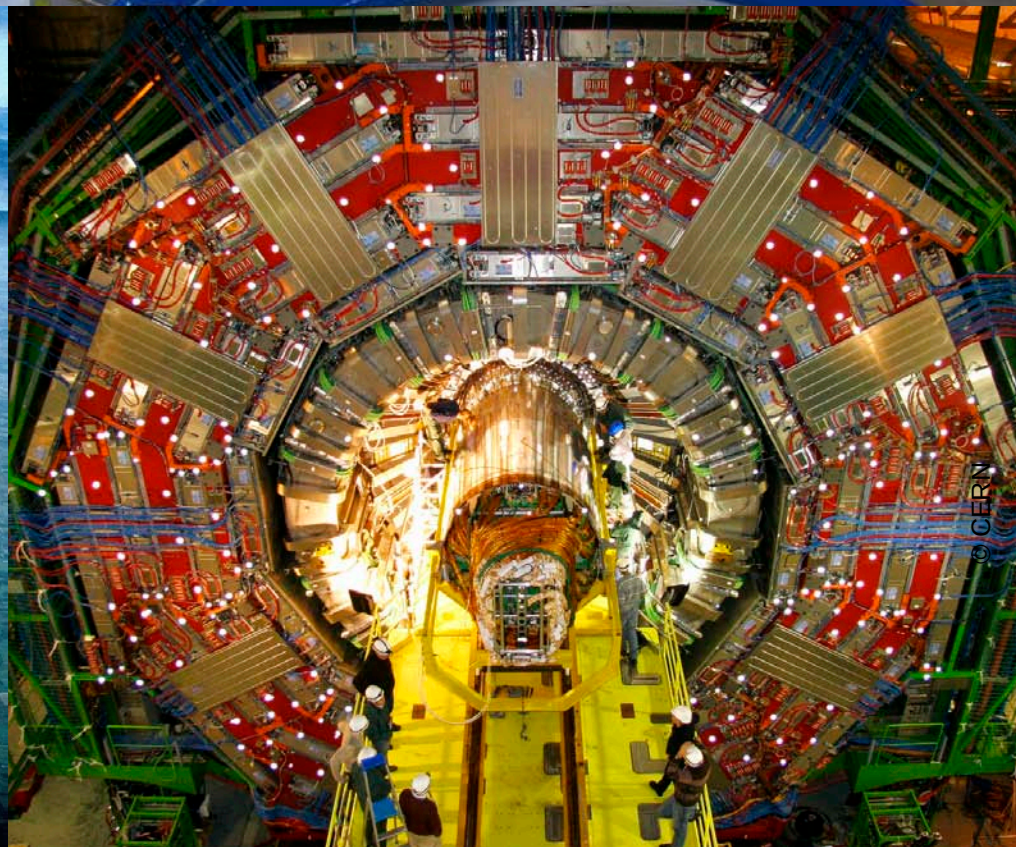
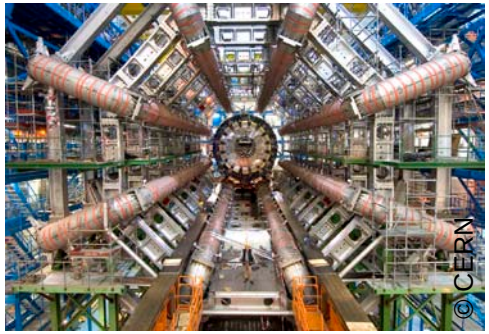
THE BIG BANG MACHINE AT CERN OUTSIDE GENEVA, SWITZERLAND

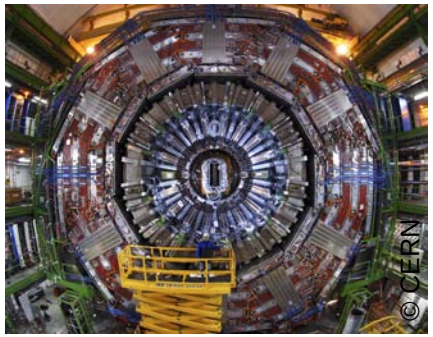
ROBERT COUSINS
PROFESSOR OF PHYSICS
UCLA

MARCH 31, 2010



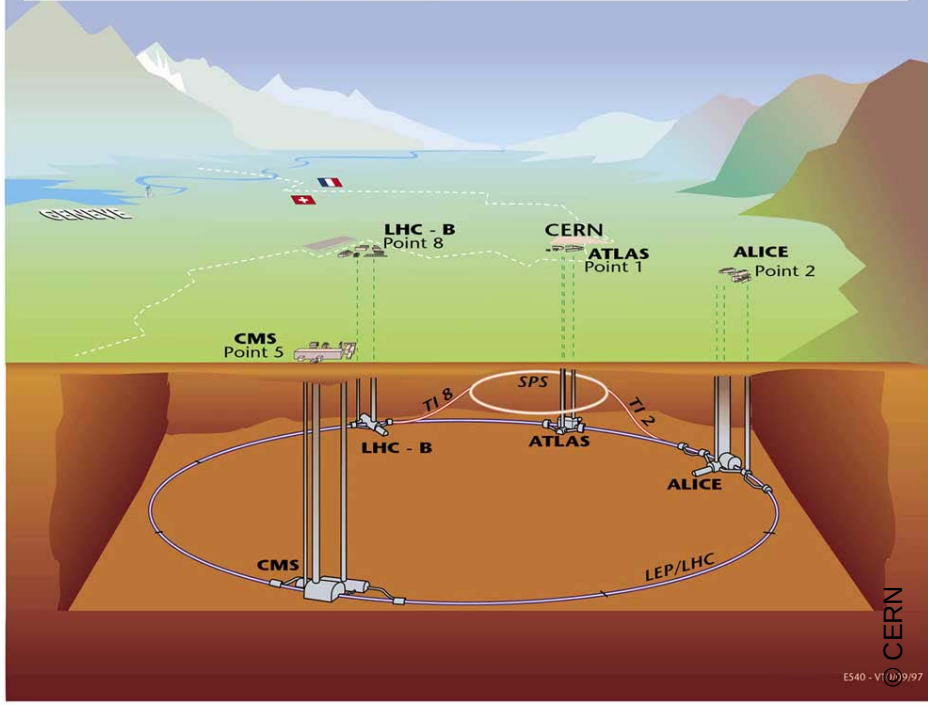
Huge instruments now in place in Switzerland and France outside Geneva:





The Large Hadron Collider.

Large is an understatement!
Hadrons referred to here are protons.
Collide is what it does, as we will see.



Tiny bunches of counter-circulating protons.

Colliding head-on 40 million times each second.

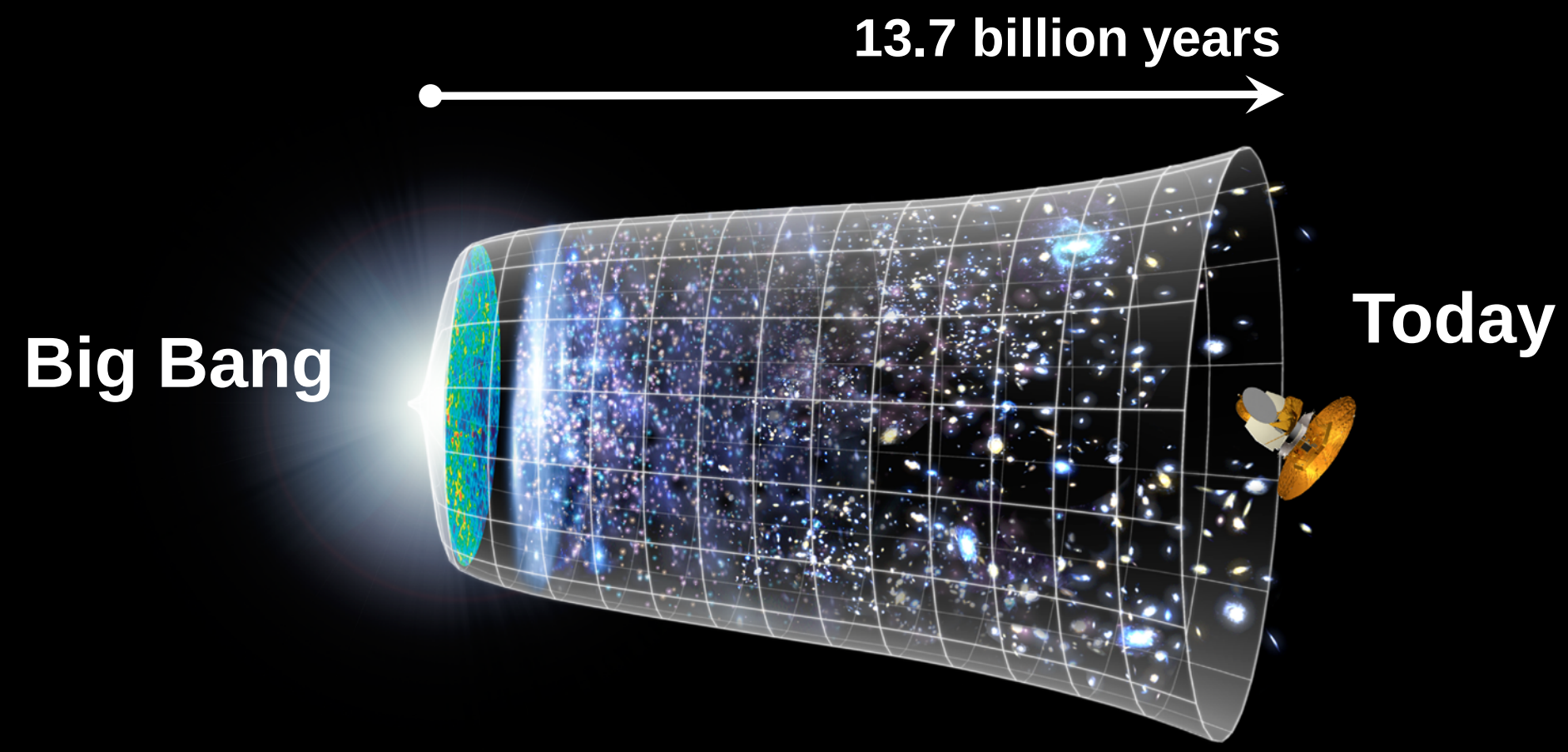
With colliding protons, we use $E=mc^2$ to convert energy into matter, to

Explore new forces and new building blocks of matter,

Open up vast new territories for physics exploration, both in *high energy* and in *extreme rarity* of new phenomena.

And…make the Cosmic Connection:

Timeline of the Universe



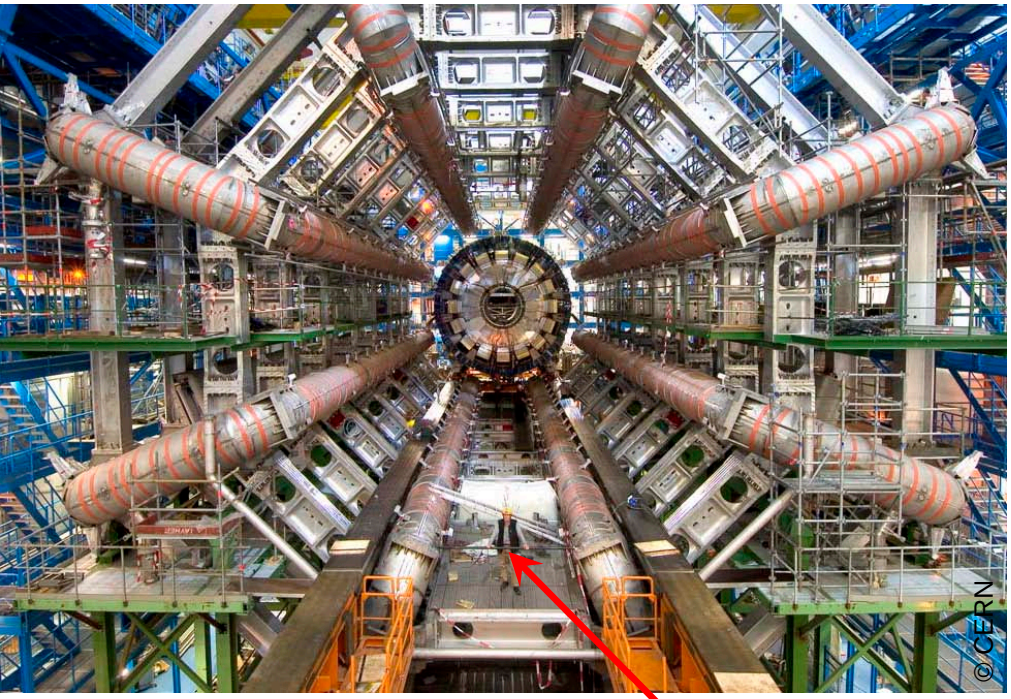
LHC will recreate the conditions one billionth of a second after Big Bang

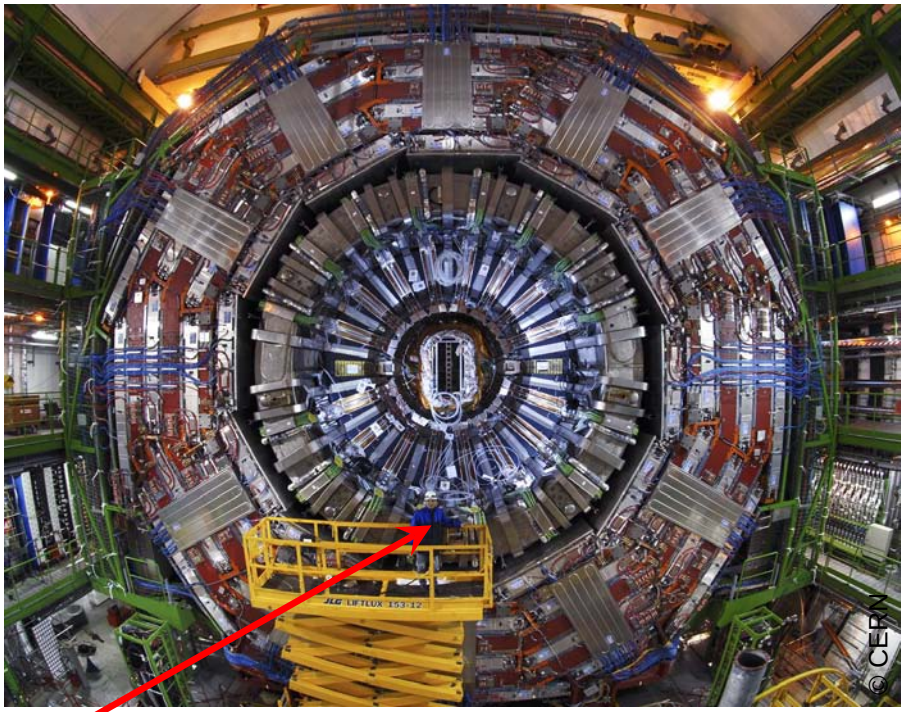
NASA/WMAP Science Team

IT'S ~~LARGE~~ HUGE!

Largest, most complex detectors ever built

Study tiniest particles with incredible precision

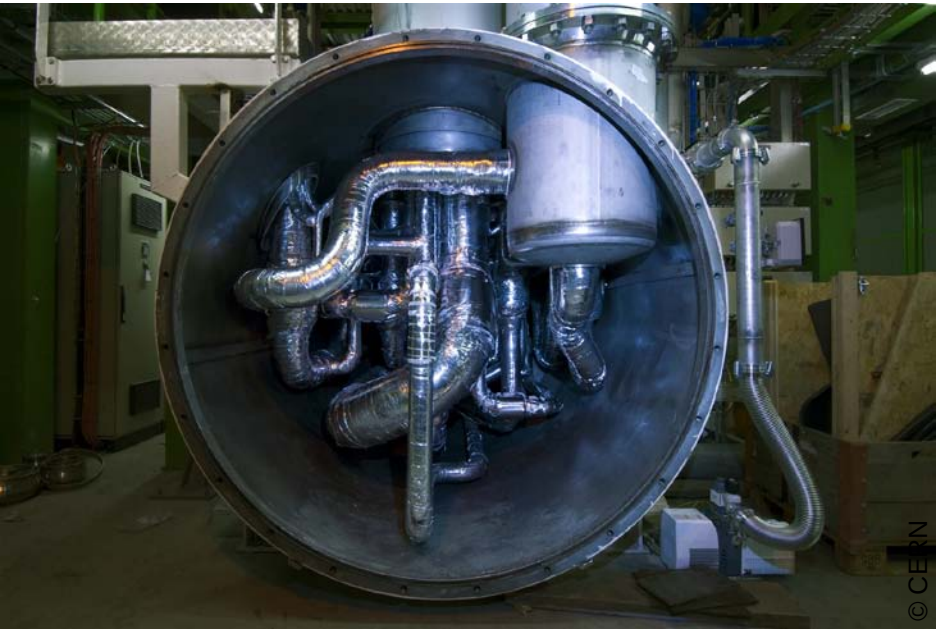




(people)

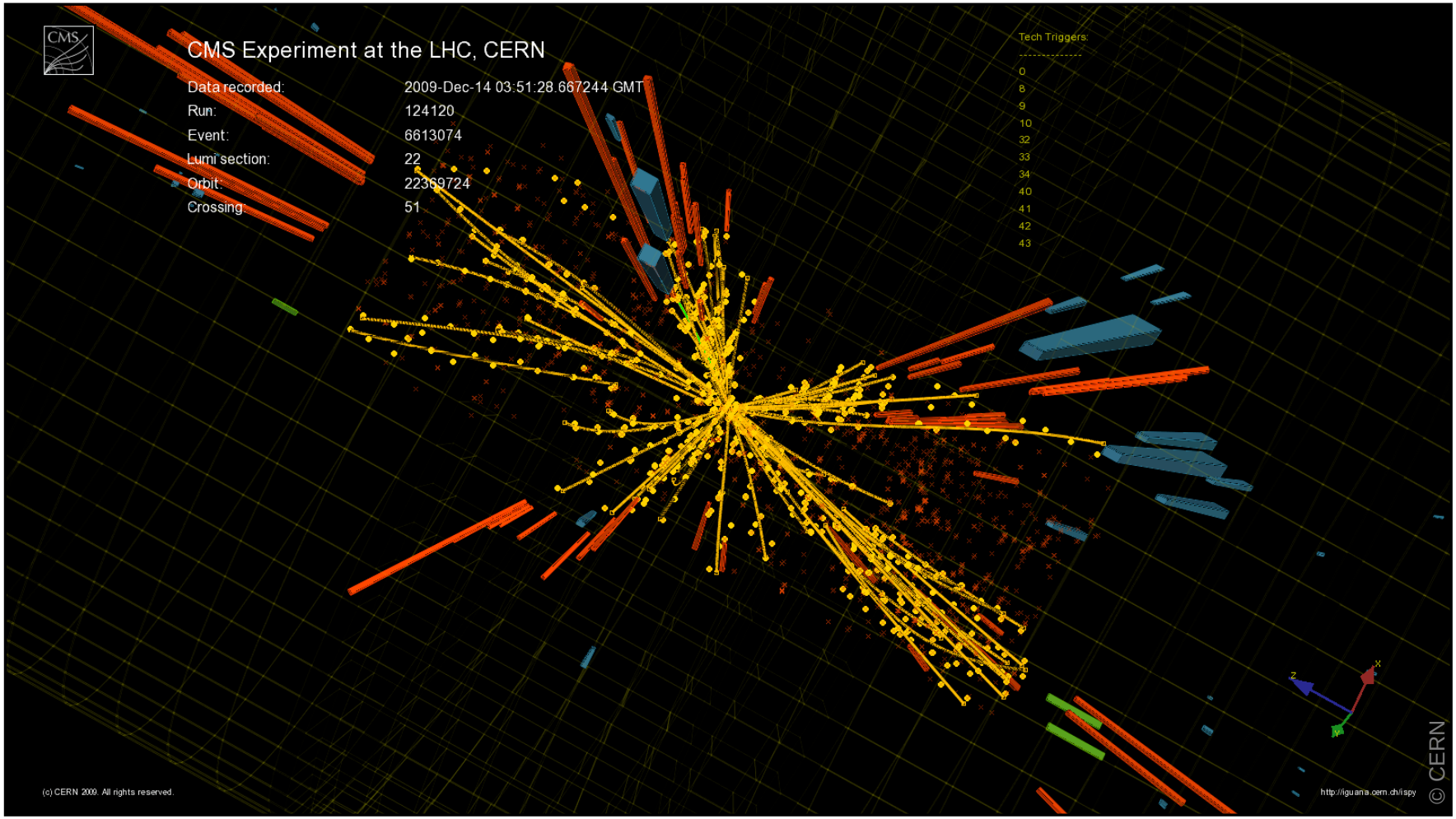
IT’S COLD!

16 miles of magnets and connections are kept colder than outer space, using over 100 tons of liquid helium.



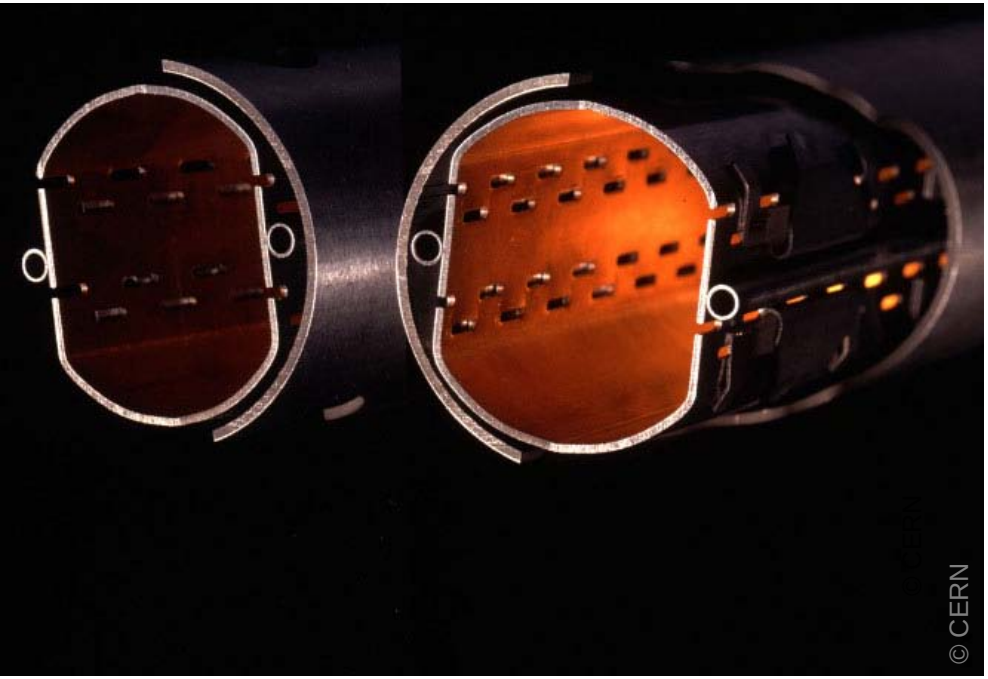
IT'S HOT!

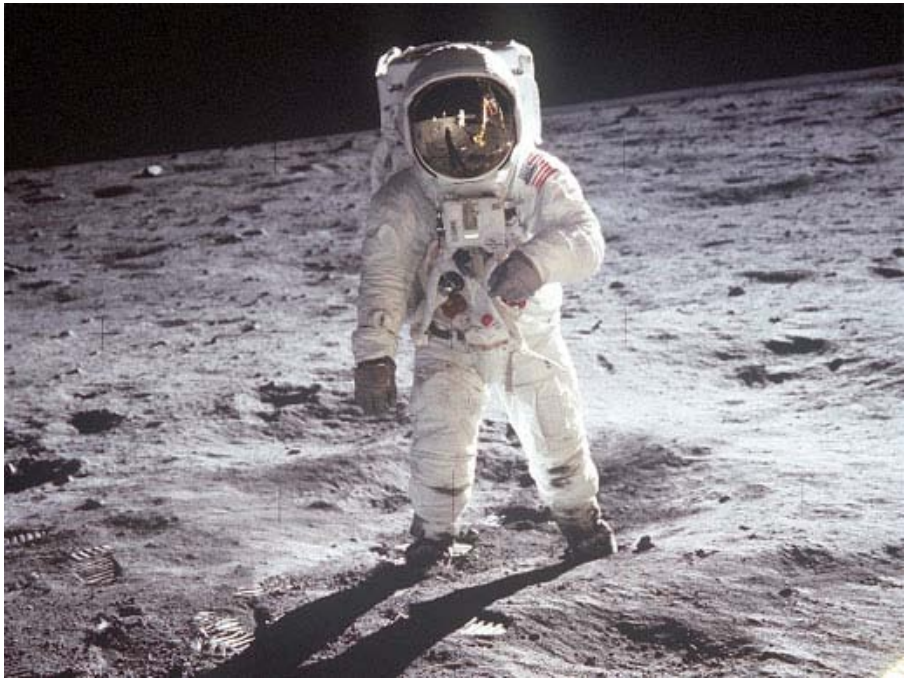
In a *tiny* volume, temperatures one billion times hotter than the center of the sun.



IT’S EMPTY!

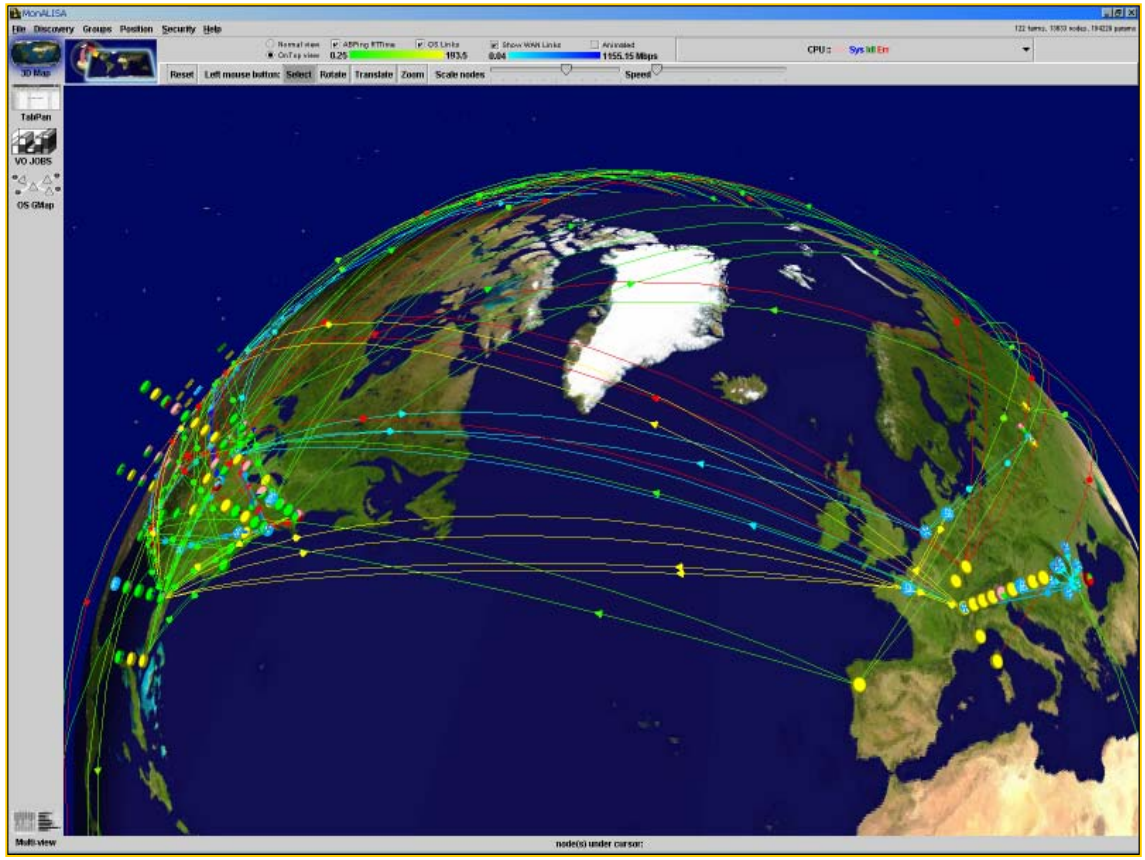
Air pressure inside the two 16-mile-long vacuum pipes is lower than on the moon.





IT'S COMPLEX!

Worldwide LHC Computing Grid connects 100,000 processors in 34 countries with ultra-high-speed data transfers



***Millions of Gigabytes* of data each year.**

IT'S COLLABORATIVE!

Bloomberg BusinessWeek

VIEWPOINT May 20, 2009, 11:57AM EST

CERN's Collaborative Management Model

Business leaders could learn valuable leadership lessons from the collaborative management style at the Large Hadron Collider at CERN

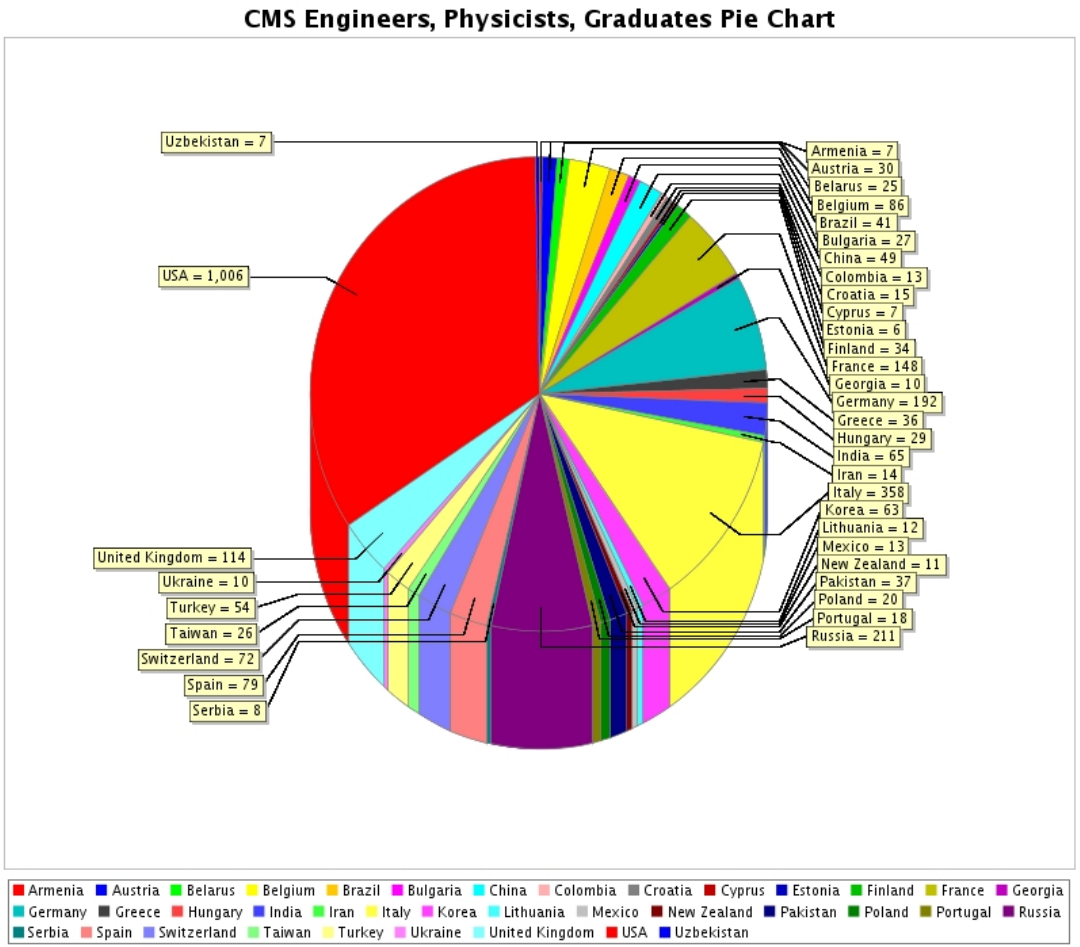
By Krisztina Holly

As a business leader, imagine trying to manage more than 7,000 scientists from 85 countries around the world—with their own languages, cultures, and expertise—on a 20-year collaboration to create the most complex system ever built.

What motivates all these people?

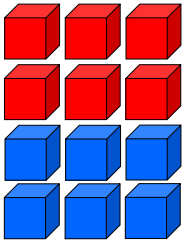
What common goals cut across so many nations and cultures?

Over 2500 scientists from 38 countries in just one of the two major experiments.

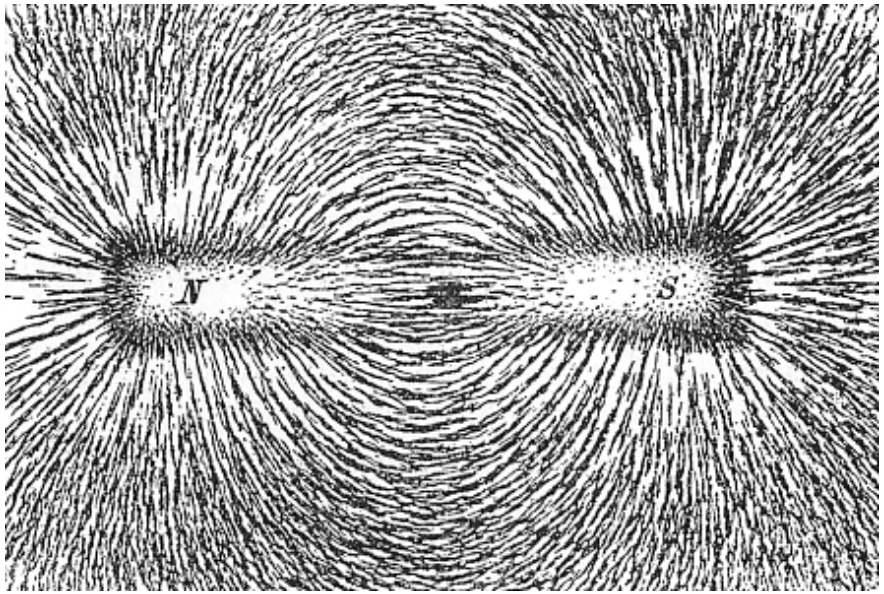


Big Questions from Physics

What are the smallest building blocks of matter?



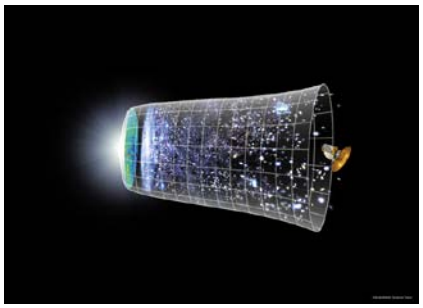
Are there undiscovered force fields?



Big Questions from Astronomy and Cosmology:

What is the invisible ("dark") matter in galaxies like ours?

What building blocks and force fields determine the physics of *the universe after the big bang?*



Outline of the rest of the presentation

What are the smallest building blocks of matter?

How will we look for discoveries?

Are there undiscovered force fields?

What is dark matter?

What was the physics of the universe after the Big Bang?

UCLA, Hot news

(With apologies for all the things I won't talk about:

Two other detectors, Alice and LHCb

The whole physics program of colliding ions.

Dark *energy*: LHC will not shed much light on that.)

A little history:

By the end of the 19th century, scientists had characterized many "elements", *indivisible* in chemical reactions, leading to the modern "periodic table":

The *periodic table* of the elements:

Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 UUb	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
Lanthanides				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

"Periodic": elements in same column have similar chemistry.

What are the smallest building blocks of matter?

Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
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5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe

How many of these elements were known to exist when Dmitri Mendeleev wrote an early version in 1869, a lot of it correctly?

What are the smallest building blocks of matter?

Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	

The right-hand column (gases helium, neon, argon, etc) was not yet known.

Mendeleev spotted gaps and predicted that elements would be found to fill them!

What are the smallest building blocks of matter?

Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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And indeed they were found
…and eventually a whole other column.
Why so many elements?

What are the smallest building blocks of matter?

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1	1 H																	2 He
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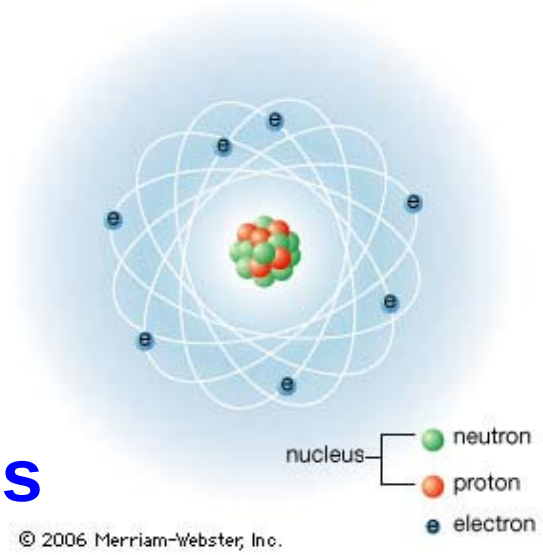
1913-1932: Each atom has electrons orbiting a nucleus made of protons and neutrons bound together by a "strong" force.



The number of protons in the nucleus determines chemical properties.

What are the smallest building blocks of matter?

Group → / Period ↓	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
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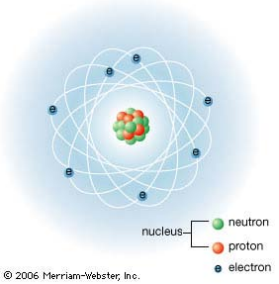
Two big lessons from "indivisible objects" table:

1) **Predicted existence of other objects.**
2) **Explanation underlying table:**
   Objects were divisible into smaller objects!

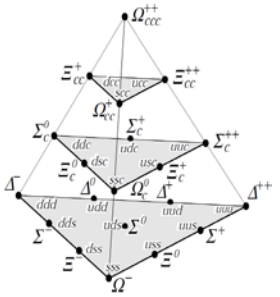


1932: Electron, proton, and neutron were the "truly indivisible" building blocks of all matter: "Elementary Particles".

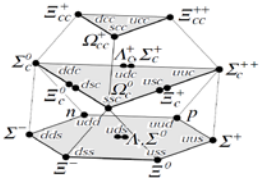
Electron is still indivisible today.

1937: Muon (μ): like electron, 200 times more mass. "Who ordered that?"

Physicists discovered dozens of "elementary particles" similar to proton and neutron.



Tables had gaps, the whole periodic table story repeats one level down.



Recall Lesson #2 of the periodic table:

Objects were divisible into smaller objects!

What are the smallest building blocks of matter?

Quarks!
u, d, s: up, down, strange…

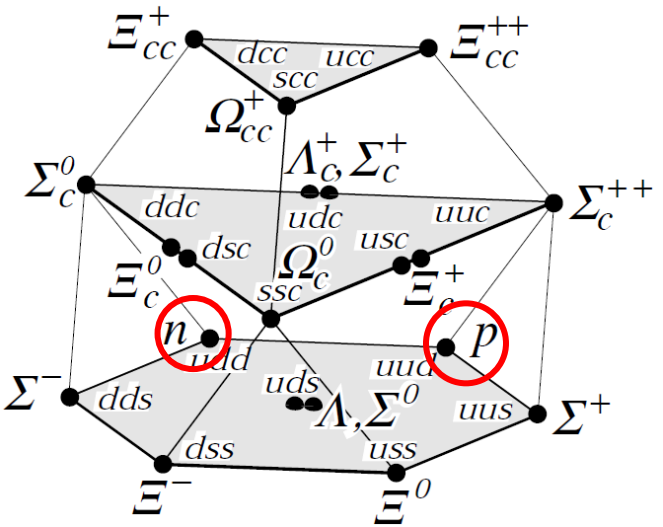
A SCHEMATIC MODEL OF BARYONS AND MESONS

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6)

6) James Joyce, Finnegan's Wake (Viking Press, New York, 1939) p.383.



proton = uud
neutron = udd

What are the smallest building blocks of matter?

"*quarks*"???

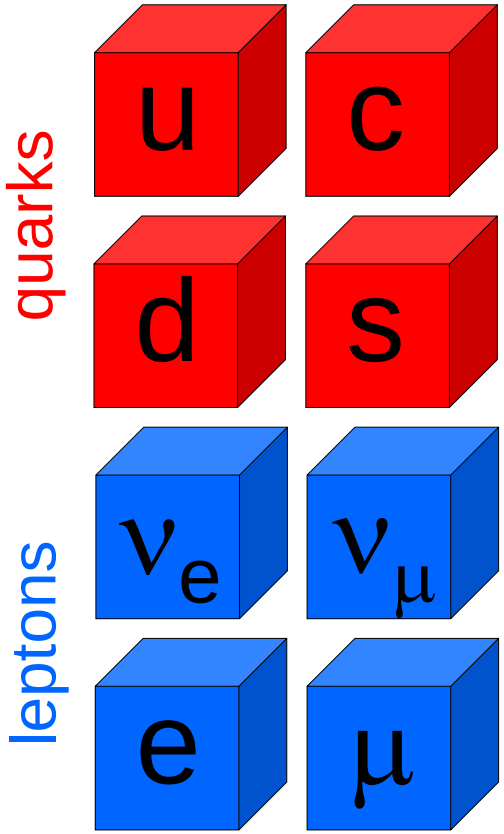
Google books:

— Three quarks for Muster Mark!
Sure he hasn't got much of a bark
And sure any he has it's all beside the mark.
But O, Wreneagle Almighty, wouldn't un be a sky of a lark
To see that old buzzard whooping about for uns shirt in the dark
And he hunting round for uns speckled trousers around by Palmerstown Park?
Hohohoho, moulty Mark!
You're the rummest old rooster ever flopped out of a Noah's ark
And you think you're cock of the wark.
Fowls, up! Tristy's the spry young spark
That'll tread her and wed her and bed her and red her
Without ever winking the tail of a feather
And that's how that chap's going to make his money and mark!

Overhoved, shrillgleescreaming. That song sang seaswans. The winging ones. Seahawk, seagull, curlew and plover, kestrel and capercallzie. All the birds of the sea they trolled out rightbold when they smacked the big kuss of Trustan with Usolde.

And there they were too, when it was dark, whilest the wildcaps was circling, as slow their ship, the winds aslight, upborne the fates, the wardorse moved, by courtesy of Mr Deaubaleau Downbellow Kaempersally, listening in, as hard as they could, in Dubbeldorp, the donker, by the tourneyold of the wattarfalls, with their vuoxens and they kemin in so hattajocky (only a

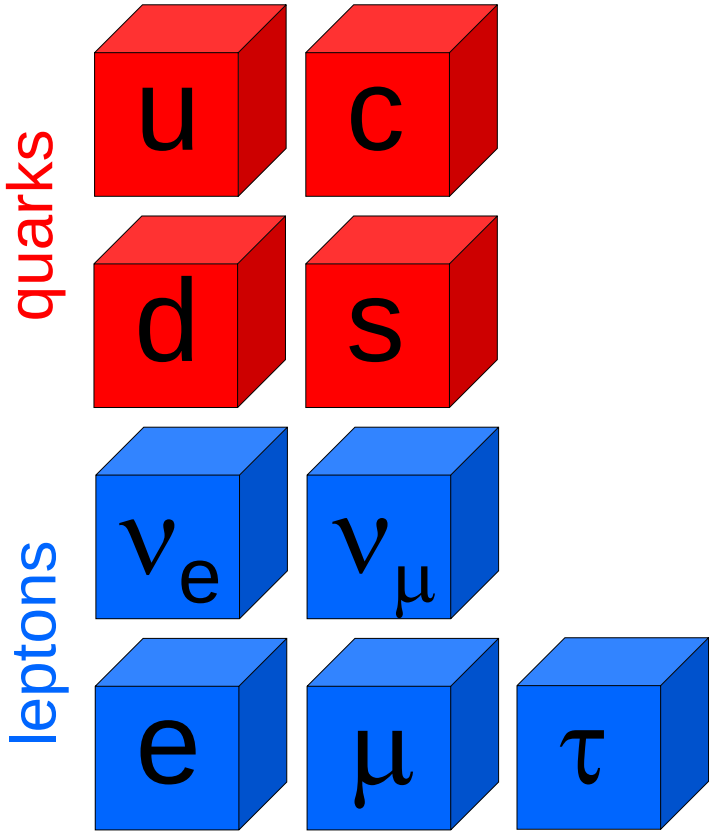
Table of the "truly" indivisible building blocks when I began graduate school in 1976:

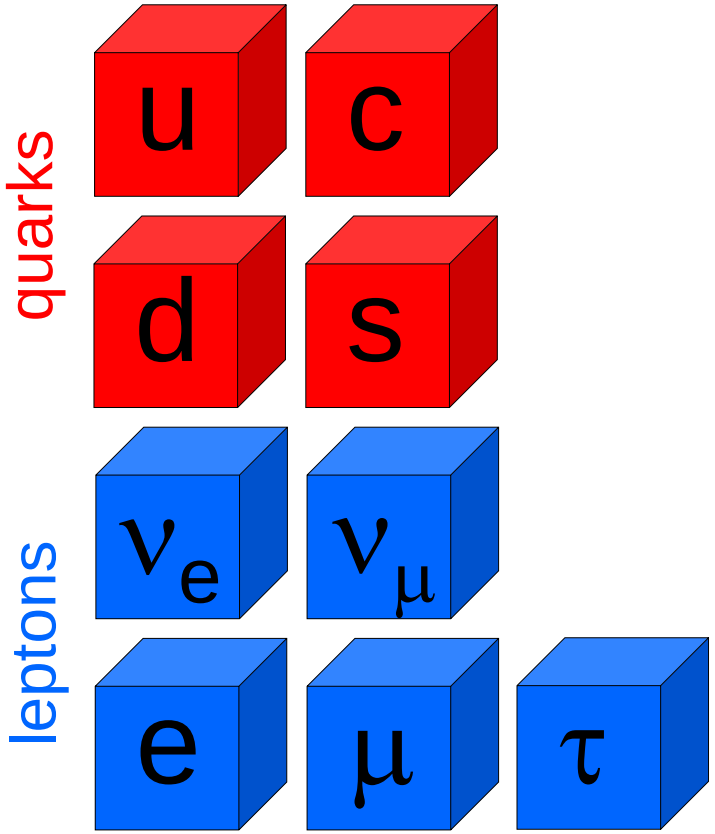


A nice complete set, until a discovery in 1977 made the table look like…

What are the smallest building blocks of matter?

…**this**:

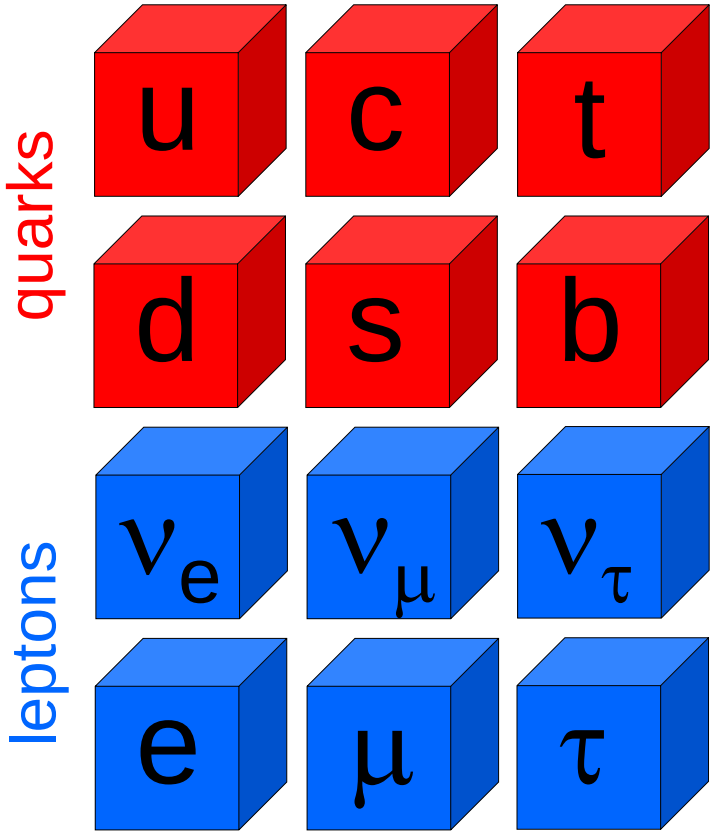




A whole missing column?

Lesson #1 from Mendeleev:
Predict existence of other objects.

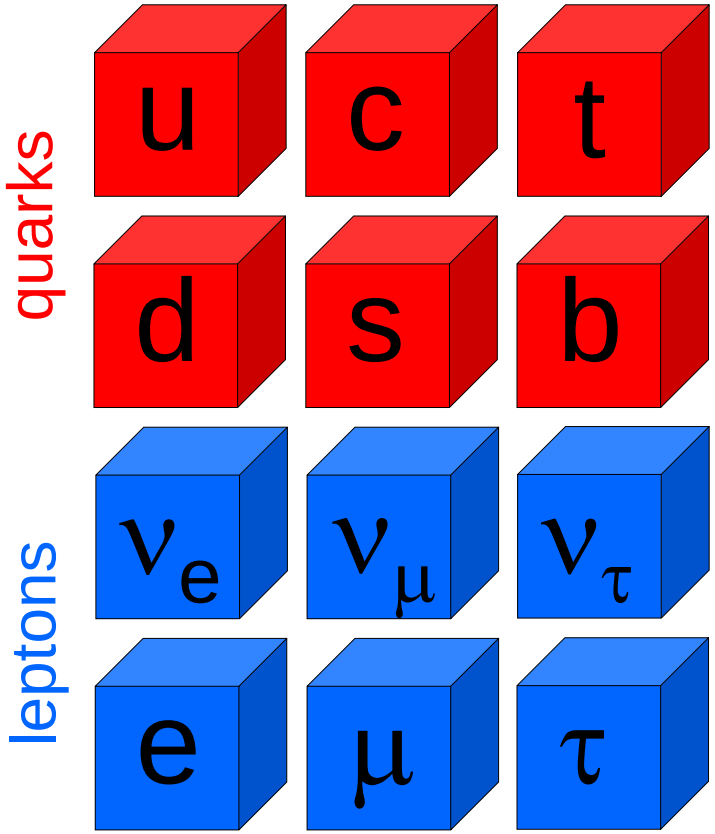
Today:



Starts to look rather like a "periodic" table!

Recall lesson #2 of Mendeleev's table:
Objects were divisible into smaller objects.

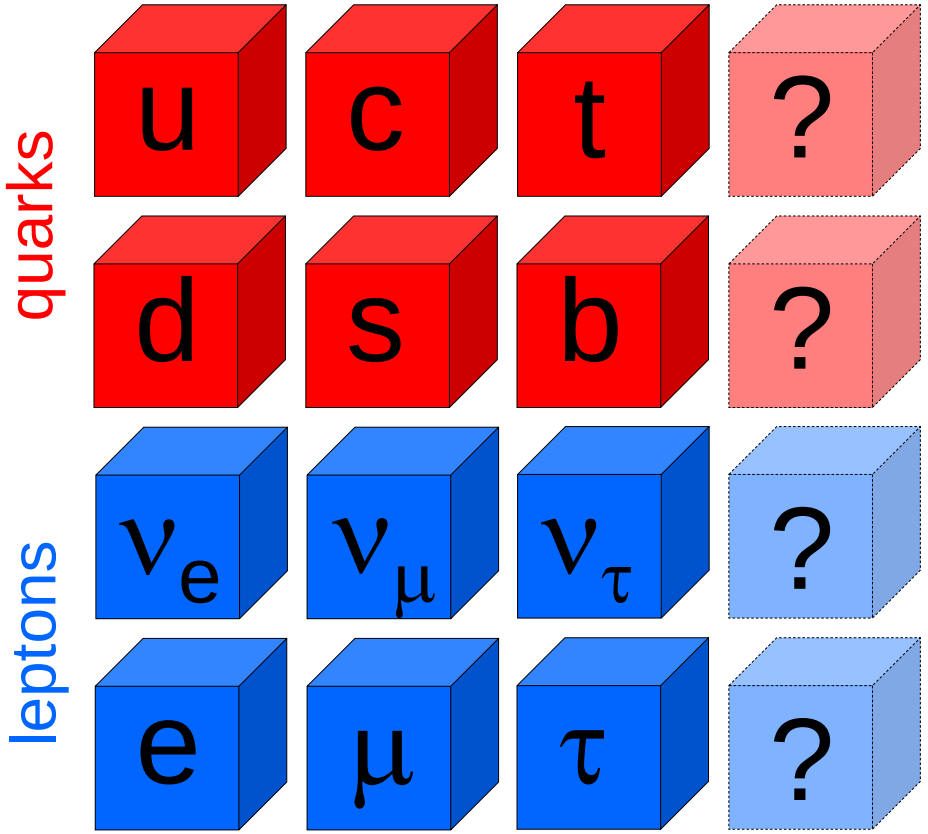
What are the smallest building blocks of matter?

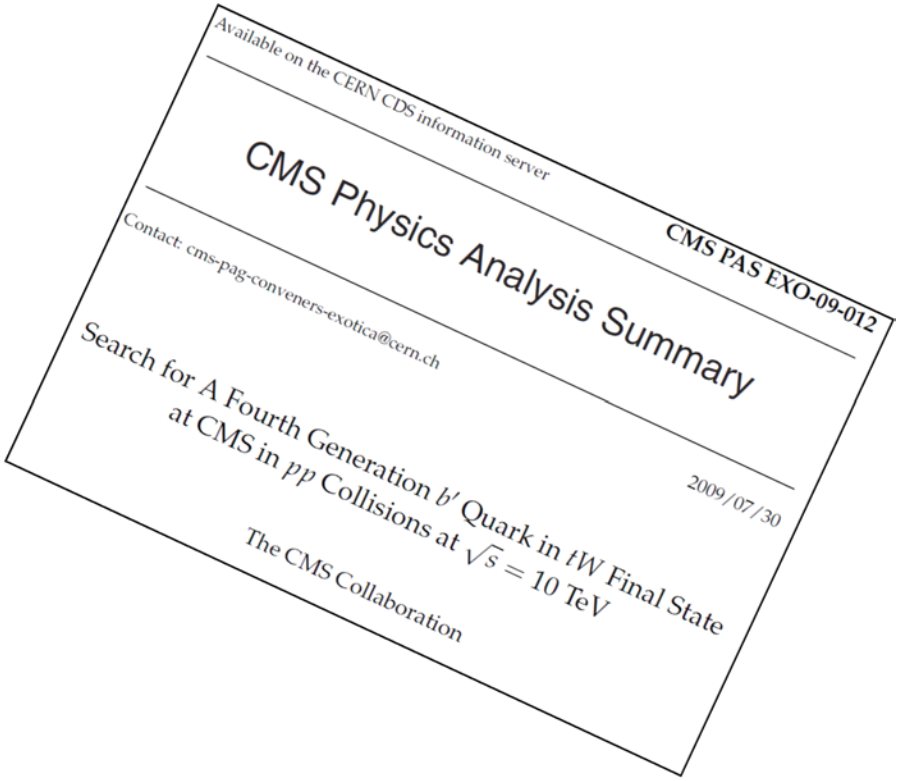


LHC experiments will look for signs of yet smaller building blocks.

And is there yet another column???

LHC experiments will look for it.





Available on the CERN CDS information server

CMS PAS EXO-09-012

CMS Physics Analysis Summary

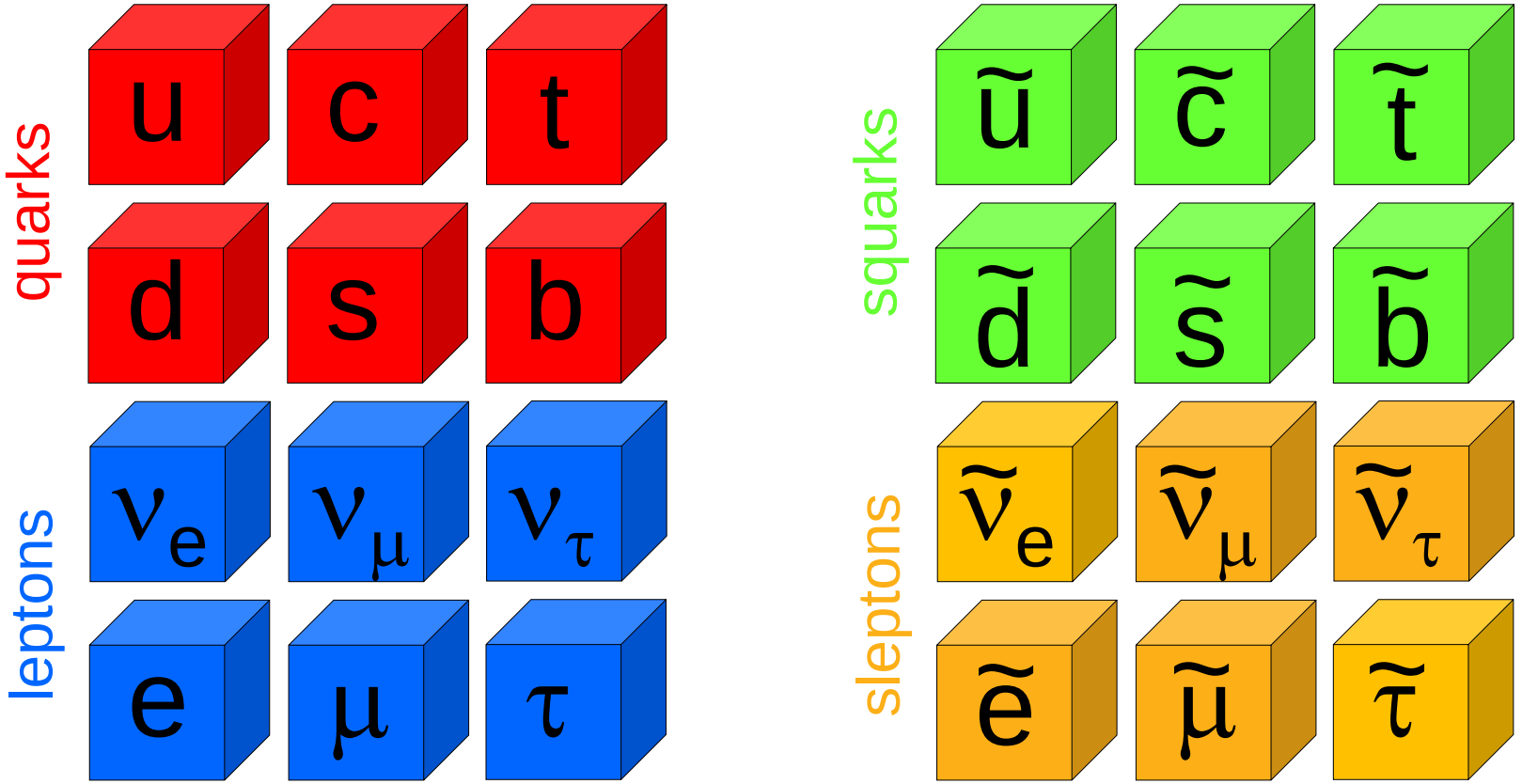
Contact: cms-pag-conveners-exotica@cern.ch

2009/07/30

Search for A Fourth Generation b' Quark in tW Final State at CMS in pp Collisions at $\sqrt{s} = 10$ TeV

The CMS Collaboration

Supersymmetry: Double the whole table with a new type of matter!?



Heavy versions of every quark and lepton!

Time out from “theory”.

How will we look for discoveries at the LHC?

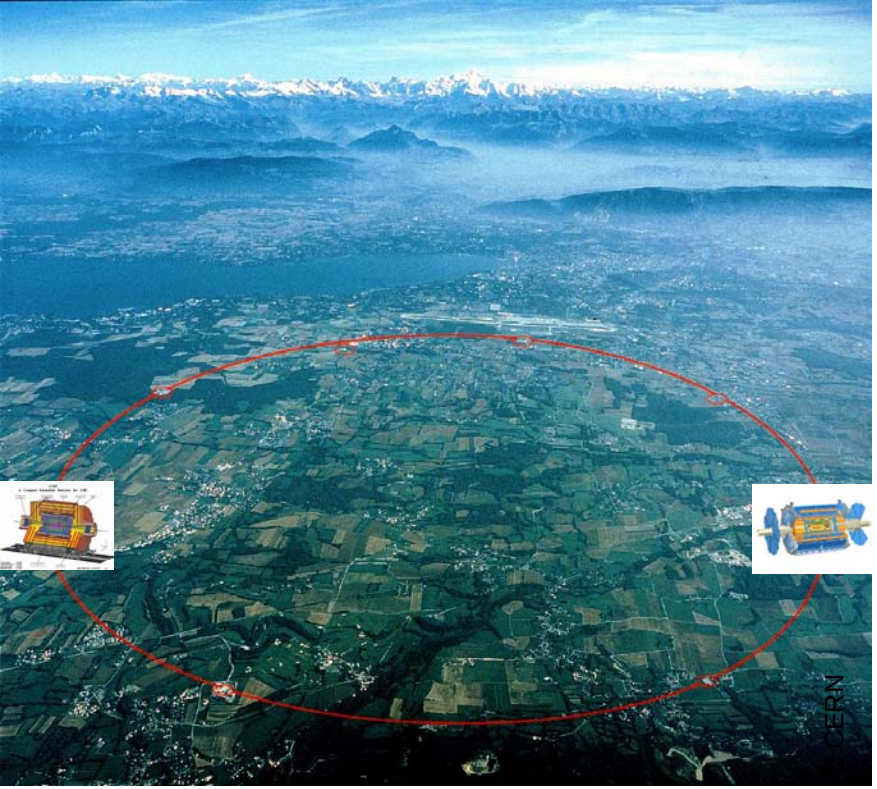
Accelerate beams of particles near to the speed of light to have high *energy* "E" of motion (kinetic energy).

Collide them with target or another beam.

Energy of beam particles is converted into *mass* ("m") of new particles, according to

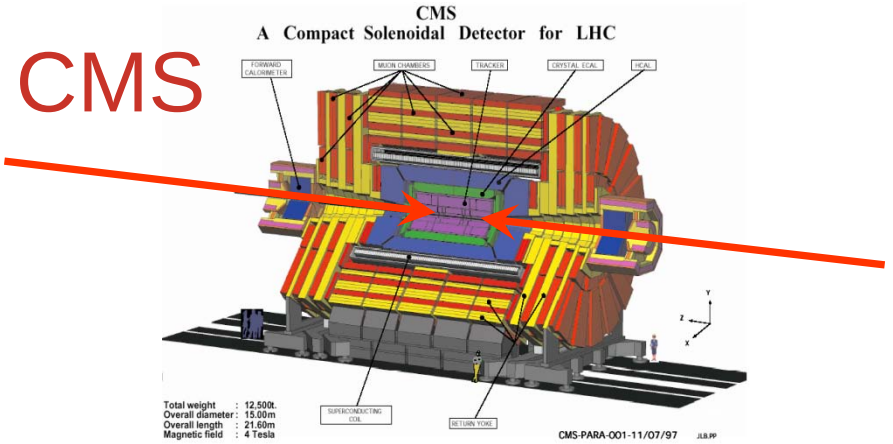
$$E = mc^2$$

How will we look for discoveries?

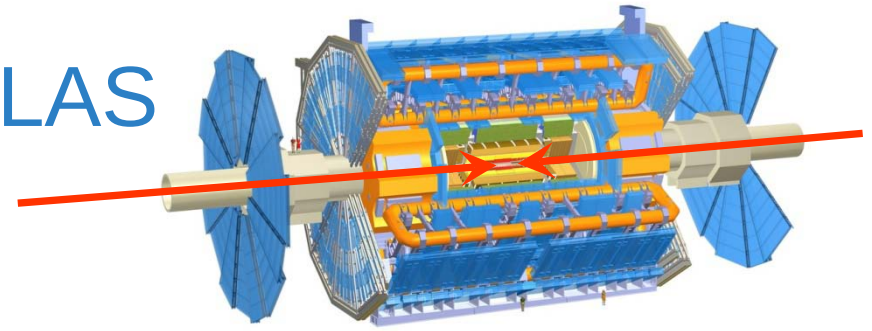


Counter-circulating beams collide at heart of detectors:

CMS

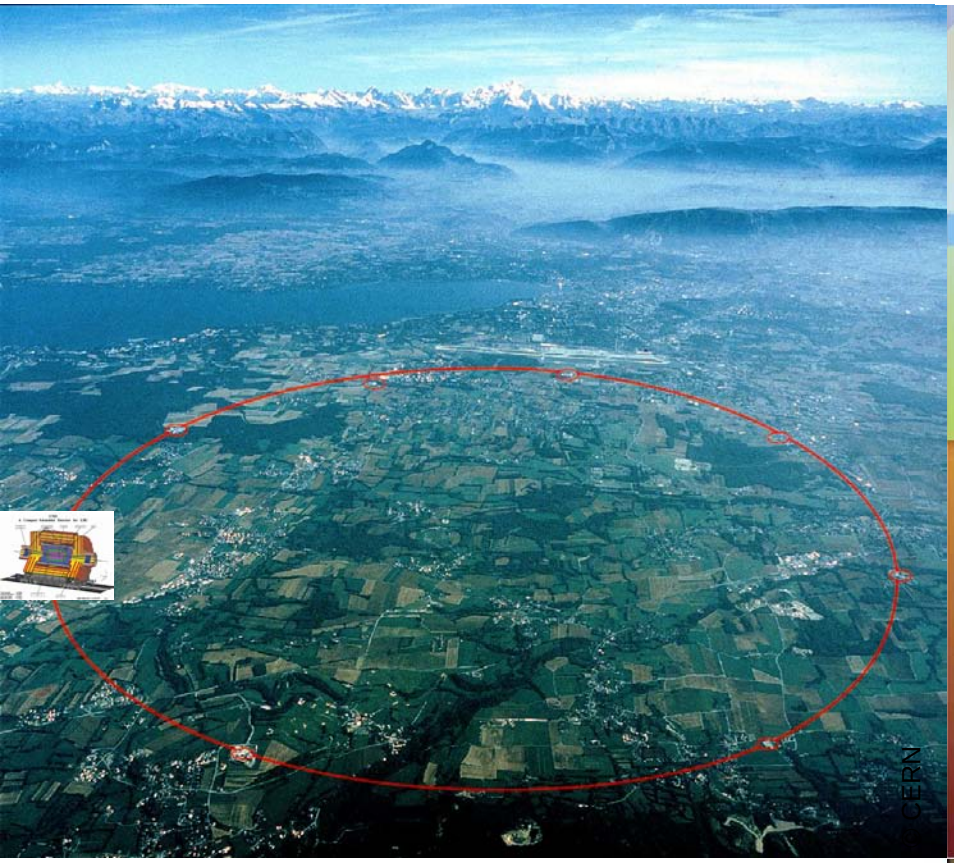


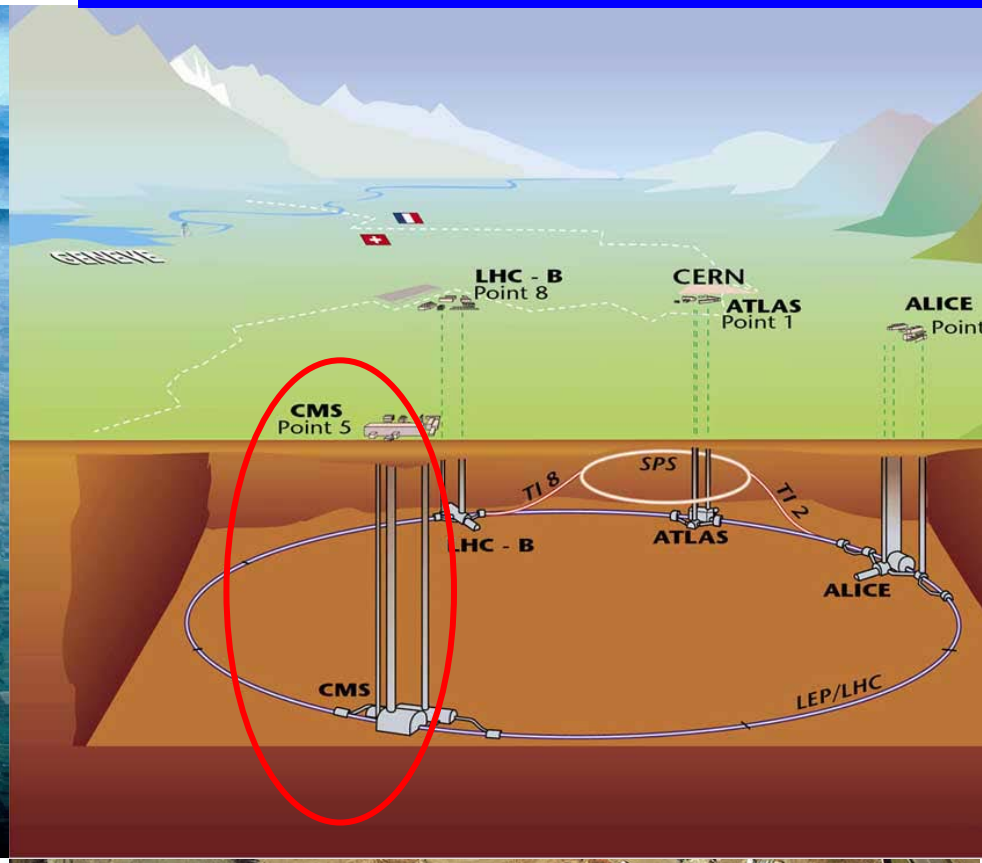
ATLAS

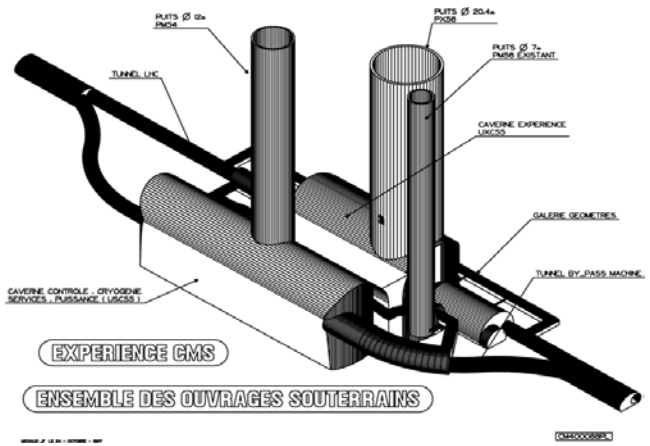


Zoom in on CMS

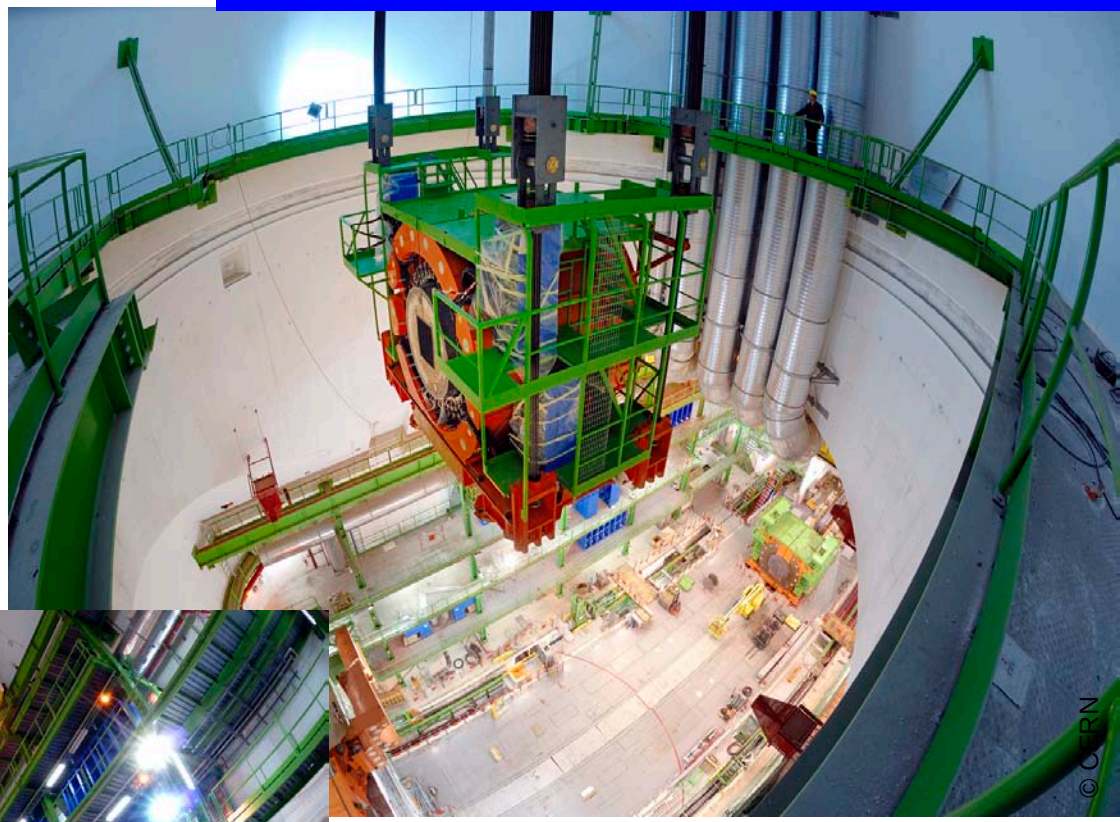
How will we look for discoveries?

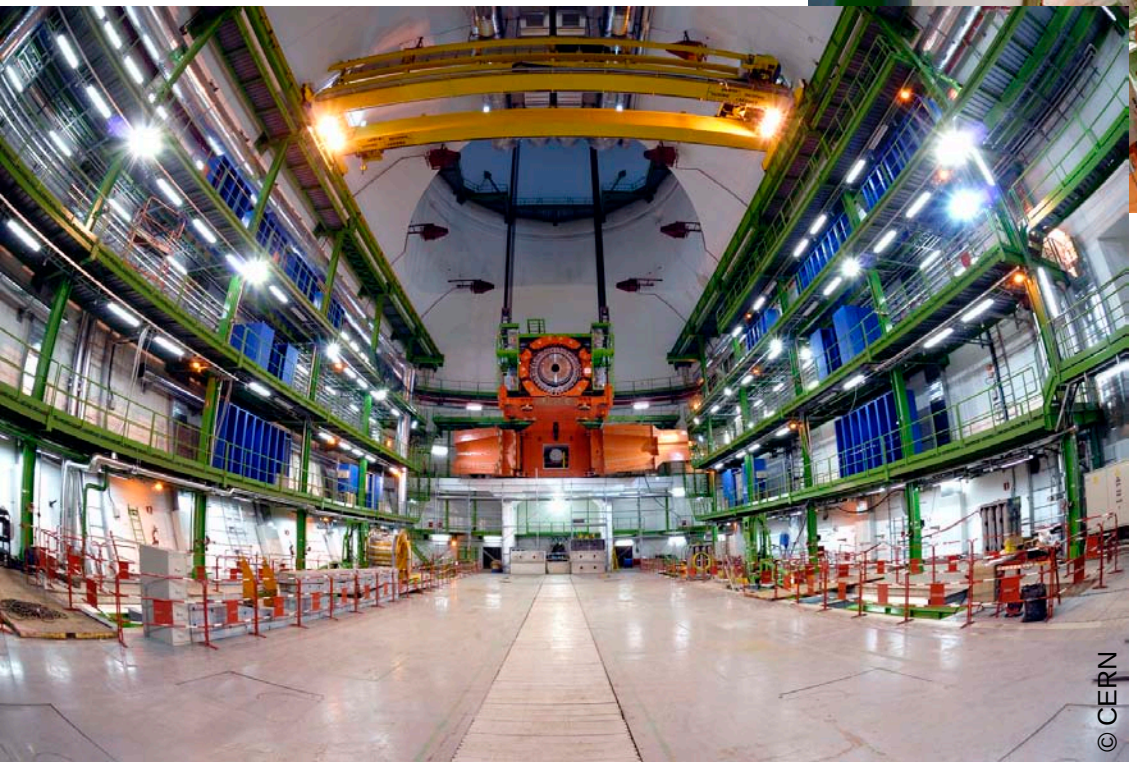


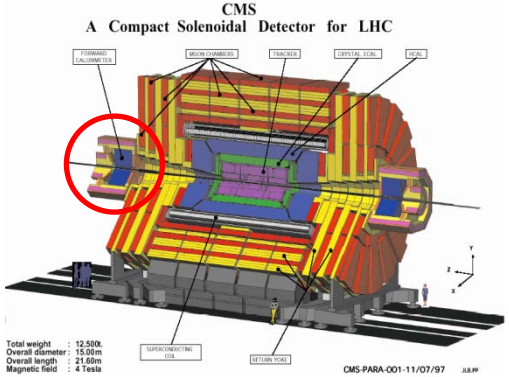




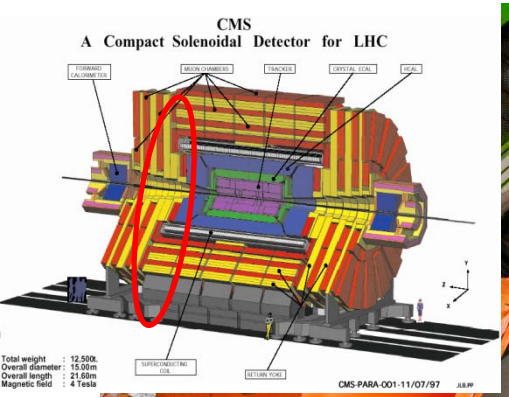
Lowering CMS to the underground cavern begins: November, 2006

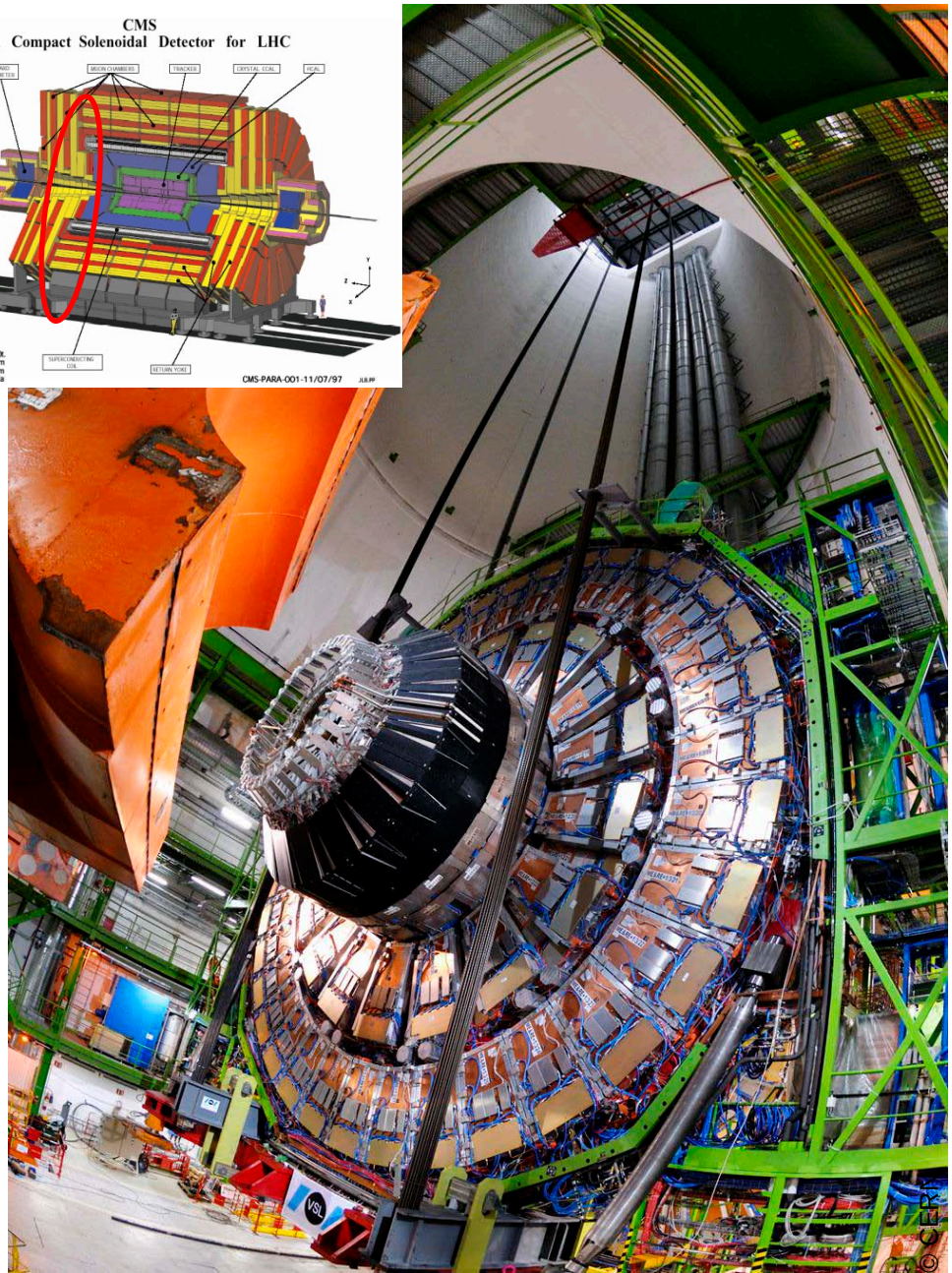


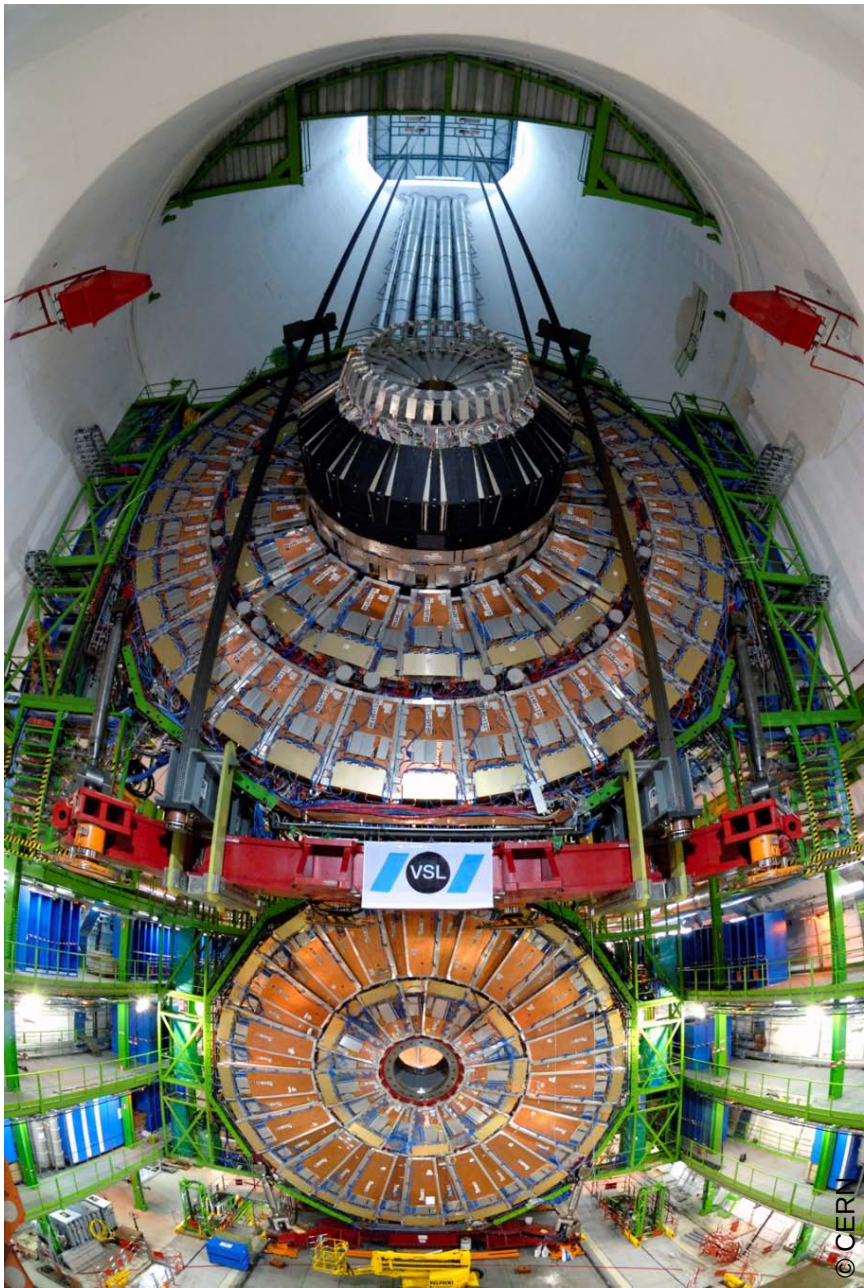




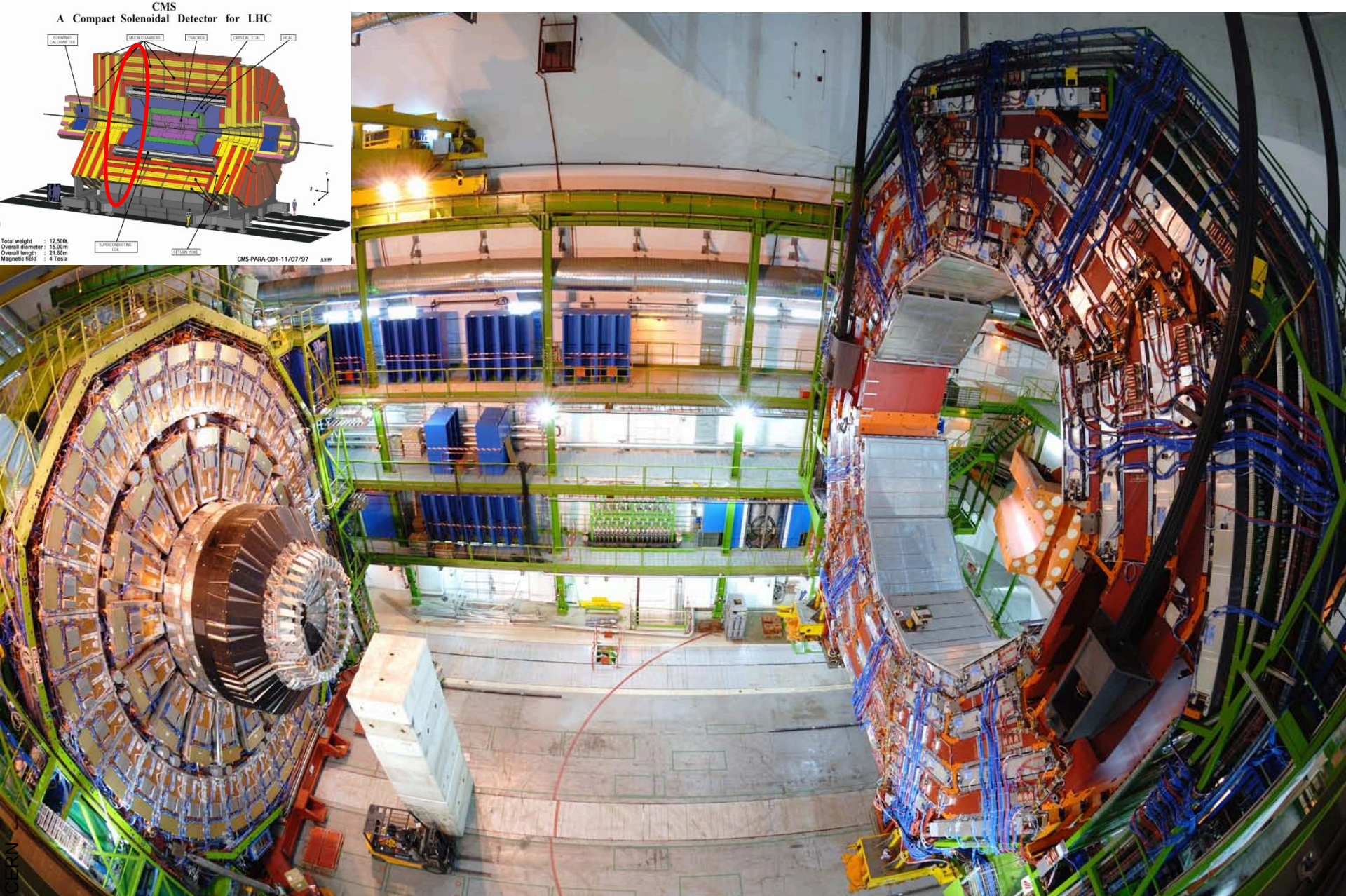
One of six huge disks.



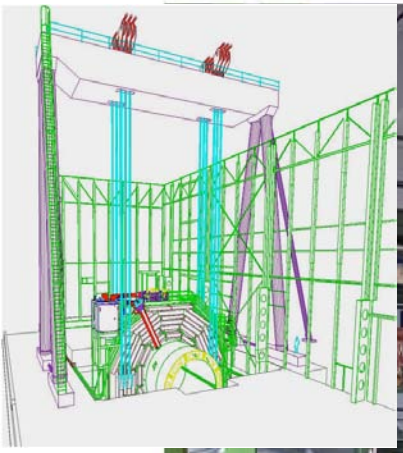


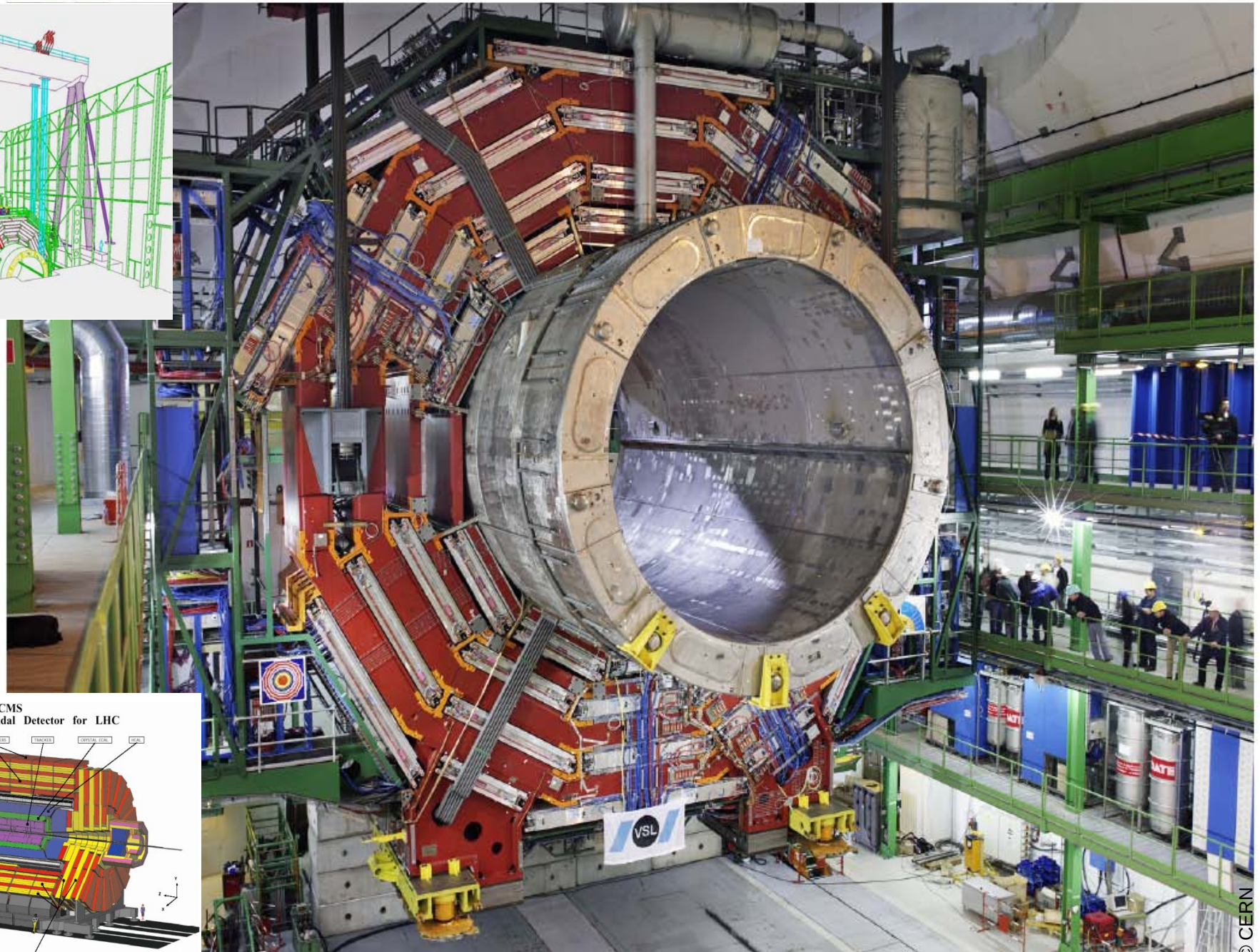


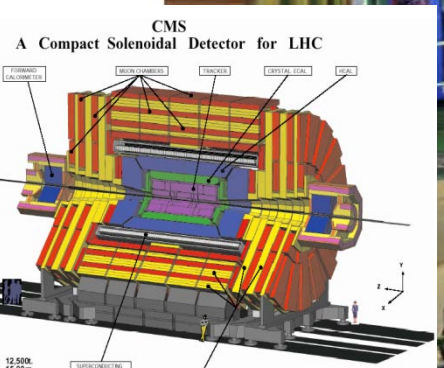
First barrel “wheel”, 1/07



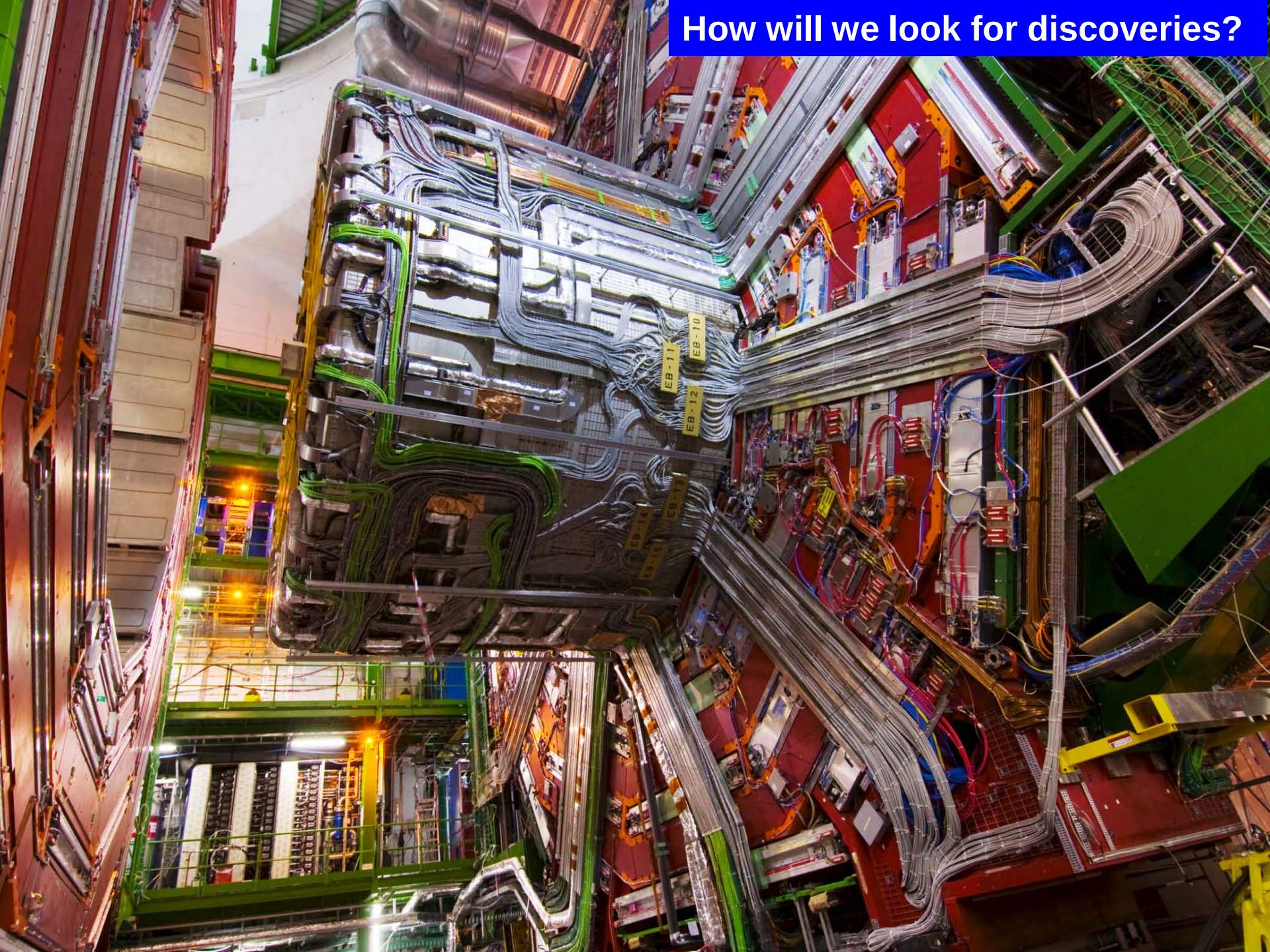
Magnet coil, 2/28/07







How will we look for discoveries?



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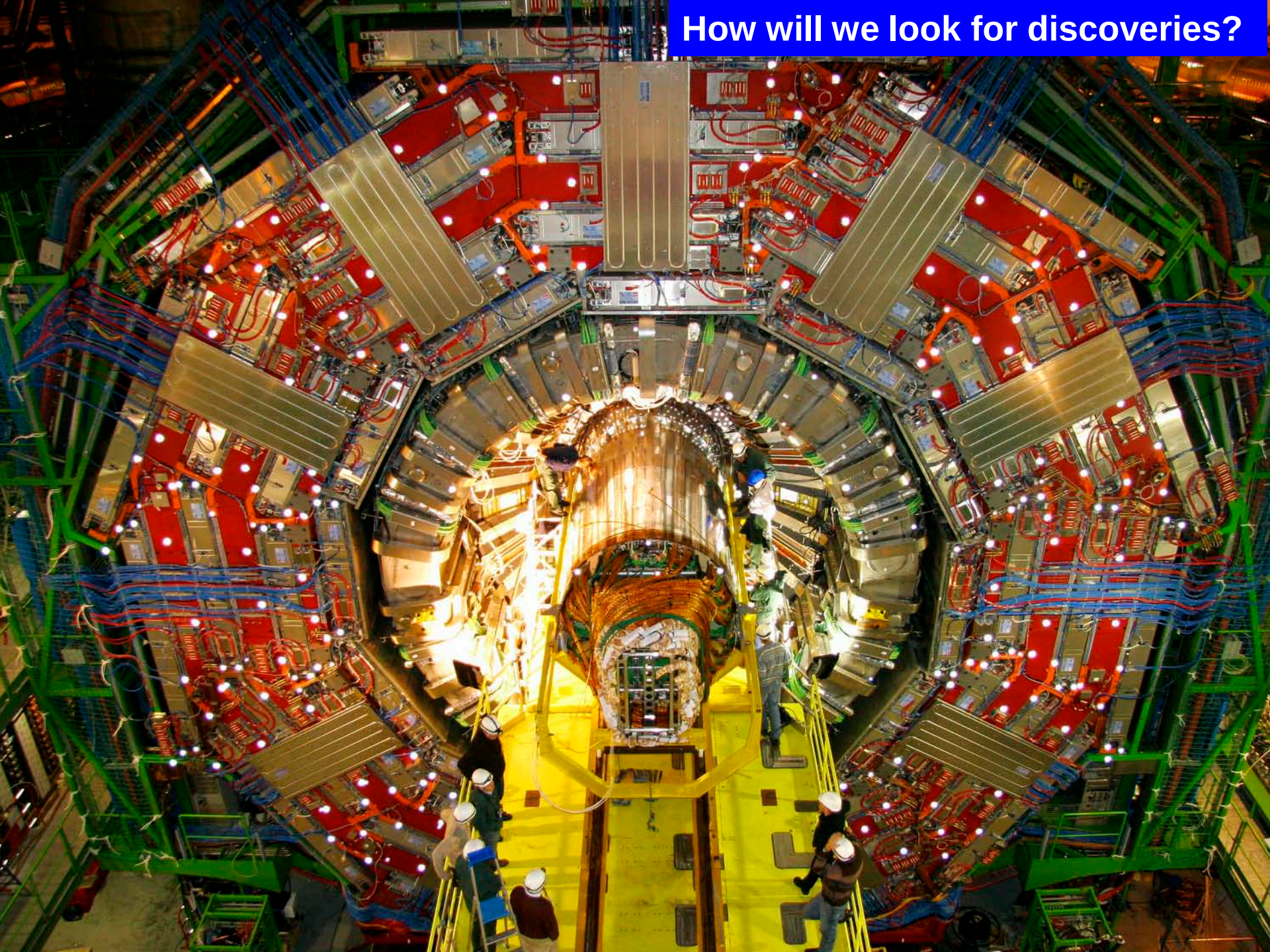
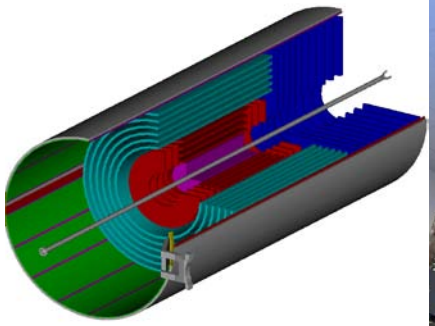
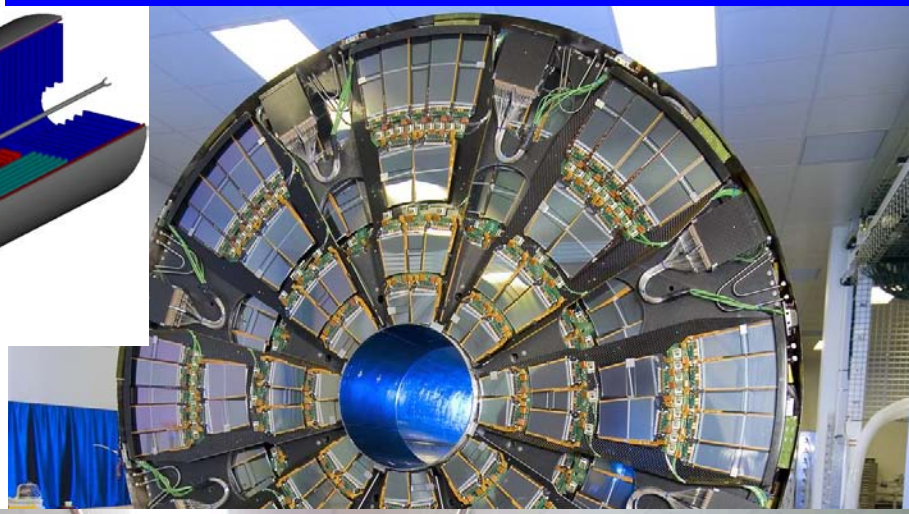
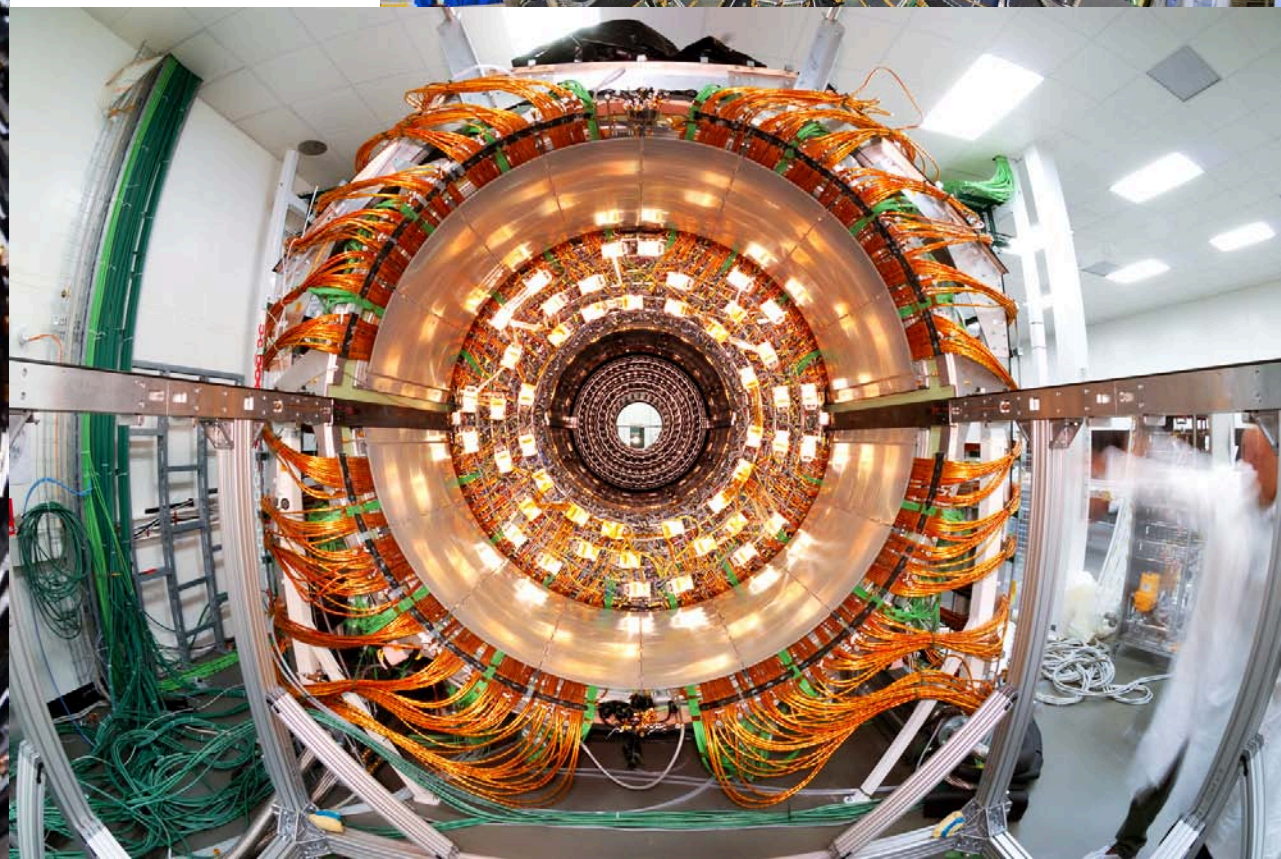


2000 square feet of silicon wafers: from cartoon to reality

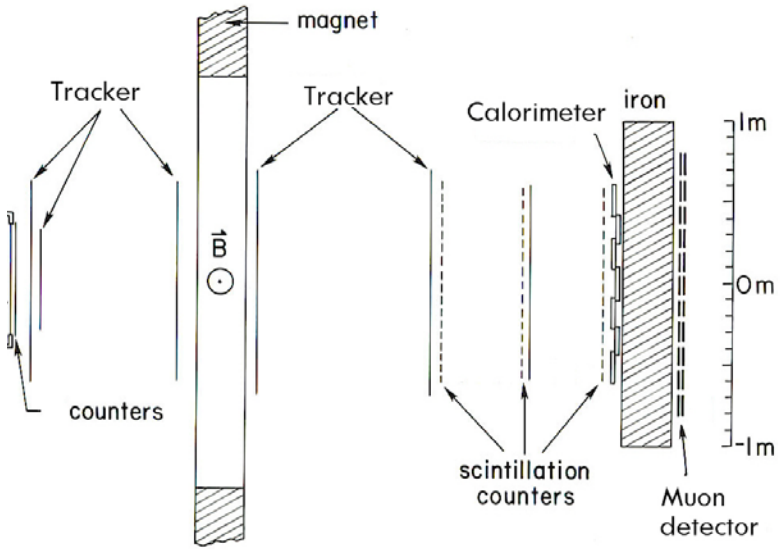




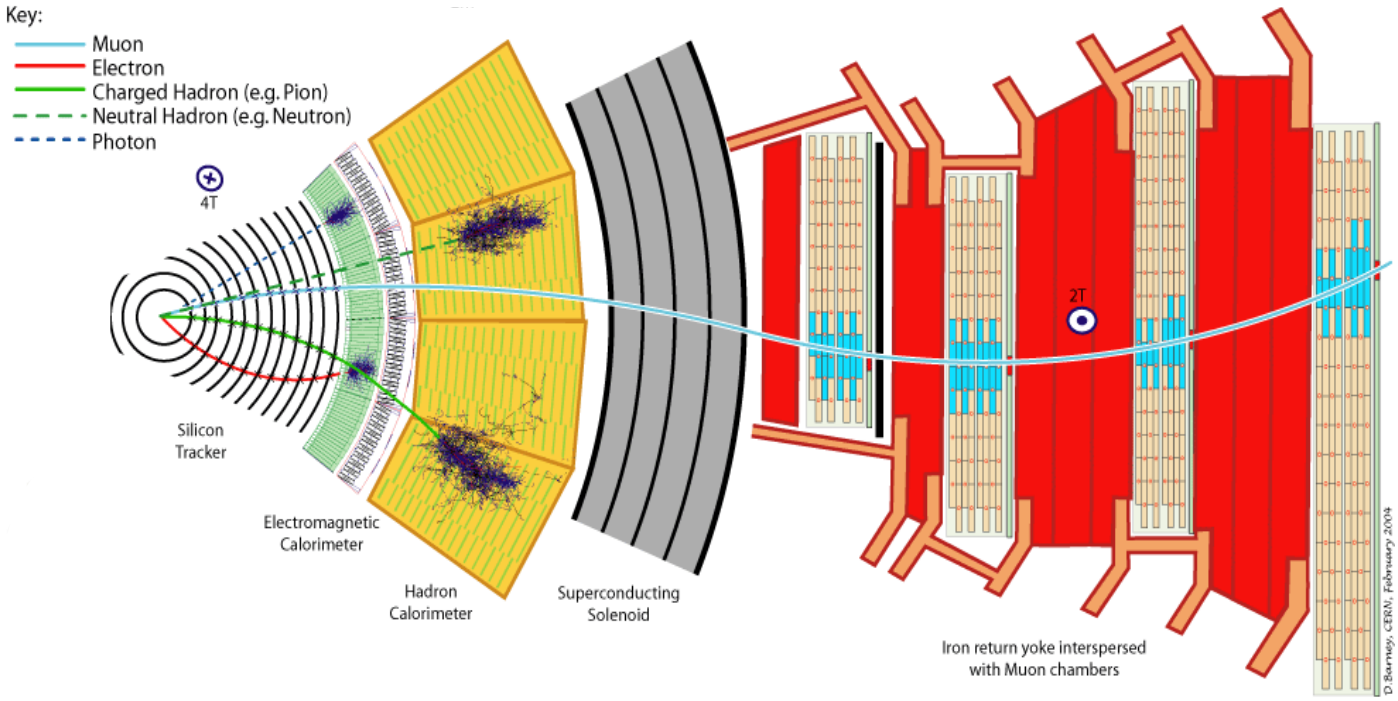


How will we look for discoveries?

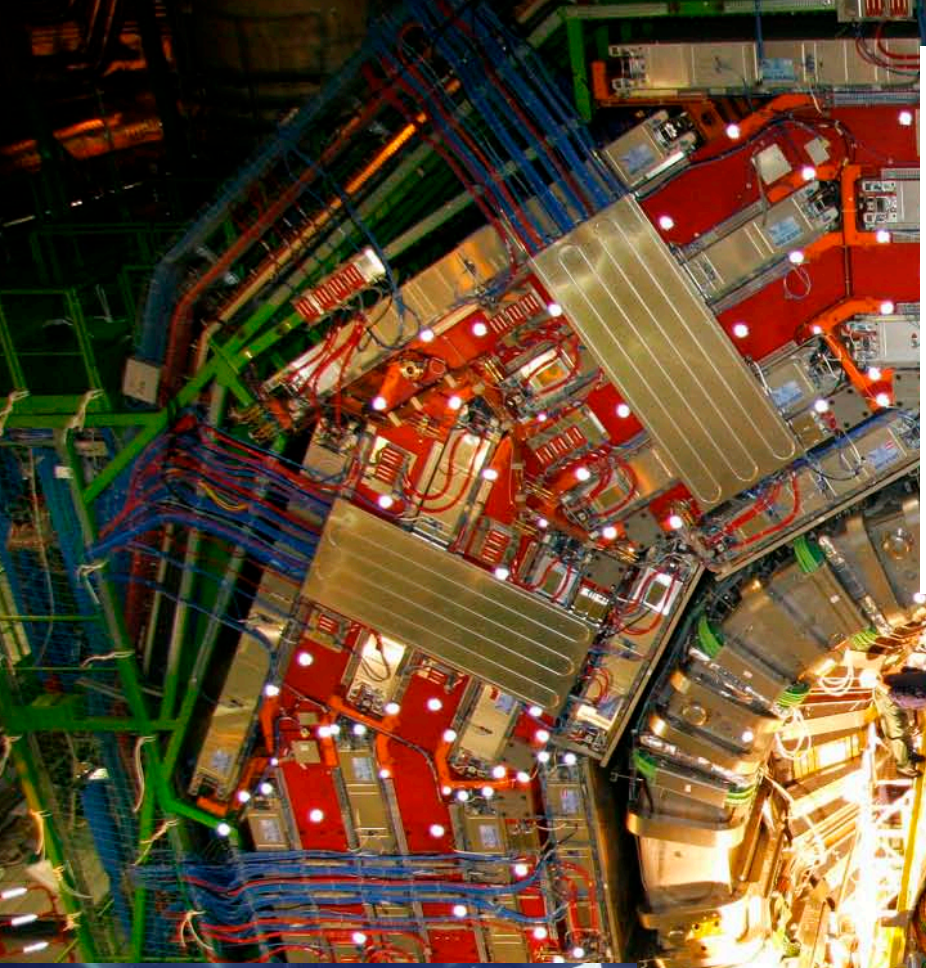
My Ph.D. thesis detector (c. 1980), basic ideas then decade or two old.

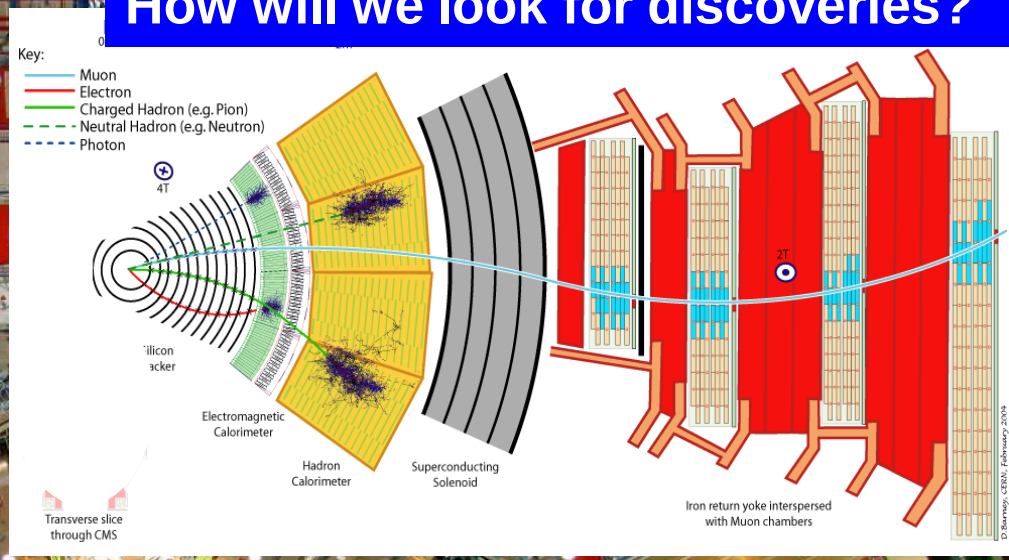


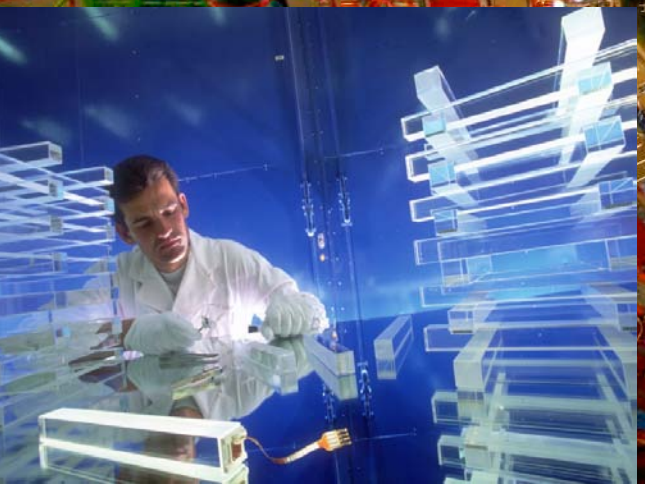
CMS: Same basic ideas, x1000 to x10,000 !

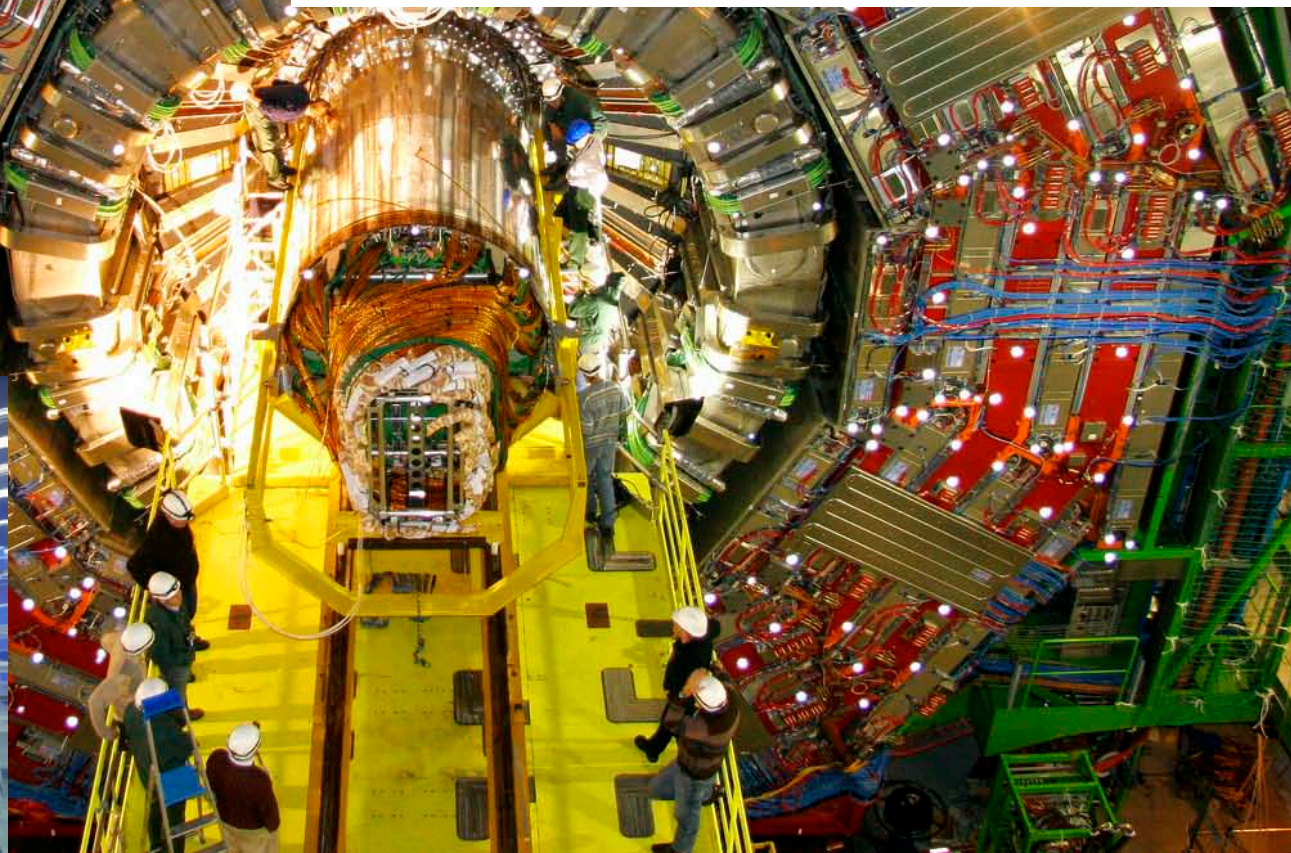


How will we look for discoveries?

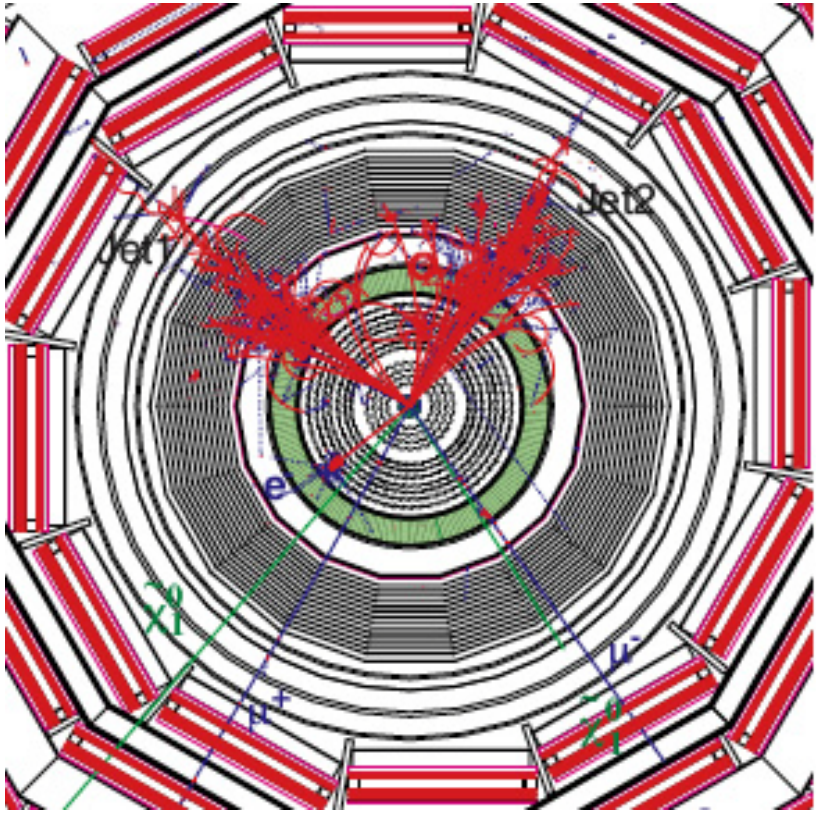


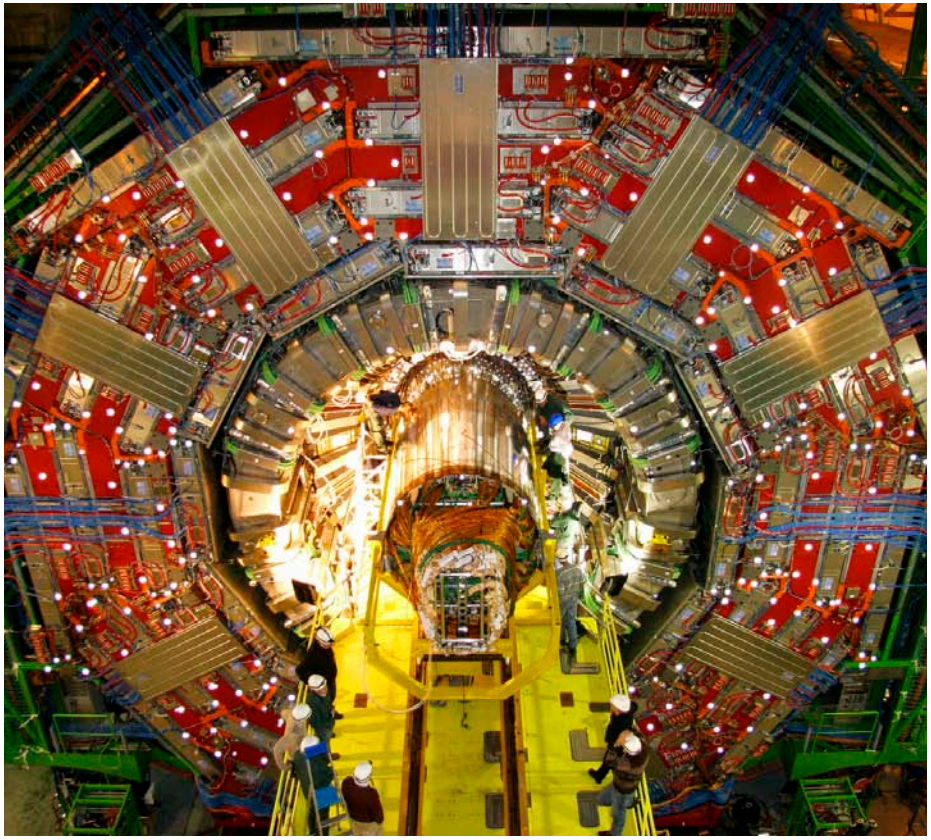




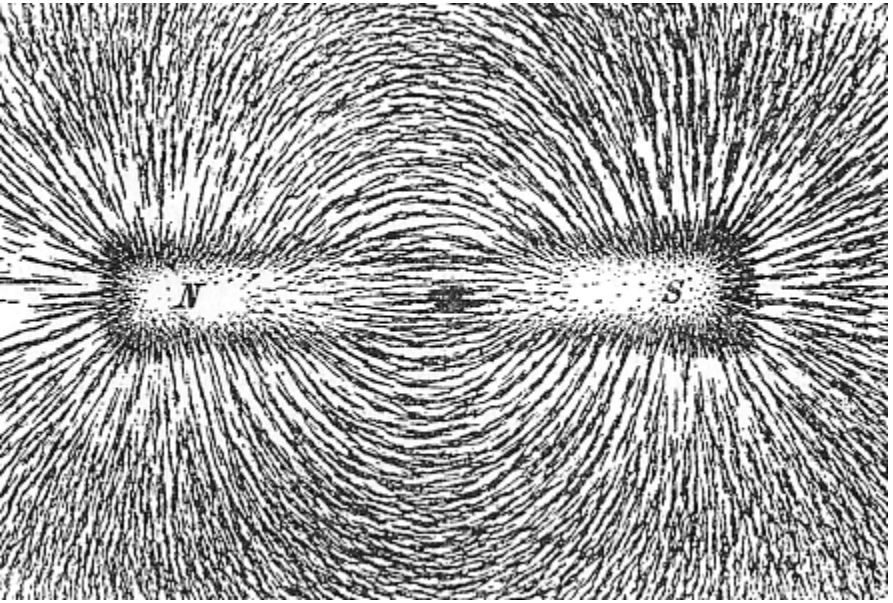


Simulation of proton-proton collision making two dark matter particles





Familiar “classical” force fields: gravity and…



Iron filings around a bar magnet: can see “field lines” of the **magnetic force field**.

Electric force field, in nature and in a flashlight.

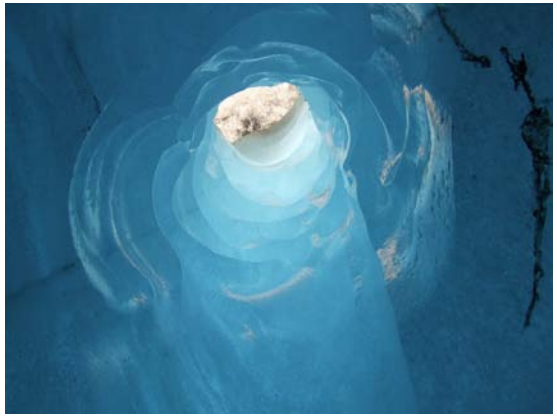
Electric and magnetic force fields are different manifestations of a single *electromagnetic* force field.

Ripples in the electromagnetic force field propagate out as waves.

Radio waves.

Microwaves.

Light!



Einstein's Nobel-prize-winning insight:

Light waves consist of packets of energy ("quanta") which we now call "photons".

Eyes and cameras "see" by absorbing photons.

Einstein, Annalen der Physik, 1905

Are there undiscovered force fields?

6. *Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt;*
von A. Einstein.

Es scheint mir nun in der Tat, daß die Beobachtungen über die „schwarze Strahlung", Photolumineszenz, die Erzeugung von Kathodenstrahlen durch ultraviolettes Licht und andere die Erzeugung bez. Verwandlung des Lichtes betreffende Erscheinungsgruppen besser verständlich erscheinen unter der Annahme, daß die Energie des Lichtes diskontinuierlich im Raume verteilt sei. Nach der hier ins Auge zu fassenden Annahme ist bei Ausbreitung eines von einem Punkte ausgehenden Lichtstrahles die Energie nicht kontinuierlich auf größer und größer werdende Räume verteilt, sondern es besteht dieselbe aus einer endlichen Zahl von in Raumpunkten lokalisierten Energiequanten, welche sich bewegen, ohne sich zu teilen und nur als Ganze absorbiert und erzeugt werden können.

Swiss citizen Albert Einstein working in Berne, Switzerland.

Concerning an Heuristic Point of View toward the Emission and Transformation of Light

"It seems to me that the observations are more readily understood if one assumes that the energy of light is discontinuously distributed in space… The energy of a light ray consists of energy quanta which are localized in space, which move without dividing, and which can only be produced and absorbed in complete units."

Translation: Arons and Peppard, Amer. J. Phys, 1965

All forces have energy quanta!

S. N. Bose, from India, sent a paper to Einstein with an important consequence:

Photons tend to clump together due to (as we now know it) a deep Quantum-Mechanical effect.

The energy quanta of *all forces* have the property of clumping discovered by Bose, and are called bosons.

Quanta of electromagnetic force: photons.

Quanta of weak force: W and Z bosons
(Crucial part of sun's ability to "burn".)
They are very massive.

Quanta of strong force: gluons *Massless.*

Quanta of gravitational force: gravitons
(Never yet detected.) *Massless.*

All are bosons.

Promising theoretical attempts at a unified theory of all force fields predict *forces not yet discovered*!

Experiments at the LHC will search for quanta of these new force fields.

A “funny” thing happened on the way to the modern theory of quarks, leptons, force fields, and their quanta:

The equations only made sense if all the bosons, and all the quarks and leptons, had no mass and moved at the speed of light!

Aside: what does it mean for a particle to have "no mass"?

The most famous equation in physics is only a "special case" of the whole equation!

$$E = mc^2$$

$E = mc^2$ is the energy of a particle *at rest*. If mass m is moving, and has momentum p, then

$$E^2 = (mc^2)^2 + (pc)^2$$

It is "legal" to put $m=0$ into this equation:

$$E = pc$$

"$E = pc$" applies to photons and anything else moving at the speed of light!

So the "funny" thing was that the equations only worked if m=0, i.e., if all particles moved at the speed of light.

Peter Higgs and others said:
Postulate a new force field (now called the "Higgs field") permeating all space.

When particles with m=0 travel through this force field, they are slowed down, in effect acquiring a mass, and thus obey $E = mc^2$!

Pretty wild speculation, no?

But like all force fields, this new "Higgs field" would have quanta, which are bosons – "Higgs bosons"!

We expect to create and detect Higgs bosons at the LHC, or…?

Meanwhile…a mystery the LHC might help solve, from a totally different direction…
looking into outer space!

Light travels really, *really* fast…
but *not* infinitely fast!

A billionth of a second to travel one foot.

Less than one ten-thousandth of a second from L.A. to UCLA.

8 minutes to go from the sun to the earth!

Constellation Andromeda: starlight left stars 50-500 years ago!

With unaided eye, also a faint smeared source of light. With binoculars:

How far back in time are you looking now?

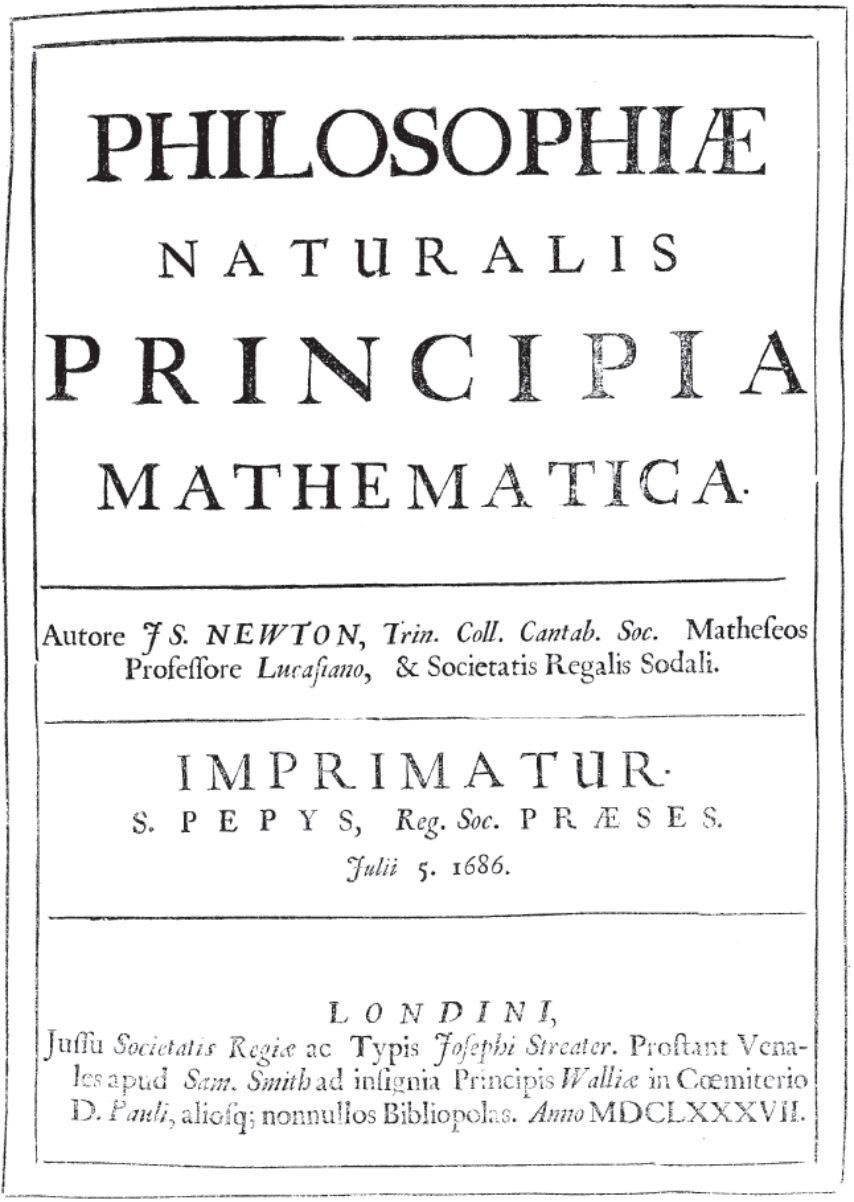
Over two million years back in time!

This blurry "nebula" is another galaxy, similar to our Milky Way: "Andromeda Galaxy", or M31.

A star on the outer part of the disk orbits the collective mass of stars inside its orbit.

The speed of an orbiting star measures the total mass of everything inside the orbit.

Newton's *Universal* Law of Gravity



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON*, *Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtant Venales apud *Sam. Smith* ad inſignia Principis *Walliæ* in Cœmiterio D. *Pauli*, alioſq; nonnullos Bibliopolas. *Anno* MDCLXXXVII.

Same force is responsible for:

- Apples falling to earth
- Moon orbiting earth
- Jupiter's moons orbiting Jupiter
- Earth orbiting the sun

Further away from orbit center, orbital speed is slower.

Orbit speed measures mass inside orbit.

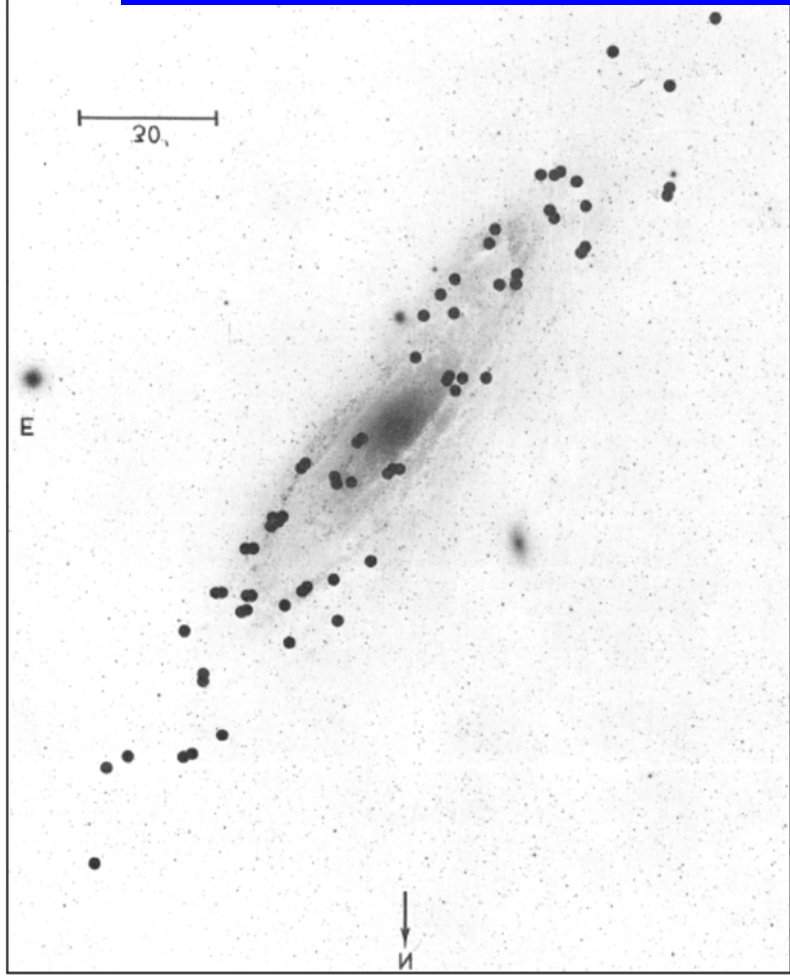
THE ASTROPHYSICAL JOURNAL, Vol. 159, February 1970

What is the dark matter?

ROTATION OF THE ANDROMEDA NEBULA FROM A SPECTROSCOPIC SURVEY OF EMISSION REGIONS*

VERA C. RUBIN† AND W. KENT FORD, JR.†
Department of Terrestrial Magnetism, Carnegie Institution of Washington and Lowell Observatory, and Kitt Peak National Observatory‡

AIP Emilio Segre Visual Archives, Rubin Collection



Further away from orbit center, is orbital speed slower?

No!

Orbital speed consistent with expected mass inside orbit?

Too fast!

Must be invisible matter ("dark matter") to account for these observations.

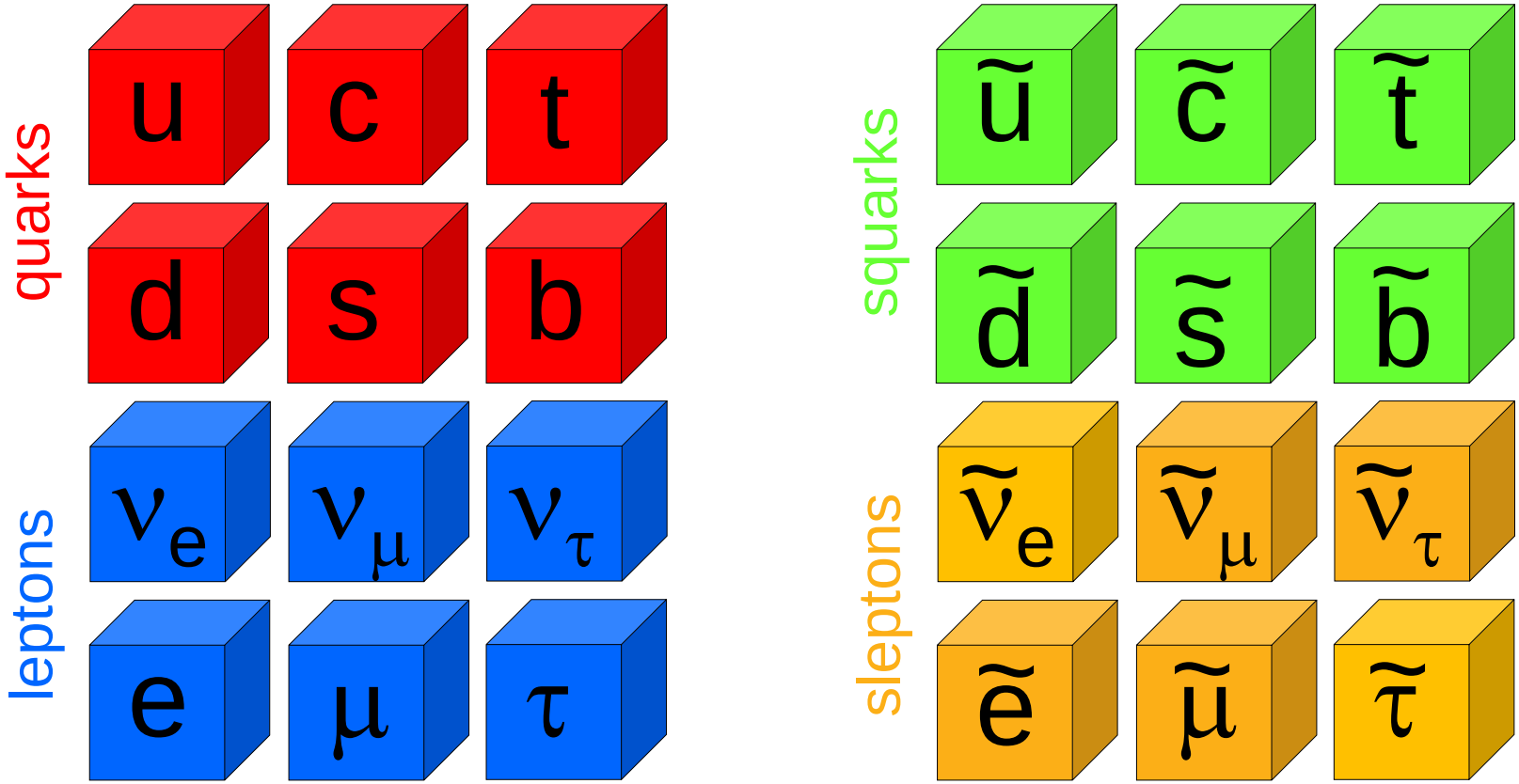
What in the world (*out* of this world?) is that?

After 40 years, answer still unknown.

"Ordinary matter" makes up only about 1/6 of the matter in the universe.

The rest is something else!

Enter Supersymmetry.
It doubles the matter particles…



…and for every "normal" force quanta (boson), there are supersymmetric partners!

photon	photino
W, Z bosons	Wino, Zino
gluon	gluino
graviton	gravitino
and even	
Higgs boson	higgsino

These "…inos" are prime suspects to be the galactic dark matter!

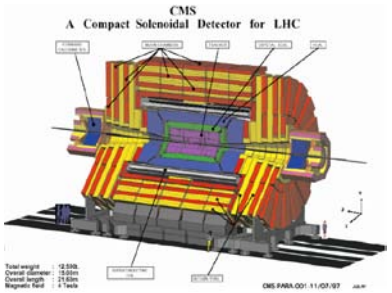
Relics from the Big Bang!

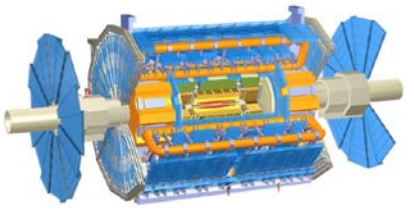
That's really wild!
Who says physicists aren't good at making things up?

Is this science?

I.e., is there any hope to get some *experimental evidence ?*

Yes!





Decent chance that LHC will make supersymmetric dark matter particles, and CMS and ATLAS will detect them.

Meanwhile deep underground, other experiments are looking for disturbances from the Milky Way's dark matter!

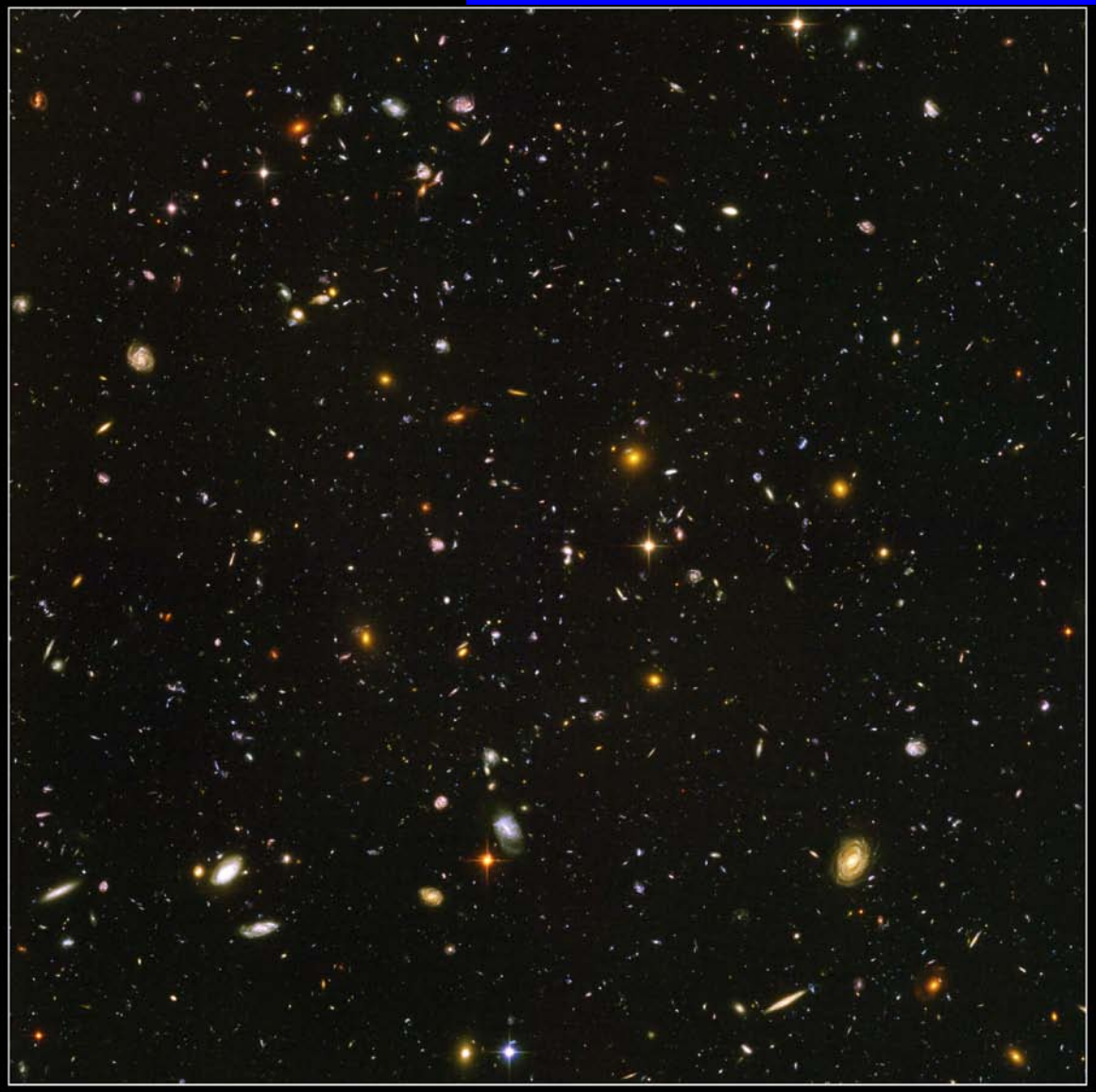
The science of the very small may once again impact the science of the very large.

We see back two million years in time when we look at the Andromeda galaxy.

Can we see further back in time than two million years?

With the Hubble Space Telescope…

What was physics of the universe after the Big Bang?



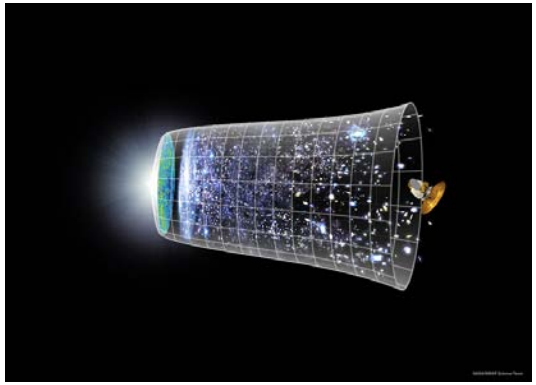
Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team STScI-PRC04-07a
http://hubblesite.org/newscenter/archive/releases/2004/07/image/b/

…some faint galaxies are *thirteen billion years* back in time!

About 10,000 galaxies in this picture, 1/10 size of the moon across as we look at it from earth.

Can we see *all the way back* to the big bang?!



No.

The first 380,000 years after the big bang, the universe was opaque to light.

Everything we infer about the first 380,000 years of the universe needs calculations using the “laws” of physics for the building blocks and force fields.

What was physics of the universe after the Big Bang?

At the LHC, we will recreate on a tiny scale conditions at times just after the Big Bang!

Goal is to understand laws of physics then and now.

Speculation gets wilder:

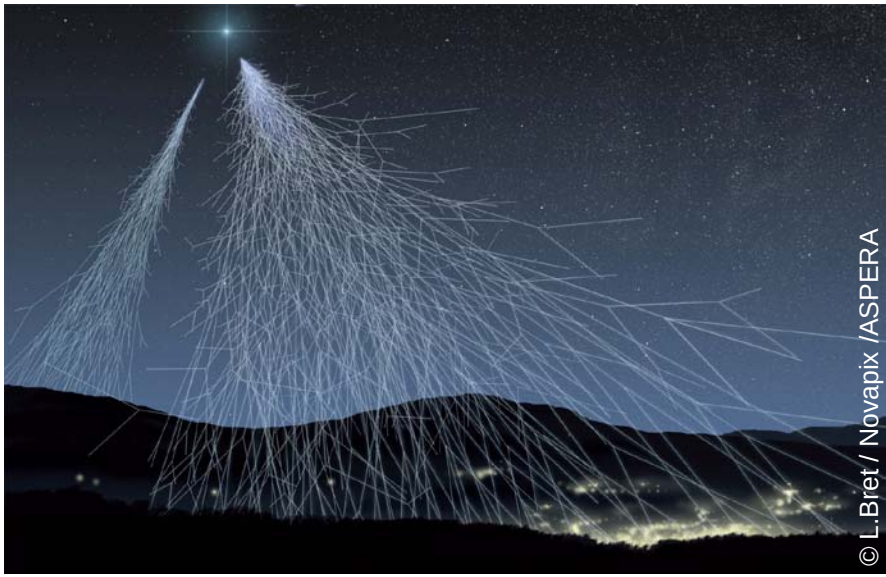
Large extra dimensions of spacetime

Short-lived black holes smaller than protons

Personally I would be thrilled if we can see quanta of new force fields, and take the next step in understanding the smallest building blocks. We'll see!

New for us, but the earth sees it all the time

- Cosmic rays exceed LHC energies
- Nature has performed 100,000 LHC experiments on Earth
- A million on Jupiter, a billion on the sun.
- And all over the galaxy, neutrons stars, etc.
- LHC collisions are safe



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We're looking for several categories of extensions to the known building blocks.

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One or more of these new particles could explain the galactic dark matter.

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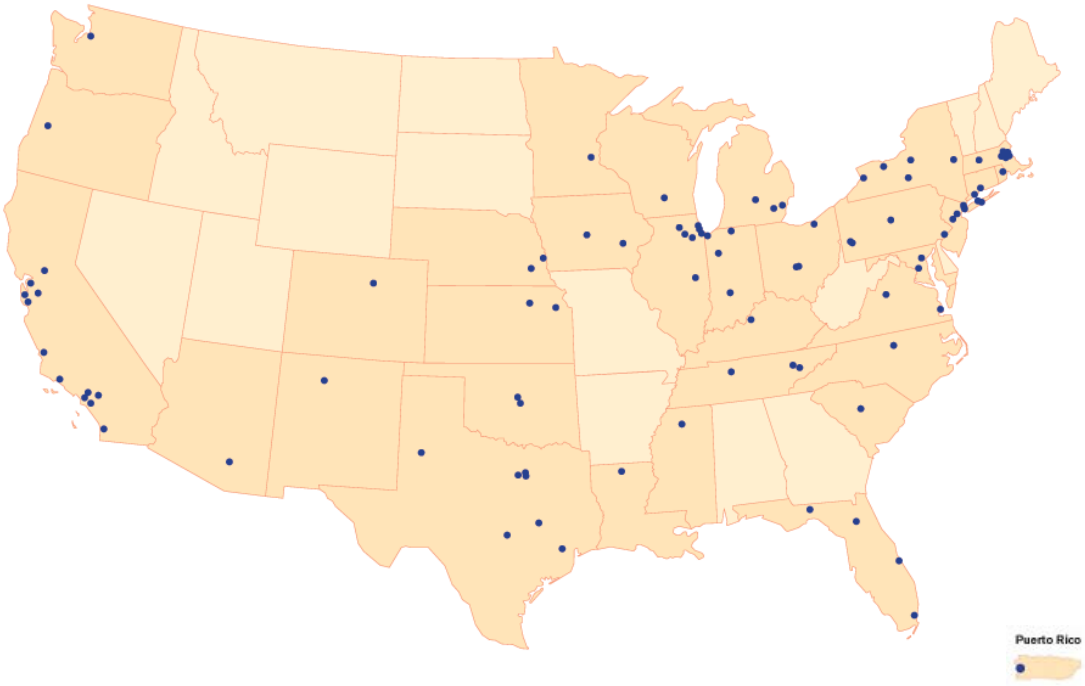
What was physics of the universe after the Big Bang?

We expect steps forward in understanding the universe, just after the Big Bang and since!

American participation

- 1,700 scientists, students, engineers, technicians
- 89 universities
- 7 national labs, 1 supercomputing center
- 32 states, Puerto Rico



Fermilab/Sandbox Studio

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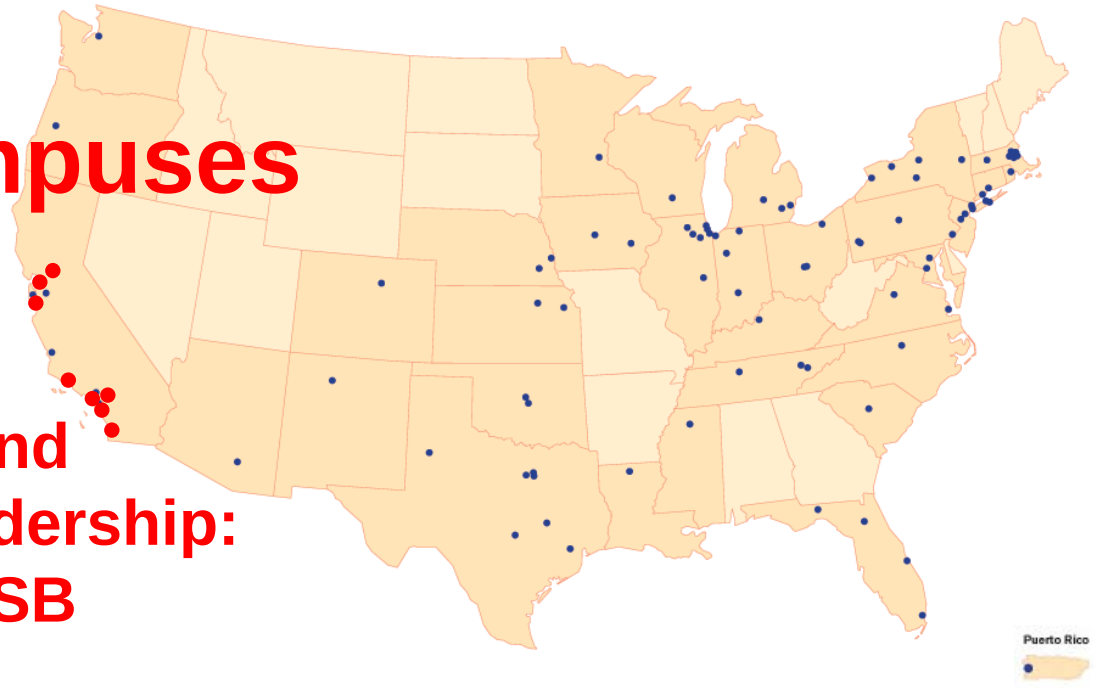
Eight UC Campuses

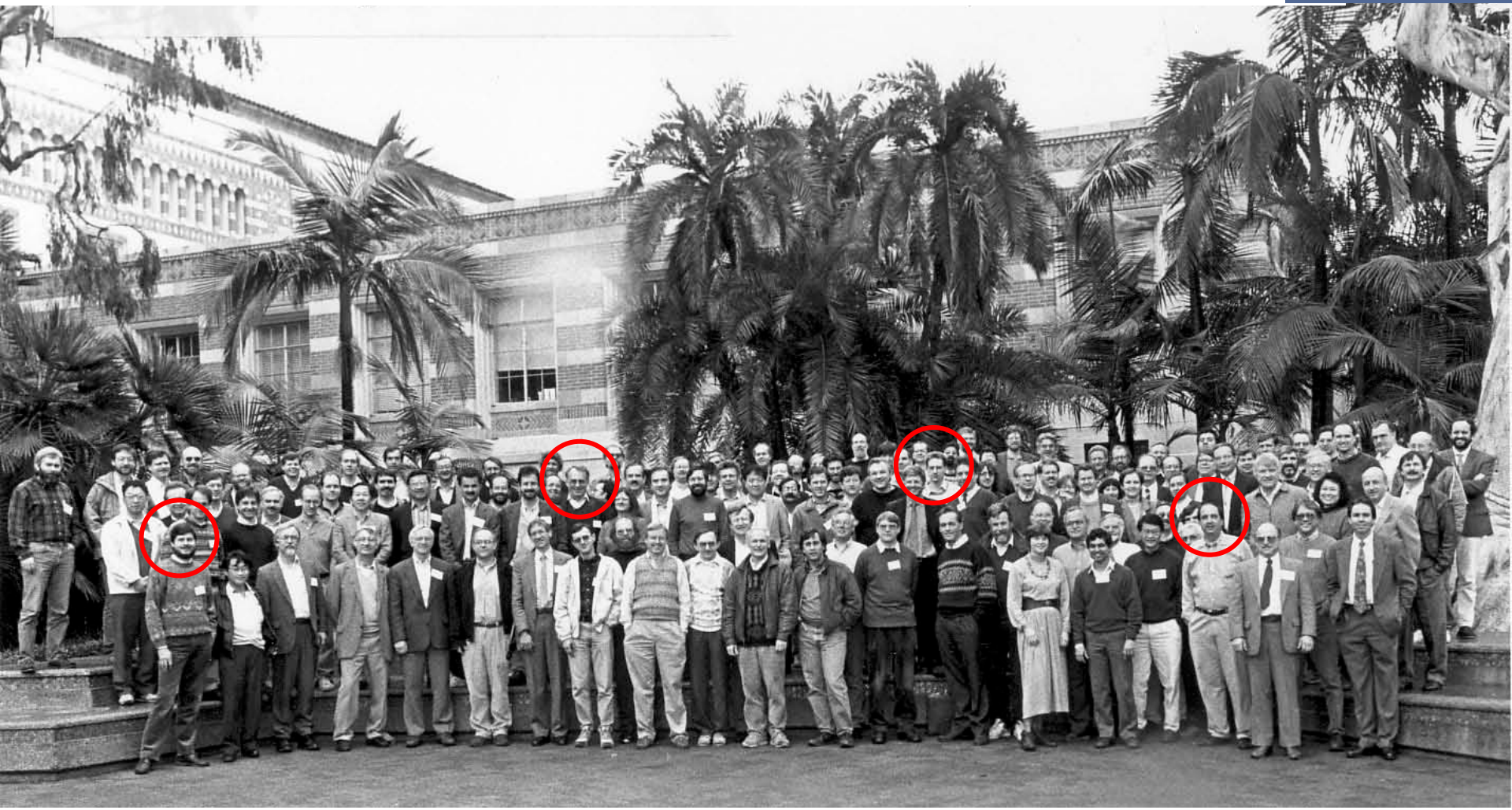


The three highest Americans in CMS and ATLAS scientific leadership: from UCLA, UCI, UCSB

Fermilab/Sandbox Studio

First U.S. CMS Collaboration Meeting

UCLA



February, 1994, hosted by UCLA Physicists

UCLA and CMS


TEN MYTHS ABOUT RUSSIA
JAPAN: HOT GREEN CARS
Newsweek
The Biggest Experiment Ever
(And It's European)
The new CERN collider in Geneva
SEPTEMBER 15, 2003

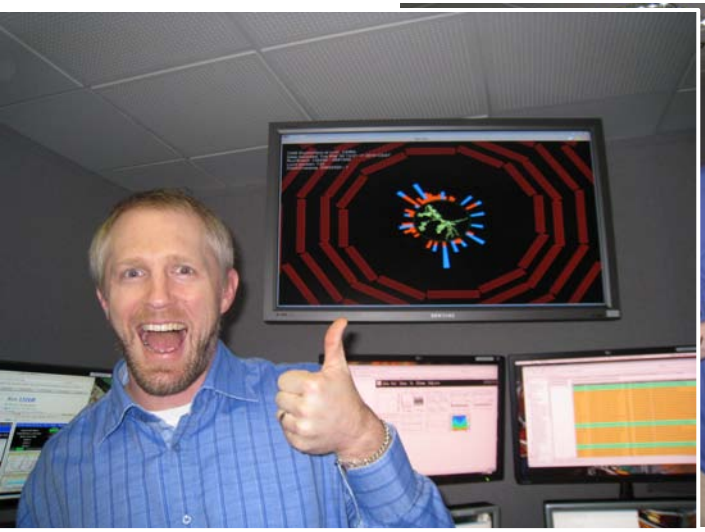

UCLA

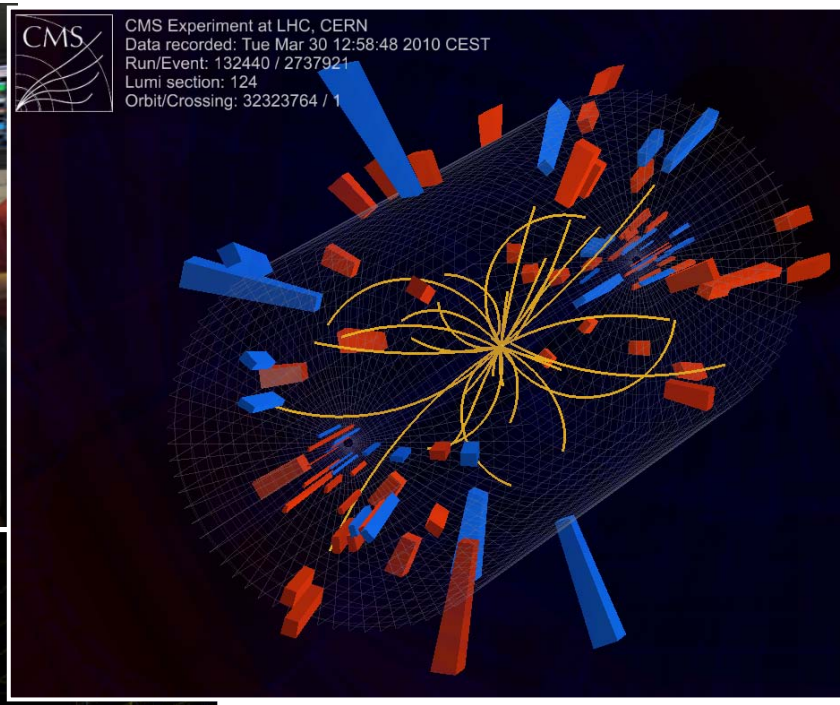

SHAWTON

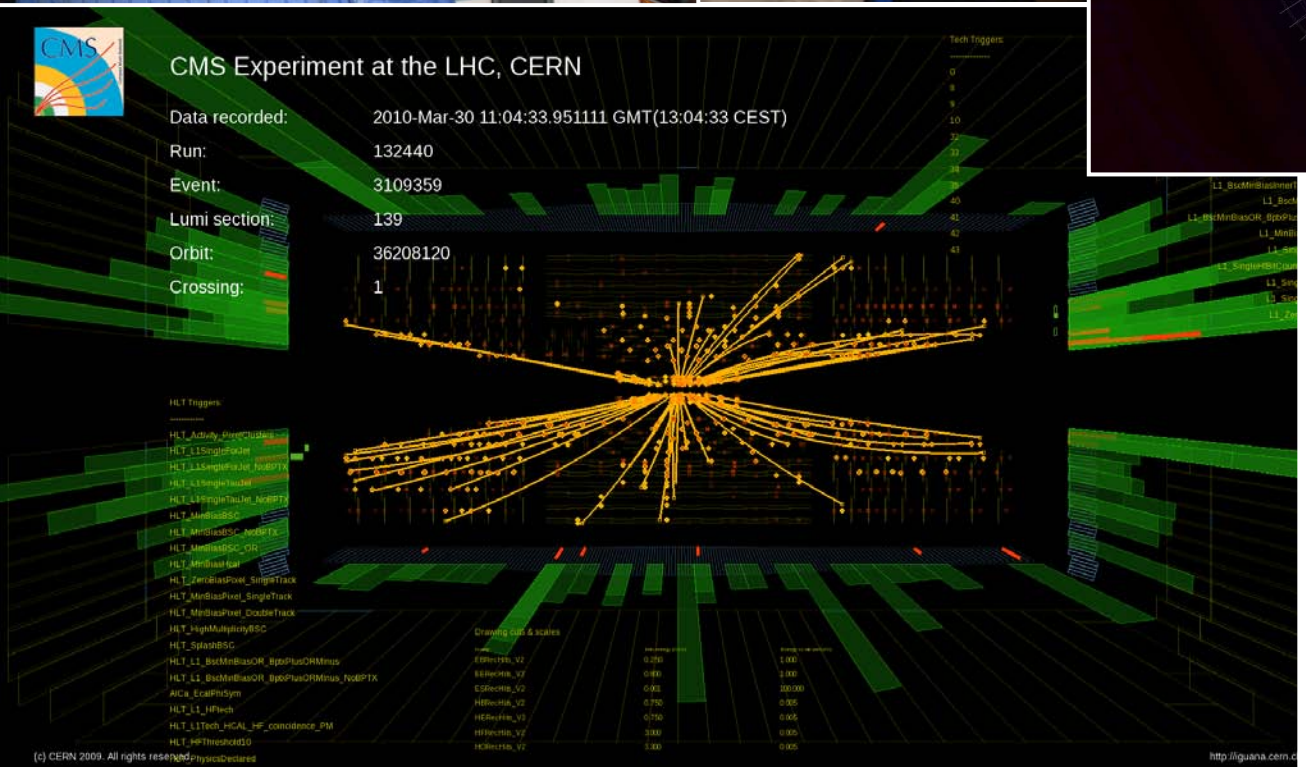
OK, we're excited!

After 20 years, when do we start taking physics data?

Yesterday!




CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Mar 30 12:58:48 2010 CEST
Run/Event: 132440 / 2737921
Lumi section: 124
Orbit/Crossing: 32323764 / 1


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2010-Mar-30 11:04:33.951111 GMT(13:04:33 CEST)
Run: 132440
Event: 3109359
Lumi section: 139
Orbit: 36208120
Crossing: 1
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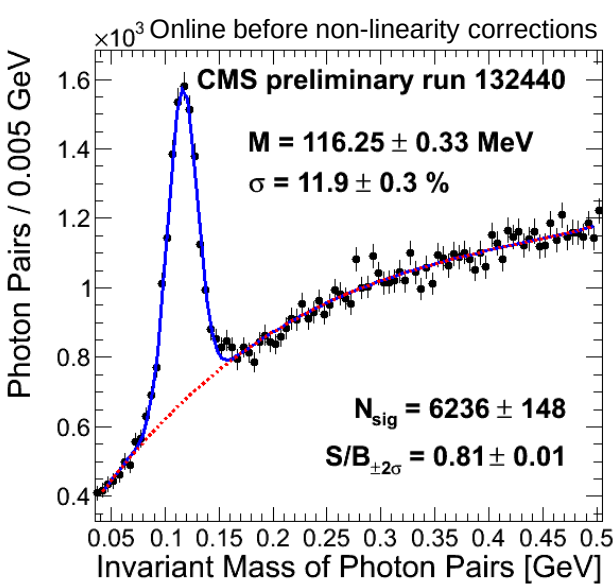

Online before non-linearity corrections
CMS preliminary run 132440
M = 116.25 ± 0.33 MeV
σ = 11.9 ± 0.3 %
N_sig = 6236 ± 148
S/B_±2σ = 0.81 ± 0.01
Photon Pairs / 0.005 GeV
×10^3
1.6
1.4
1.2
1
0.8
0.6
0.4
0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5
Invariant Mass of Photon Pairs [GeV]

"All the News That's Fit to Print"

The New York Times

Late Edition

VOL. CLIX... No. 54,996 © 2010 The New York Times Company NEW YORK, WEDNESDAY, MARCH 31, 2010 $2.00

Particles Collide, and Champagne Glasses Clink

Plan to Widen Use of Statins Has Skeptics

Cholesterol Pills Aimed at Healthy People

By GARDINER HARRIS

OBAMA TO OPEN OFFSHORE AREAS TO OIL DRILLING

SEEKS MAJOR EXPANSION

Atlantic, Eastern Gulf of Mexico and Alaska Are in Plan

By JOHN M. BROWER

WASHINGTON — The Obama administration is proposing to open vast expanses of water along the Atlantic coastline, the eastern Gulf of Mexico and the north coast of Alaska to oil and natural gas drilling for the first time, officials said Tuesday.

The proposal — a compromise that will please oil companies and demand drilling advocates but anger some lawmakers in affected states and many environmental organizations — would end a moratorium that has kept most of the nation's coastal waters off limits to exploration and drilling since President George H. W. Bush imposed it in the aftermath of the Exxon Valdez oil spill in Prince William Sound in Alaska in 1989.

Under the plan, the coastline from New Jersey northward to the Canadian border would be opened to drilling, as would most of the Gulf of Mexico and the Alaskan coastline in the Beaufort and Chukchi Seas.

We are grateful for the past and continuing support from over one hundred funding agencies world-wide that contribute to the physics program of the LHC.

The key U.S. federal agencies are:

All of the universities involved also support this research directly or indirectly, including of course UCLA.

(I do not speak for any of the sponsoring organizations.)

Many thanks to the Swiss Consulate for initiating and co-sponsoring this evening!

For further information

CERN: http://www.cern.ch

CMS: http://cms.cern.ch

ATLAS: http://atlas.ch

US LHC: http://www.uslhc.us

Connecting Quarks with the Cosmos: National Academy of Science report, http://www.nap.edu/openbook.php?isbn=0309074061

The Quantum Universe: Two reports by DOE and NSF advisory panel, http://www.interactions.org/quantumuniverse/

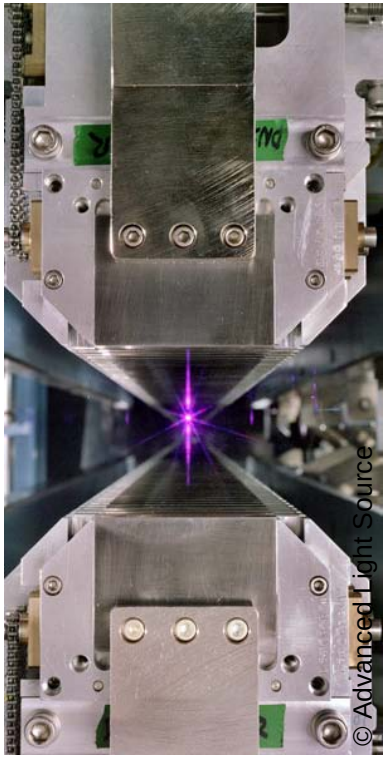
Backup slides follow

Training tomorrow's scientists

- The LHC inspires students of all ages
- More than 375 graduate students work on LHC research
- Undergraduate students gain research experience
- High school students learn with LHC data

Fermilab

Benefits of particle physics



© Advanced Light Source

More than 17,000 particle accelerators are in operation around the world today.

Industry, hospitals and research institutions all use them to manufacture household products, treat cancer and make new scientific discoveries.

© symmetry Magazine

Vague but exciting ...

CERN DD/OC

Information Management: A Proposal

Tim Berners-Lee, CERN/DD

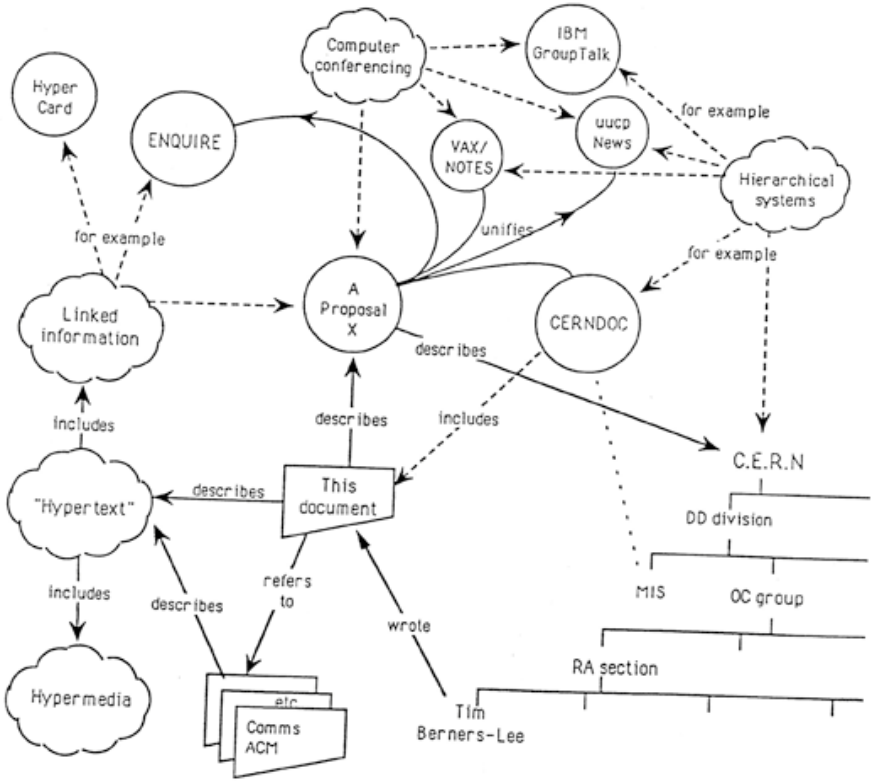
March 1989

Information Management: A Proposal

Abstract

This proposal concerns the management of general information about accelerators and experiments at CERN. It discusses the problems of loss of information about complex evolving systems and derives a solution based on a distributed hypertext sytstem.

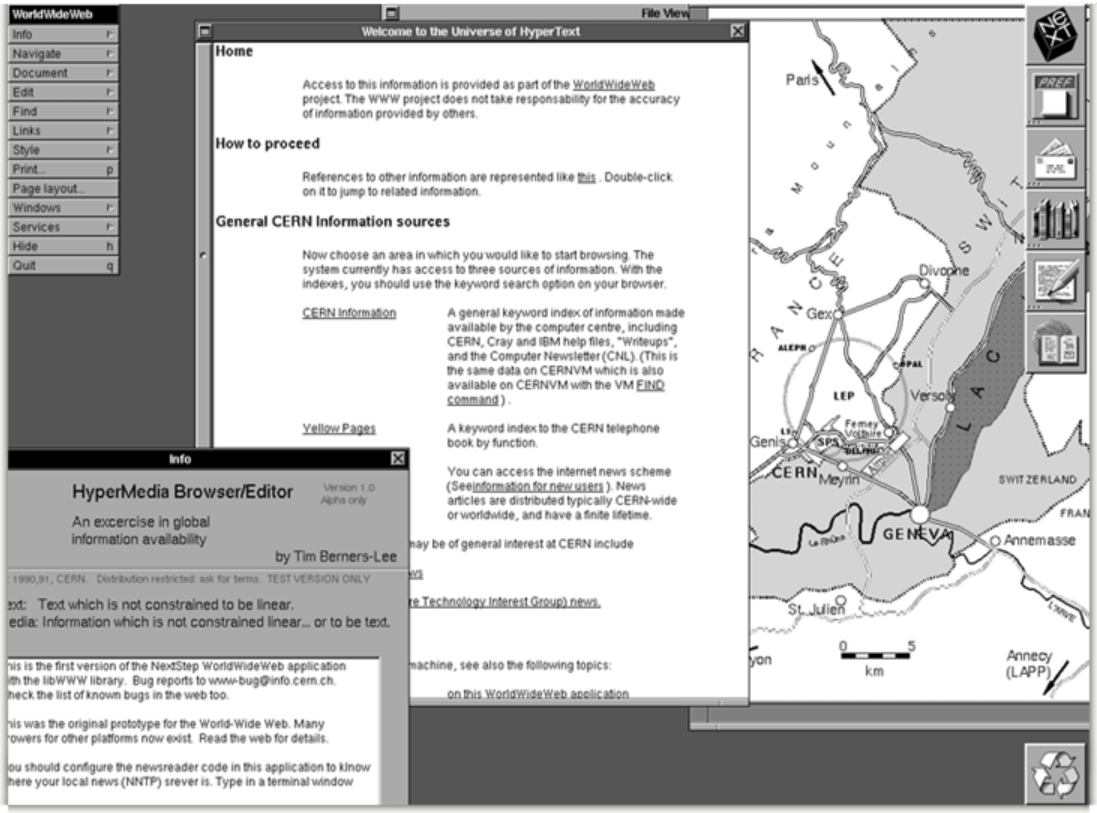
Keywords: Hypertext, Computer conferencing, Document retrieval, Information management, Project control



Tim Berners-Lee's original World Wide Web browser

A screen shot taken from a NeXT computer running Tim Berners-Lee's original WorldWideWeb browser. It has taken a long time for technology to catch up with Berners-Lee's original vision. The first ever web browser was also an editor, making the web an interactive medium, the problem was that it only ran on the NeXTStep operating system. With recent phenomena like blogs and wikis, the web is beginning to develop the kind of collaborative nature that its inventor envisaged from the start.

See also a screen shot taken later, in 1993.



Version note: This printing of the talk, on April 11, has some small proofreading changes, and the slide added on “For further information”.