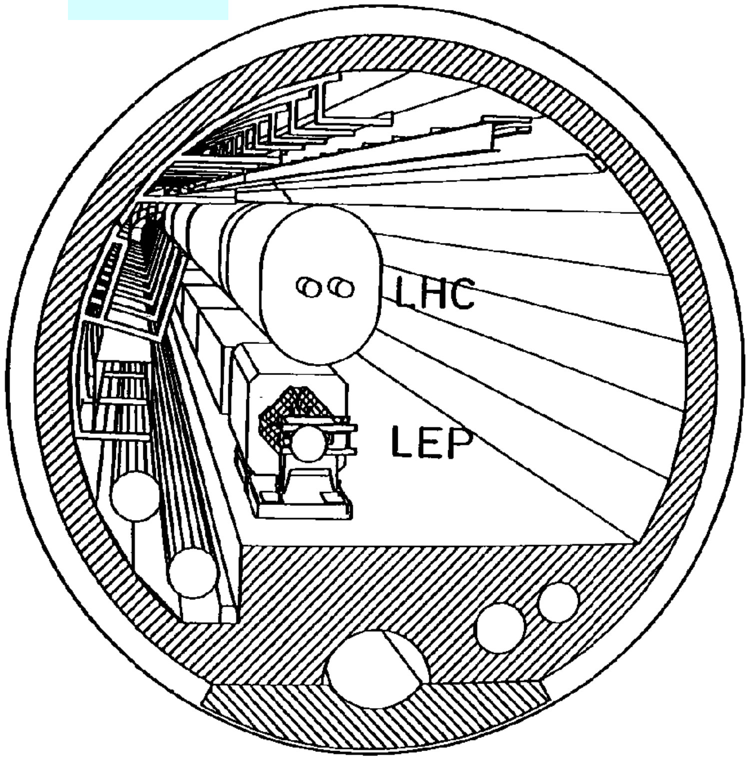
LHC History

1982 : First studies for the LHC project
1983 : Z0/W discovered at SPS proton antiproton collider
1989 : Start of LEP operation (Z boson-factory)
1994 : Approval of the LHC by the CERN Council
1996 : Final decision to start the LHC construction
1996 : LEP operation > 80 GeV (W boson -factory)
2000 : Last year of LEP operation above 100 GeV
2002 : LEP equipment removed
2003 : Start of the LHC installation
2005 : Start of LHC hardware commissioning
2008 : Expected LHC commissioning with beam

Luminosity=# events/cross section/sec

1984

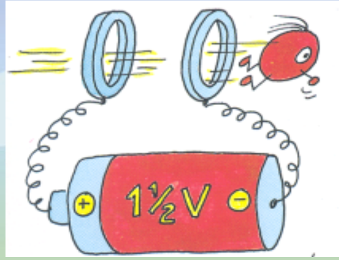
ECFA 84/85
CERN 84-10
5 September 1984

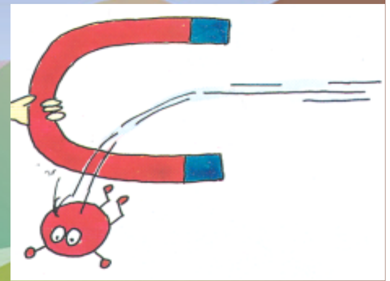


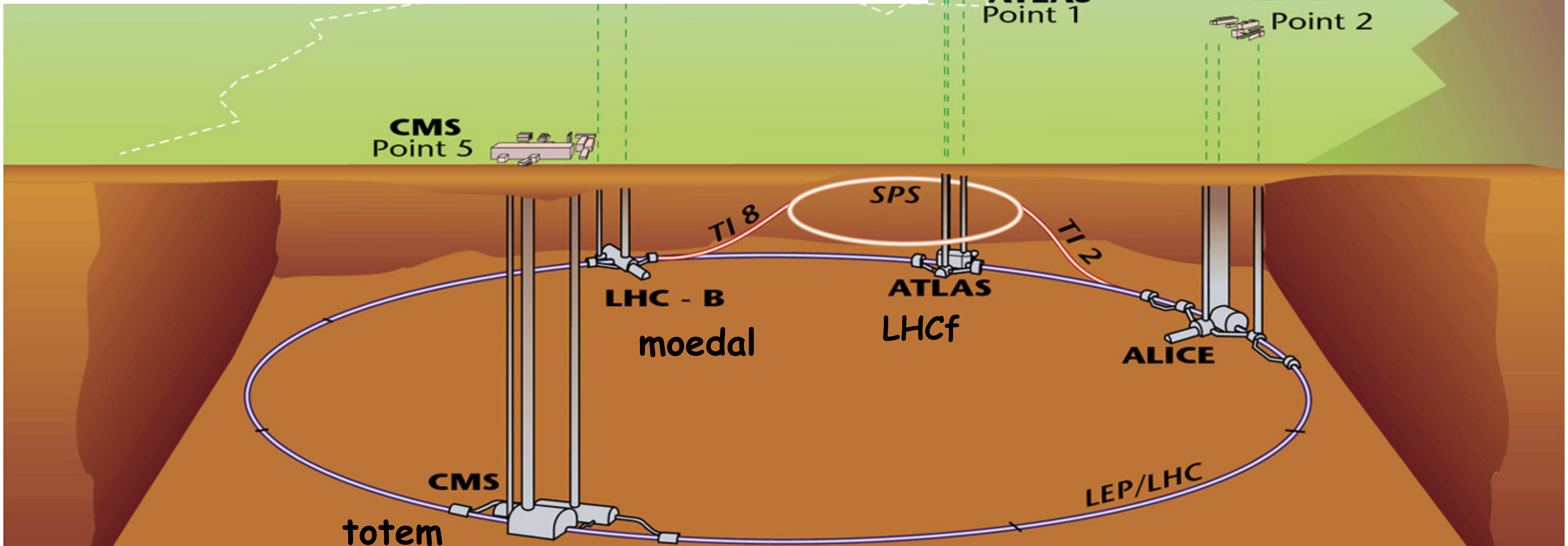
1984: cms energy 10-18 TeV
Luminosity 10^{31}-10^{33} $cm^{-2}s^{-1}$
1987: cms energy 16 TeV
Luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$
Final: cms energy 14 TeV
Luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$

The LHC Machine and Experiments

LHC is 100m underground
LHC is 27 km long
Magnet Temperature is 1.9 Kelvin = -271 Celsius
LHC has ~ 9000 magnets
LHC: 40 million proton-proton collisions per second
LHC: Luminosity 10-100 fb^{-1}/year (after start-up phase)





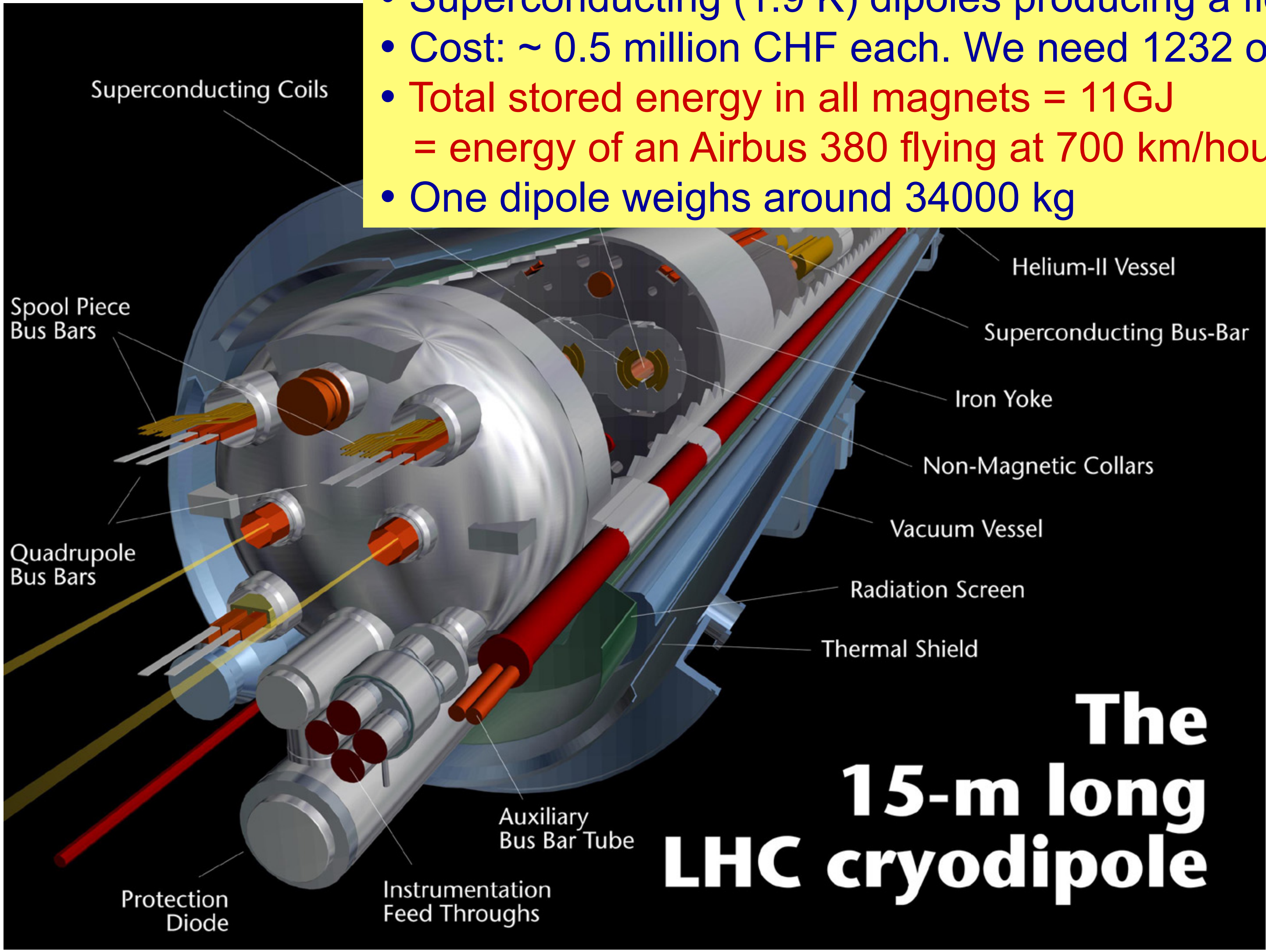


- High Energy ⇒ factor 7 increase w.r.t. present accelerators
- High Luminosity (# events/cross section/time) ⇒ factor 100 increase

0/09/97

The Cryodipole Magnets

- Superconducting (1.9 K) dipoles producing a field of 8.4 T
- Cost: ~ 0.5 million CHF each. We need 1232 of them
- Total stored energy in all magnets = 11GJ
  = energy of an Airbus 380 flying at 700 km/hour
- One dipole weighs around 34000 kg



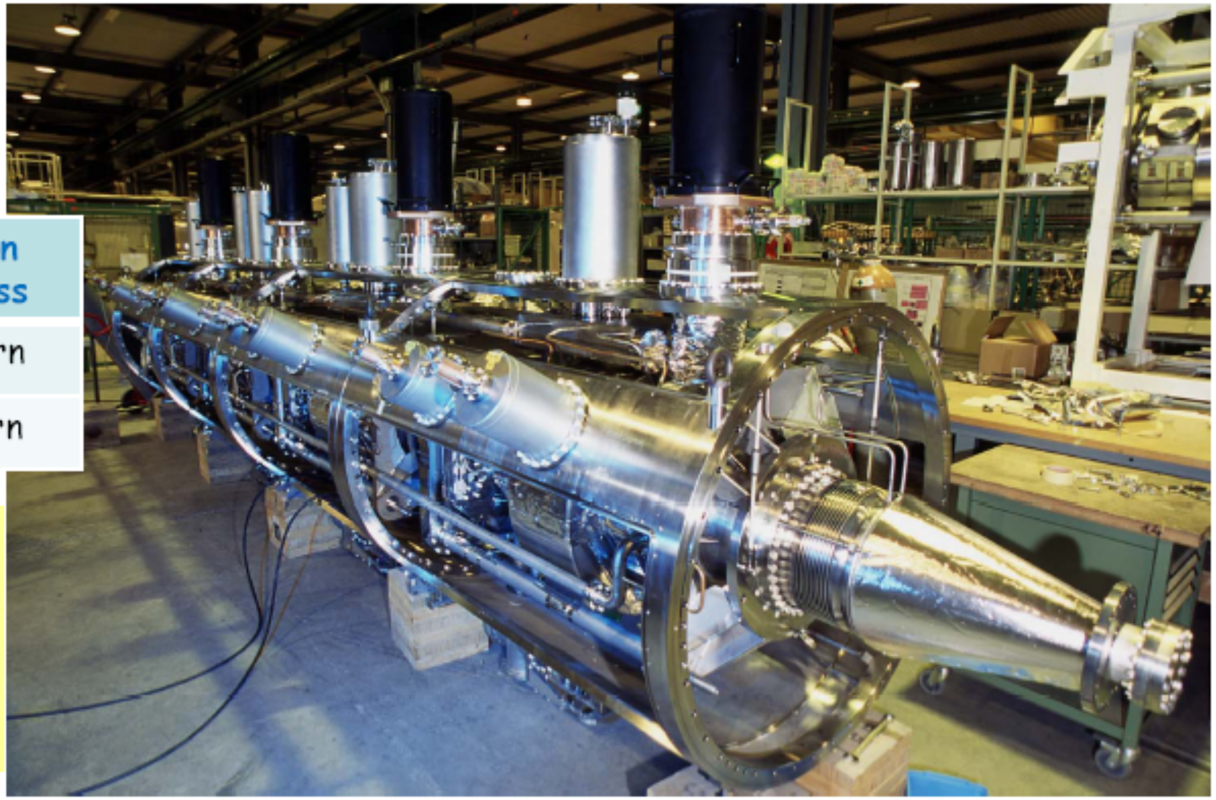
LHC RF system

- The LHC RF system operates at 400 MHz.
- It is composed of 16 superconducting cavities, 8 per beam.
- Peak accelerating voltage of 16 MV/beam.

For LEP at 104 GeV : 3600 MV/beam !

	Synchrotron radiation loss
LHC @ 7 TeV	6.7 keV /turn
LEP @ 104 GeV	~3 GeV /turn

The LHC beam radiates a sufficient amount of visible photons to be actually observable with a camera ! (total power ~ 0.2 W/m)



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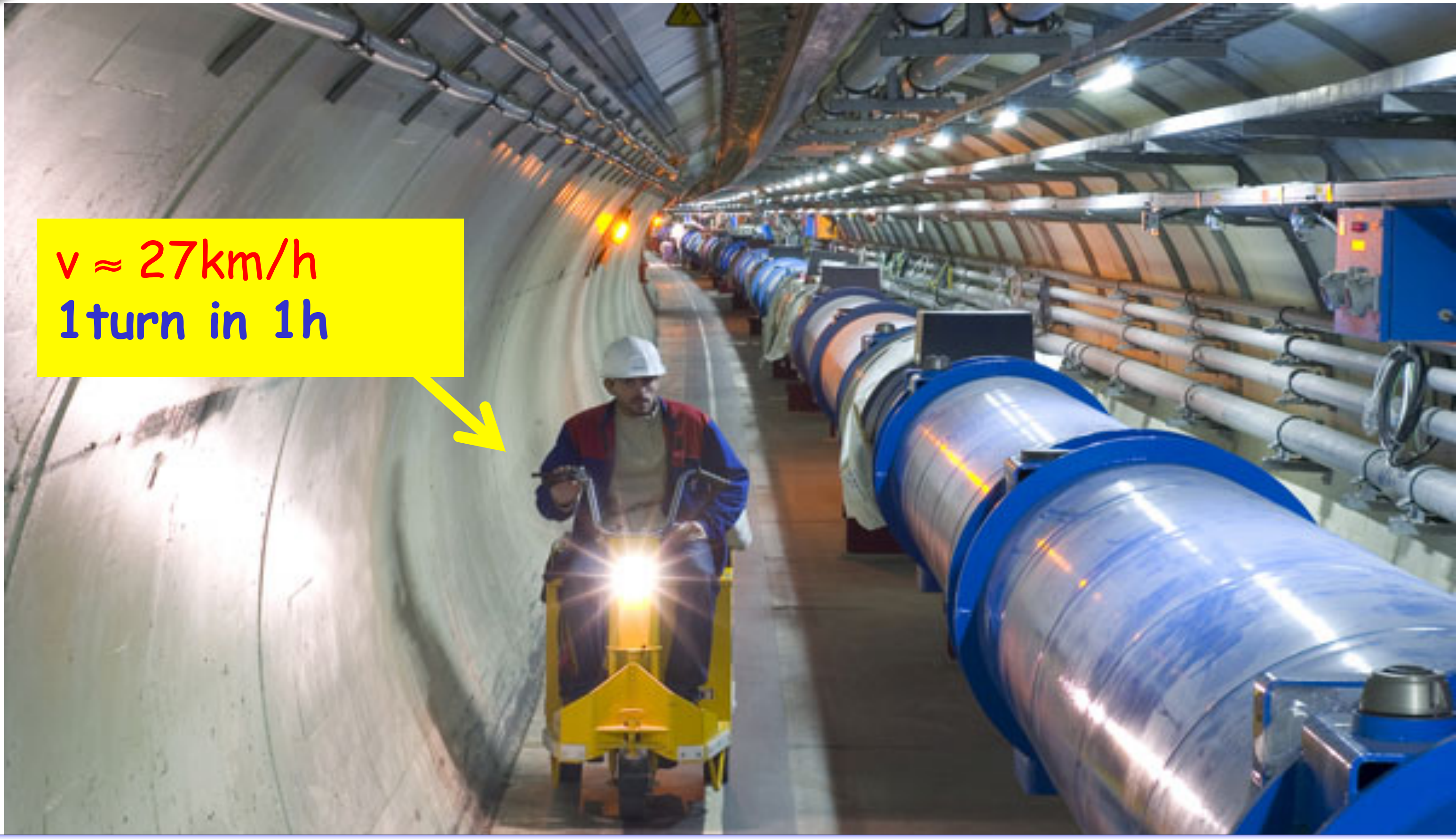
LHC facts

100 m underground: a tunnel 27 km circumference

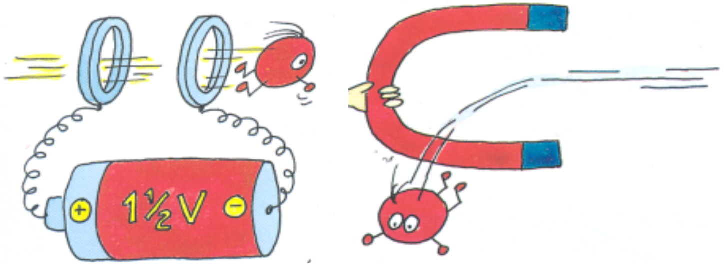
One of the **fastest** racetracks on the planet

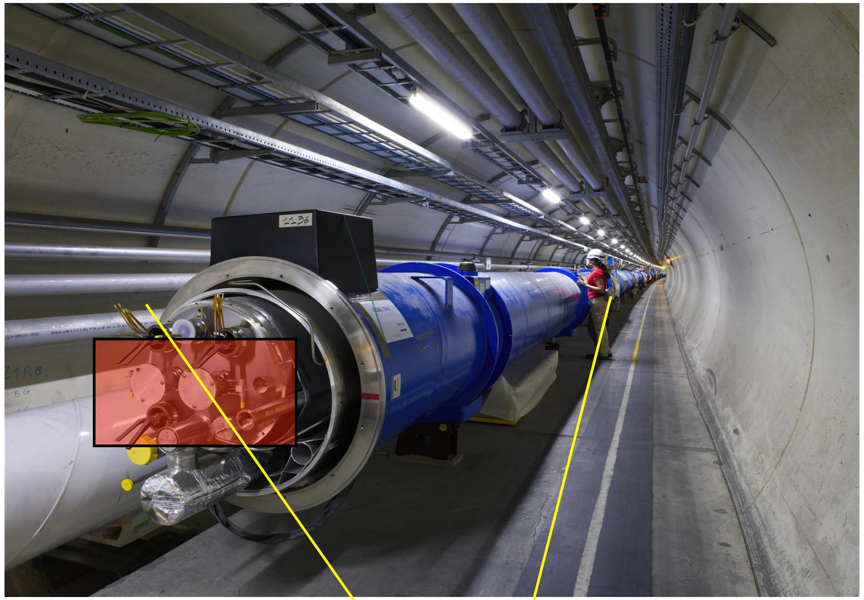


Several thousand billion protons traveling at 99.9999991% of the speed of light will travel round the 27km ring over 11000 times a second

LHC facts

The emptiest space in the solar system…





To accelerate protons to almost the speed of light, we need a vacuum similar to interplanetary space. The pressure in the beam-pipes of the LHC will be about ten times lower than on the moon.

LHC facts

One of the coldest places in the Universe…

the largest cryogenic system ever built

54 km fridge!

With a temperature of around -271 degrees Celsius, or 1.9 degrees above absolute zero, the LHC is colder than interstellar space.

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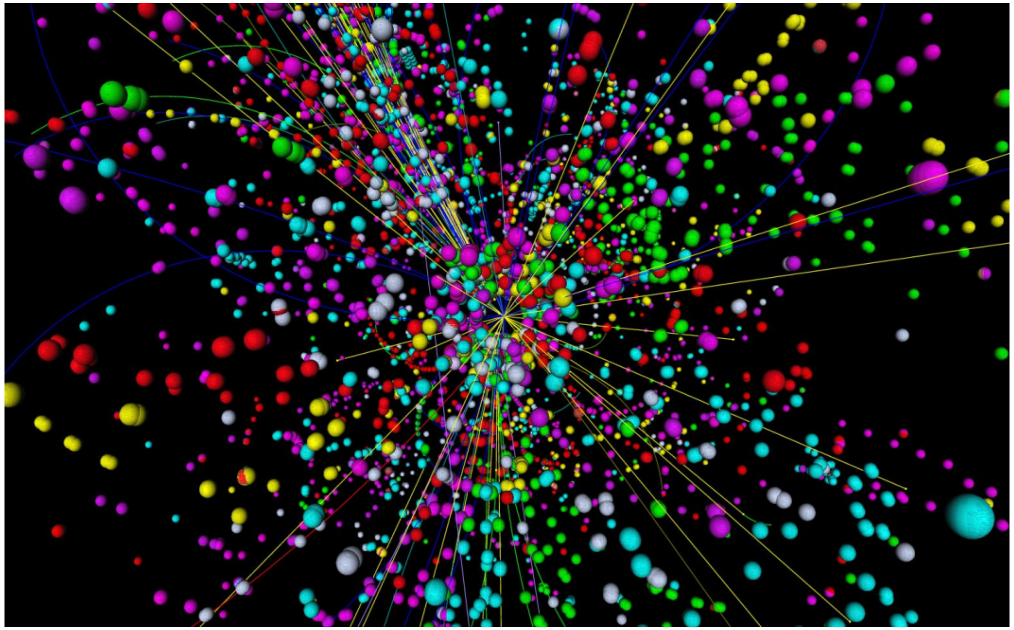
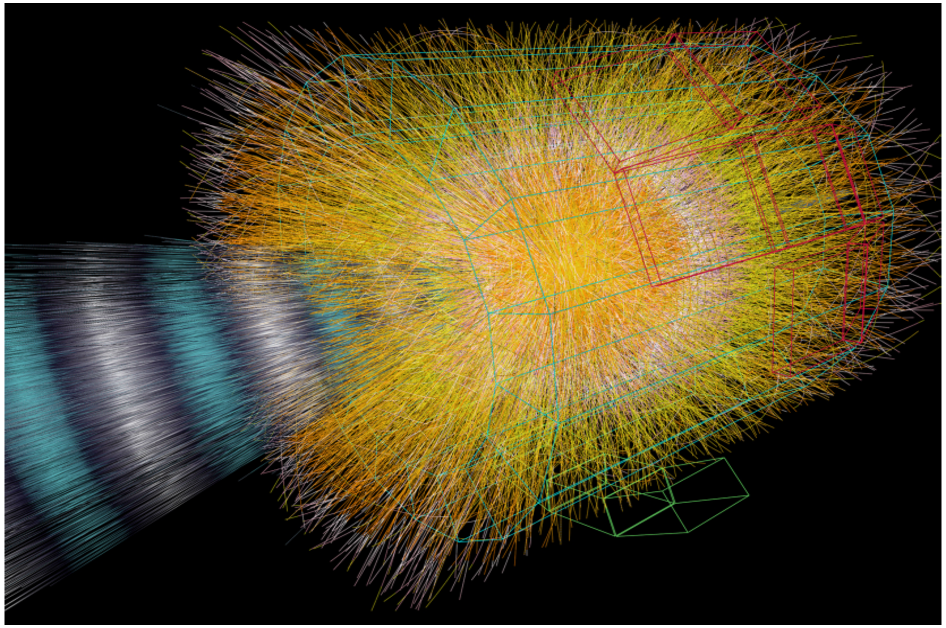
LHC facts

One of the **hottest** places in the Galaxy…



Simulation of a collision in the CMS experiment



Simulation of a collision in the ALICE experiment

When two beams of protons collide, they generate within a tiny volume, temperatures more than a billion times those in the very heart of the Sun.

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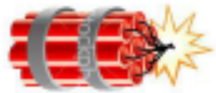
Energy in the beam

Comparison…

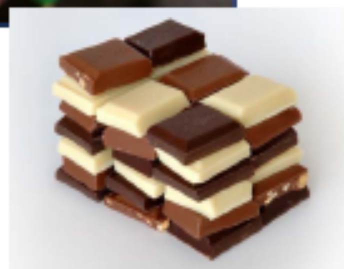
The energy of an A380 at 700 km/hour corresponds to the energy stored in the LHC magnet system :

Sufficient to heat up and melt 12 tons of Copper!!



The energy stored in one LHC beam corresponds approximately to…

- 90 kg of TNT
- 8 litres of gasoline
- 15 kg of chocolate



It's how ease the energy is released that matters most !!

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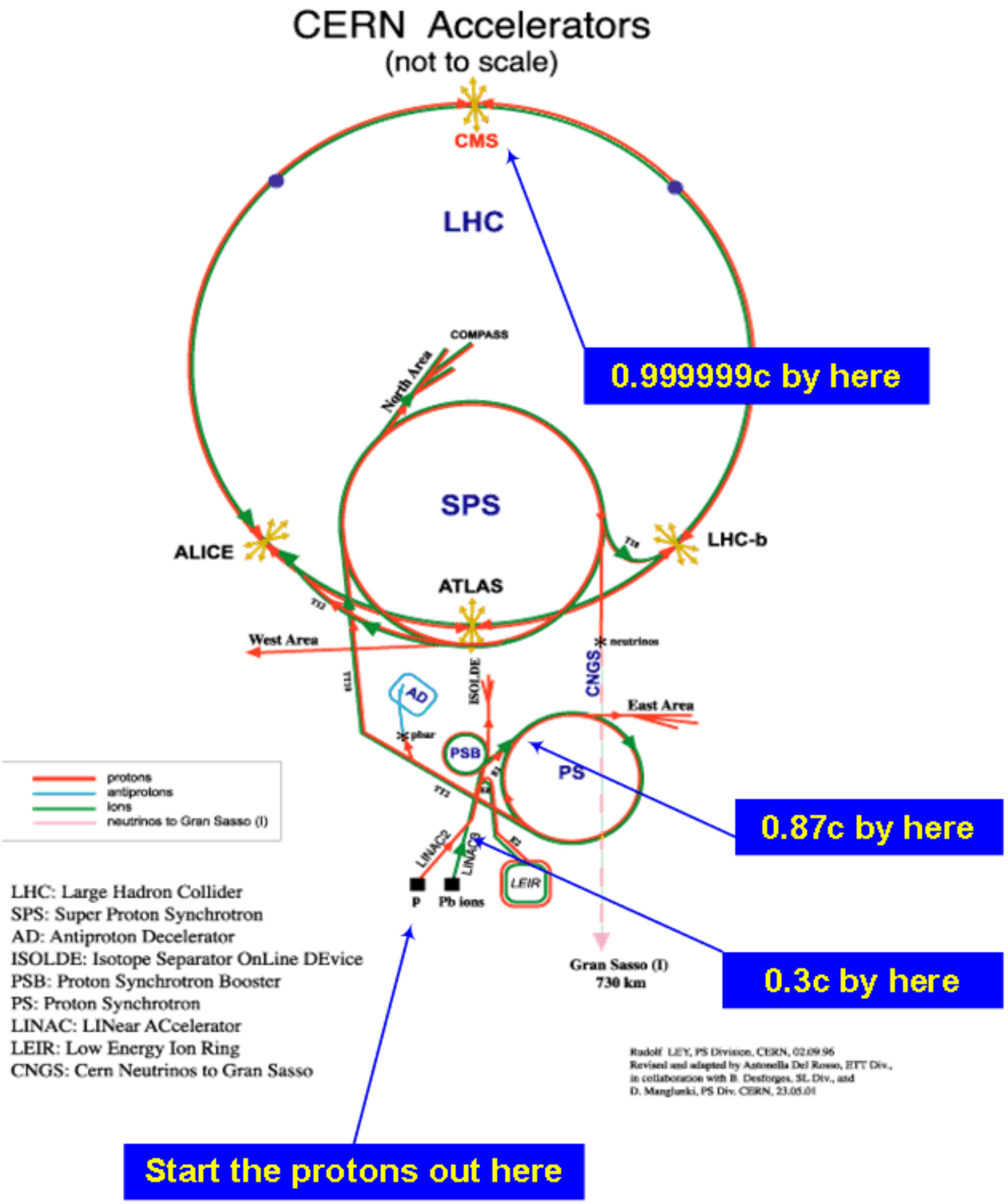
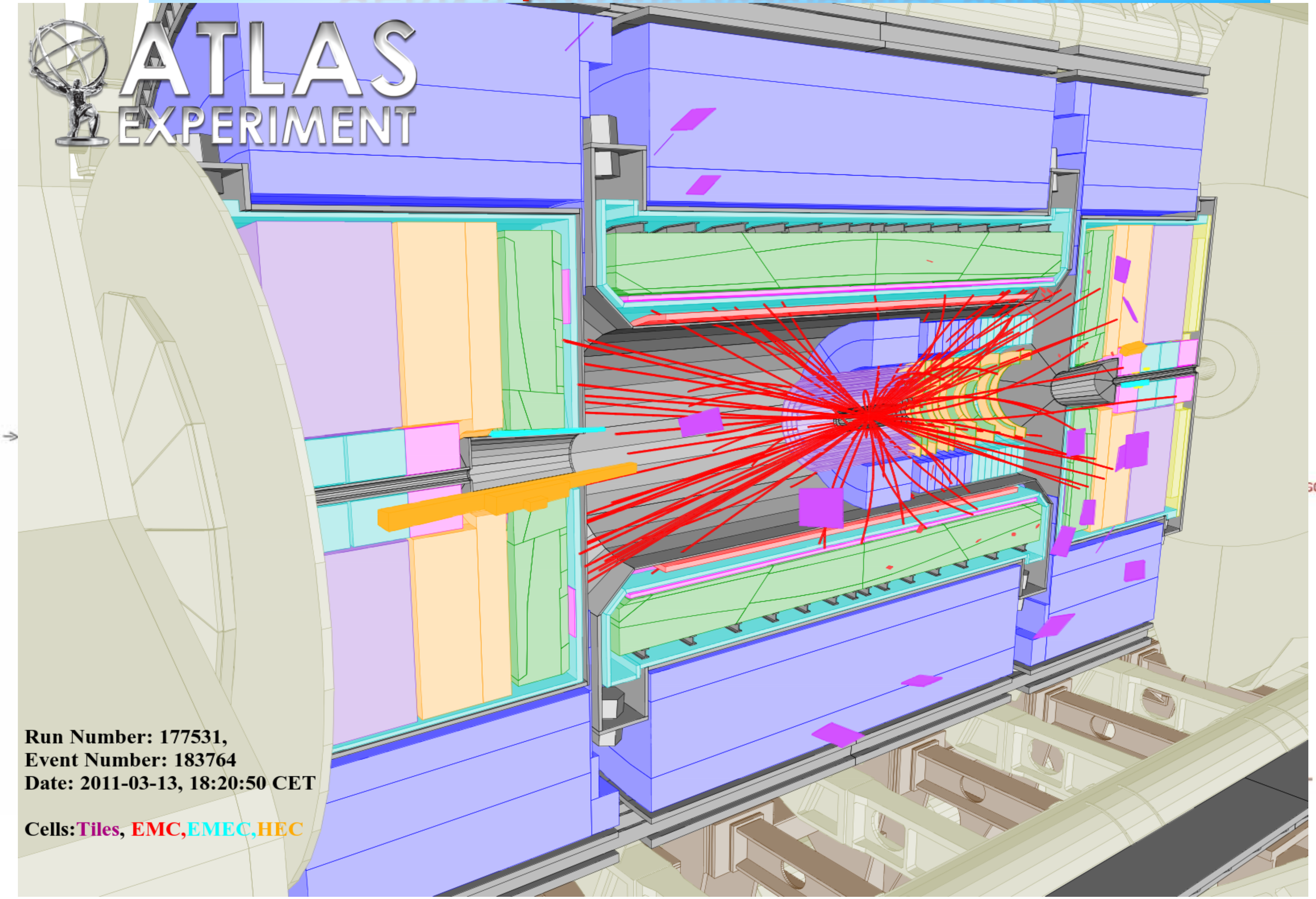
The Accelerator Scheme

Linac
↓
Booster
↓
PS
↓
SPS
↓
LHC



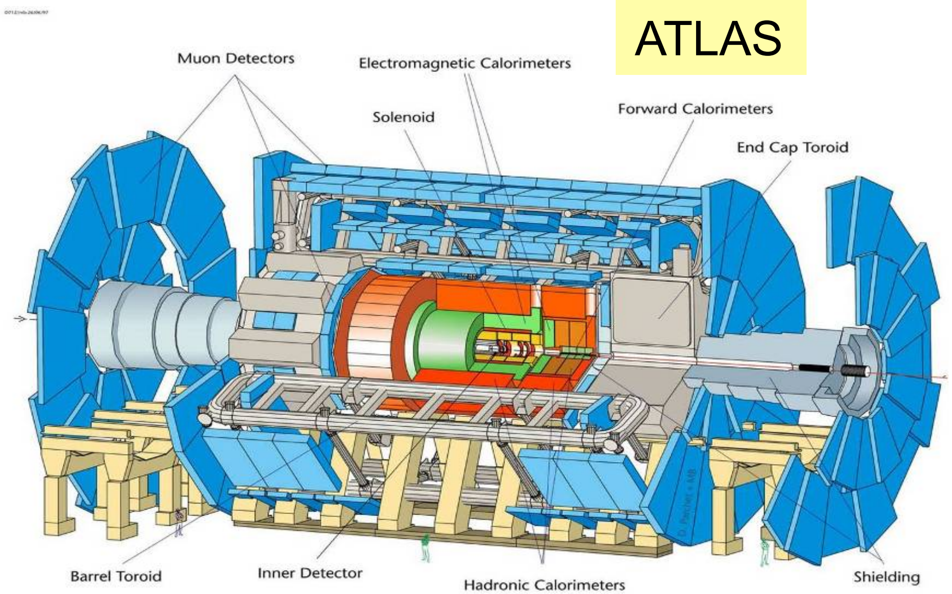
CERN's particle accelerator chain

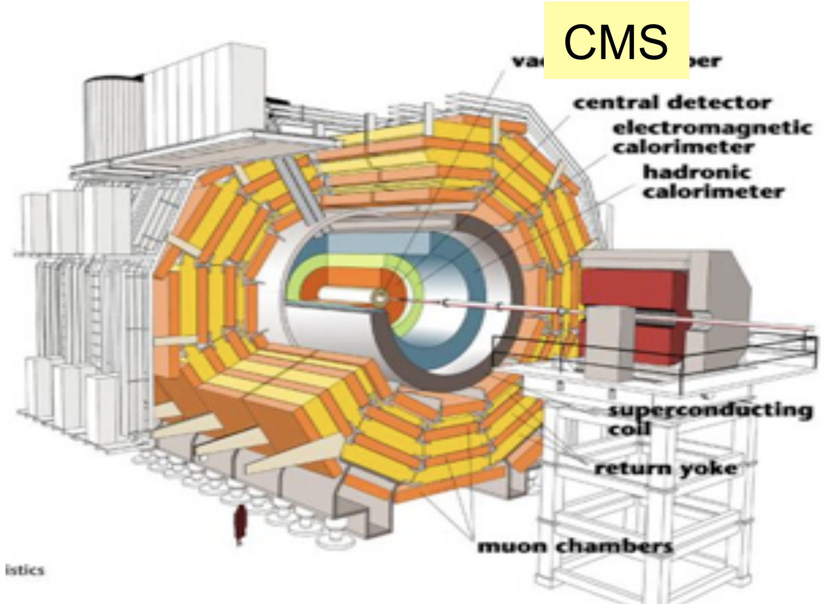


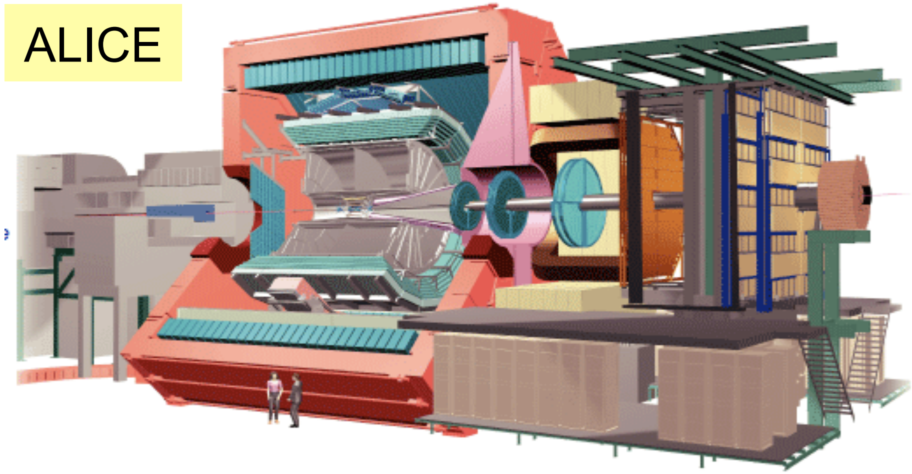
LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron
AD Antiproton Decelerator CTF3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

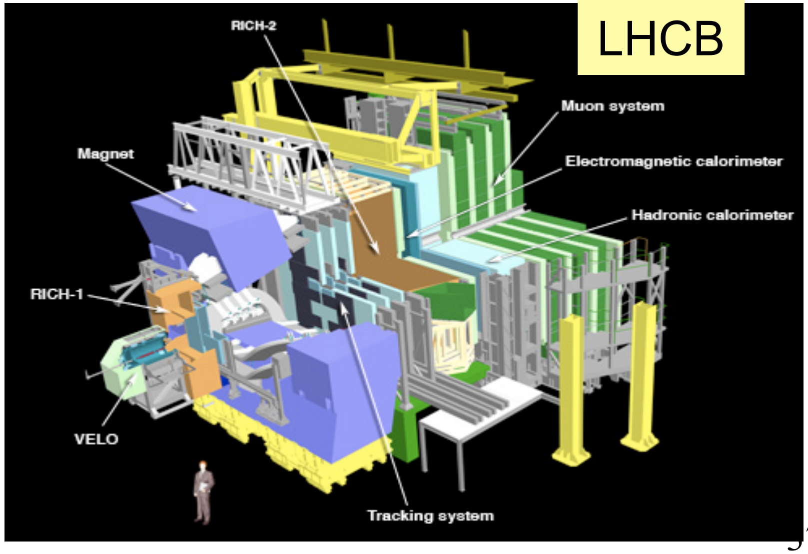
Experiments at the LHC

The Four Main LHC Experiments

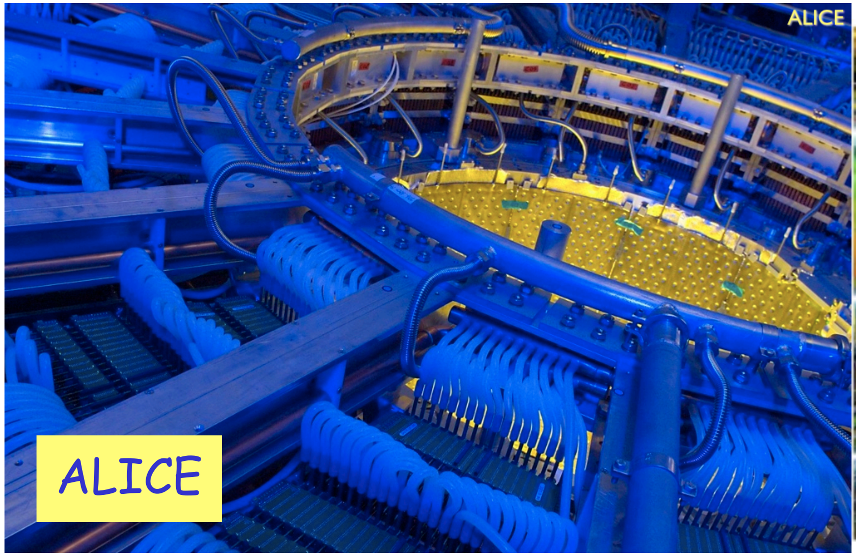


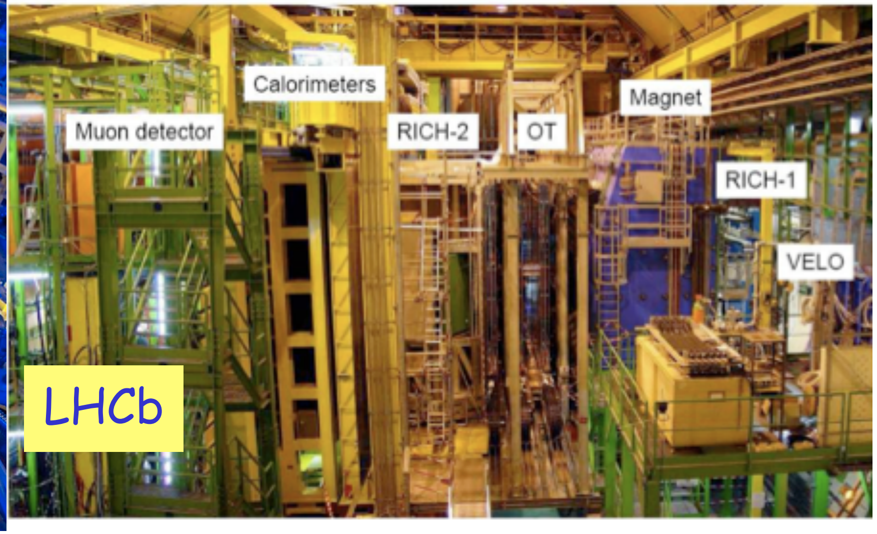


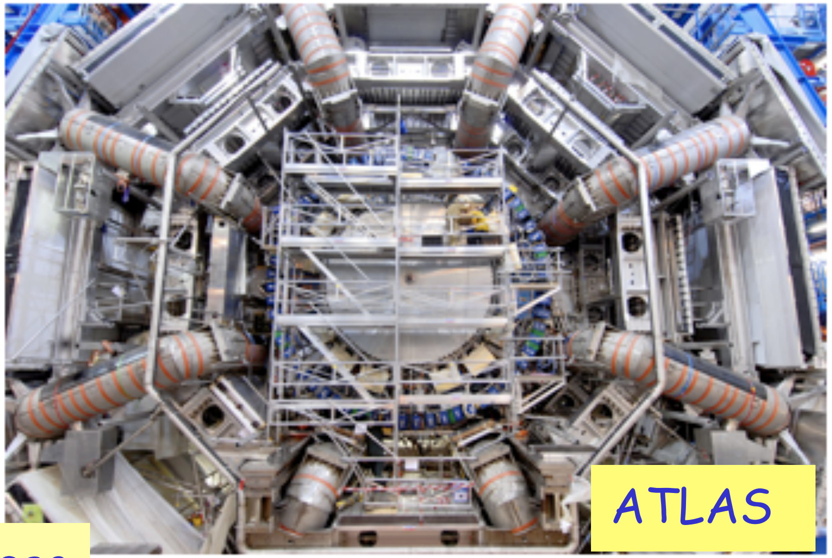




Detectors are completed







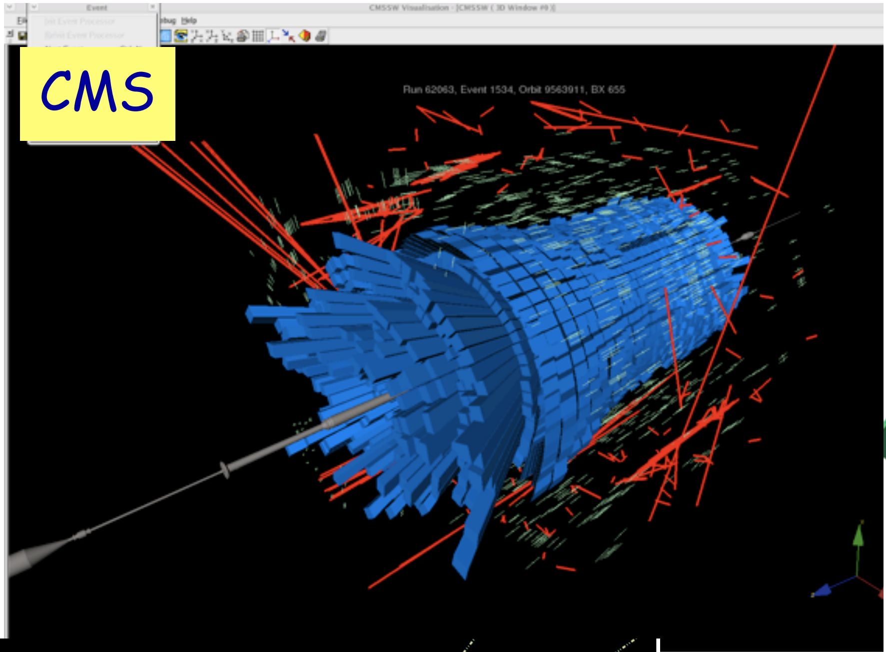
Atlas & CMS construction started 9 years ago

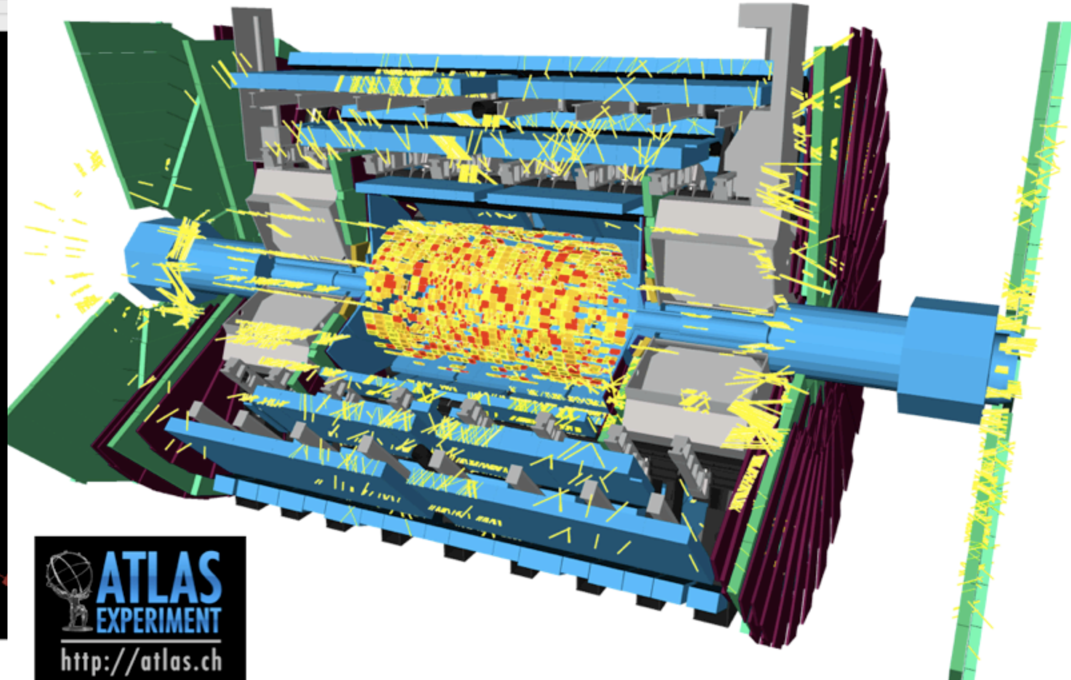
+TOTEM, LHCf, MOEDAL

Now gearing up for first collisions…

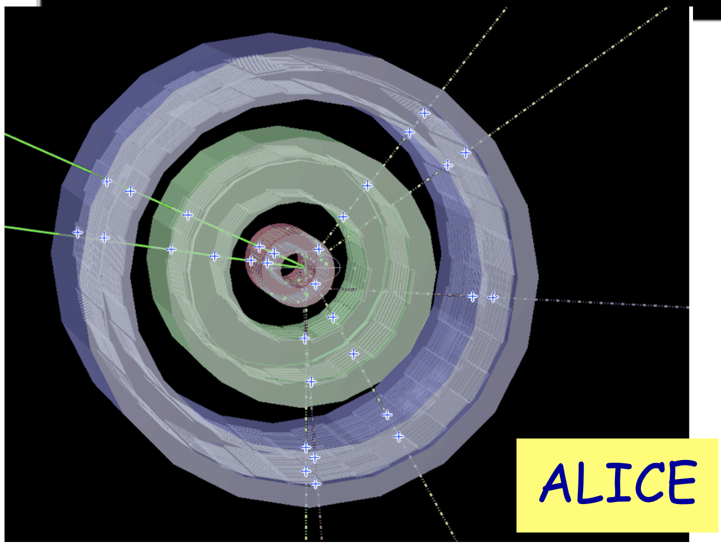
[redacted]

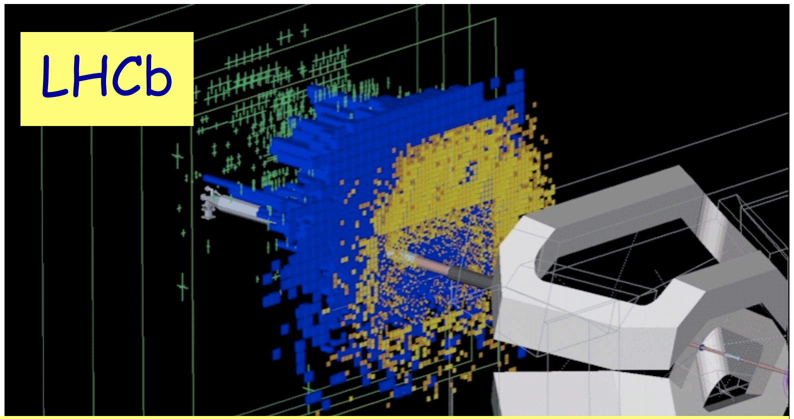
LHC Story: Beam Halo and Splashes on 10/9/08





first beam event seen in ATLAS

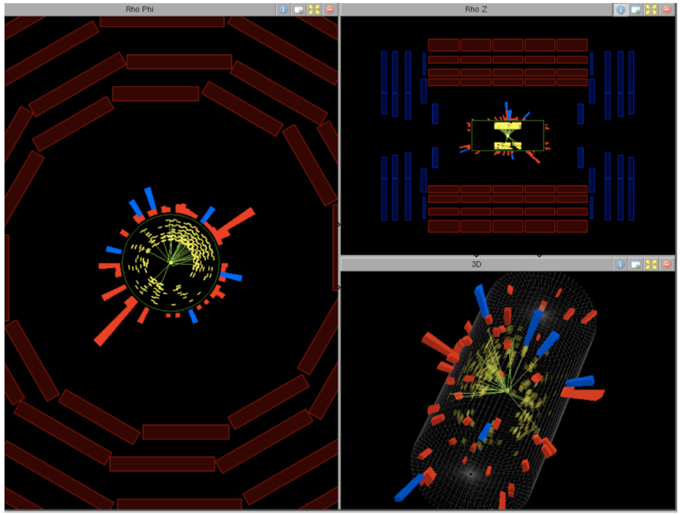


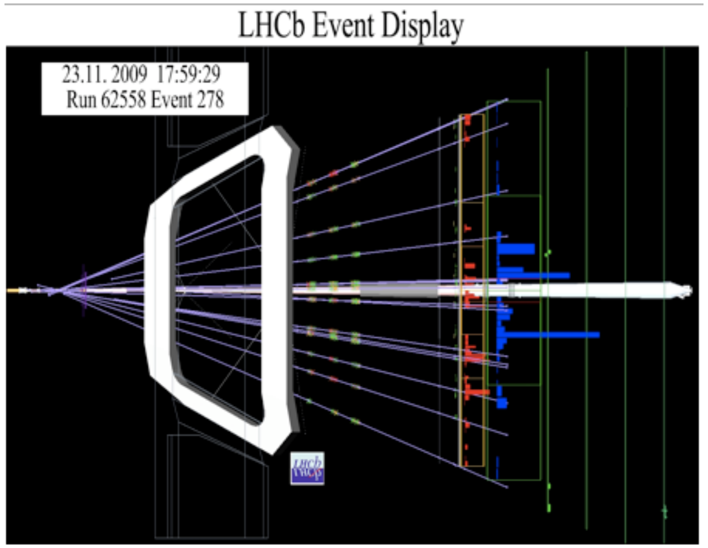


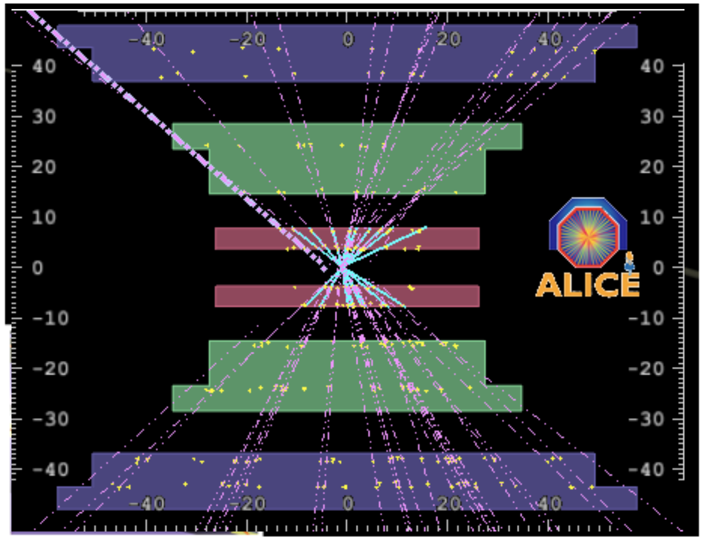
First LHC activity in the detectors in Sept. 2008, followed by the LHC accident

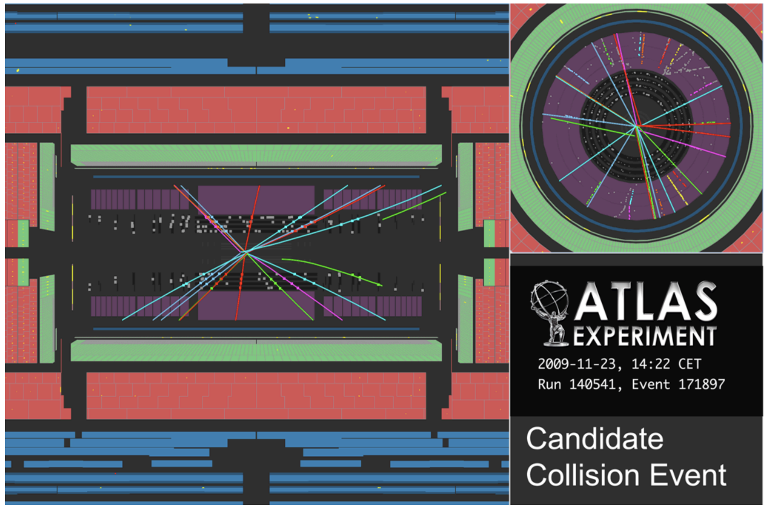
LHC Story: First Collisions in Nov. 2009

23/11 First ‘trial’ collisions in the experiments
A run with collisions at √s = 900 GeV or 2.36 TeV in December 2009









Key Moments

Sep 10,2008
Circulating beam...

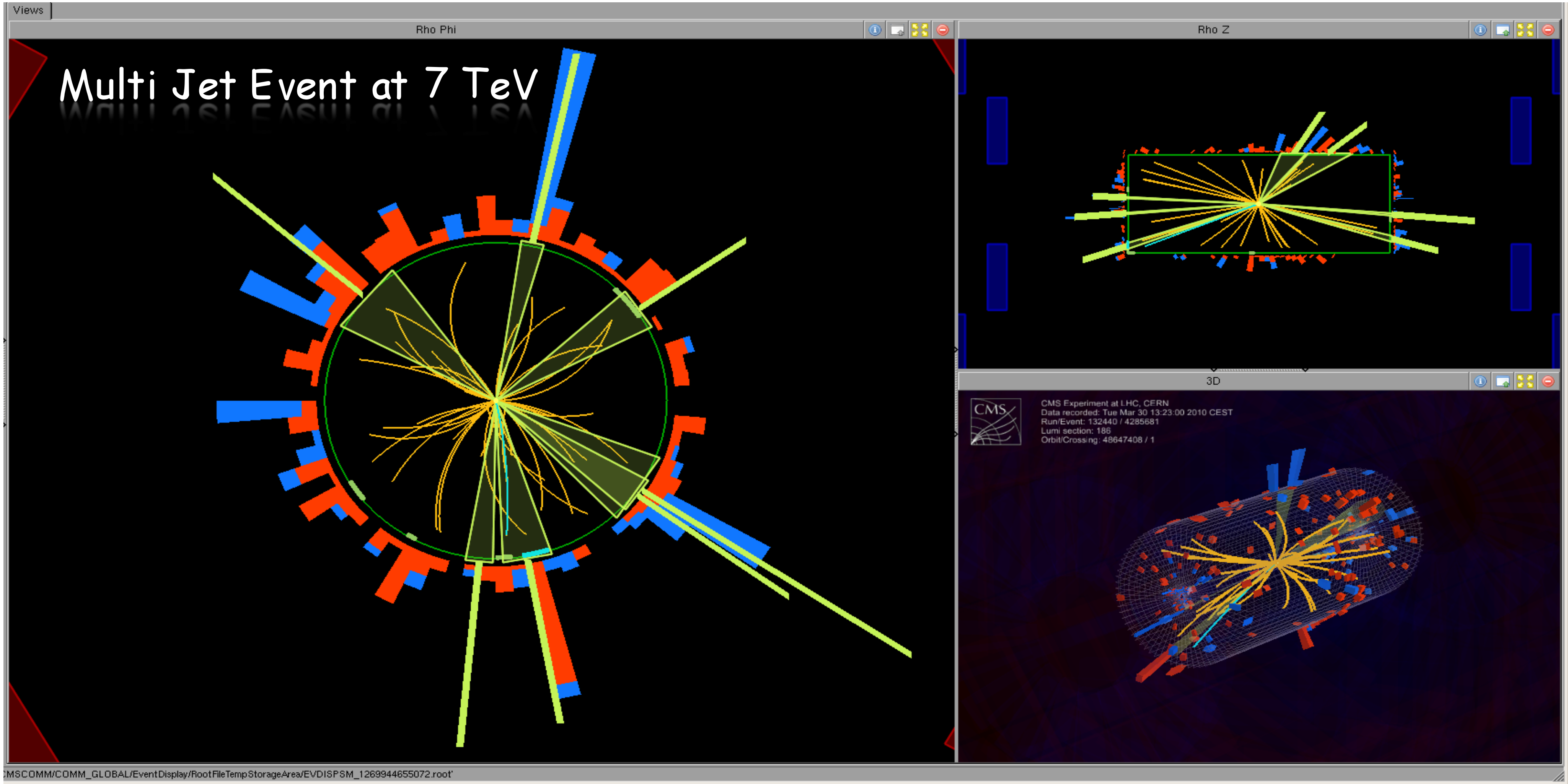
Mar 30,2010
first 7 TeV collisions

00:37 Nov 7,2010
First Heavy Ion Collisions

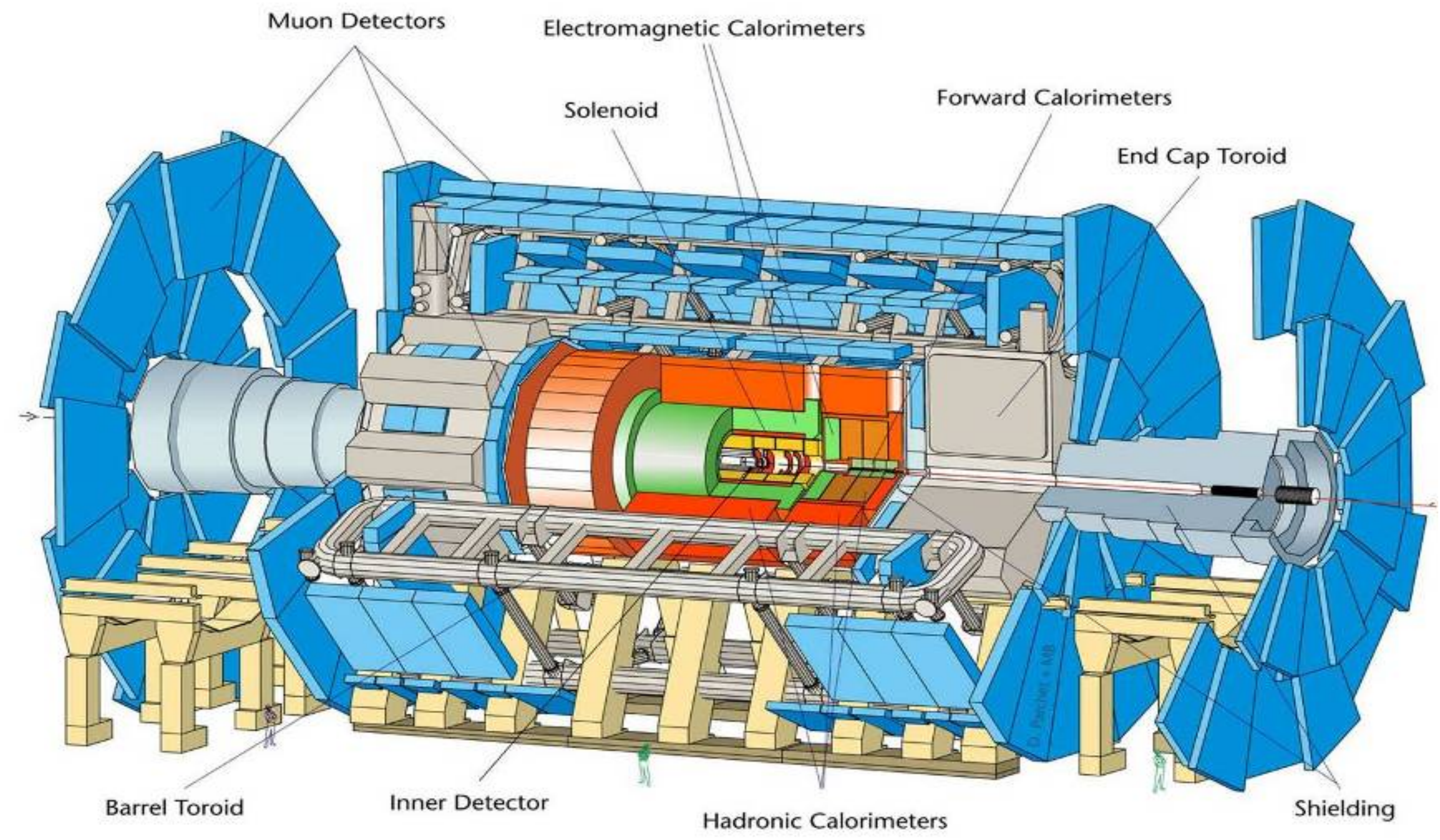
22:00 Mar 13,2011
First 2011 collisions

Some of the key moments the last years

First Collisions at 7 TeV

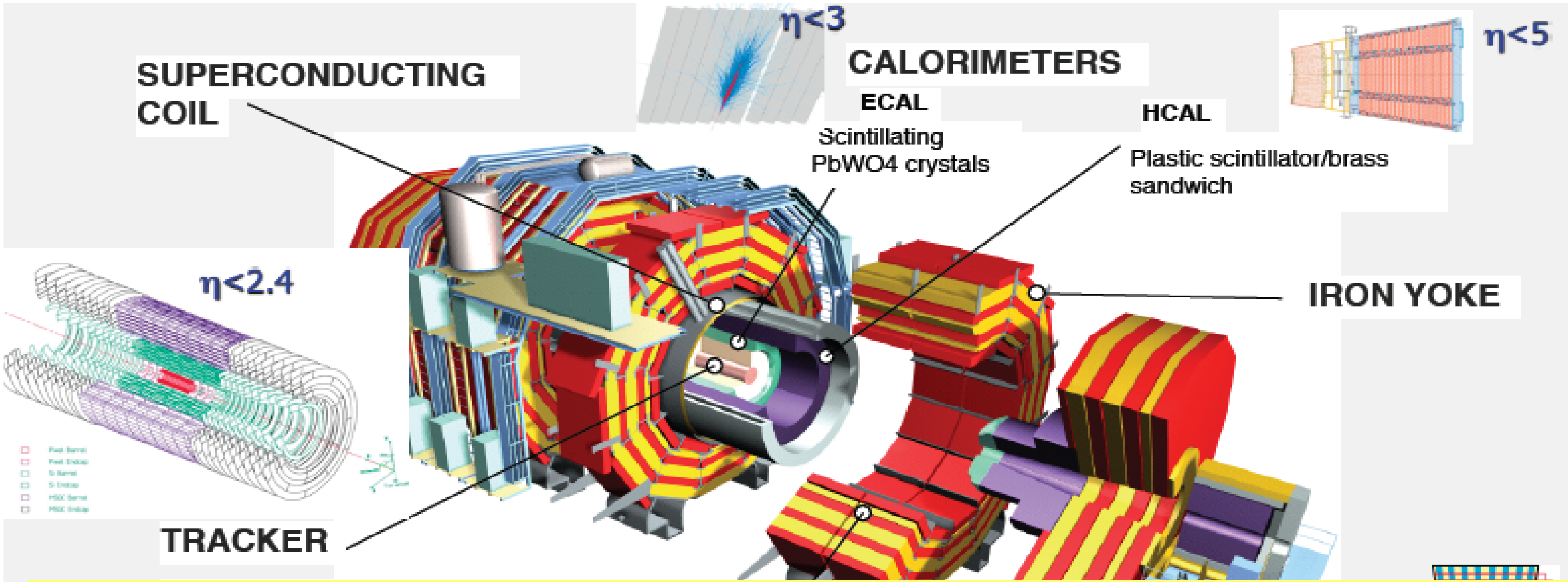


A Brave New World….



Length = 55 m Width = 32 m Height = 35 m but spatial precision ~ 100 μm

The Compact Muon Solenoid Experiment



In total about

~100 000 000 electronic channels

Each channel checked

40 000 000 times per second (collision rate is 40 MHz)

An on-line trigger selects events and reduces the rate from 40MHz to 100 Hz

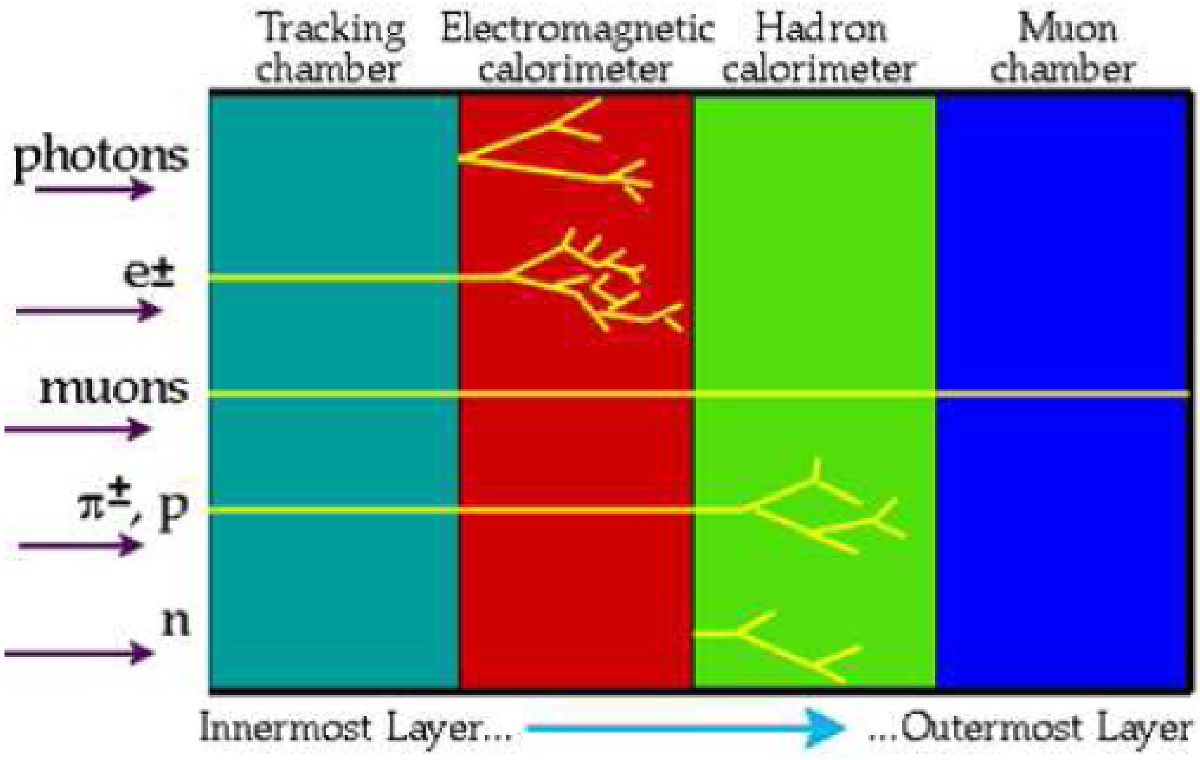
Amount of data of just one collisions

>1 500 000 Bytes

Detectors at Accelerators

Particle Detection: What we "see" as particles:

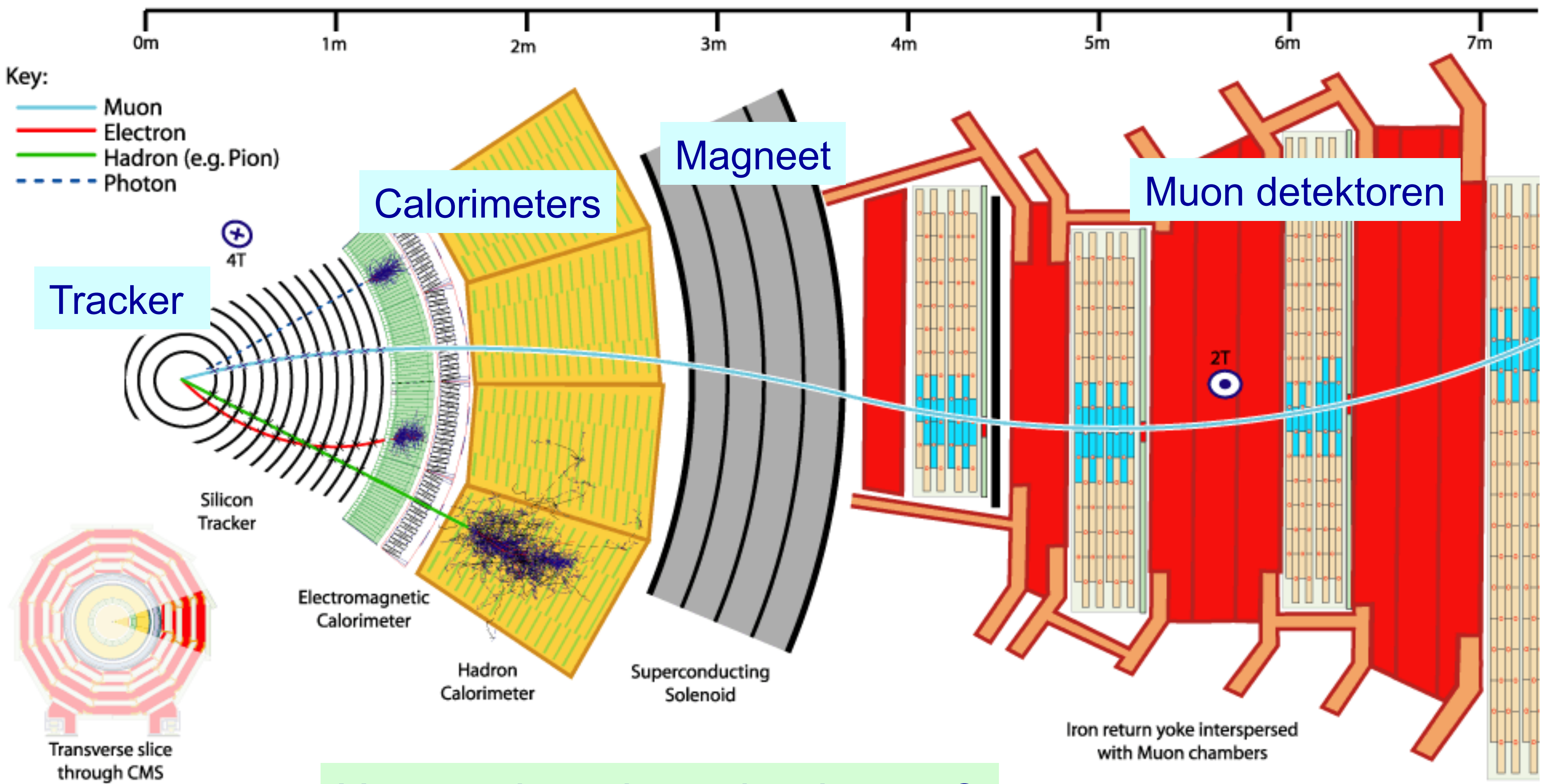
For "stable particles" of life time $\geq 10^{-10}$ s:



For charged tracks : $\Delta p/p \propto p$,

for calorimetry : $\Delta E/E \propto \frac{1}{\sqrt{E}}$.

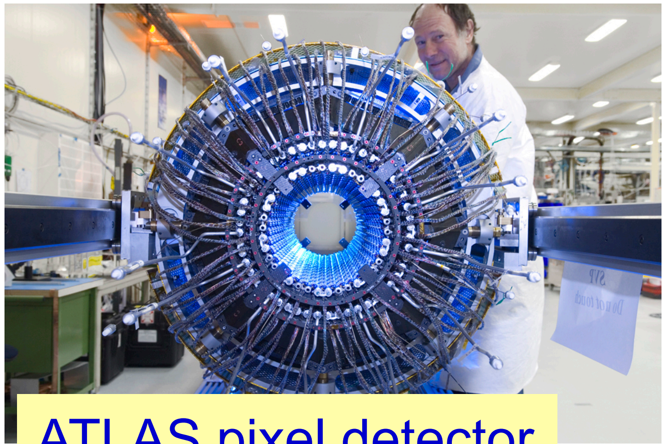
Particles in the detector



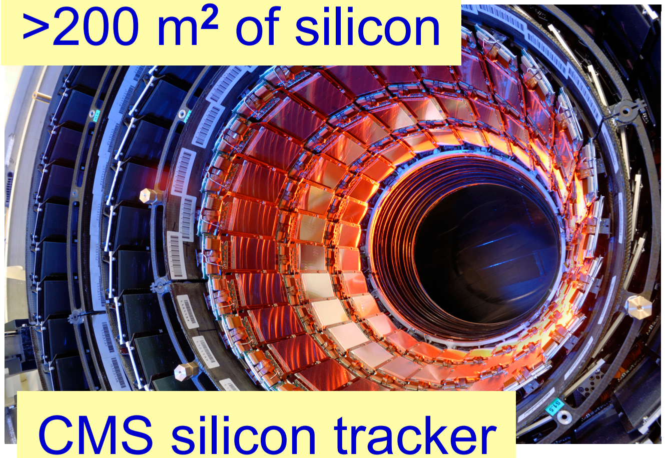
Hoe werken deze detektoren?
⇒ Lessen 2,3,4

The LHC Detectors are Major Challenges

- CMS/ATLAS detectors have about 100 million read-out channels
- Collisions in the detectors happen every 25 nanoseconds
- ATLAS uses over 3000 km of cables in the experiment
- The data volume recorded at the front-end in CMS is 1 TB/second which is equivalent to the world wide communication network traffic
- Data recorded during the 10-20 years of LHC life will be about all the words spoken by mankind since its appearance on earth
- A worry for the detectors: the kinetic energy of the beam is that of a small aircraft carrier of 10^4 tons going 20 miles/ hour



ATLAS pixel detector



CMS silicon tracker

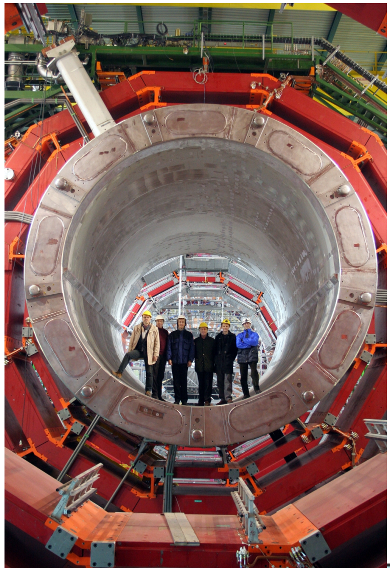
Object	Weight (tons)
Boeing 747 [fully loaded]	200
Endeavor space shuttle	368
ATLAS	7,000
Eiffel Tower	7,300
USS John McCain	8,300
CMS	12,500

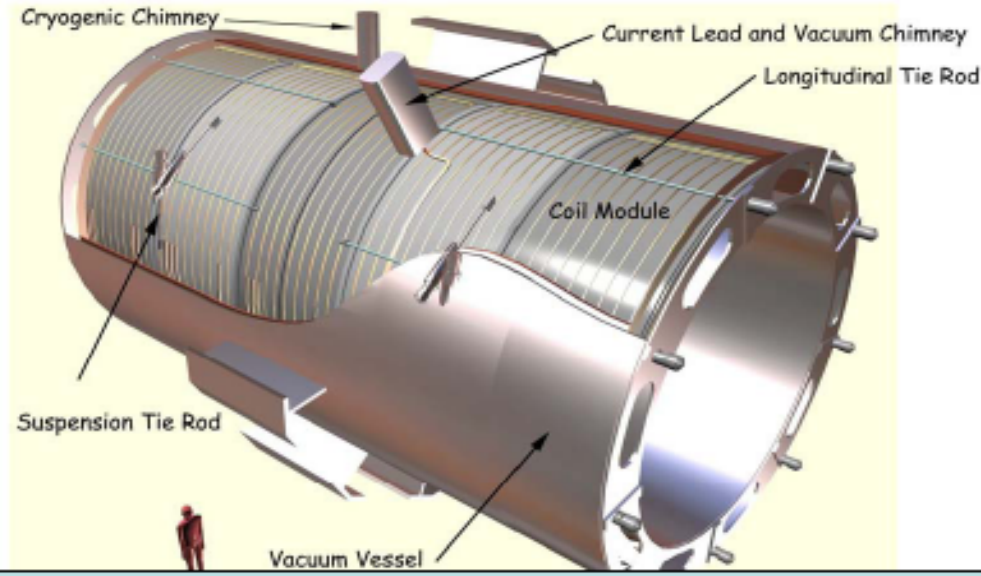
CMS Solenoid

Successfully tested in August '06!!

The largest high field solenoid magnet ever build!!

Magnetic length	12.5 m
Free bore diameter	6 m
Central magnetic induction	4 T ≈100,000 times earth magnetic field
Temperature	4.2 degrees Kelvin ≈-269 degrees Celcius
Nominal current	20 kA
Stored energy	2.7 GJ
Magnetic Radial Pressure	64 Atmospheres

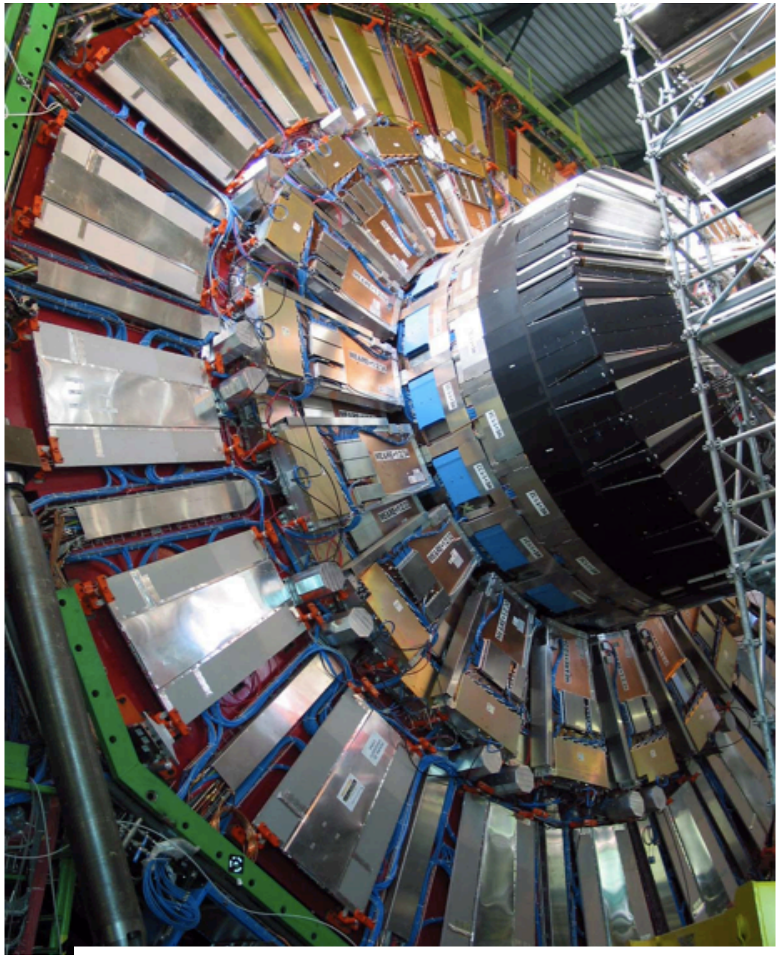




CMS	ALEPH	factor

Construction of CMS (≥2002)

…In a large hall on surface



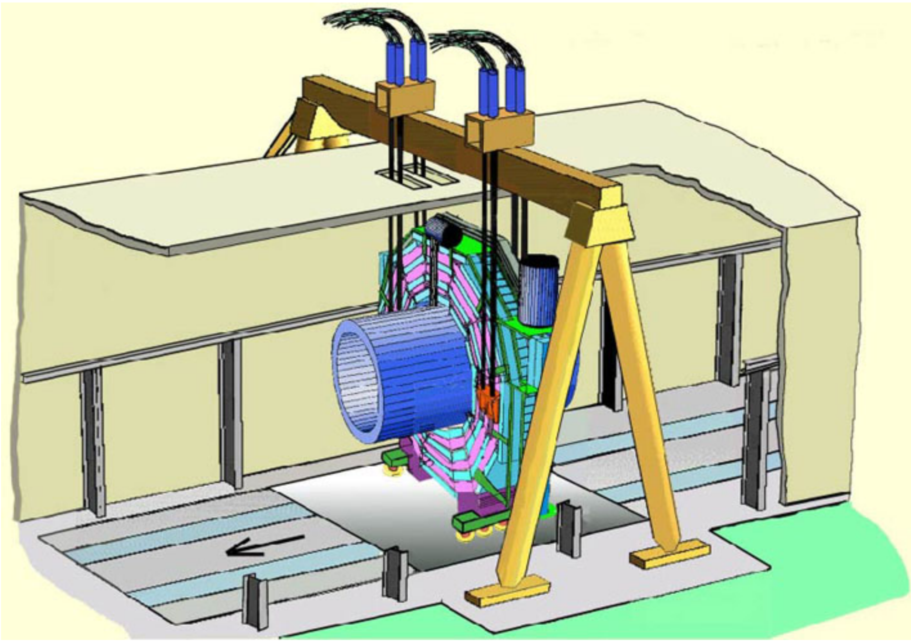
Muon detectors

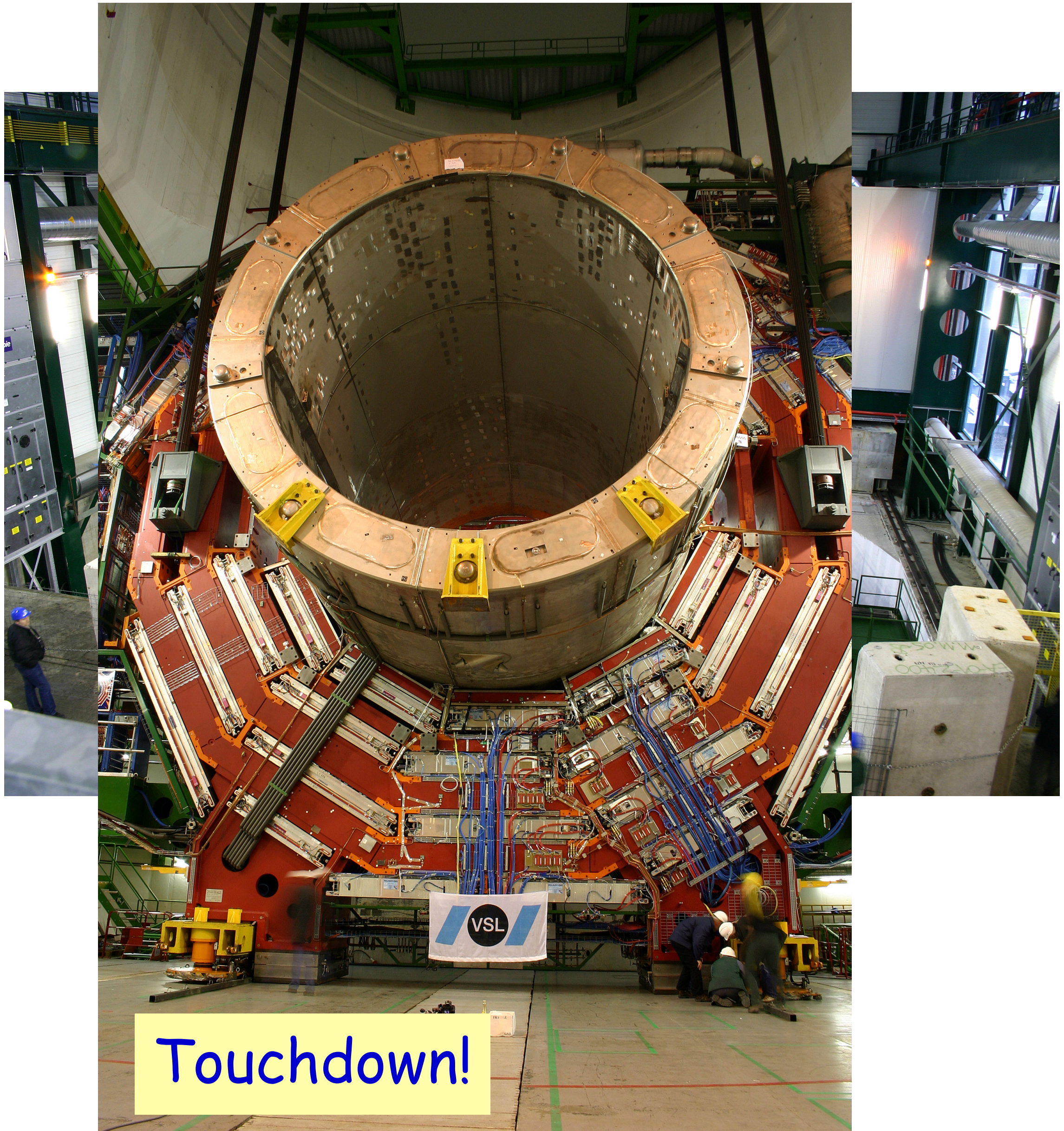
832 000 read-out channels

Lowering of the Solenoid

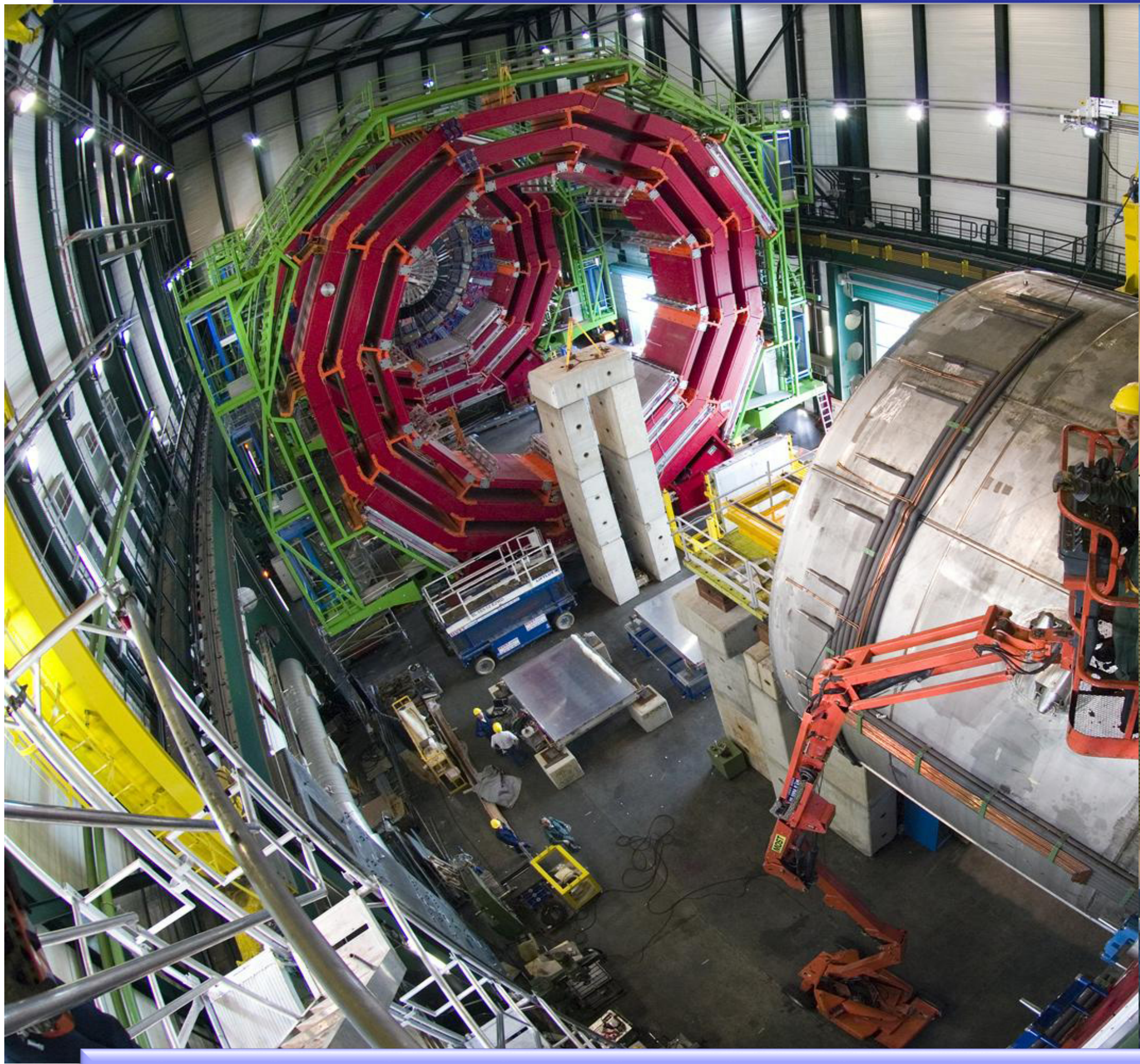
The Central piece of CMS
⇒The barrel wheel with the solenoid

Total weight ~ 2Ktons
= 5 jumbo jets
Lowered February 28 (2007)

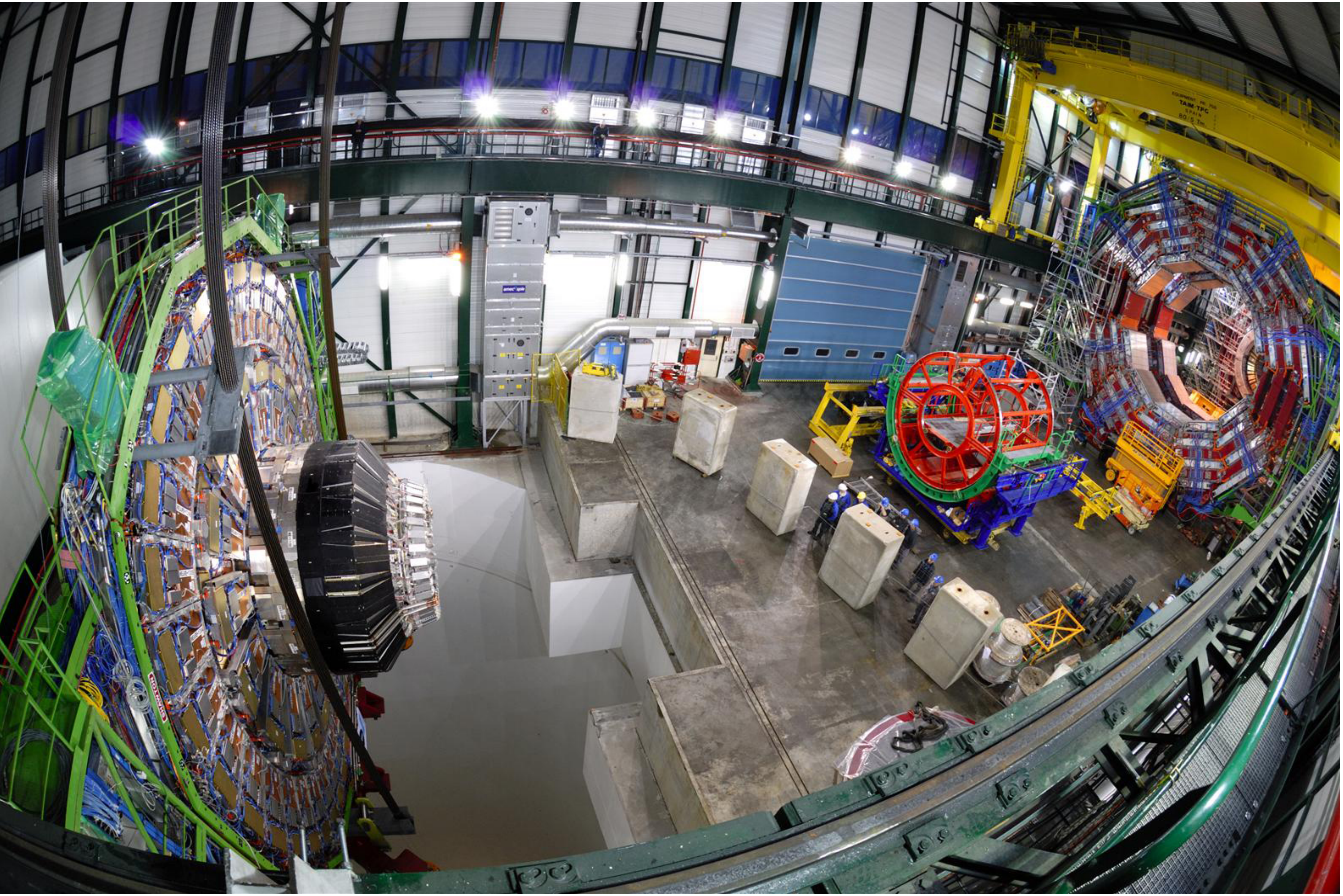




CMS built on the surface and lowered in the cavern 100m below
Piece by piece over three years



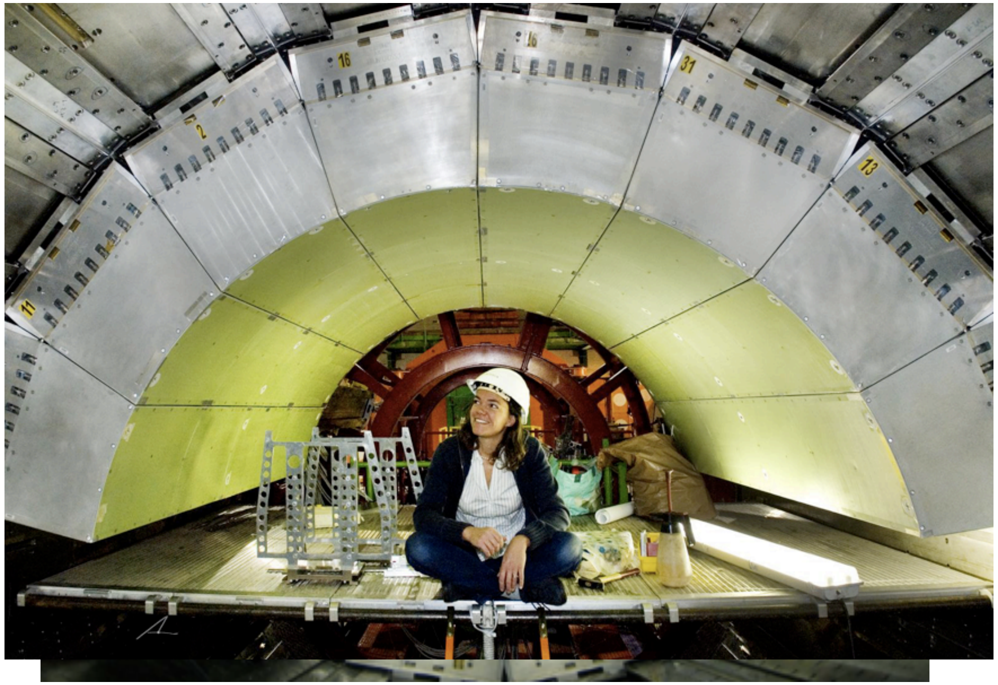
Hydraulic jacks and control tower used in CMS will be used
in Durban to lift the roof of the stadium for World Cup 2010


TAIM-TFG
SPAIN

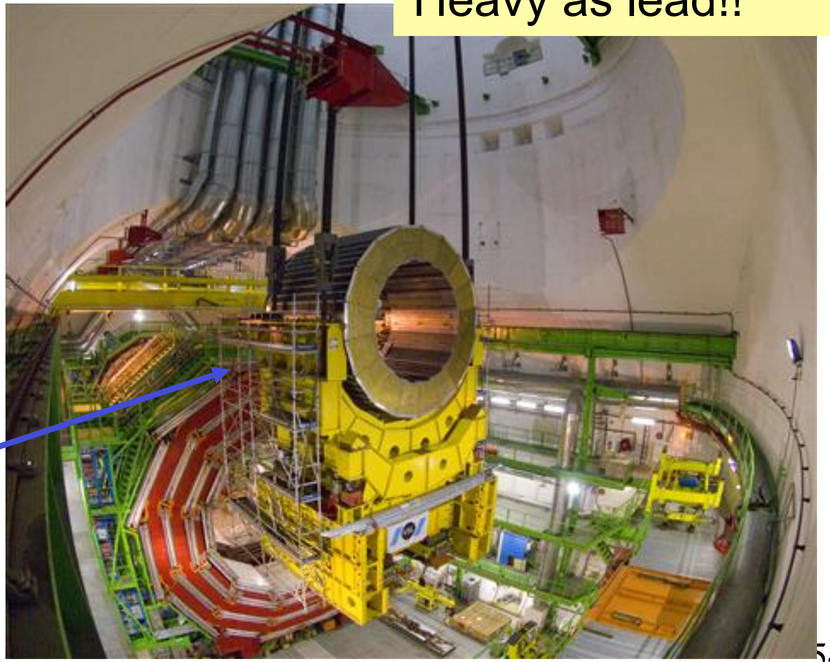
The CMS Detector: Calorimeters

ECAL: Barrel 36 super modules/1700 crystals
Endcaps detectors completed in summer 2008
Total of ~70000 crystals for this detector

Lead tungstanate.
Transparent like glass
Heavy as lead!!

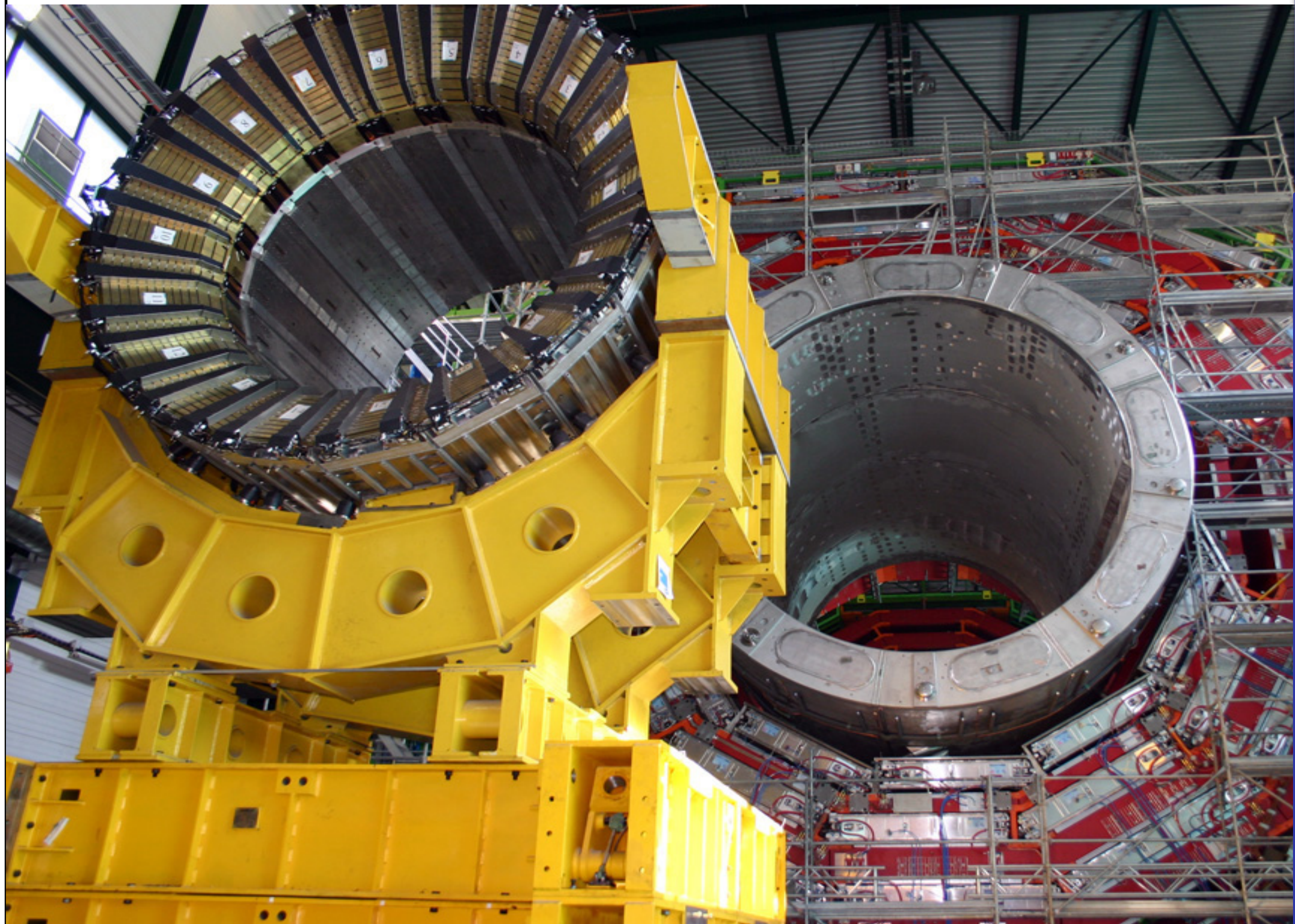


Central ECAL installation in CMS



Hadronic Calorimeter (brass/scintillator)
completed in 2006
Lowering in the experimental hall

Hadron Calorimeter (HCAL)



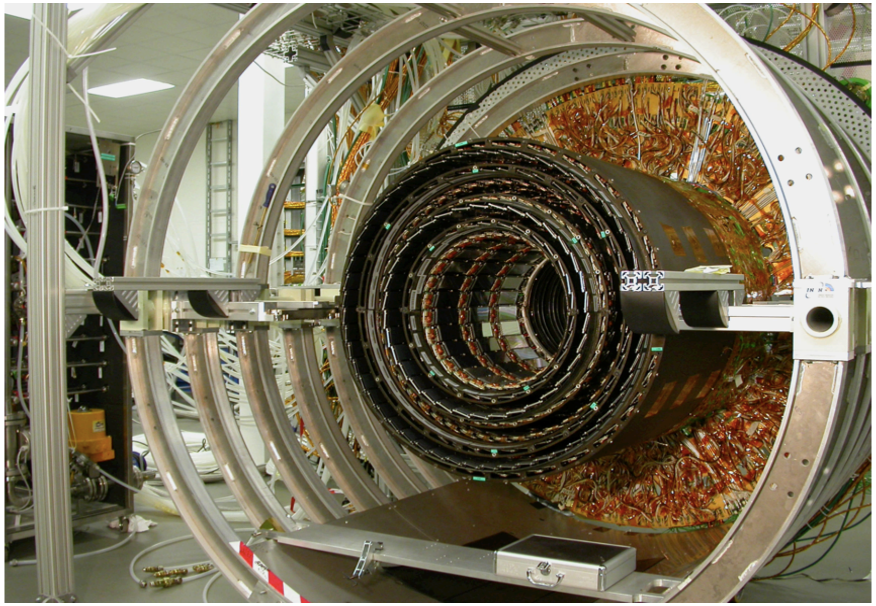
Made of dense brass layers interspersed with plastic scintilitaors

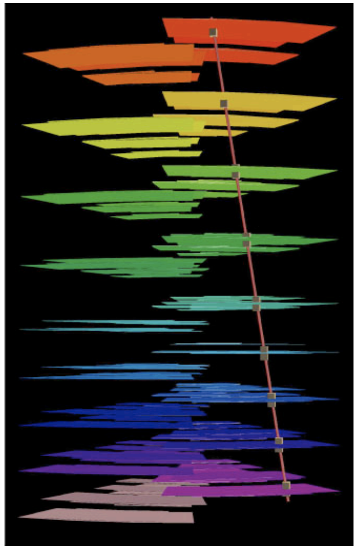
Used over a million World War II brass shell casements from the Russian Navy in making some of its detector components;
is made up of 36 wedges, each of which weighs as much as 6 African elephants;
contains over 400 "optical decoder" units, all of which were made by American high school students through the QuarkNet programme.

Function:
Measure energy of hadrons (protons, neutrons)




The CMS Central Tracker

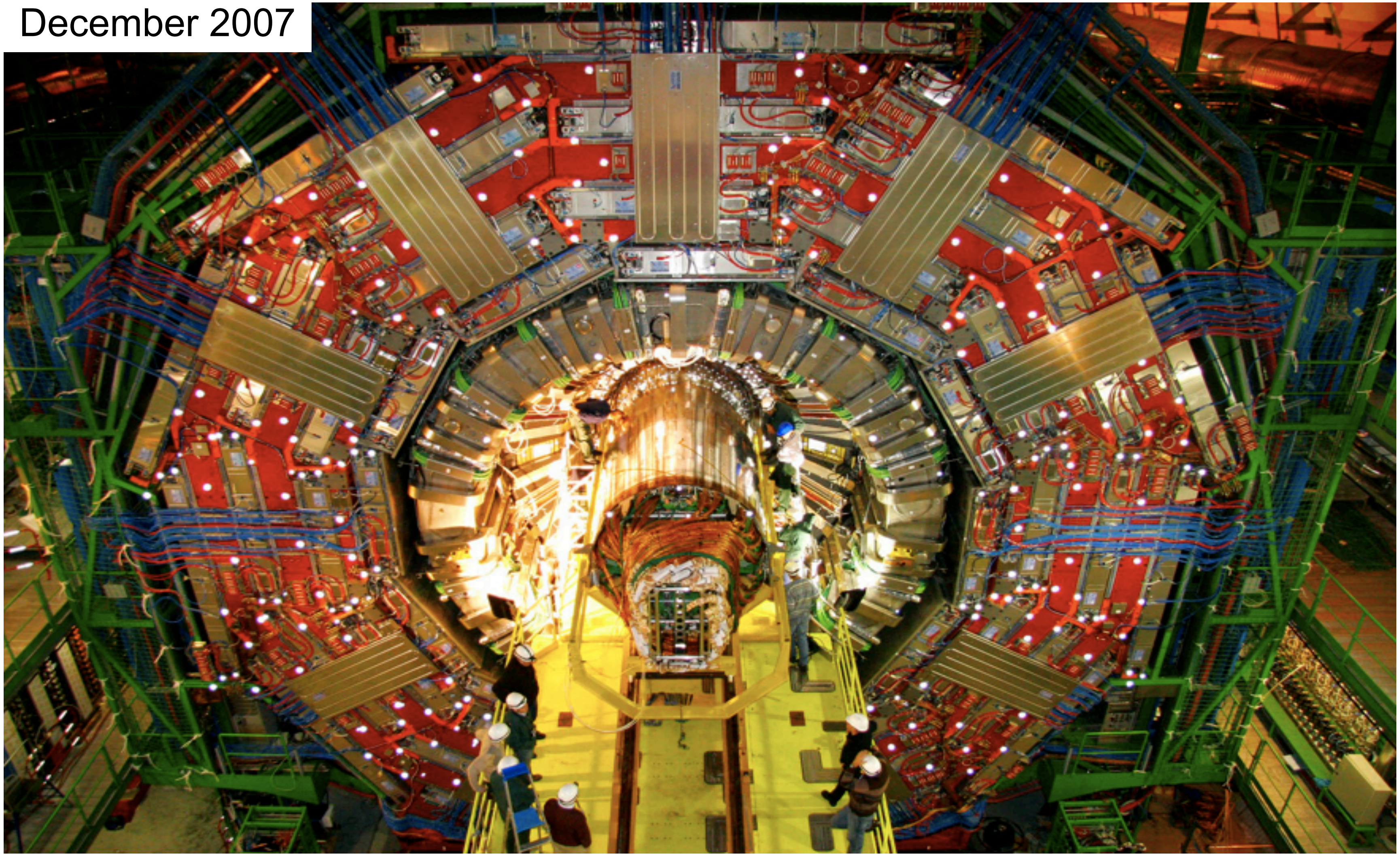




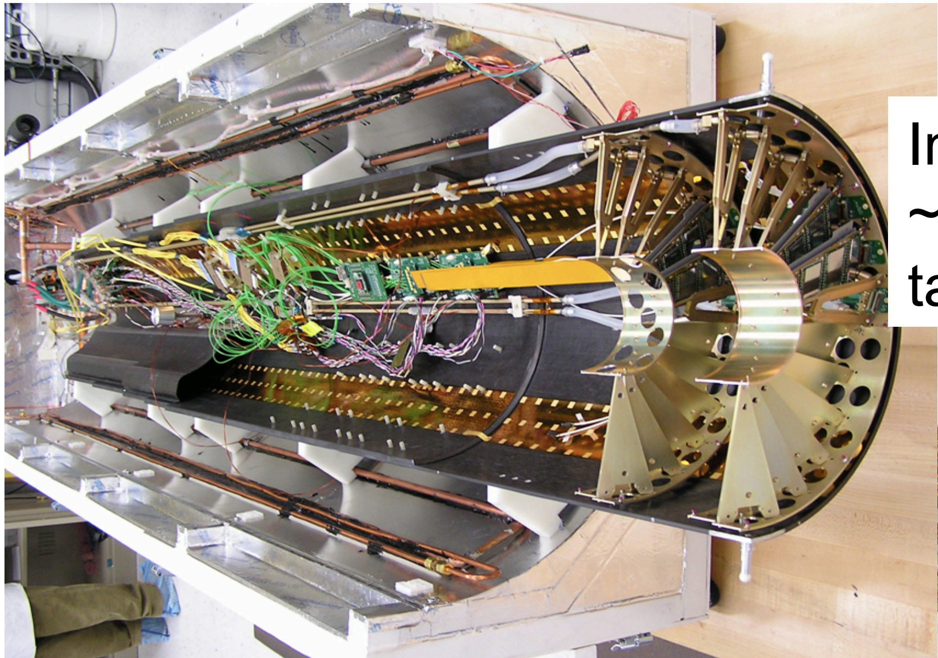
- 200 m^2 silicon detectors (~ tennis court)
- ~ 10^7 read-out channels: silicon strips

Installation of the Central Tracker in CMS

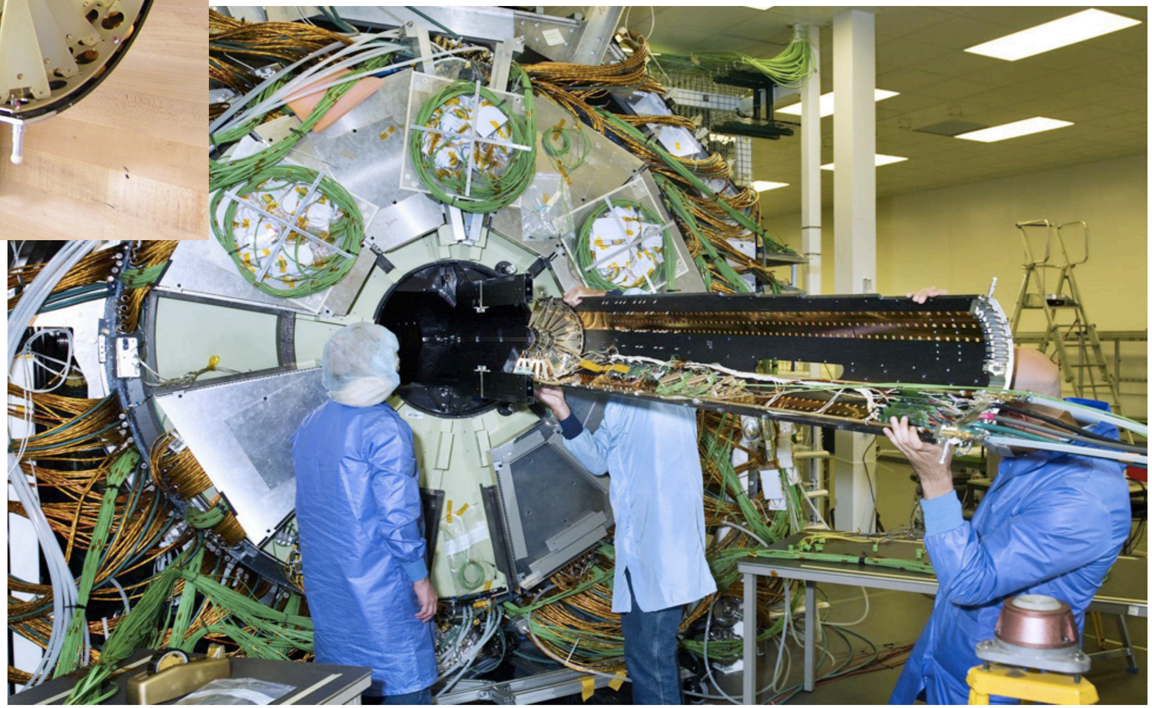
December 2007



Pixel Tracking Detector



In total 7.10^{7} read out channels
~ photo camera with 70 milion pixels
taking 40 million photos per second!!



The LHC Data Challenge

The LHC accelerator will run for 10-15 years

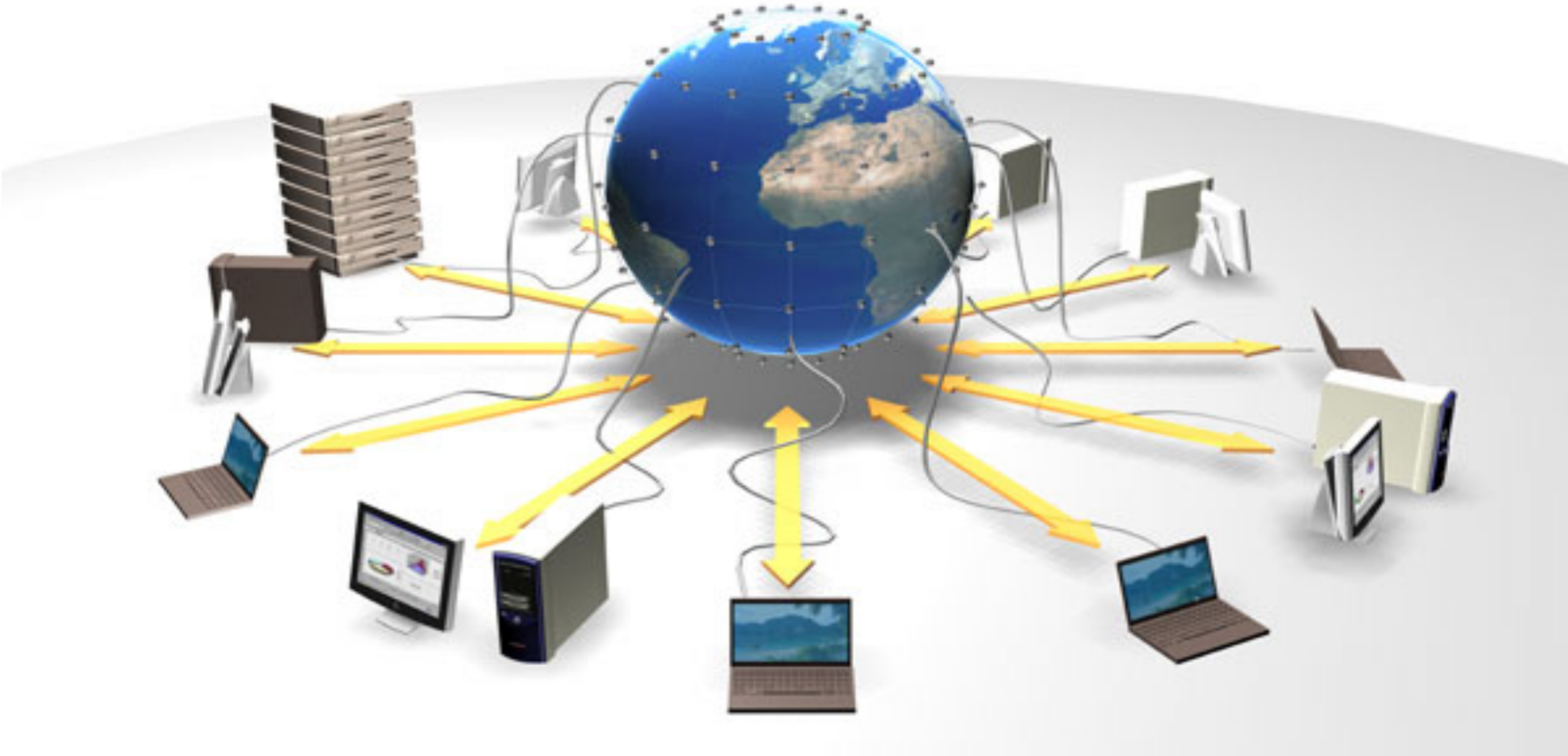
Experiments will produce about **15 Million Gigabytes** of data each year (about 20 million CDs!)

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

The LHC computing challenge

furthest reaching computer in the world...



Tens of thousands of computers based all over the world are used to analyse data from CERN. The computing GRID is the next advance in decentralised computing from the laboratory that brought you the World-Wide Web.

.

LHC Computing Grid project (LCG)

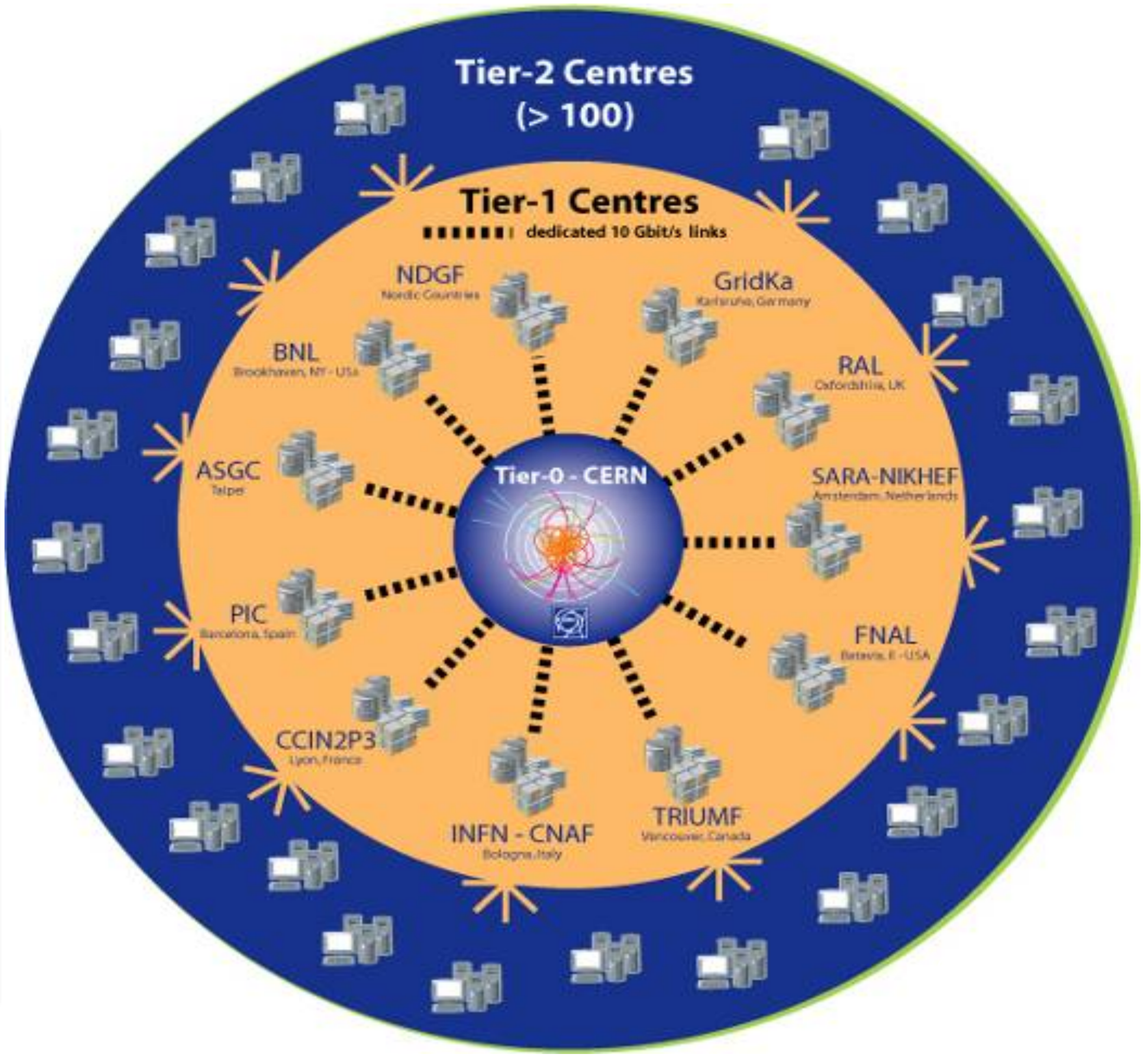
More than 140 computing centres
12 large centres for primary data management:
CERN (Tier-0)

Eleven Tier-1s

38 federations of smaller Tier-2 centres

India – BARC, TIFR, VECC

35 countries involved



The Science of the LHC

⇒ Explore the new high energy regime: The Terascale

The Origin of Mass

Some particles have mass, some do not

Where do the masses come from ?

Newton:

Weight proportional to Mass

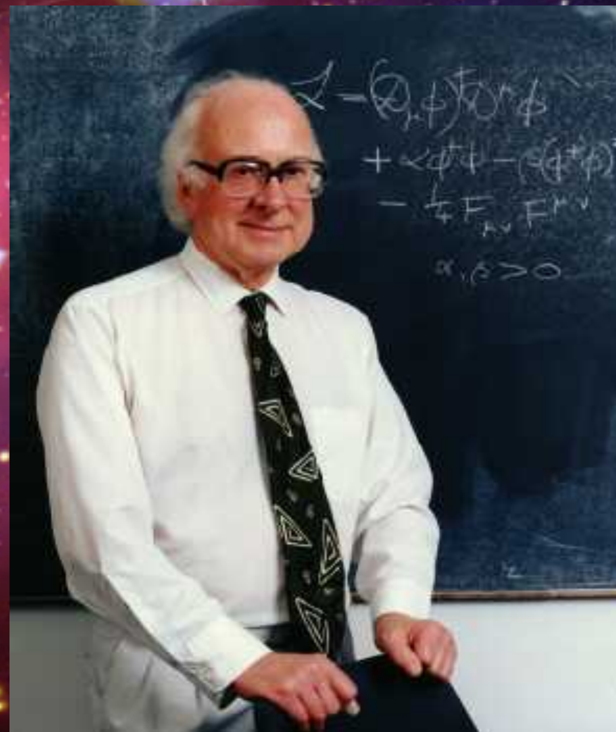
Einstein:

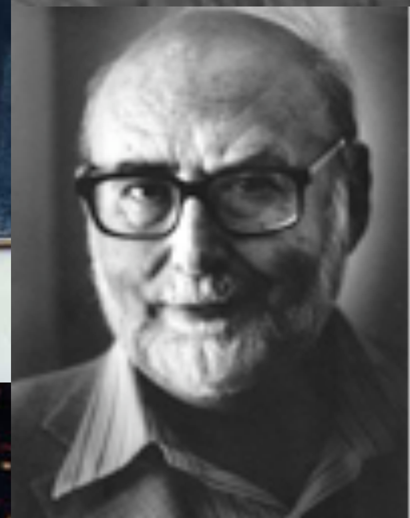
Energy related to Mass

Neither explained origin of Mass

Explanation of Profs P. Higgs R. Brout en F. Englert

⇒ A new field and particle





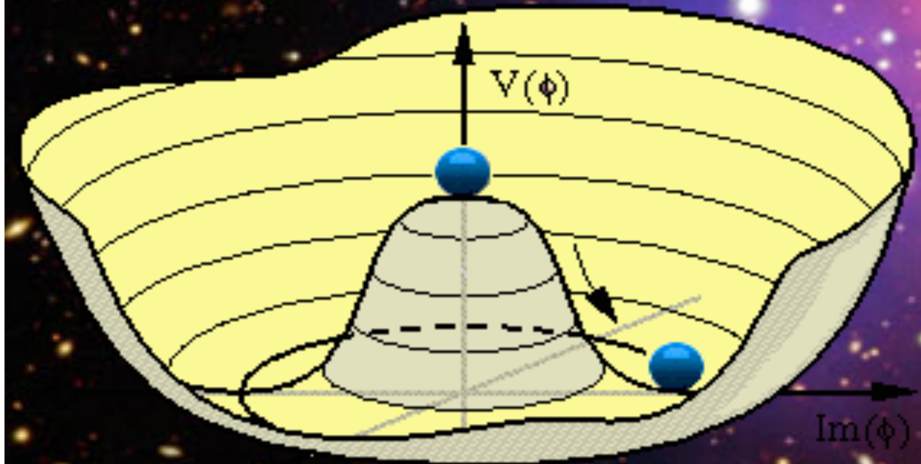
The Hunt for the Higgs

Where do the masses of elementary particles come from?

The key question: Where is the Higgs?

Massless particles move at the speed of light -> no atom formation!!

We do not know the mass of the Higgs Boson



Scalar field with at least one scalar particle

It could be anywhere from 114 to 700 GeV

The Higgs Boson

The Washington Post

NATIONAL

Spring 2012

Physicists hope to find the Higgs boson, key to unified field theory, this year

Fabrice Coffrini/Agence France-Presse via Getty Images - A superconducting solenoid magnet, the largest of its kind, is part of the Large Hadron Collider, which is searching for the Higgs boson.

Peter Higgs

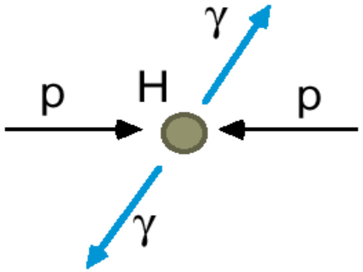
Higgs Boson Searches

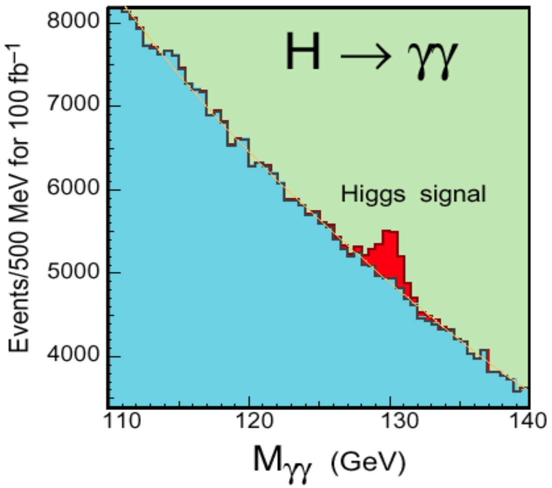
Low M_H < 140 GeV/c²

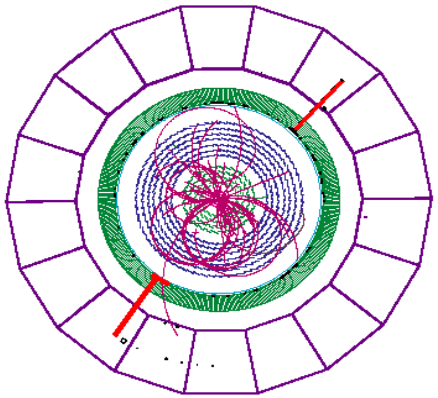
Medium 130<M_H<500 GeV/c²

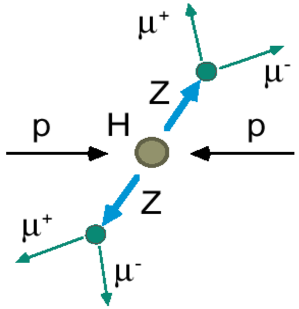
High M_H > ~500 GeV/c²

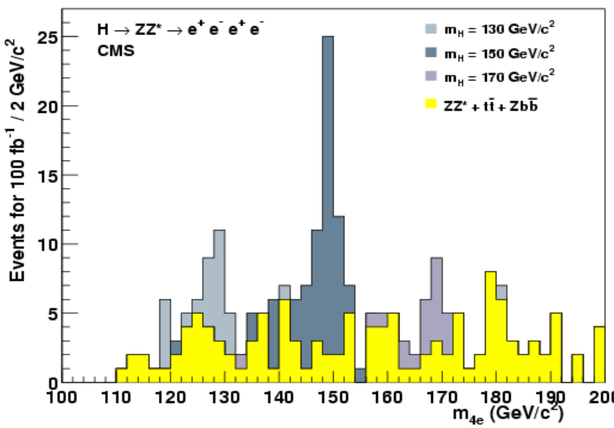
simulation

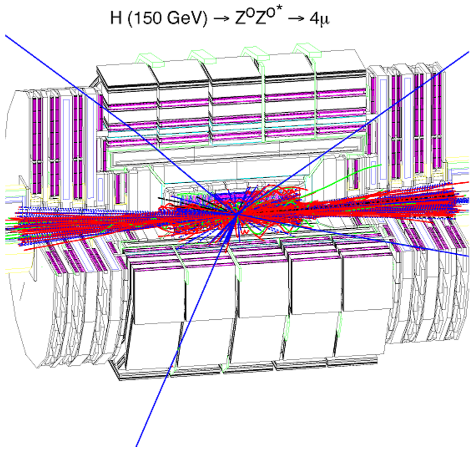


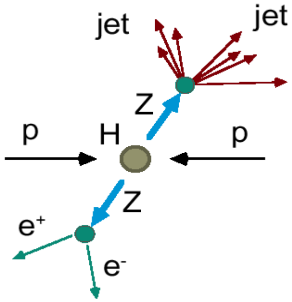


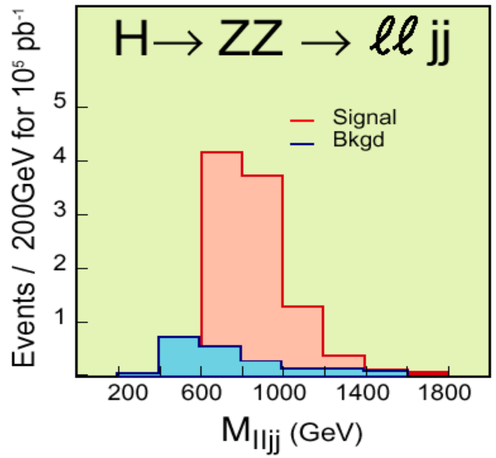


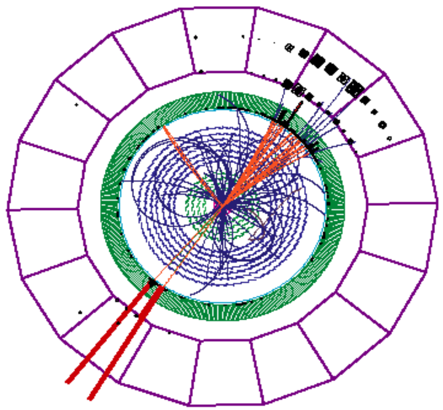










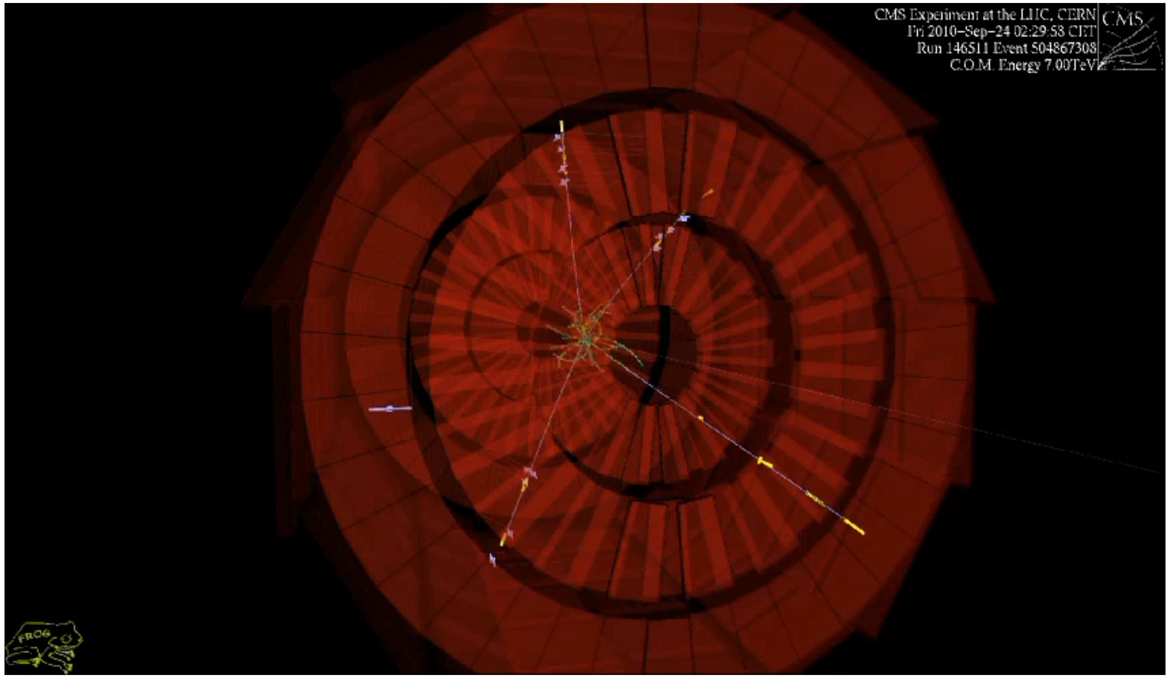


Searches for the Higgs Particle

A Higgs particle will decay immediately, eg in two heavy quarks or two heavy (W,Z) bosons

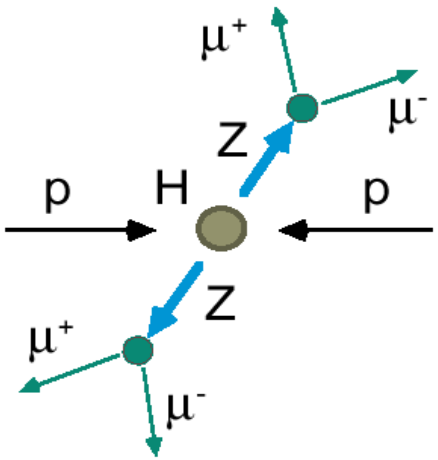
Example: Higgs(?) decays into ZZ and each Z boson decays into μμ

So we look for 4 muons in the detector

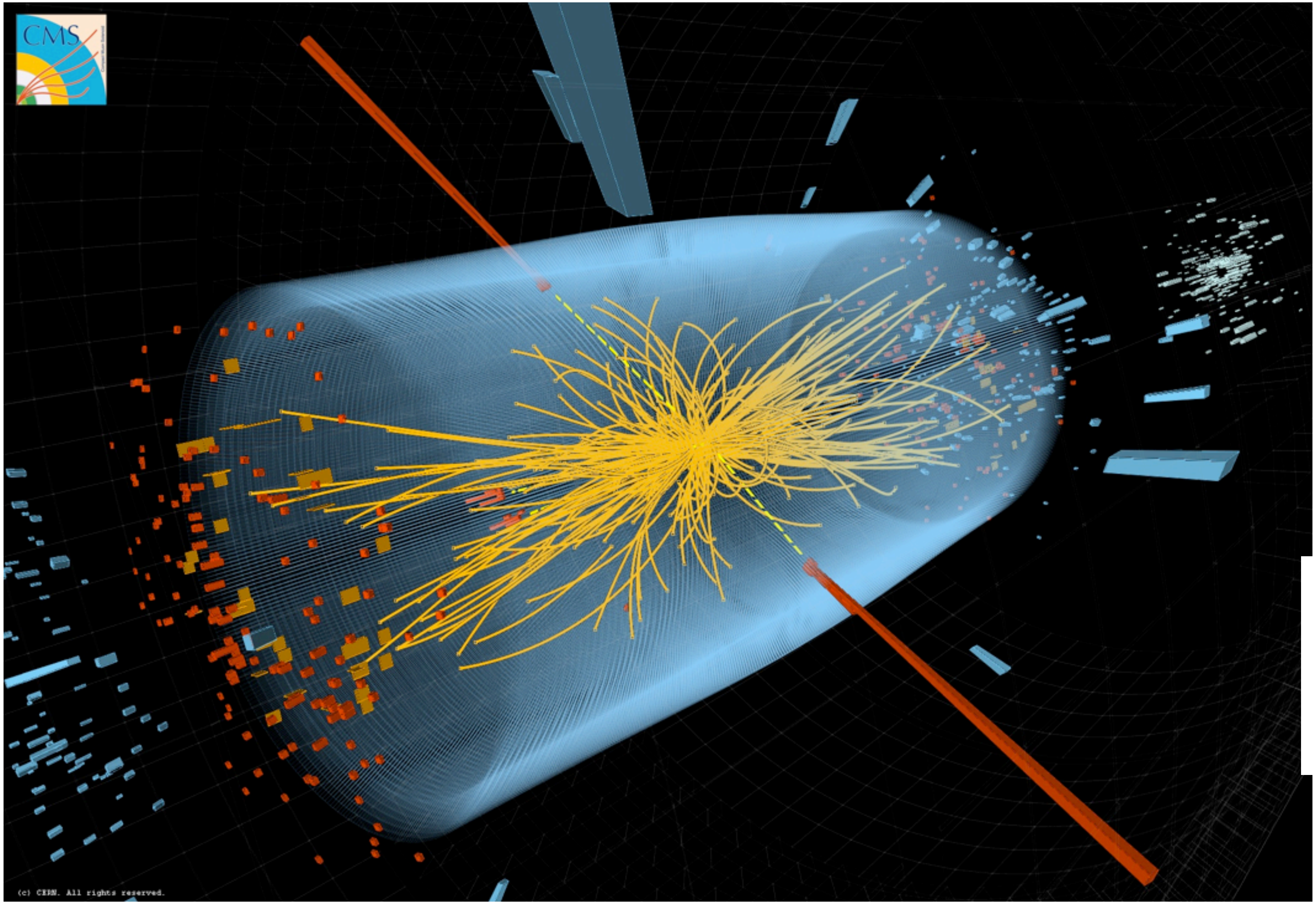


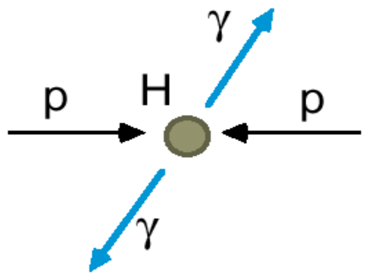
But two Z bosons can also be produced in LHC collisions, without involving a Higgs!

We cannot say for on event by event (we can reconstruct the total mass with the 4 muons)



A Collision with two Photons





A Higgs or
a 'background'
process without
a Higgs?

July 4th 2012

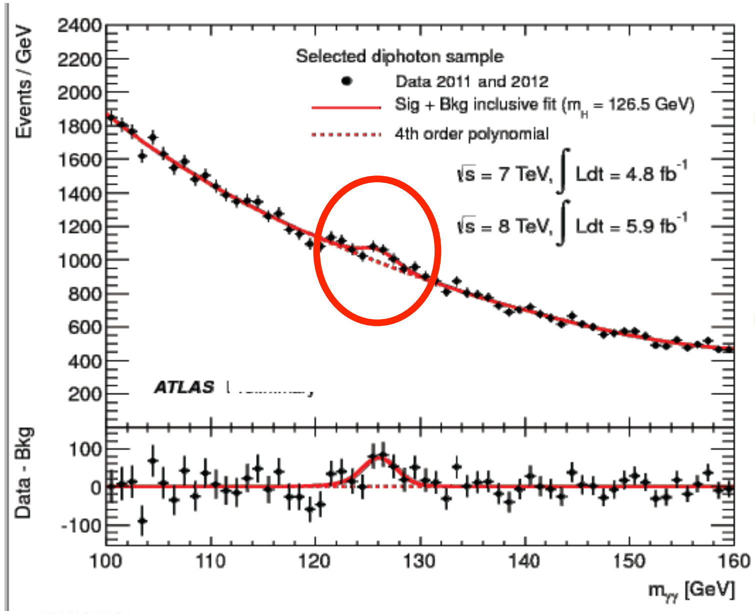
- Official announcement of the discovery of a Higgs-like particle with mass of 125-126 GeV by CMS and ATLAS.
- Historic seminar at CERN with simultaneous transmission and live link at the large particle physics conference of 2012 in Melbourne, Australia

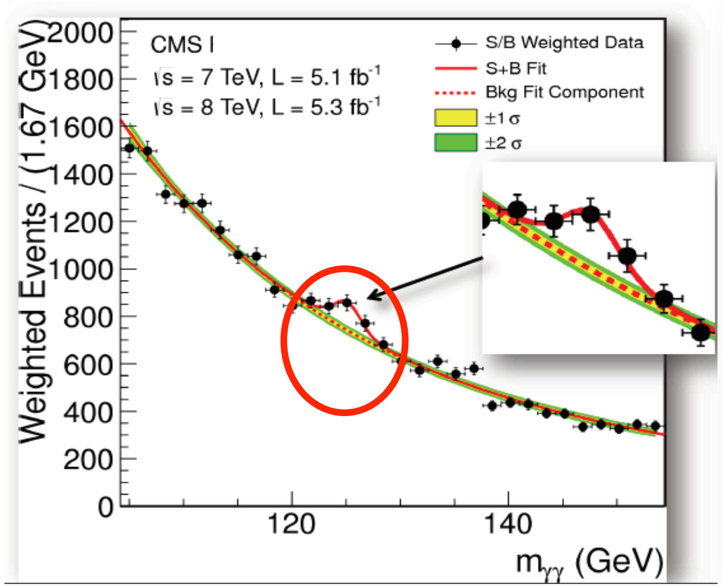
CERN

Melbourne

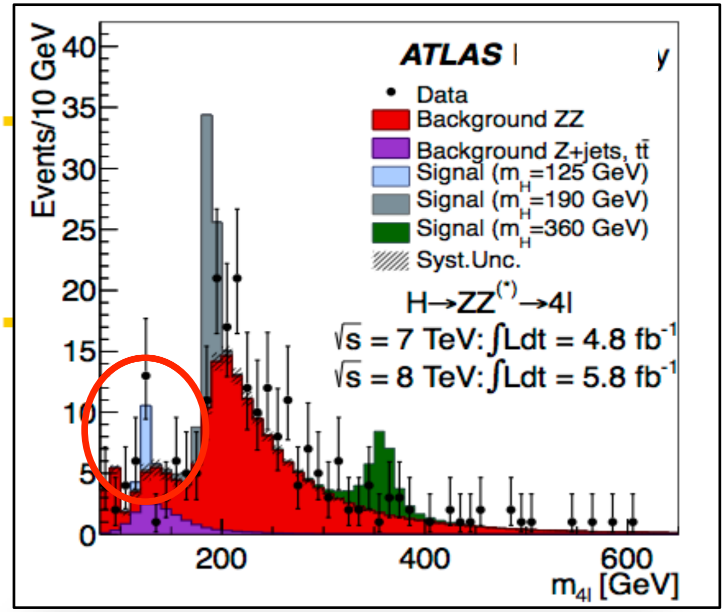
Results from the Experiments

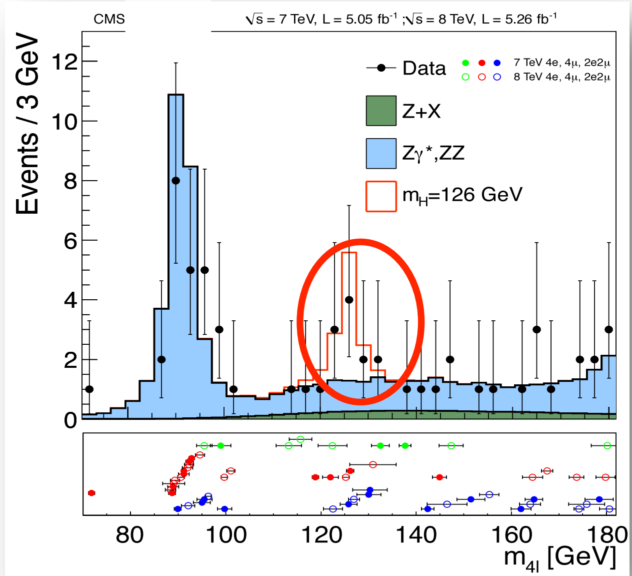
Higgs → 2 photons!!





Higgs → 2 Z →4 leptons!!





A clear "excess" of events seen in both experiments around 125-126 GeV

It became very significant in 2012

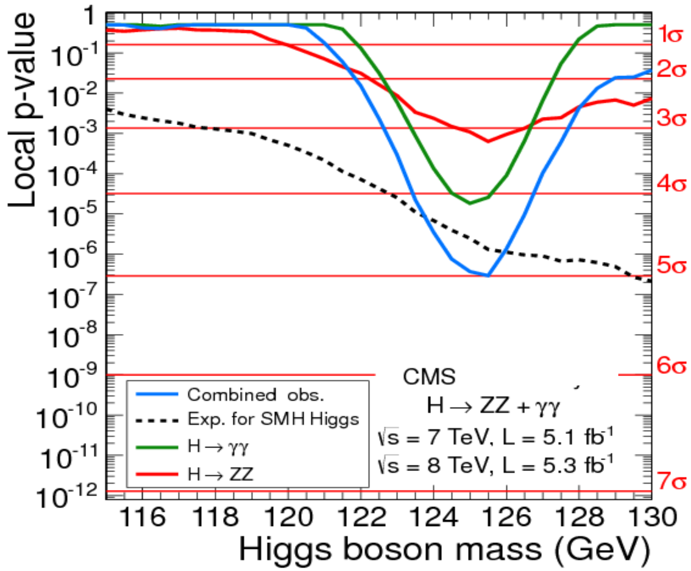
Sophisticated Statistical Methods have used to fully analyse this.

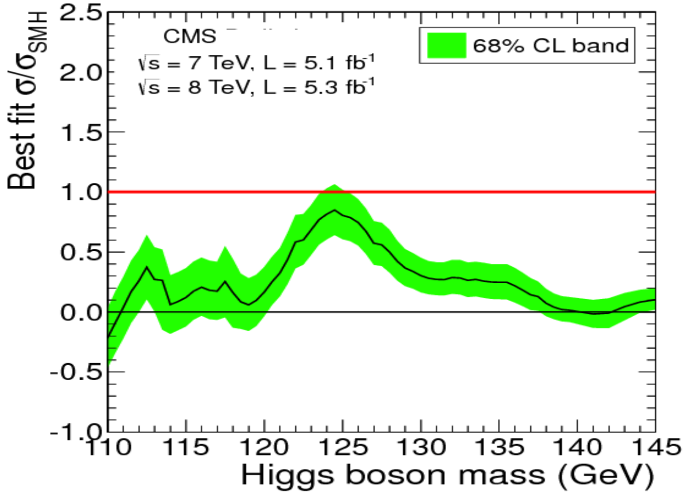
And the result is…→

Results from the Experiments

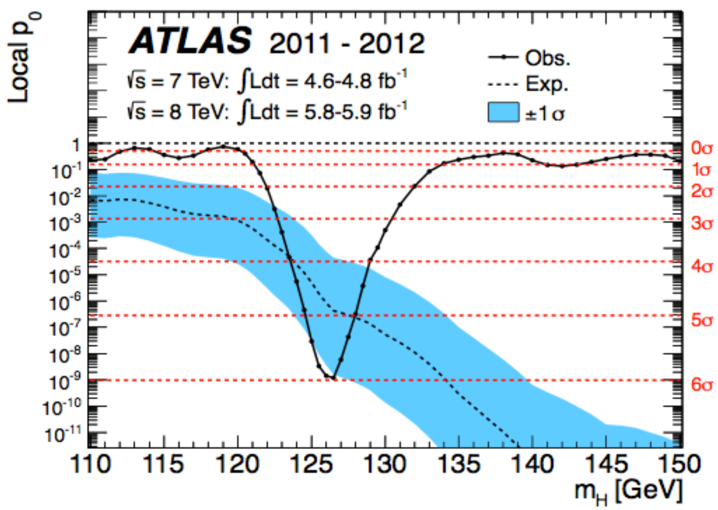
Statistical combination:
Total signal strength

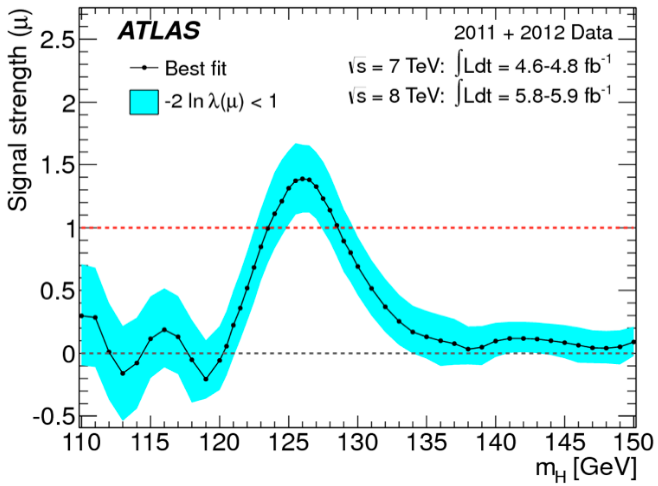
Compatibility with
a SM Higgs





CMS and ATLAS observe a new boson with a significance of about 5 sigma





The particle is consistent with a Higgs-like boson

The Press…

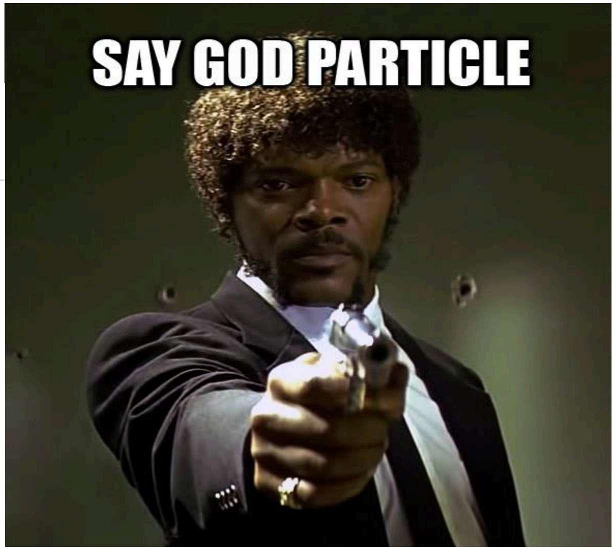
The discovery of the Higgs made the headlines worldwide

Hawking lost $100 bet over Higgs boson

What Comes After Higgs Boson?

Atlantic wire what matters now

'God Particle' 'Discovered': European Researchers Claim Discovery of Higgs Boson-Like Particle



HOW THE HIGGS COULD BECOME ANNOYING

Yes, the discovery of the Higgs boson is thrilling and game-changing. But it could also introduce some aggravating situations.

Хиггс увидит бозон

В CERN открыли бозон Хиггса

Текст

— 3.07.12 15:13 —

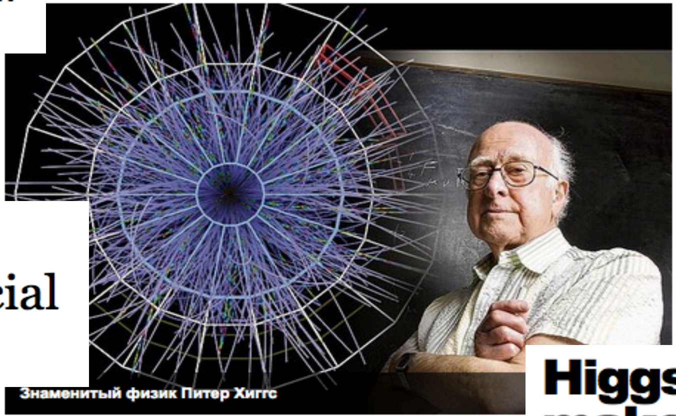
ТЕКСТ: АЛЕКСАНДРА БОРИСОВА

D: SCIENCEUNSEEN.COM

Discovery of Higgs Boson Bittersweet News in Texas

Scientists Set The Higgs Boson To Music

3 Ways the Higgs Boson Discovery Will Impact Financial Services



Знаменитый физик Питер Хиггс

Higgs boson discovery could make science fiction a reality

Discovery of the 'God particle' could make science fiction a reality, and answer one of the most basic questions of our universe: How did light become matter — and us?

Higgs boson researchers consider move to Cloud computing

"Within another decade the Cloud will be where grid computing is now"

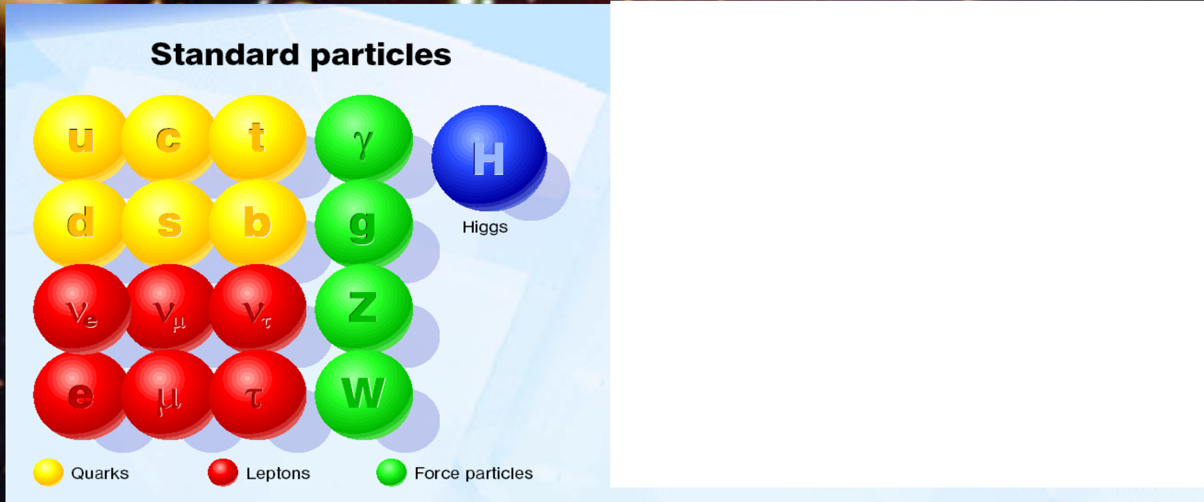
Is it really the Higgs Boson?

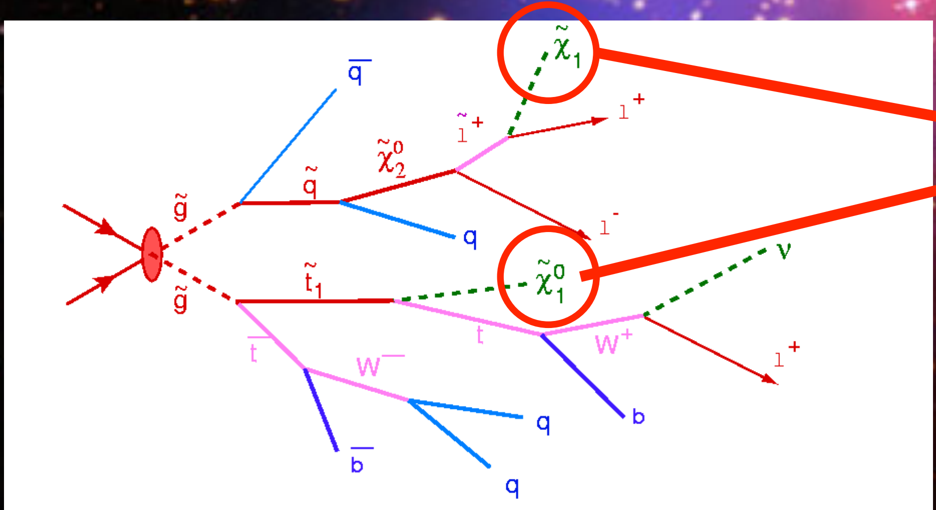
We, experimentalists, call it a "Higgs-like" particle

- Does this new particle have all the properties that we expect a Higgs Boson to have?
  - So far it seems to couple as expected to photons, heavy Z and W bosons, but we have not seen that they also couple to quarks or leptons
- What are the quantum numbers of this new particle?
  - EG Spin and Parity: for the SM Higgs we expect it to have spin = 0 and parity = +.
- Is there more than one Higgs-like particle? Some theories beyond the Standard Model predict these…
- Does it have 'exotic' properties?

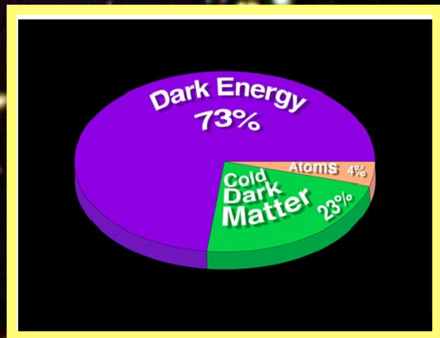
Beyond the Higgs Particle

Supersymmetry: a new symmetry in Nature





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

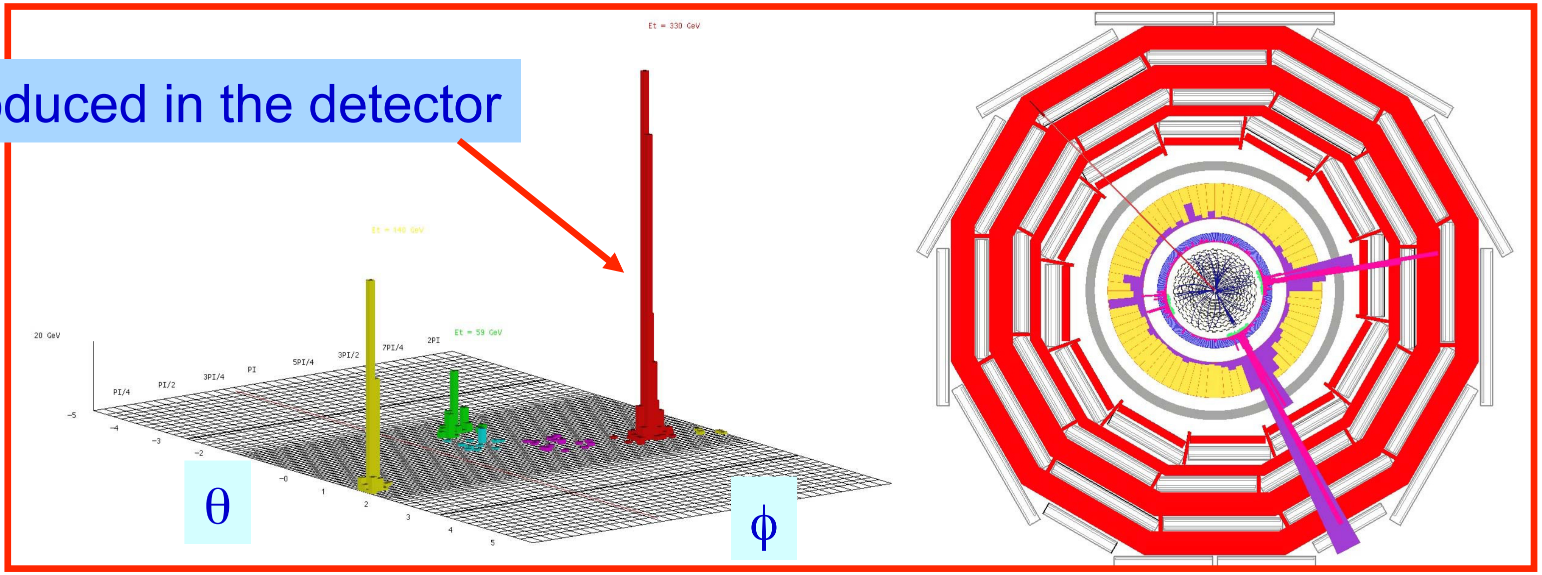


SUSY particle production at the LHC

+ 2 b-jets
+ 4 jets

Detecting Supersymmetric Particles

Energy produced in the detector



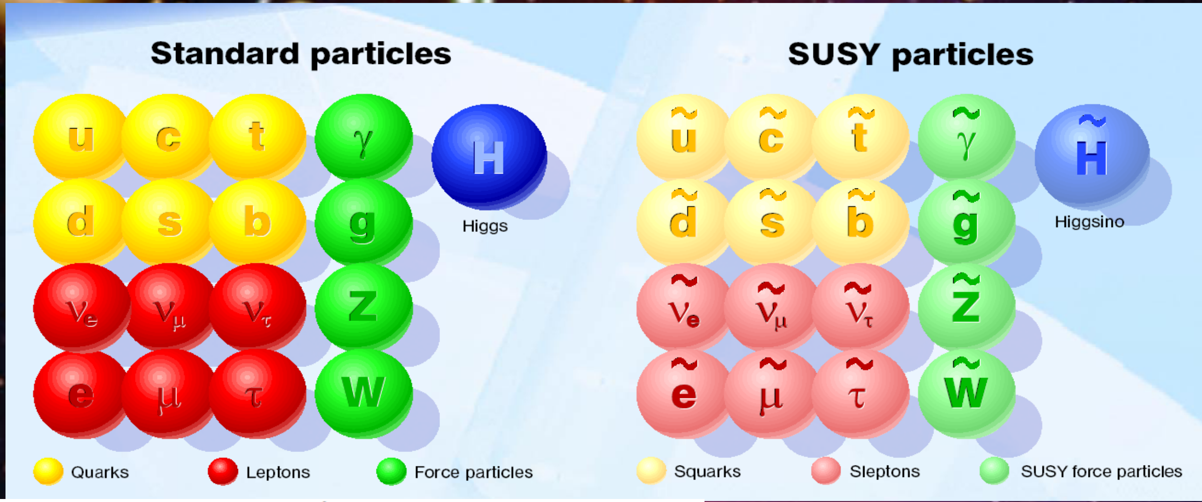
Supersymmetric particles decay and produce a cascade of jets, leptons and missing (transverse) energy due to escaping ‘dark matter’ particles

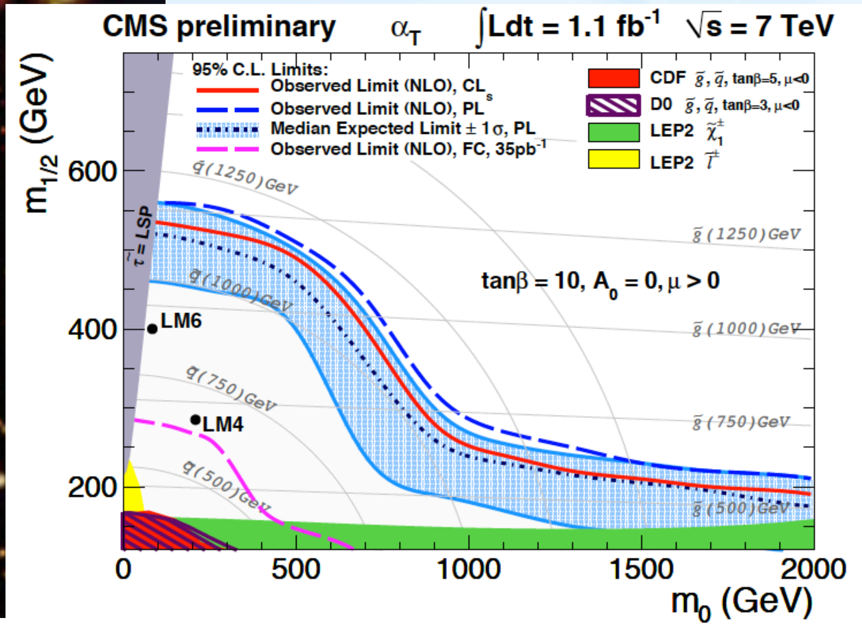
⇒ Very clear signatures in CMS and ATLAS

LHC can discover supersymmetric partners of the quarks and gluons as heavy as 2 to 3 TeV

The expected cross sections are huge!! ⇒ 10,000 to 100,000 particles per year

Supersymmetry: a new symmetry in Nature





Susy partners are very heavy
~ 1000 mass of the proton

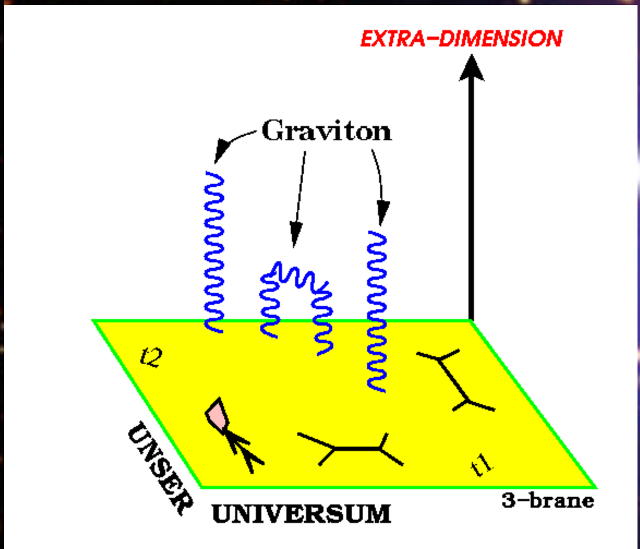
Picture from Marusa Bradac

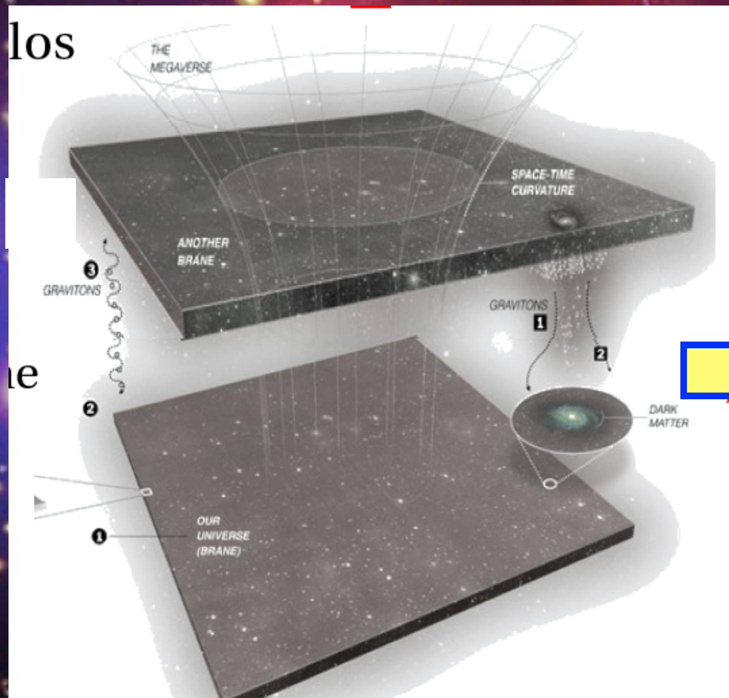
Beyond the Higgs Particle

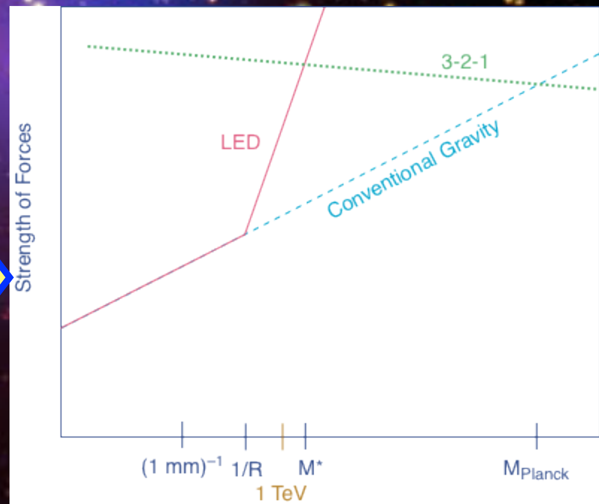
Extra Space Dimensions

Problem:

$$m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\ \text{GeV} \quad \longleftrightarrow \quad M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\ \text{GeV}$$



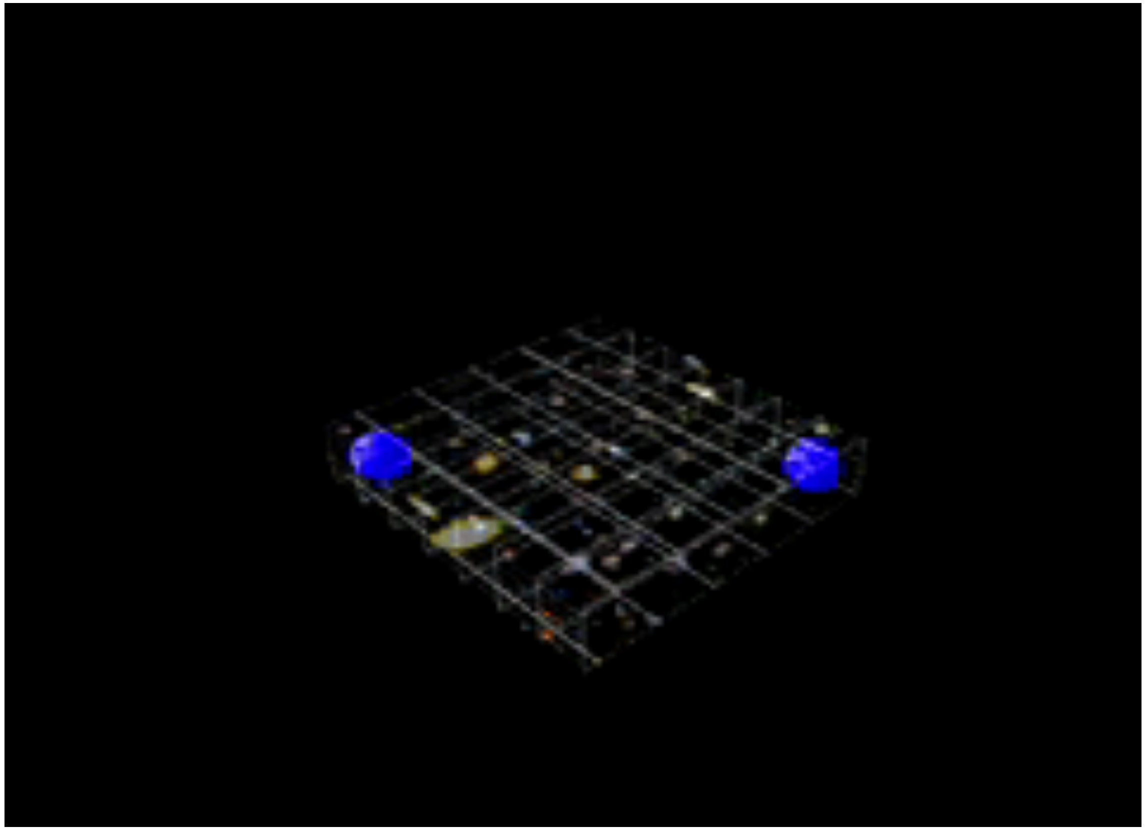


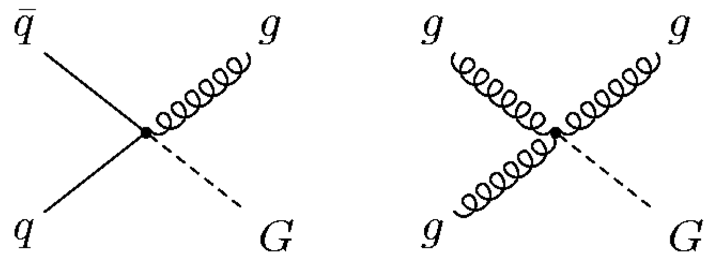


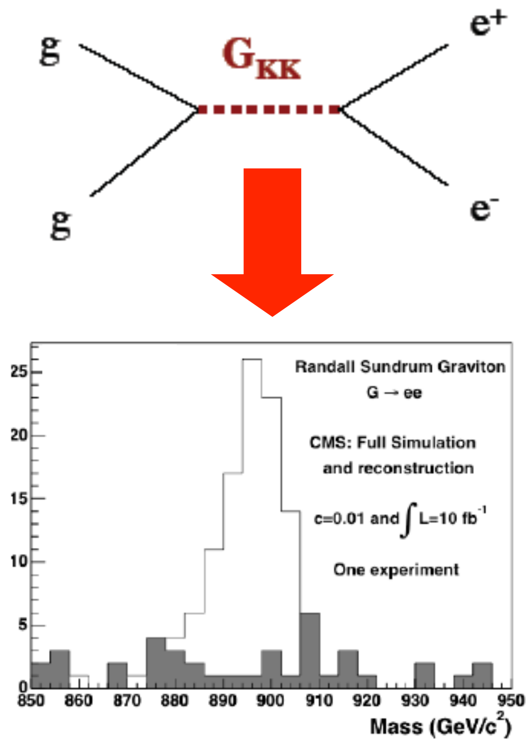
The Gravity force becomes strong!

Detecting Extra Dimensions at the LHC

Main detection modes at the experiments
- Large missing (transverse) energy
- Resonance production



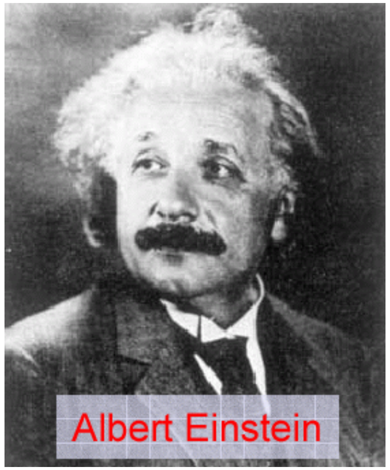




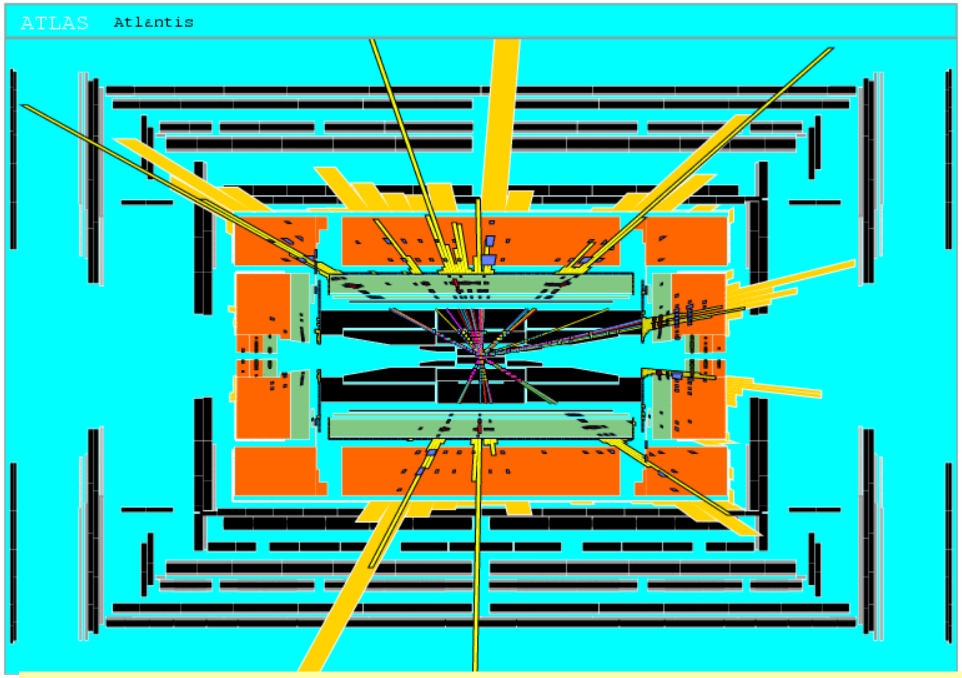
LHC can detect extra dimensions for scales up to 5 to 9 TeV

Quantum Black Holes at the LHC?

Black Holes are a direct prediction of Einstein's general theory on relativity



If the Planck scale is in ~TeV region:
can expect Quantum Black Hole production



Simulation of a Quantum Black Hole event

Quantum Black Holes are harmless for the environment: they will decay within less than 10^{-27} seconds

Quantum Black Holes open the exciting perspective to study Quantum Gravity in the lab!

Quantum Back Holes

- Schwarzschild radius

Landsberg, Dimopoulos
Giddings, Thomas, Rizzo…

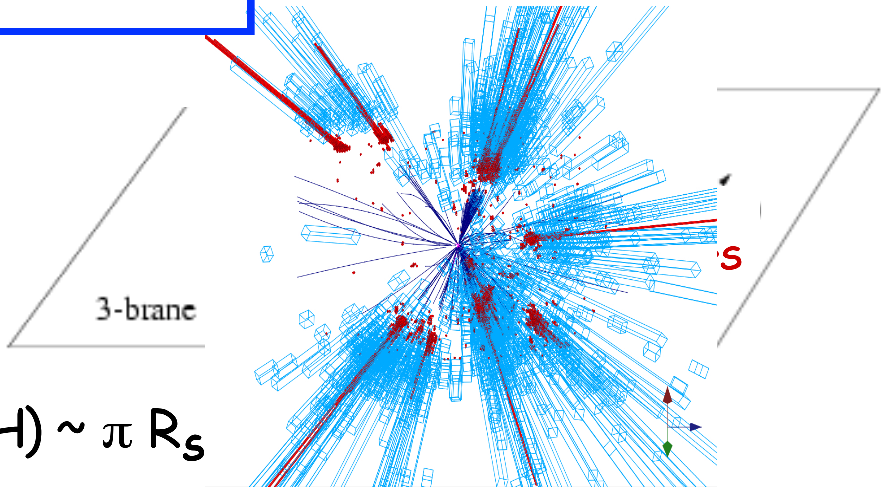
$R_s \rightarrow \ll 10^{-35}$ m

$R_s \rightarrow \sim 10^{-19}$ m

4-dim., $M_{gravity} = M_{Planck}$

4 + n-dim., $M_{gravity} = M_D \sim$ TeV

Since M_D is low, tiny black holes of $M_{BH} \sim$ TeV can be produced if partons ij with $\sqrt{s_{ij}} = M_{BH}$ pass at a distance smaller than R_S



- Large partonic cross-section : $\sigma(ij \rightarrow BH) \sim \pi R_S$
- $\sigma(pp \rightarrow BH)$ is in the range of 1 nb – 1 fb

e.g. For M_D ~1 TeV and n=3, produce 1 event/second at the LHC

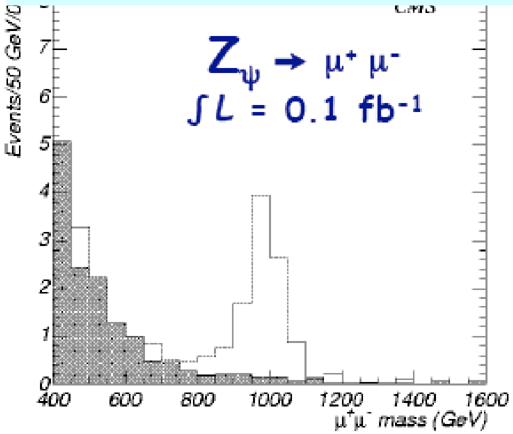
- Black holes decay immediately by Hawking radiation (democratic evaporation) :
  - -- large multiplicity
  - -- small missing E
  - -- jets/leptons ~ 5

expected signature (quite spectacular …)

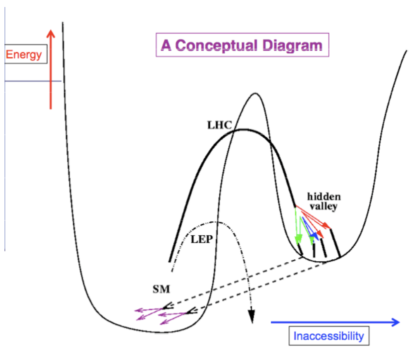
Black Holes Hunters at the LHC…

New Physics at the LHC

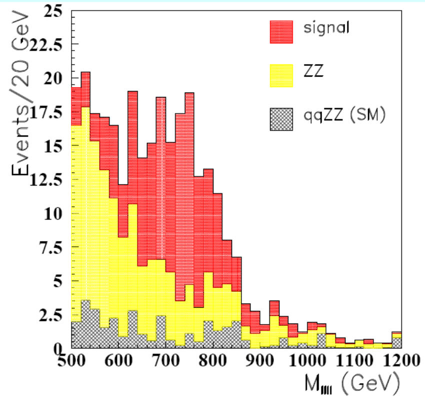
New Gauge Bosons?



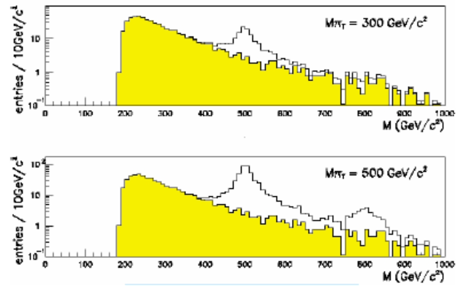
Hidden Valleys?



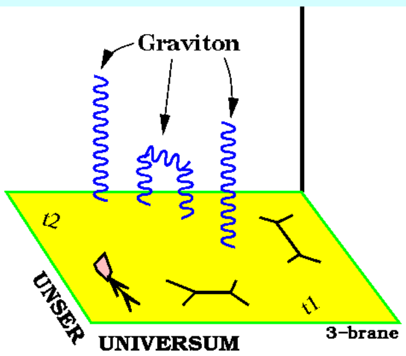
ZZ/WW resonances?



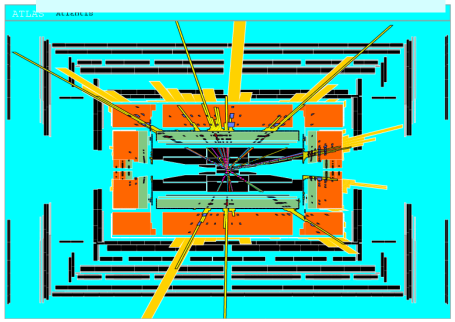
Technicolor?



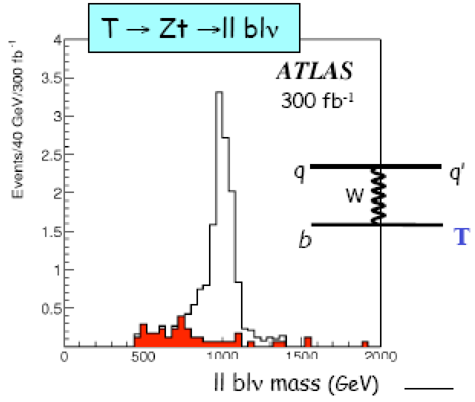
Extra Dimensions?



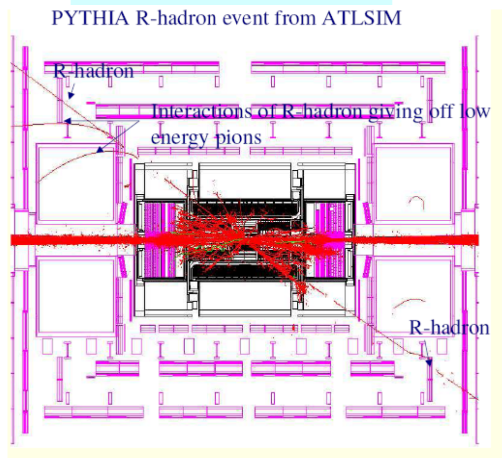
Black Holes???



Little Higgs?



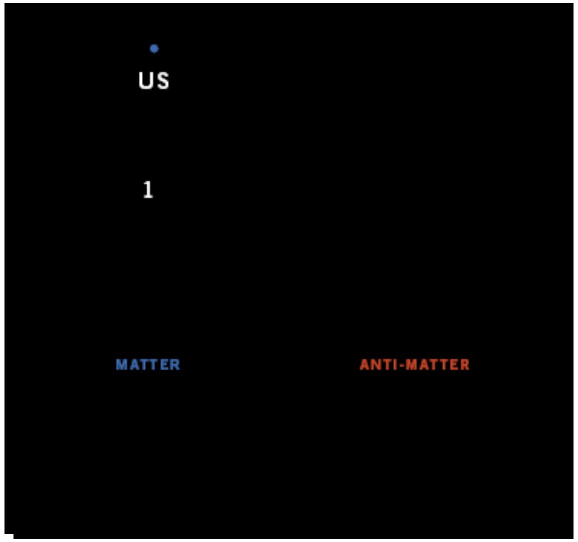
Split Susy?

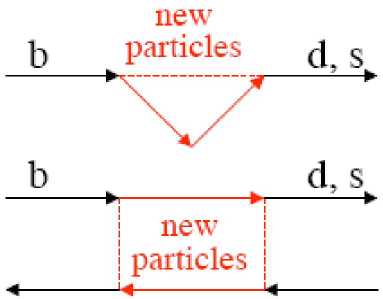


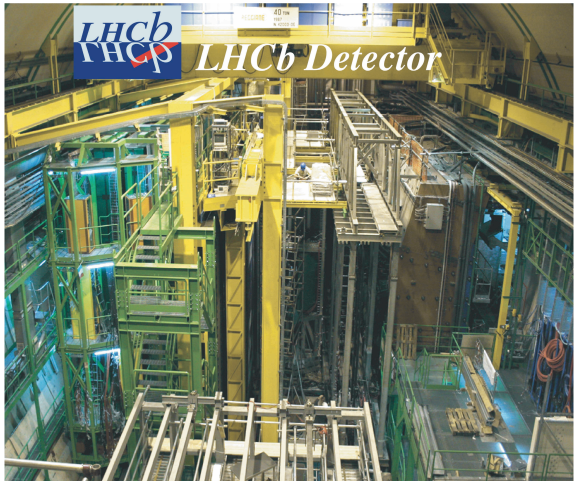
We do not know what is out there for us…

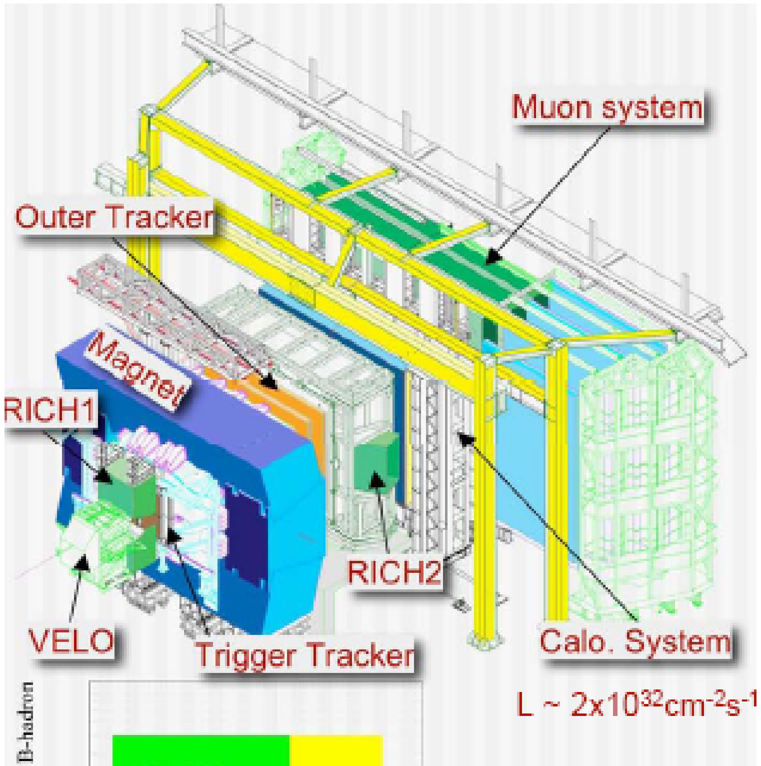
Matter-Antimatter

The properties and subtle differences of matter and anti-matter using mesons containing the beauty quark, will be studied further in the LHCb experiment



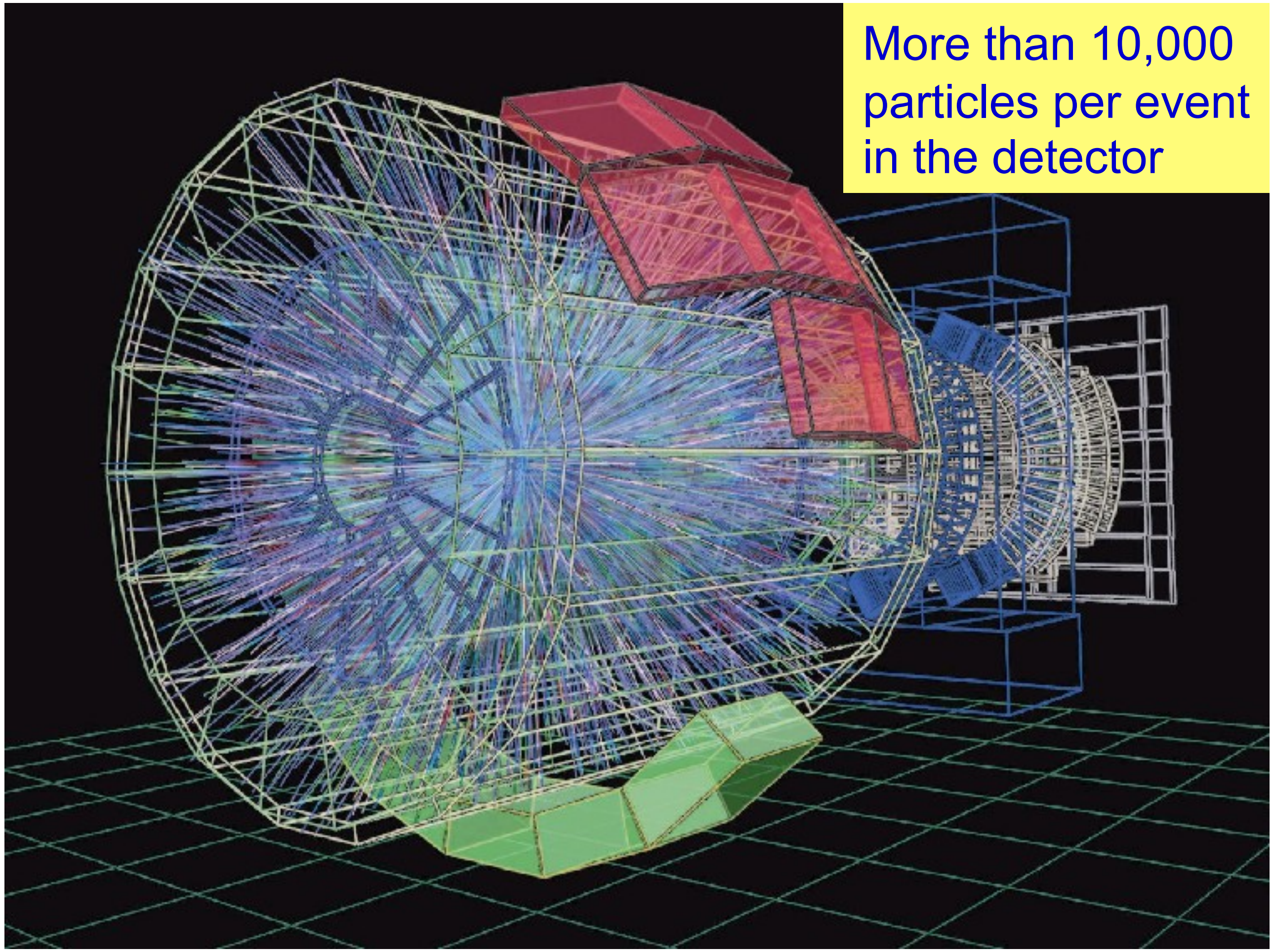






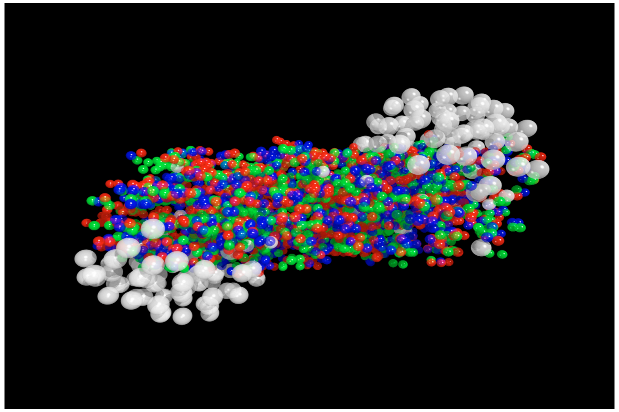
Primordial Plasma

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



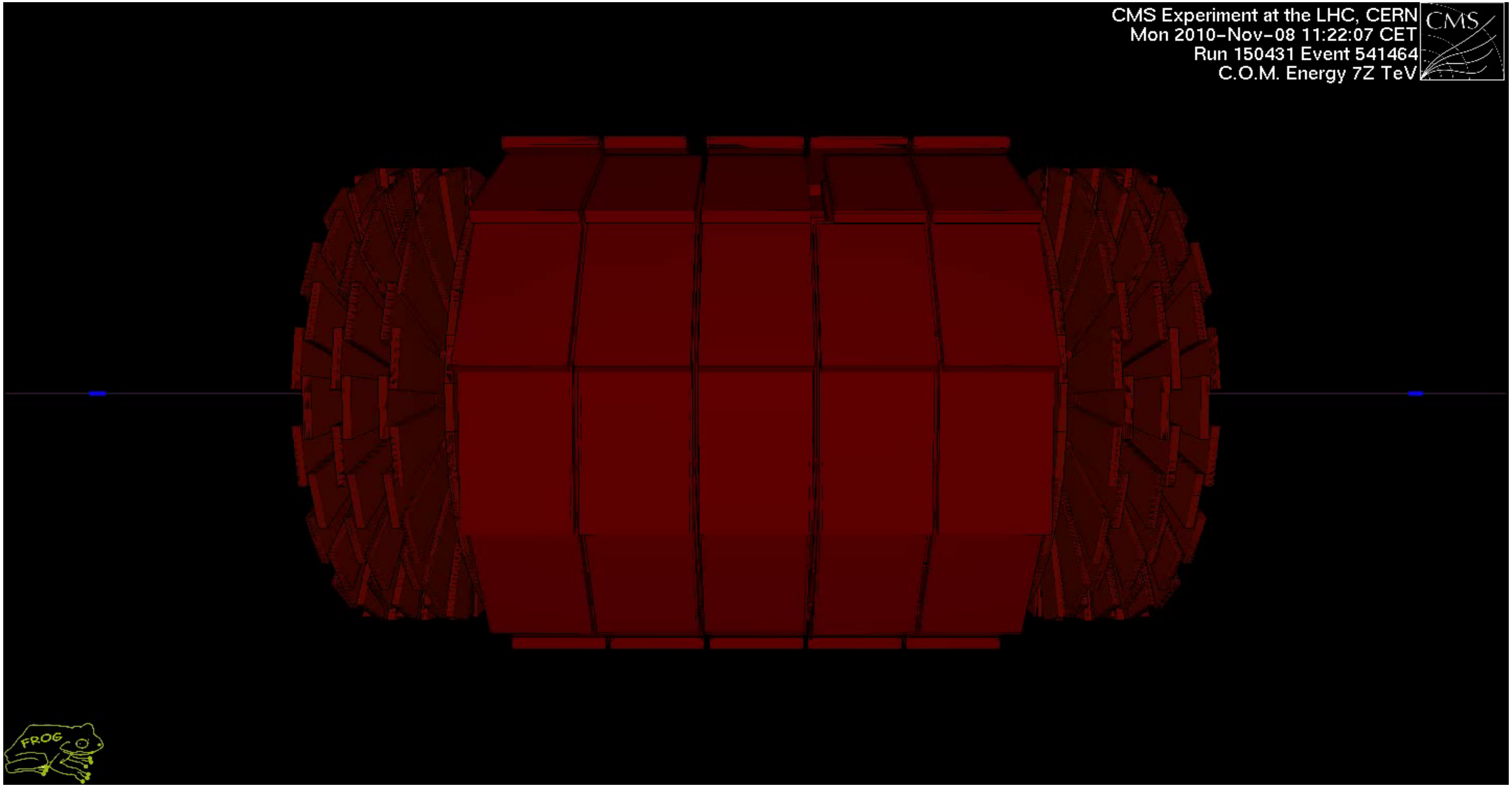
More than 10,000 particles per event in the detector

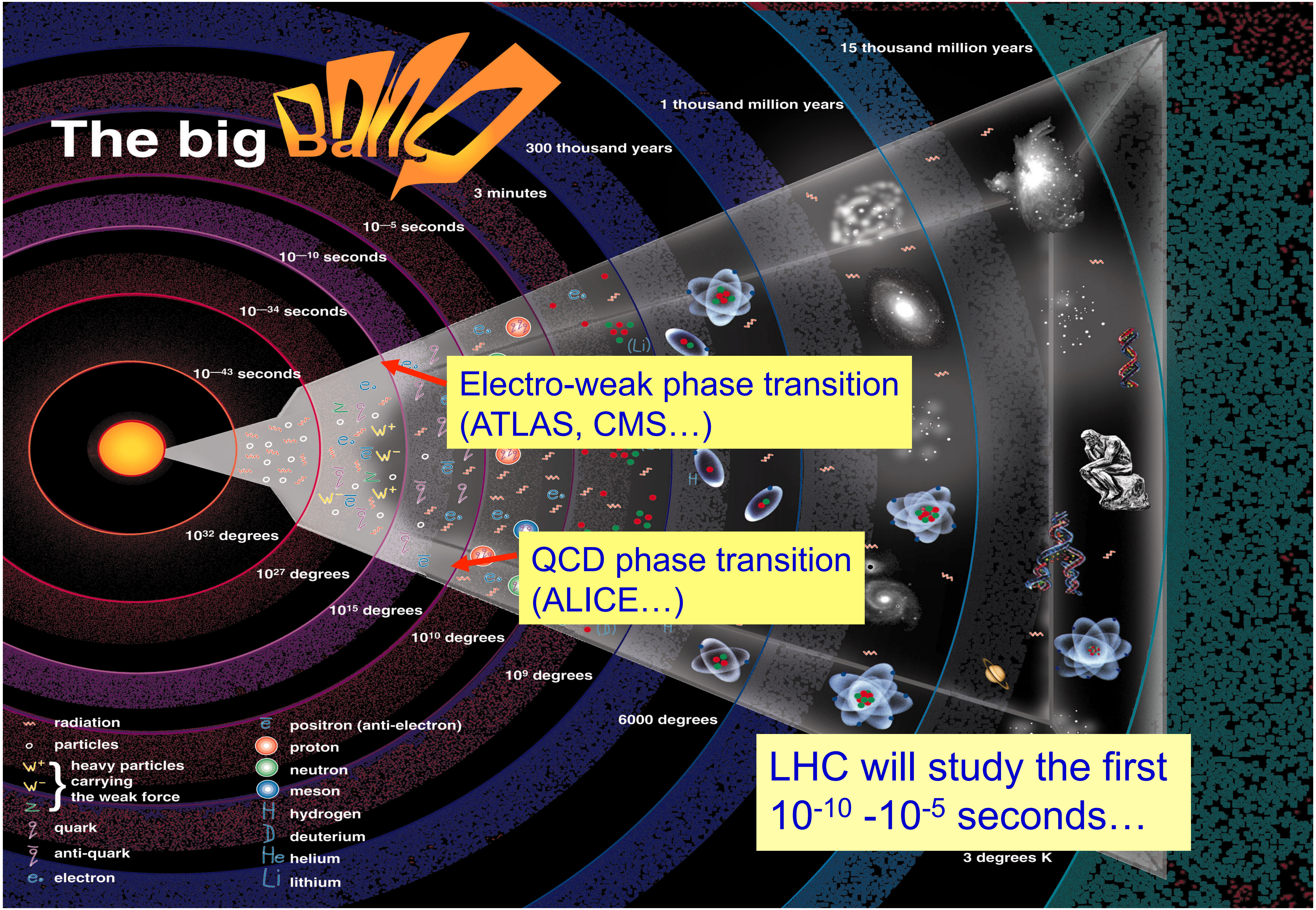
A lead lead collision simulated in the ALICE detector



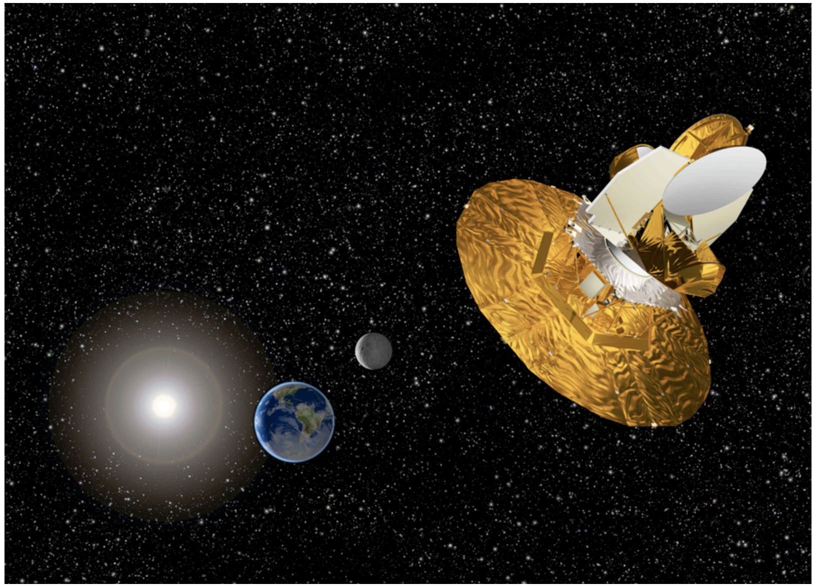
Study the phase transition of a state of quark gluon plasma created at the time of the early Universe to the baryonic matter we observe today

A Recorded Heavy Ion Collision

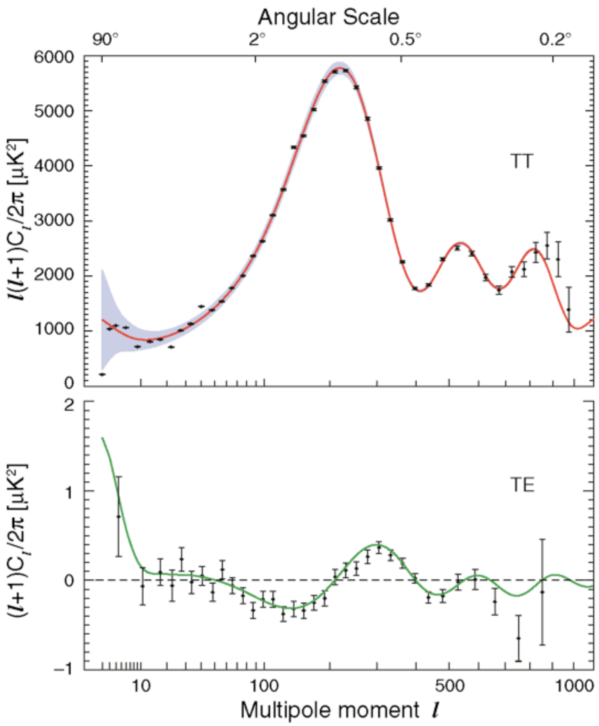


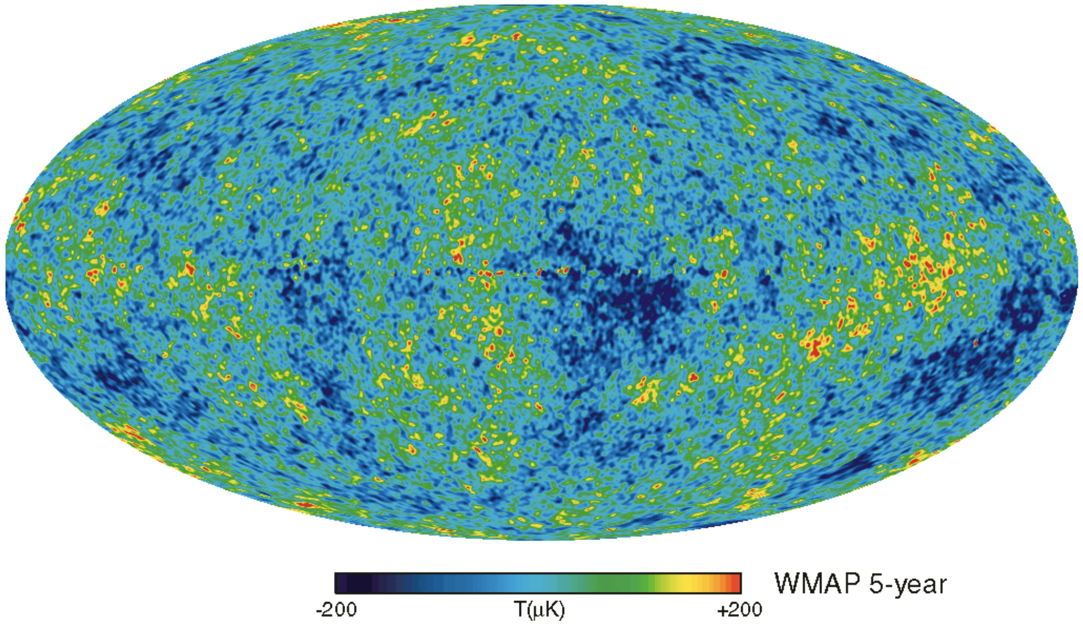

The big Bang
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
10⁻⁵ seconds
10⁻¹⁰ seconds
10⁻³⁴ seconds
10⁻⁴³ seconds
10³² degrees
10²⁷ degrees
10¹⁵ degrees
10¹⁰ degrees
10⁹ degrees
6000 degrees
3 degrees K
Electro-weak phase transition
(ATLAS, CMS…)
QCD phase transition
(ALICE…)
LHC will study 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

Other Detectors



Dark matter/dark energy





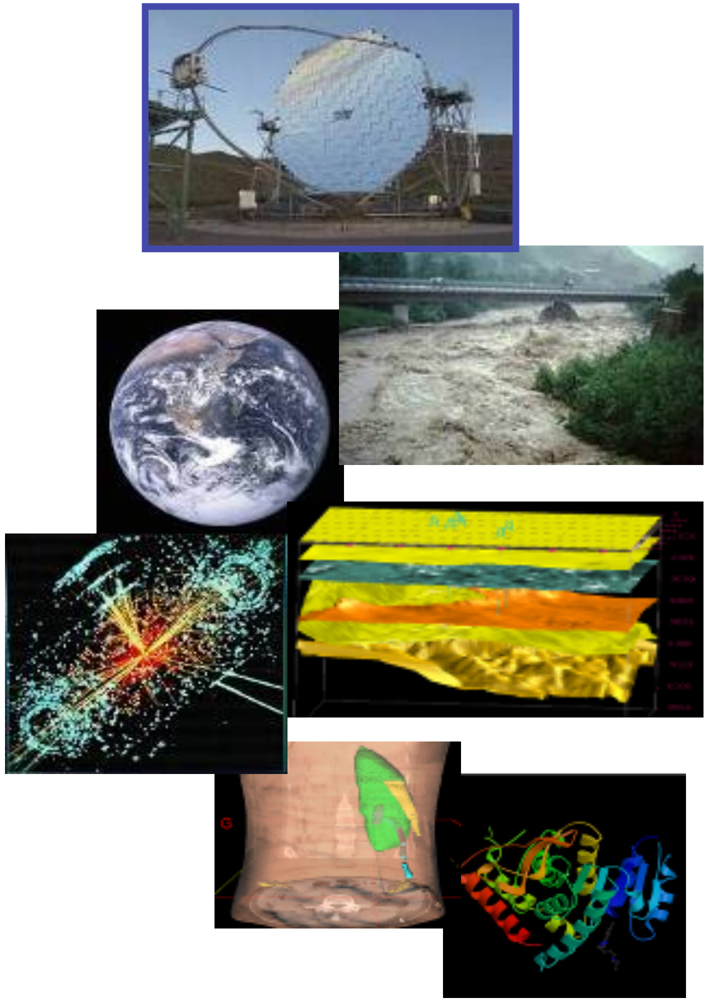
CERN and Technology

⇒ Direct Spin-off of the technologies developed and used at CERN

Applications of Grid Computing

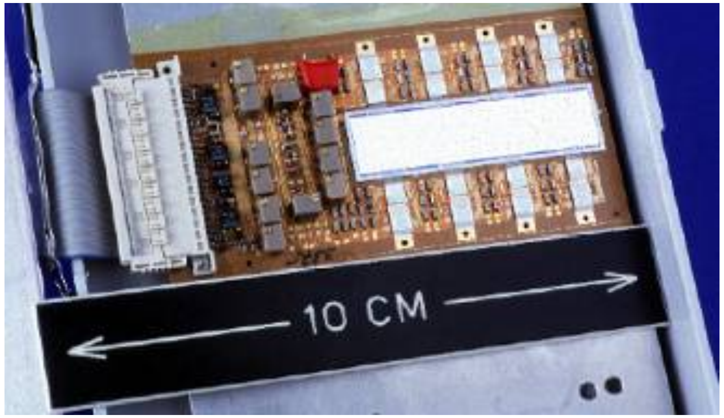
Multitude of applications from a growing number of domains

- Archeology
- Astronomy & Astrophysics
- Civil Protection
- Computational Chemistry
- Earth Sciences
- Financial Simulation
- Fusion
- Geophysics
- High Energy Physics
- Life Sciences
- Multimedia
- Material Sciences
- …

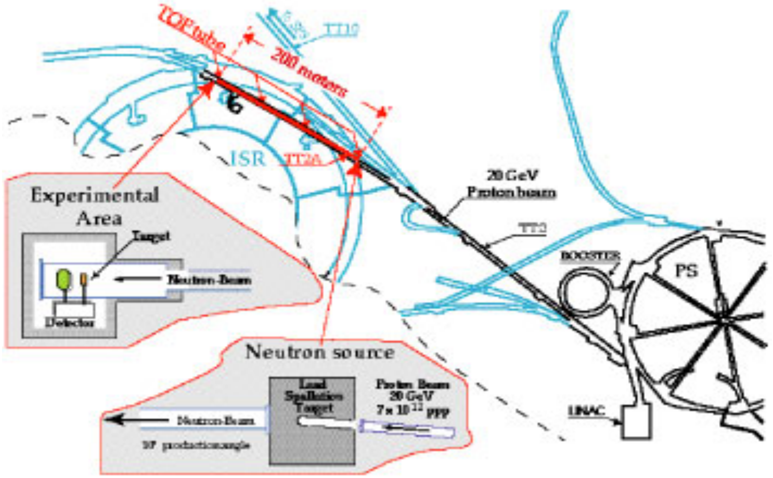


Infrastructure used by >5000 researchers
- submitted ~20 millions jobs in 2006

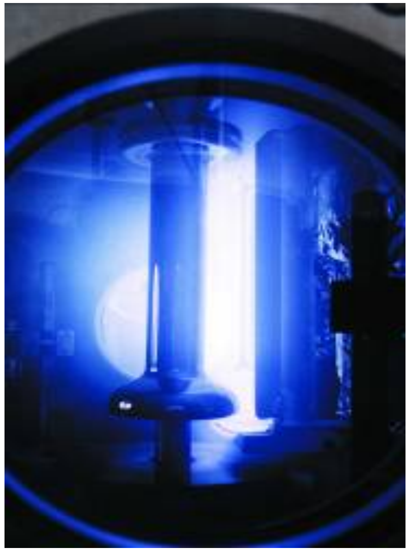
Technology Transfer Projects



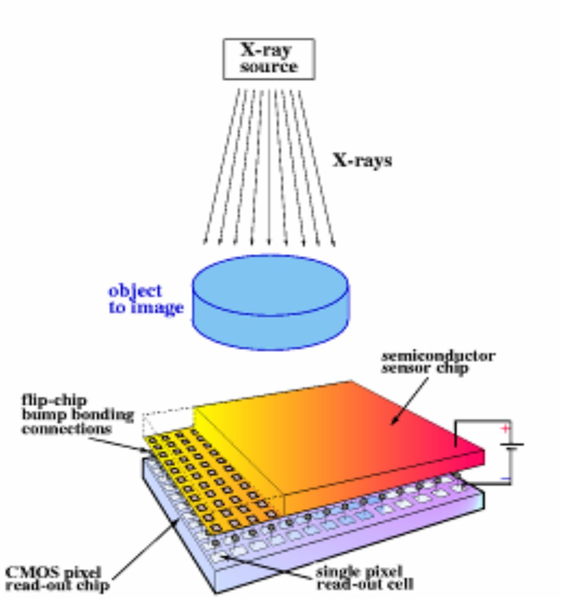
Silicon detector for a Compton camera in nuclear medical imaging



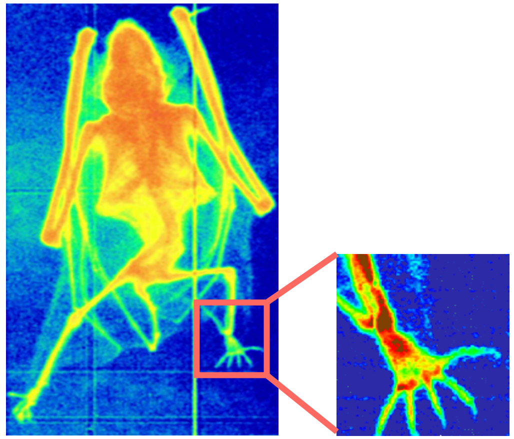
Radio-isotope production for medical applications



Thin films by sputtering or evaporation

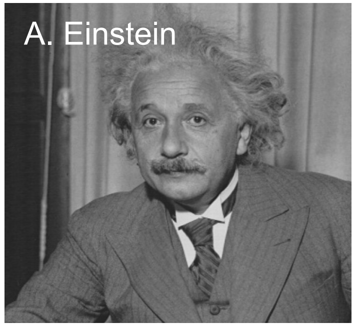


Medipix: Medical X-ray diagnosis with contrast enhancement and dose reduction



Radiography of a bat, recorded with a GEM detector

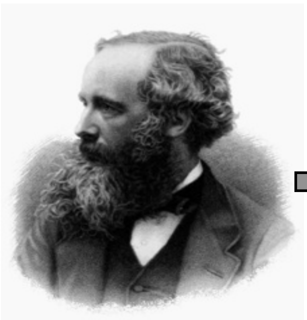
Fundamental research has always been a driving force for innovation



Relativity

100% SCIENCE

For GPS to work, we have to take into account the correction due to time dilation. Otherwise, there would be a position error of around 10m after just 5 minutes of travel-time!


J.C. Maxwell

Electromagnetism

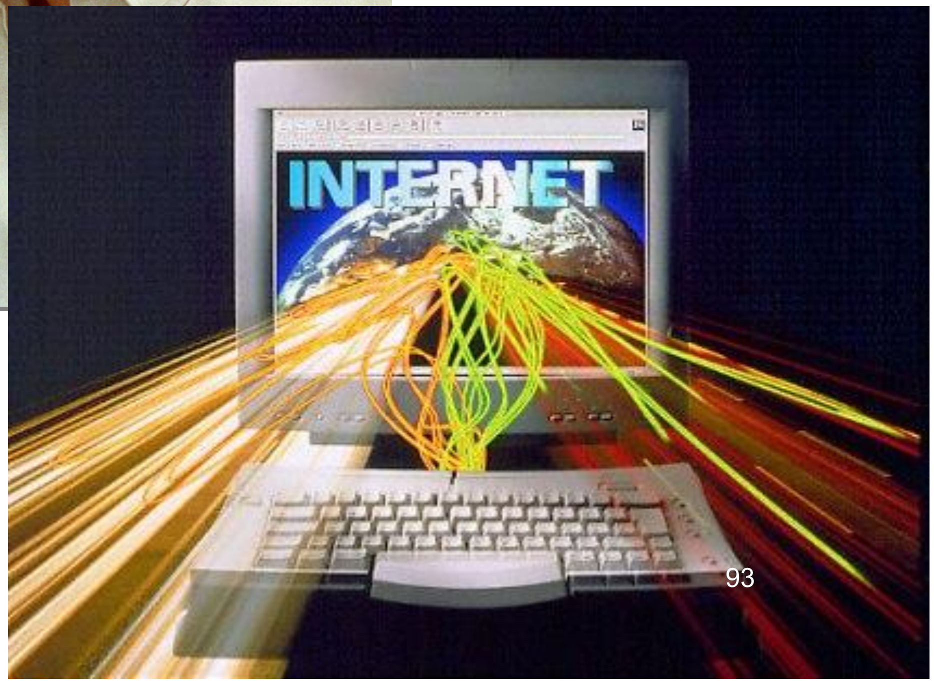
100% SCIENCE

Telephones use electromagnetic waves to communicate

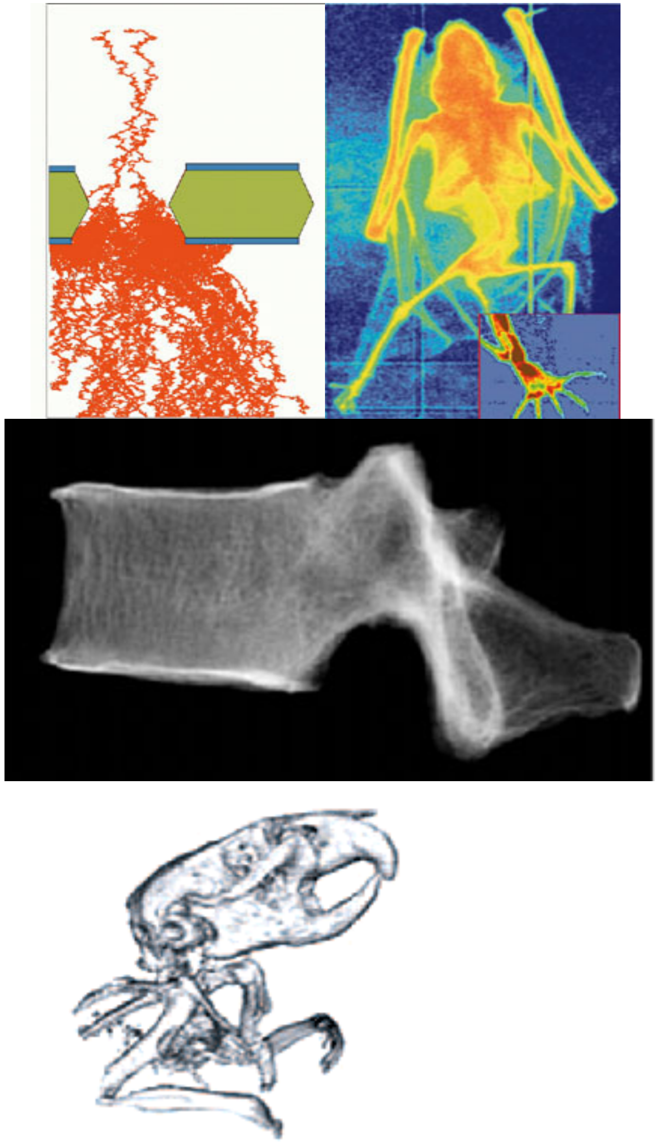
Have you heard of the World Wide Web or the Internet ?

Tim Berners Lee Developed the WWW at CERN initially for sharing particle physicists data

I think there is a world market for maybe five computers.
--THOMAS WATSON, chairman of IBM, 1943.



Instrumentation at CERN



Detectors used in LHC

We use state-of-the-art instruments to explore our understanding of nature. Physicists take this knowledge to other fields. Studies have demonstrated that the transfer of knowledge from fundamental research enables high-tech companies to remain on the cutting edge of innovation and generates a variety of social and economic benefits. It also has an important impact on our culture and education.

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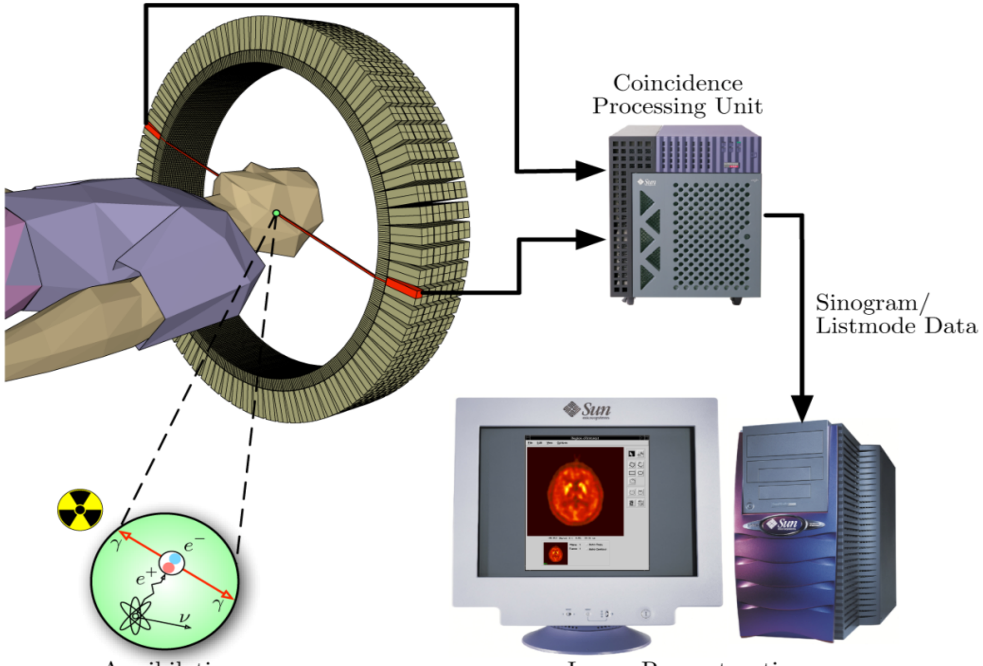
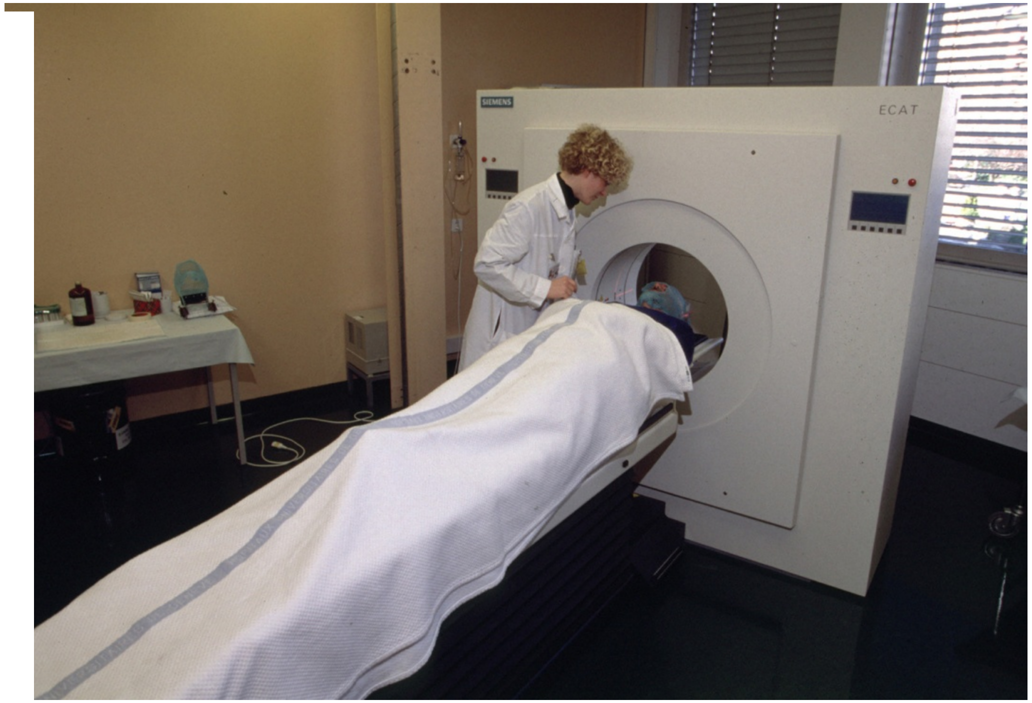
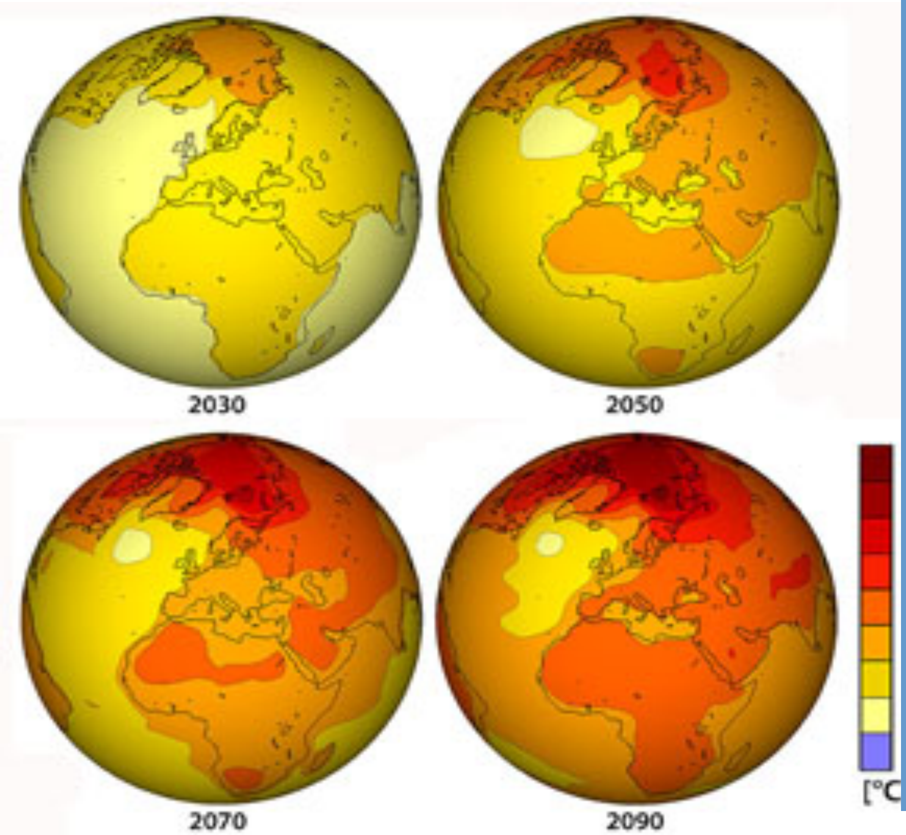
Detectors: developed in physics labs are used for medical imagery





PET (Positron Emission Tomography) is a very important technique for localising and studying certain types of cancer using the Fluor-18 isotope produced by particle accelerators. PET uses antimatter (positrons).



GRID today

ClearSpeed | digipede | hp | IBM | intel

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Scientific Applications:

EGEE Makes Rapid Earthquake Analysis Possible

Using the advanced Grid infrastructure of the Enabling Grids for E-sciencE (EGEE) project, researchers at the Institut de Physique du Globe de Paris (IPGP), France, were able to analyze, within 30 hours of it occurring, the large Indonesian earthquake that struck on March 28. Although less severe than the one in December, which caused a tsunami wave in the Indian Ocean, more than 1,000 people were killed in this second major earthquake.

The analysis showed that the March earthquake was not a belated aftershock of the December one, although they are intricately linked. The March earthquake was probably triggered by the one in December, but happened in a different part of the fault line further south, and the mechanisms of the two earthquakes were different. Although the basic geometry of the region is known, the strength of the earthquake was astonishing.

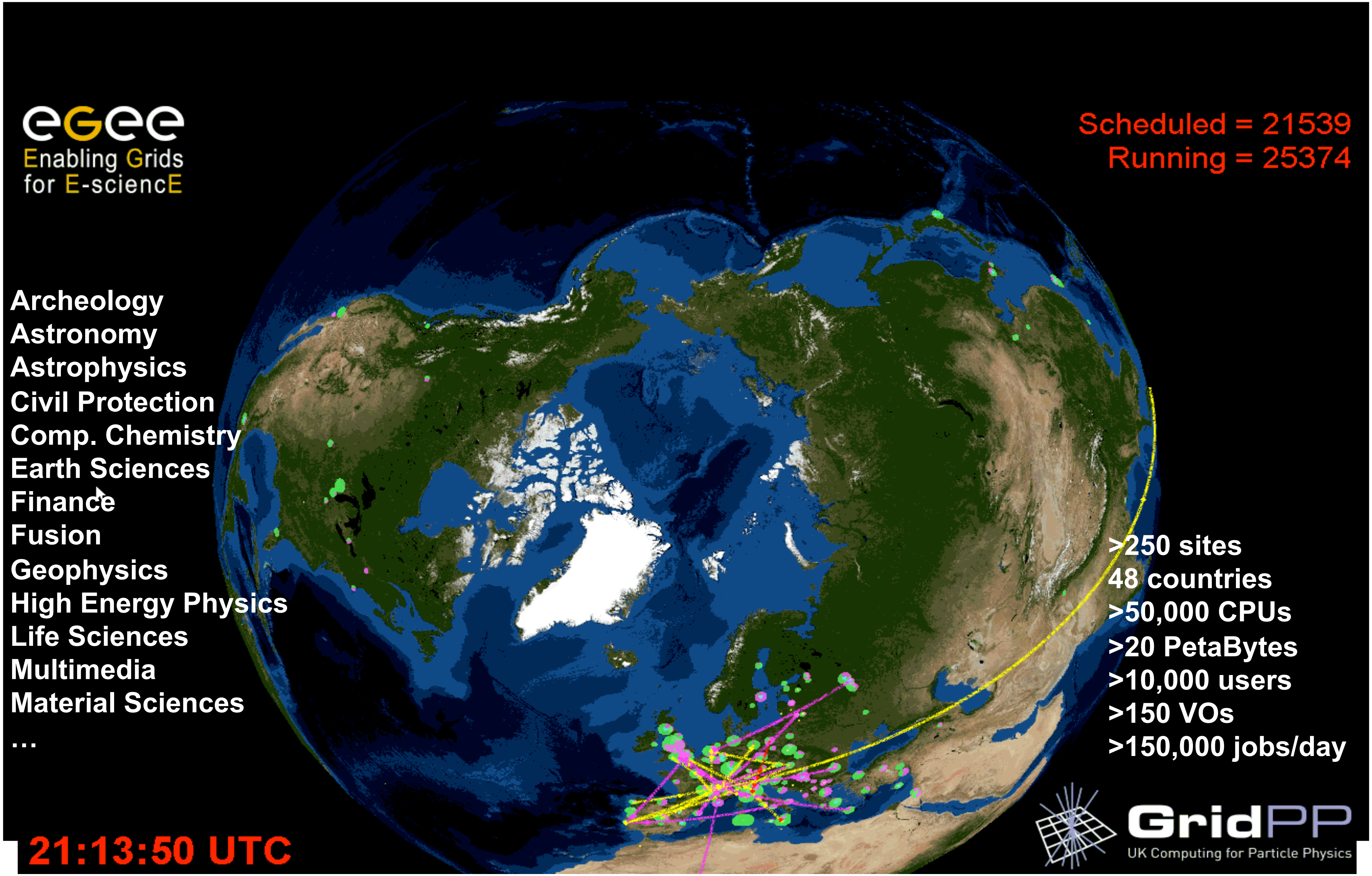
Understanding the exact parameters of when, where and how an earthquake occurs brings researchers closer to comprehending why earthquakes happen. This might make it possible to predict when and where earthquakes will happen in the future and to assess the potential impact they could have on specific regions. Rapid analysis is particularly important for the relief efforts after a major earthquake, where those in charge need to have accurate information about the epicenter, magnitude

In the recent report from the Intergovernmental Panel on Climate Change, data from various models and sources were combined to project the future climate. This image shows Scenario A1B: simulated mean temperature change relative to 1980-1999.

Grids open new perspectives to *in silico* drug discovery

- Reduced cost and adding an accelerating factor in the search for new drugs

- Diseases such as HIV/AIDS, SRAS, Bird Flu etc. are a threat to public health due to world wide exchanges and circulation of people



eGee
Enabling Grids
for E-sciencE
Scheduled = 21539
Running = 25374
Archeology
Astronomy
Astrophysics
Civil Protection
Comp. Chemistry
Earth Sciences
Finance
Fusion
Geophysics
High Energy Physics
Life Sciences
Multimedia
Material Sciences
…
>250 sites
48 countries
>50,000 CPUs
>20 PetaBytes
>10,000 users
>150 VOs
>150,000 jobs/day
GridPP
UK Computing for Particle Physics
21:13:50 UTC

CERN as an Educator

The End