

Title: The Large Hadron Collider - World's Most Powerful Microscope

Date: Nov 07, 2007 07:00 PM

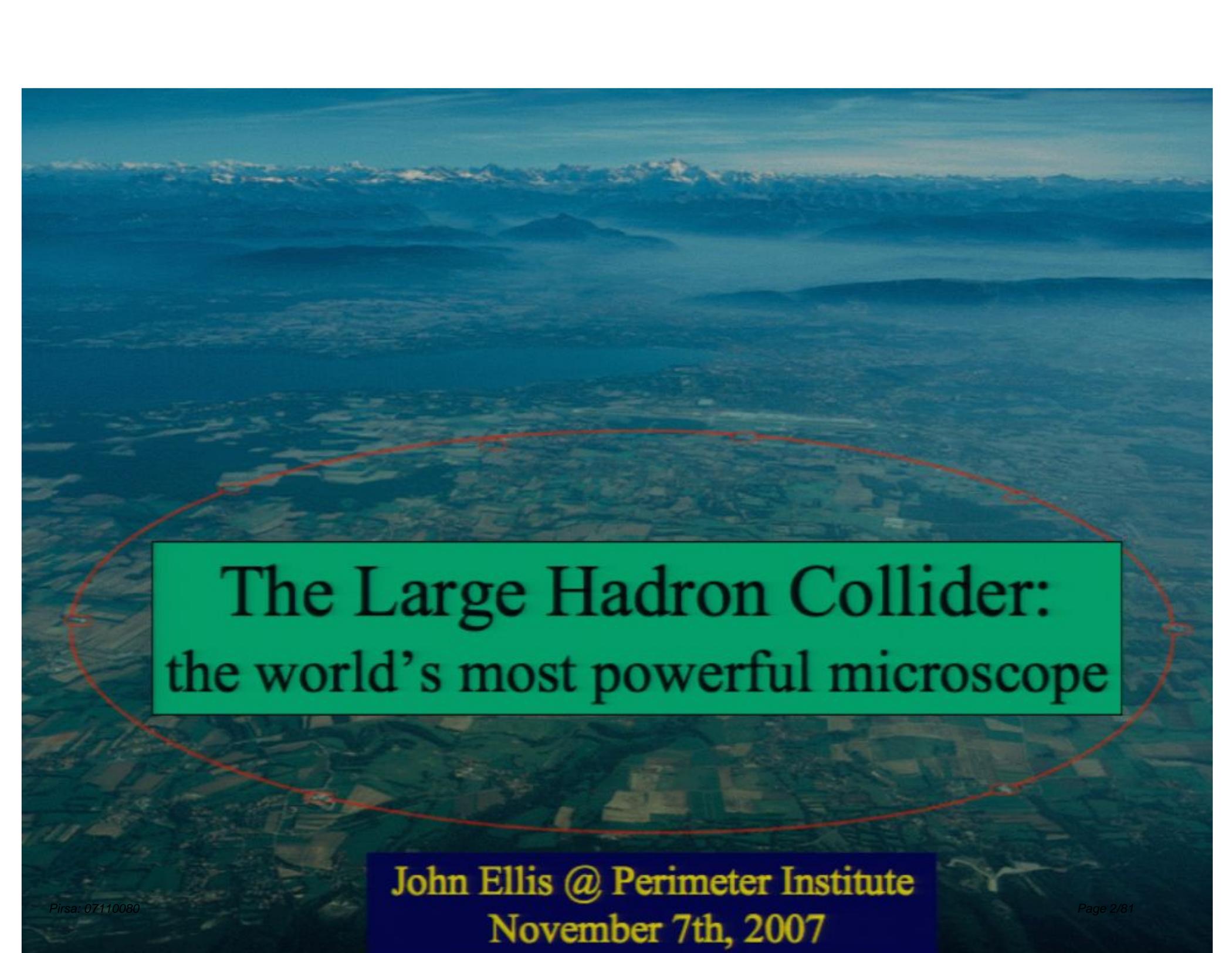
URL: <http://pirsa.org/07110080>

Abstract: <div id="Cleaner">"International researchers at the Large Hadron Collider (LHC), in Geneva, Switzerland, will soon embark on one of science's greatest adventures. With its very high energy, previously seen only in cosmic rays, the particle collider will probe the inner structure of matter at distances ten times smaller than any previous experiments. The LHC will address many of the mysteries surrounding the smallest particles of matter. It may also pierce secrets that the Universe has hidden since the early stages of the Big Bang, such as the nature of dark matter and the origin of matter itself. This will be the largest scientific experiment ever attempted and the complex international efforts to bring the 27km-long machine to life, including Canada's involvement, will also be explained."

<div id="Cleaner"><div id="Cleaner"><div id="Cleaner">About John Ellis<div id="Cleaner">Born in London on July 1st, 1946, Ellis grew up in Potters Bar, a suburb that some Londoners used to regard as the northern boundary of civilization. It was there, at around the age of 12, he decided to become a physicist " largely due to the interesting science books he read at the local library. Ellis obtained his BA and PHD from Cambridge University where he studied mathematics and theoretical physics. Following a year at the Stanford Linear Accelerator Center and an additional year at the California Institute of Technology as a research associate, Ellis joined CERN in 1973 and became leader of the Theory Division for six years. Currently, he is a senior staff member. Ellis is also an advisor on CERN's relations with non-Member States.<div id="Cleaner"><div id="Cleaner">Ellis has published over 700 scientific articles in particle physics and related areas of cosmology and astrophysics. His research interests include the possible experimental consequences and tests of new theoretical ideas such as gauge theories of strong and electroweak interactions, grand unified theories, supersymmetry, and string theory. He was elected a Fellow of the Royal Society in 1985, and was awarded the Dirac Medal of the Institute of Physics in 2005. Ellis is also responsible for popularizing the term "Theory of Everything" in an article published in the journal Nature in 1986.

<div id="Cleaner"><div id="Cleaner"><div id="Cleaner">About Robert S. Orr<div id="Cleaner">Professor Orr was born in Iran, and grew up in Scotland and South Wales. His father and uncles were all engineers in the ship building industry. His interest in physics was sparked early in his childhood by trying to make sense of his father's textbooks. "Ever since I was a child, I took things apart to see how they worked" says Orr. "Doing that with matter is the ultimate challenge."

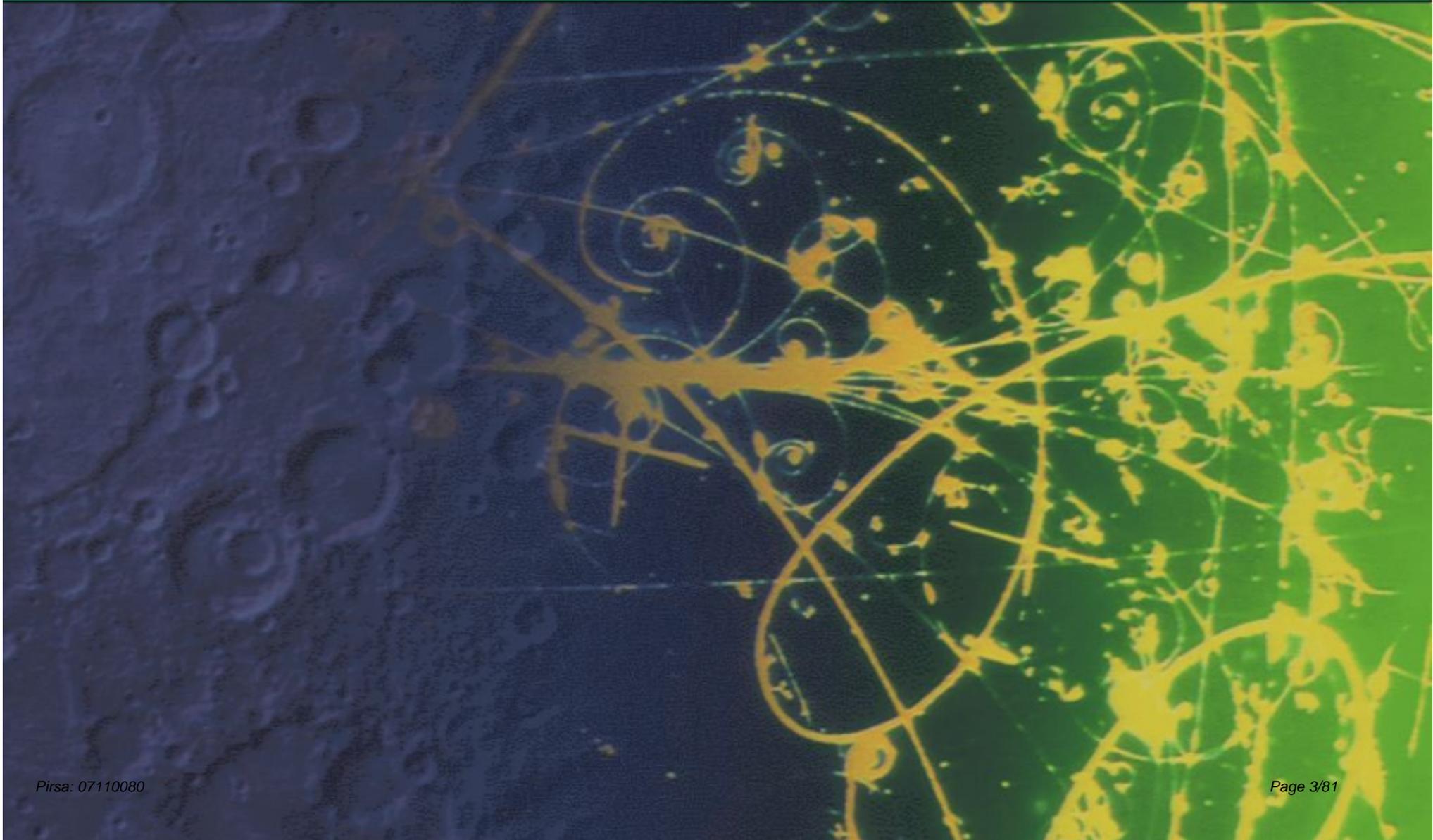
<div id="Cleaner"><div id="Cleaner">At present he is a Professor in the Department of Physics at the University of Toronto. He was NSERC Principal Investigator for ATLAS Canada from 1994 to 2007. ATLAS is a detector within the LHC at CERN. Orr earned his B.Sc. and Ph.D. at Imperial College, University of London, UK, and was a Post Doctoral Researcher at Rutherford Laboratory, also in the UK, as well as at the University of Wisconsin, Madison, USA. From 1974 to 1981 he was a CERN Fellow and Staff Physicist. He came to Canada in 1981 as an Institute of Particle Physics Research Scientist, and became a member of the faculty at the University of Toronto in 1989. Orr has worked at many of the world's particle physics labs in the USA, Germany and Japan. He has a particular interest in the application of large scale computing clusters in this field, and in the development of new finds of detection devices.



The Large Hadron Collider: the world's most powerful microscope

**John Ellis @ Perimeter Institute
November 7th, 2007**

What is the Nature of Matter and the Universe?



What is the Nature of Matter and the Universe?



What is the Nature of Matter and the Universe?



Where are we coming from?

What are we?

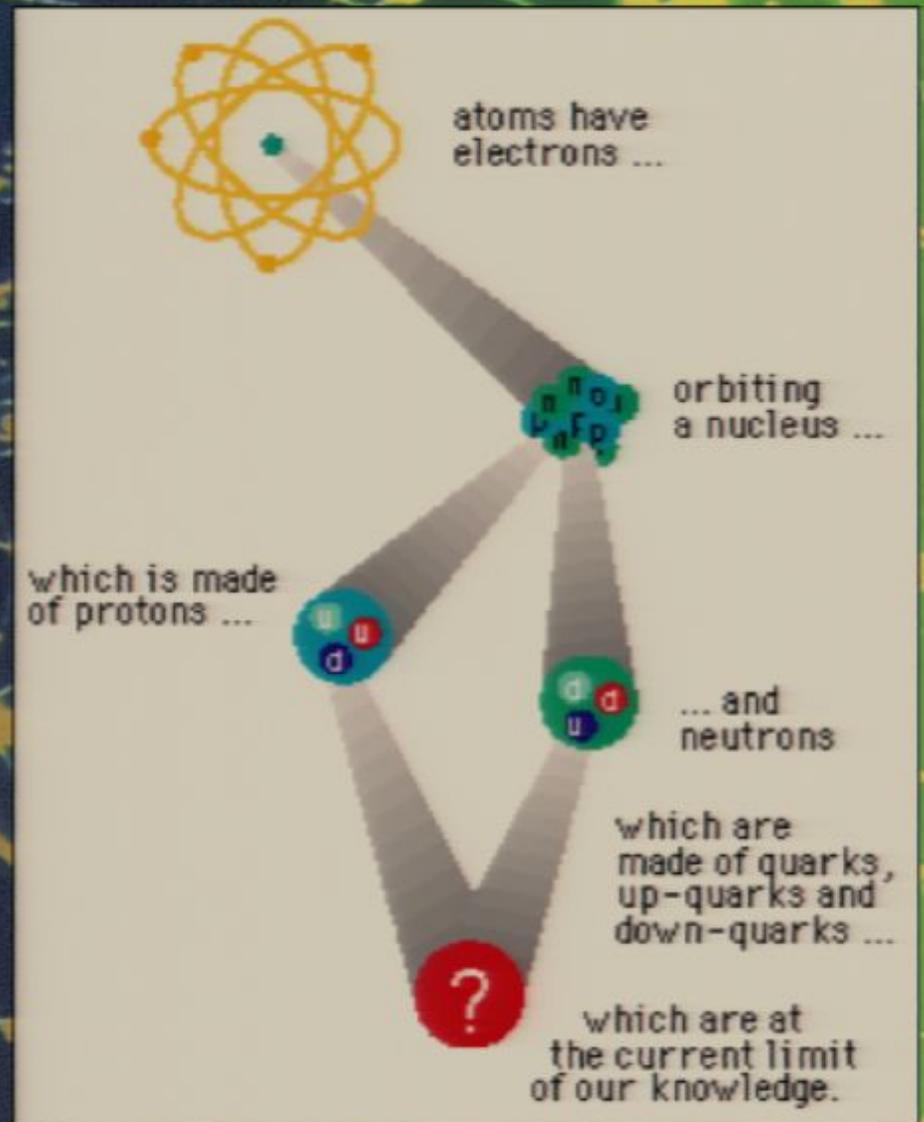
Where are we going?

Inside Matter



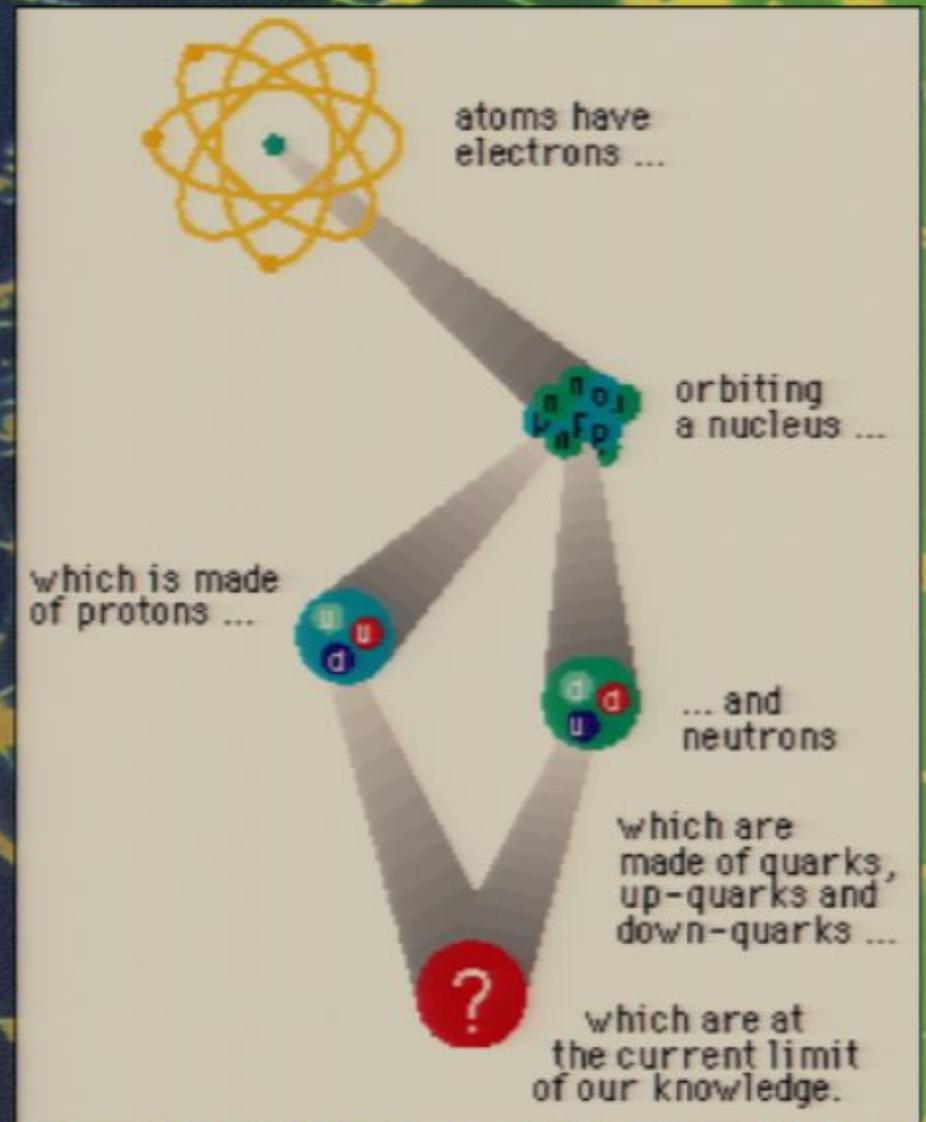
**All matter is made of
the same constituents**

Inside Matter



All matter is made of the same constituents

Inside Matter

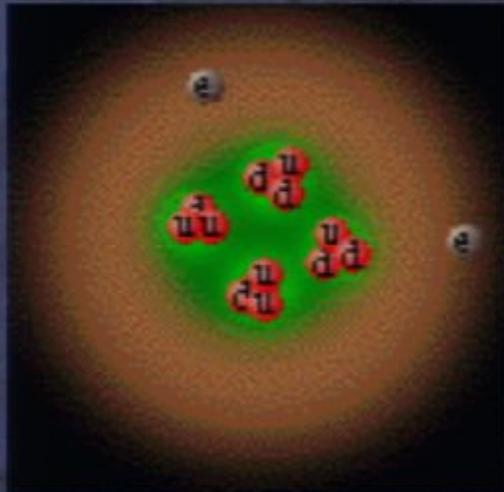


All matter is made of the same constituents

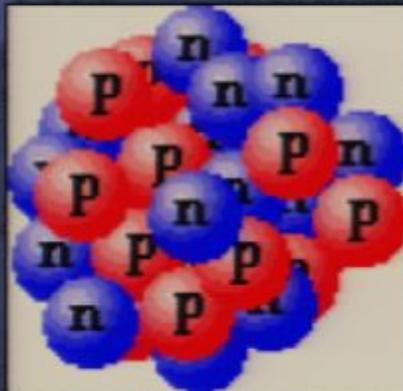
What are they?
What are the forces between them?

All the different Elements ...

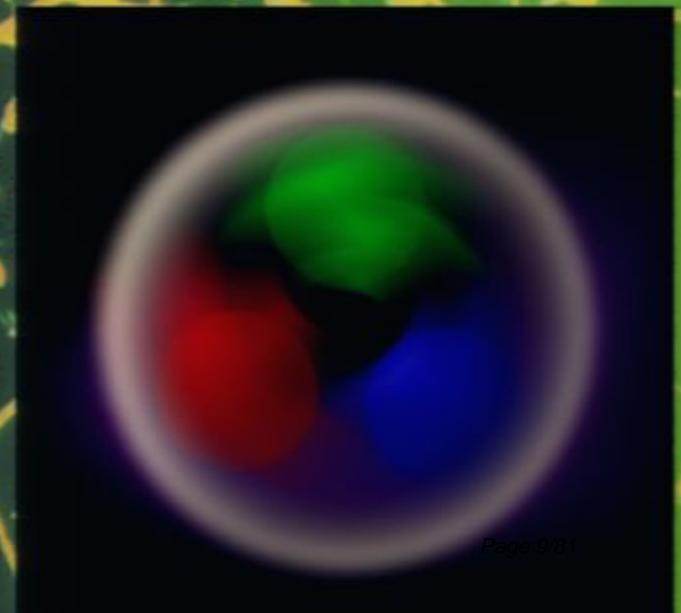
... are made of atoms ...



... whose nuclei contain Protons & Neutrons ...



... whose structure we study at CERN



... are made of atoms ...

Periodic Table of the Elements

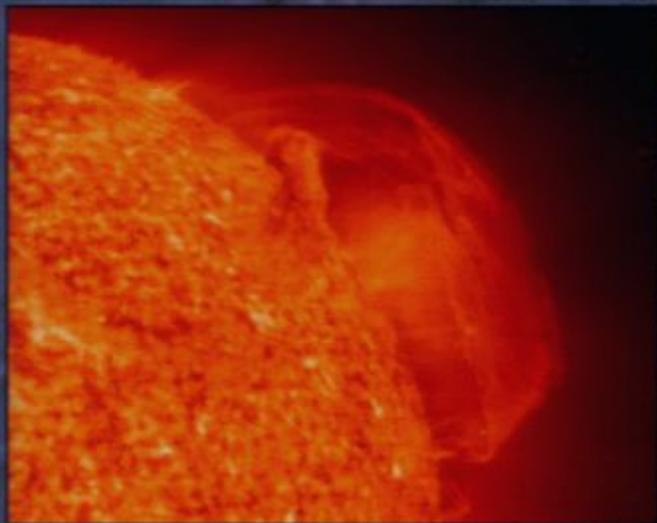
1A	1	H	IIA																	0	2	He				
	3	Li	4	Be																	5	6	7	8	9	10
	11	Na	12	Mg	IIIB	IVB	VB	VIB	VIB	VII	IB	IB					13	14	15	16	17	18				
	19	K	20	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	31	32	33	34	35	36						
	37	Rb	38	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	49	50	51	52	53	54						
	55	Cs	56	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	81	82	83	84	85	86						
	87	Fr	88	Ra	+Ac	Rf	Ha	106	107	108	109	110	111	112												
<i>Naming conventions of new elements</i>																										
		* Lanthanide Series																								
		58	59	60	61	62	63	64	65	66	67	68	69	70	71											
		Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu											
		+ Actinide Series																								
		90	91	92	93	94	95	96	97	98	99	100	101	102	103											
		Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr											

The Fundamental Forces of Nature

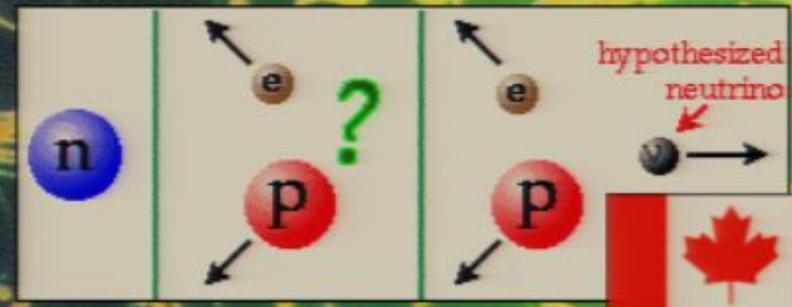
Electromagnetism:
gives light, radio, holds atoms together

Strong Nuclear Force:
holds nuclei together

Weak Nuclear Force:
gives radioactivity



together
they make
the Sun
shine



Gravity:
holds planets and stars together

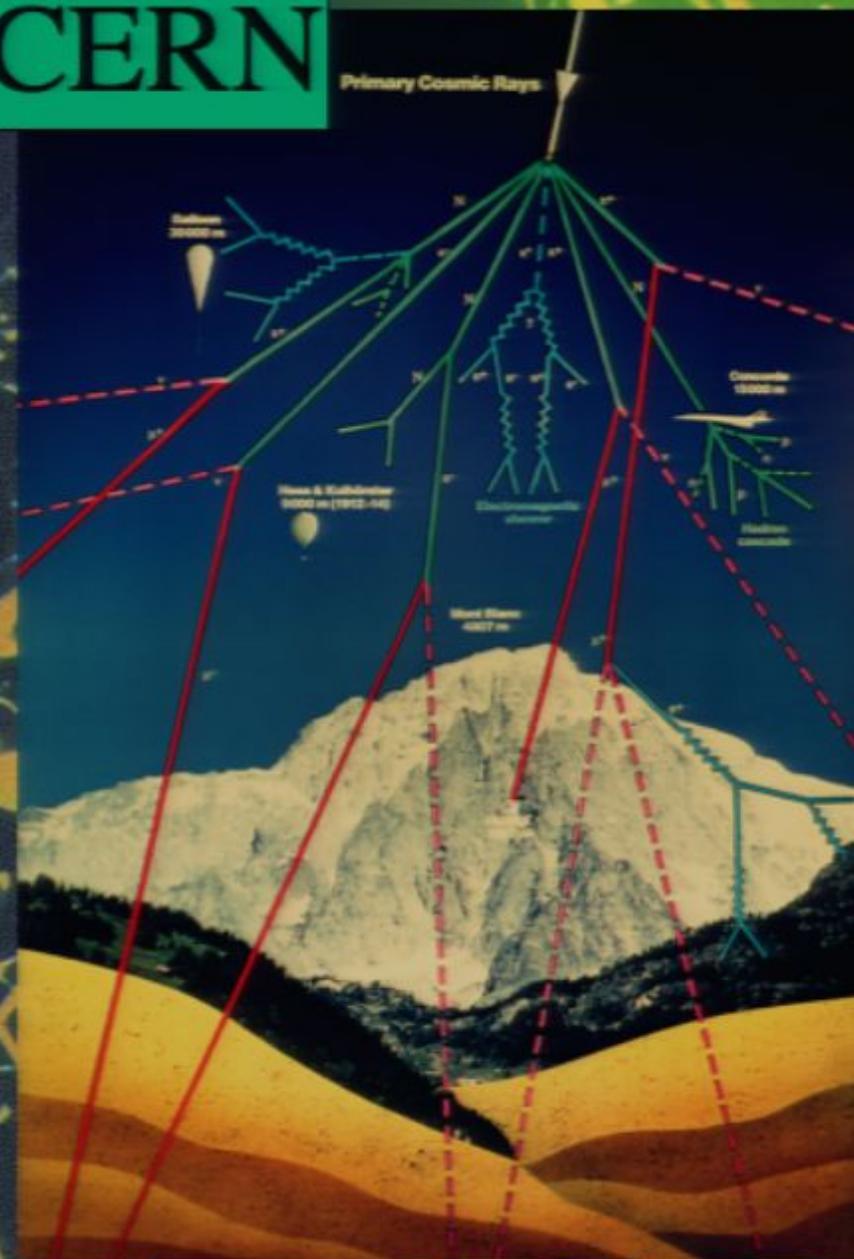


From Cosmic Rays to CERN

Discovered a century ago ...



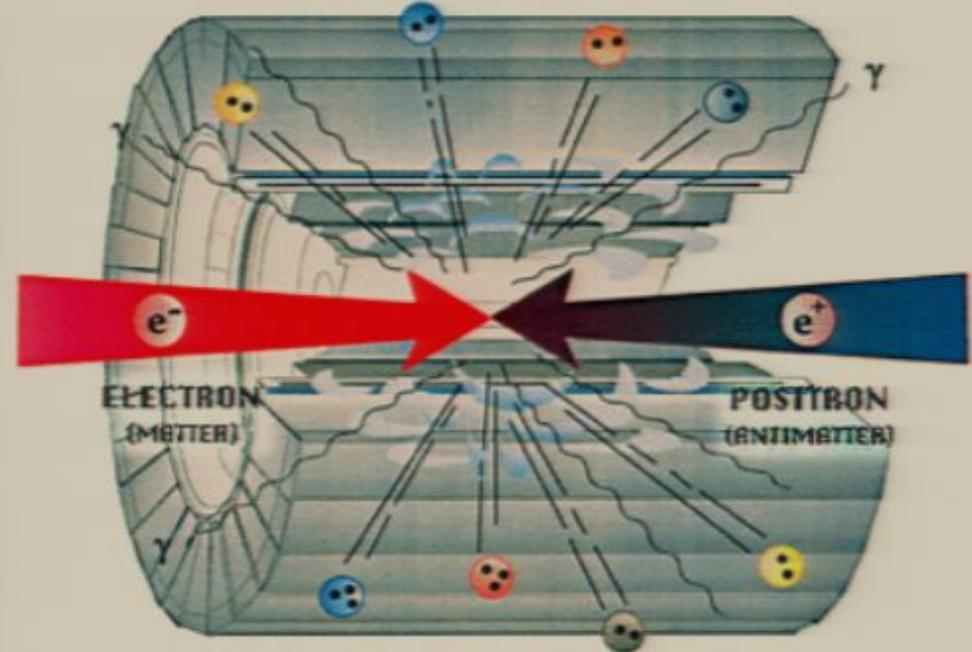
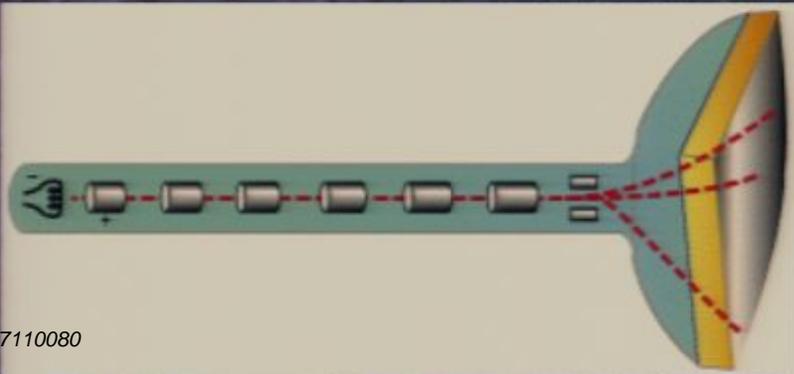
... cosmic-ray showers were found to contain many different types of particles ...



Experiments at Accelerators

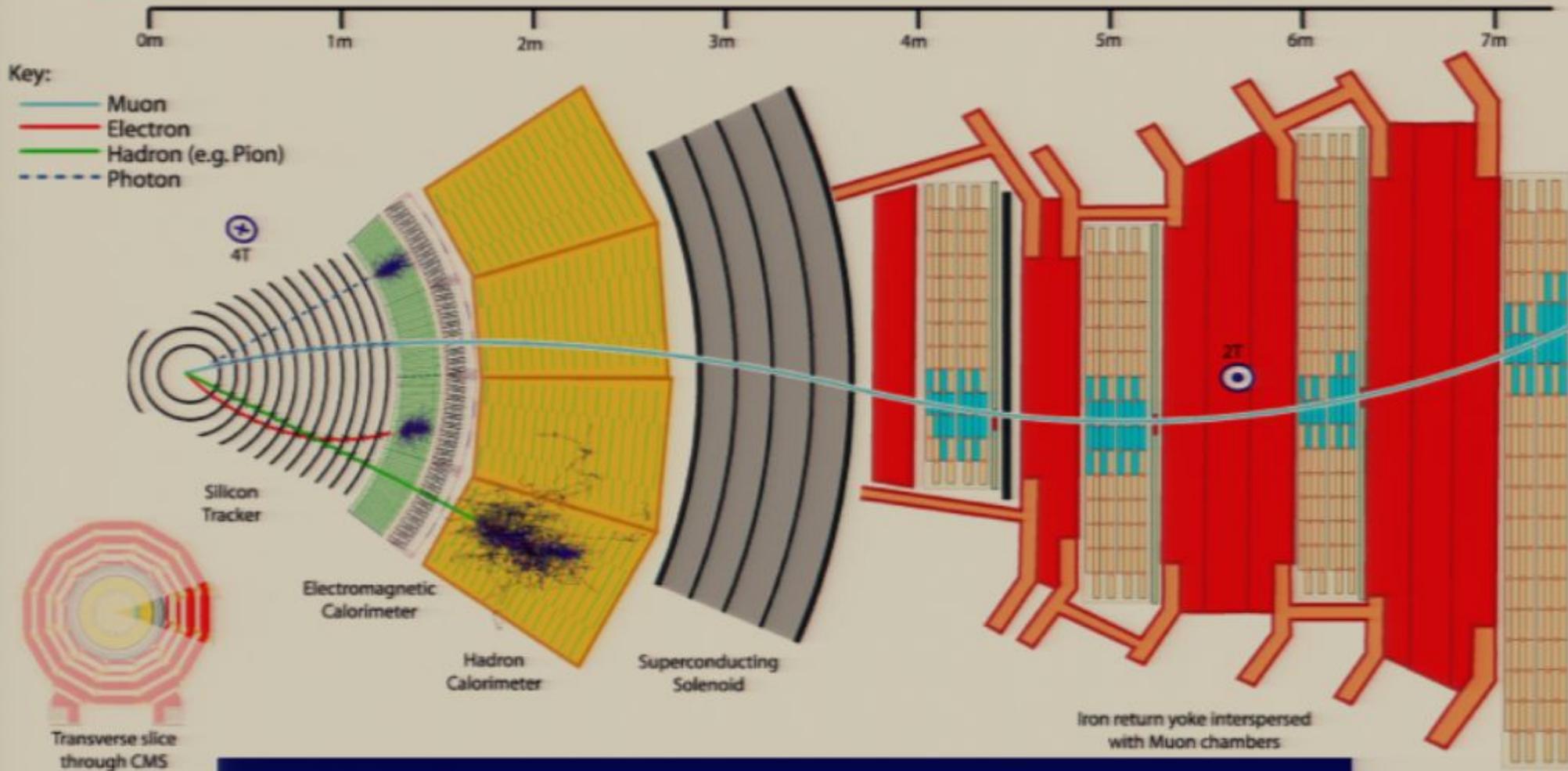
Probing matter at very small scales requires super-microscopes going to very high energies

Large accelerators are based on same principles as TV set



Accelerate and direct particle beams using electric and magnetic fields

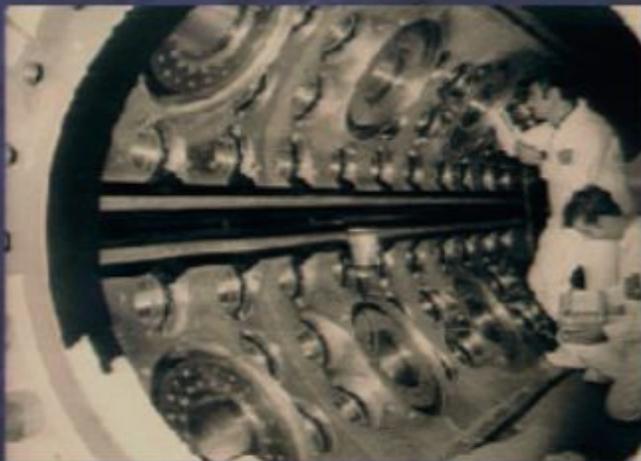
Particle Detectors are Onions



Each layer designed to detect a different type of particle

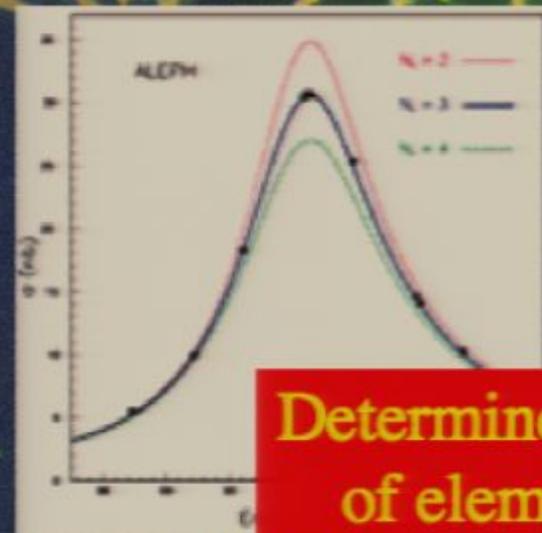
The 'Standard Model' of Particle Physics

Proposed by Abdus Salam,
Glashow & Weinberg



Crucial tests in
experiments at CERN, etc.

In agreement with all
confirmed laboratory
experiments



Determine how many types
of elementary particles

The 'Standard Model'

= Cosmic DNA

The matter particles



The fundamental interactions



Open Questions beyond the Standard Model

- What is the origin of particle masses?
due to a Higgs boson?
- Why so many types of matter particles?
- What is the astrophysical dark matter?
- Unification of fundamental forces?
- Quantum theory of gravity?

LHC

LHC

LHC

LHC

LHC

Some particles have mass, some do not

Where do the masses
come from?

Newton:

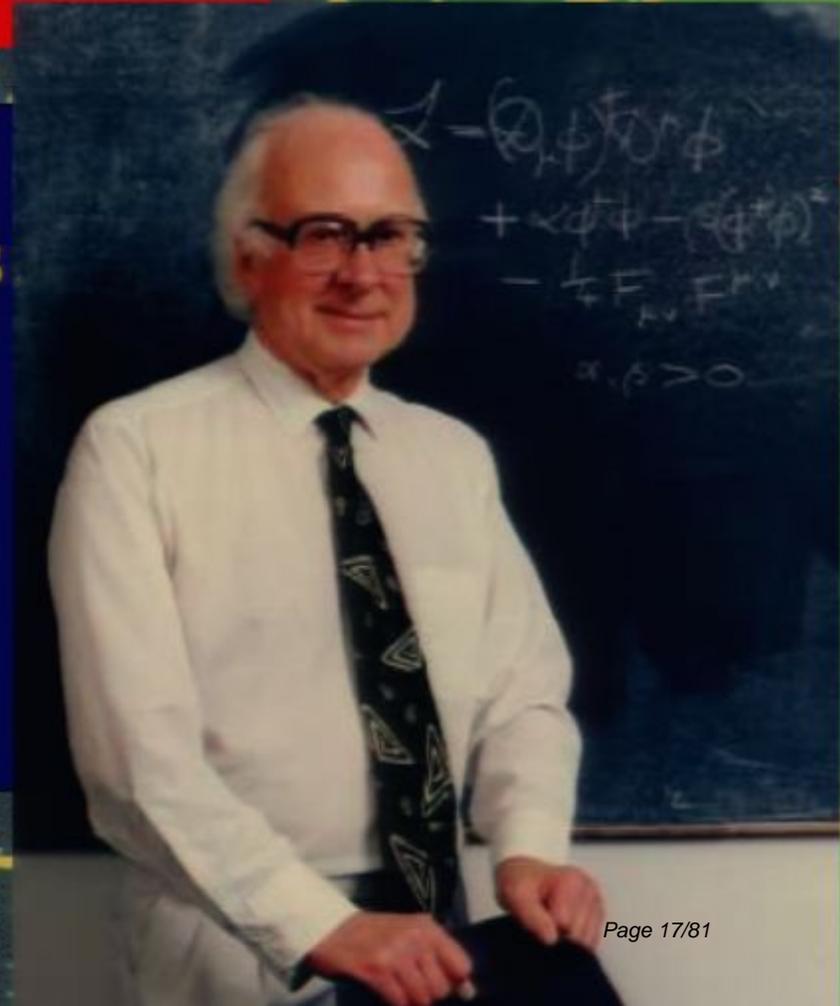
Weight proportional to Mass

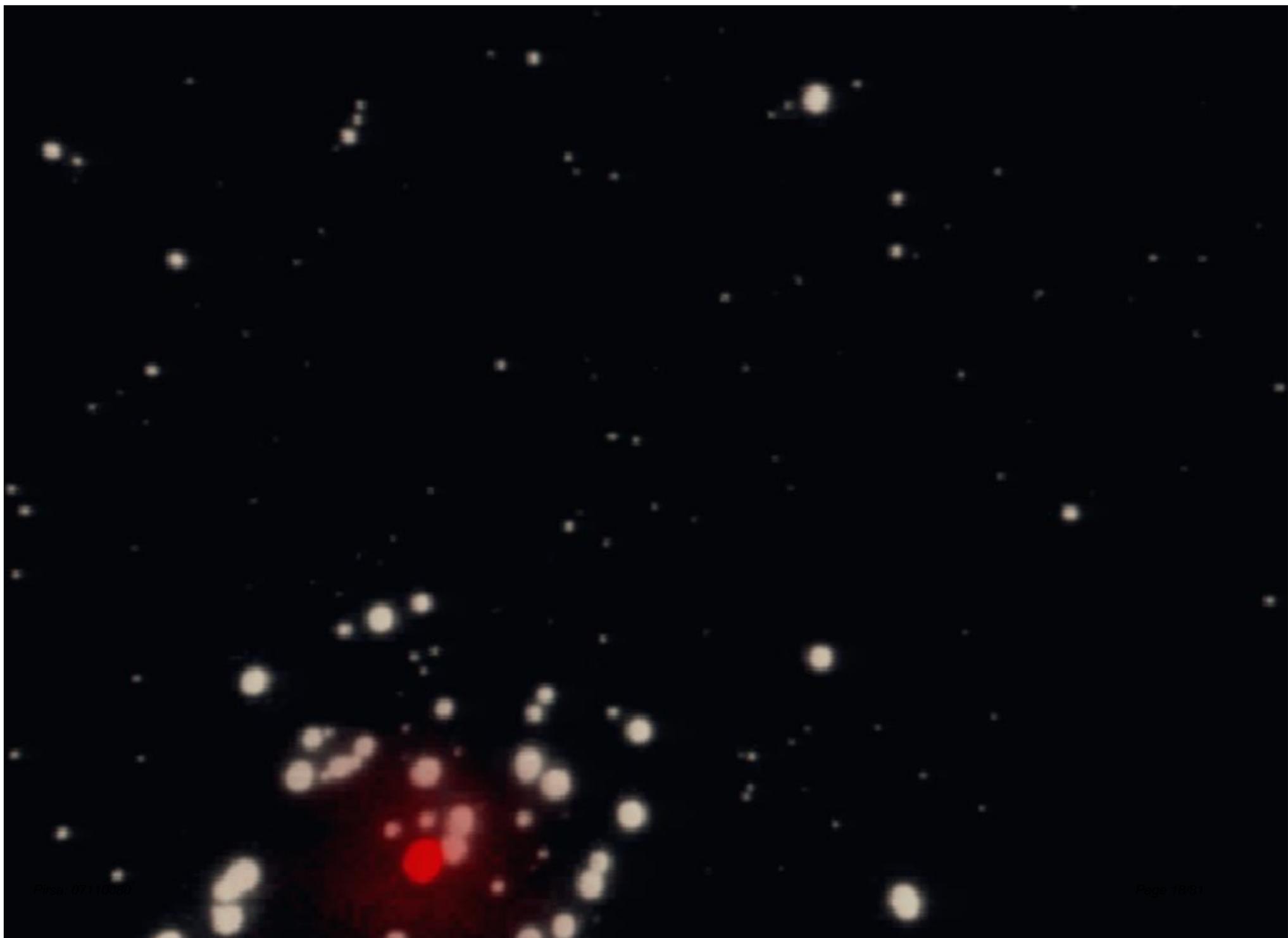
Einstein:

Energy related to Mass

Neither explained origin of Mass

**Are masses due to Higgs boson?
(yet another particle)**





And Supersymmetry?

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

0 - $\frac{1}{2}$ - 1 - $\frac{3}{2}$ - 2

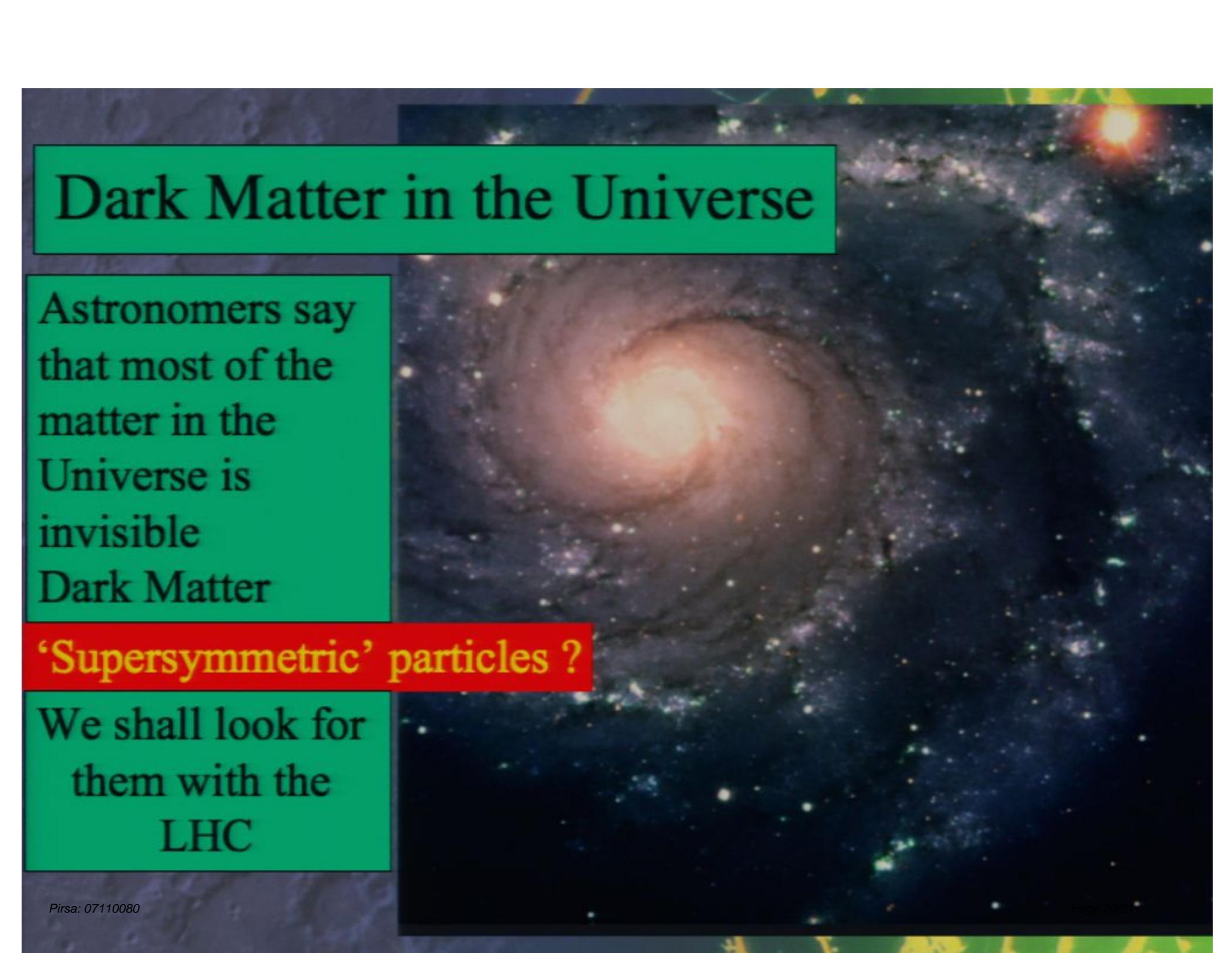
Higgs - Electron - Photon - Gravitino - Graviton

(Every particle is a 'ballet dancer')

- Would help fix particle masses
- Would help unify forces
- Could provide dark matter wanted by astrophysicists and cosmologists



Dark Matter in the Universe



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

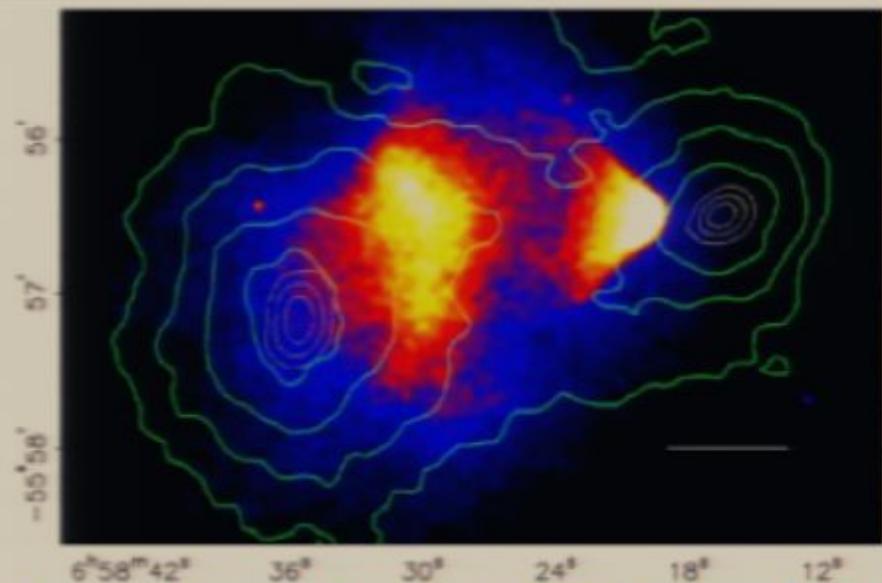
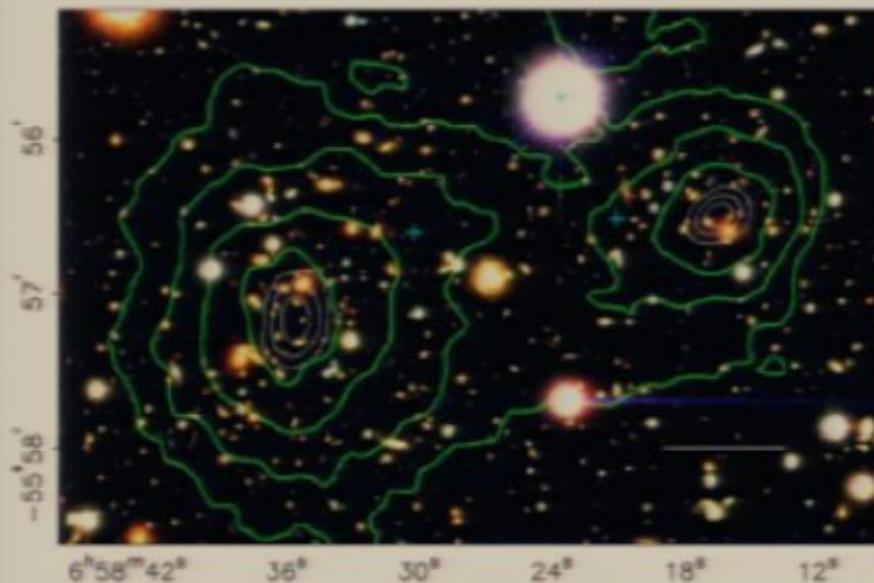
‘Supersymmetric’ particles ?

We shall look for
them with the
LHC

Direct Evidence for Collisionless Dark Matter

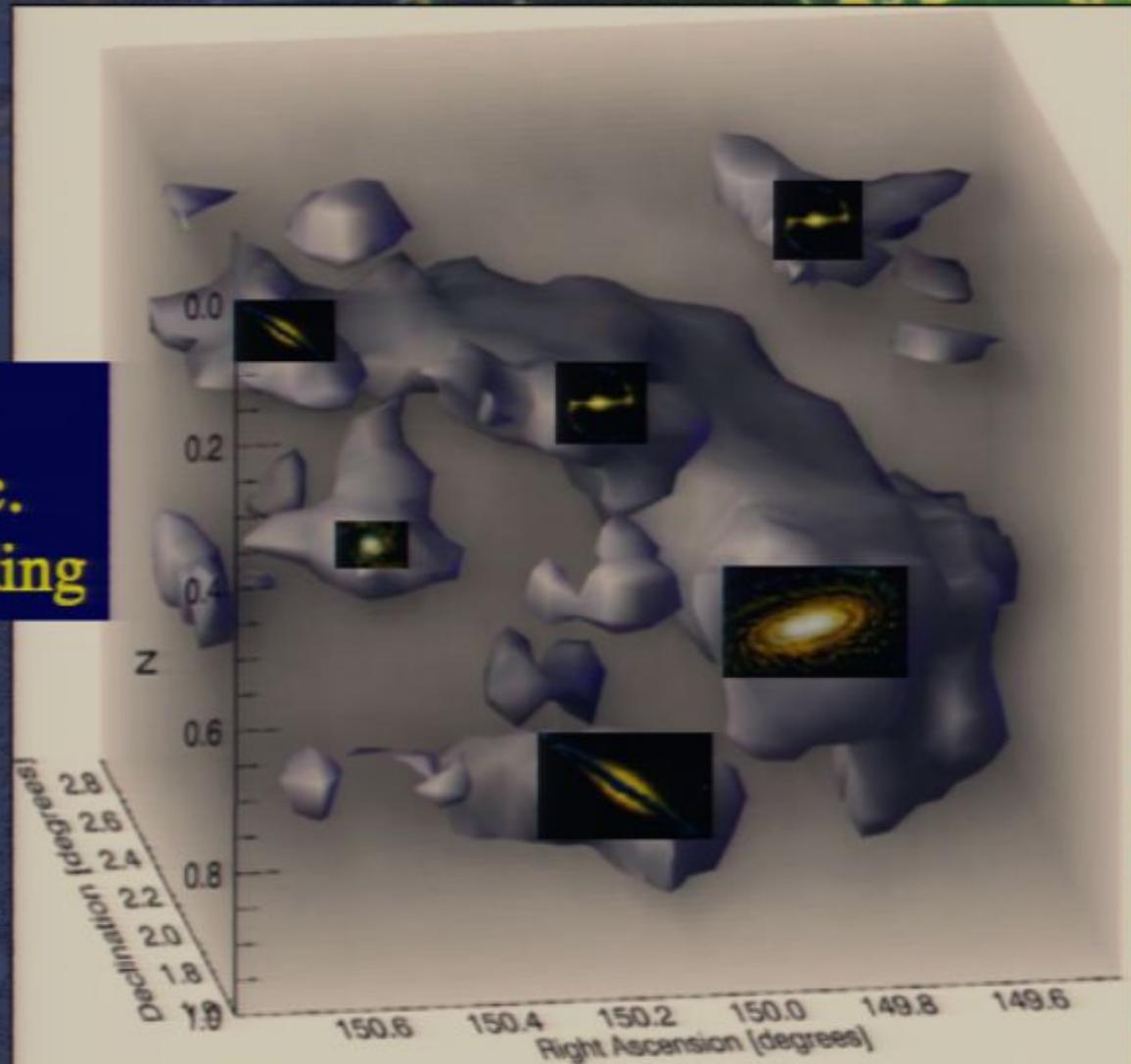
Collision of two galaxies:
dark matter lumps pass through

Collision of two galaxies:
gaseous matter stuck in between



The Dark Matter Scaffolding

Visible matter:
galaxies, stars, etc.
hang on the scaffolding



How do Matter and Antimatter Differ?

Dirac predicted the existence of antimatter:

same mass

opposite internal properties:

electric charge, ...

Discovered in cosmic rays

Studied using accelerators

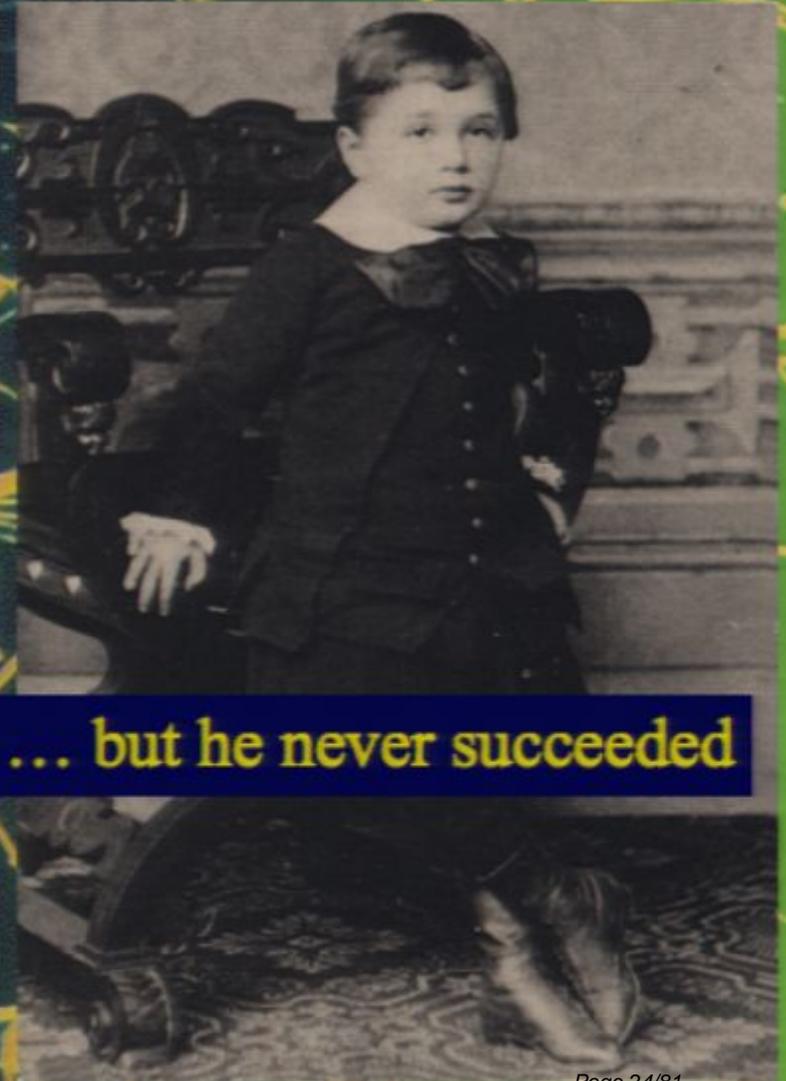
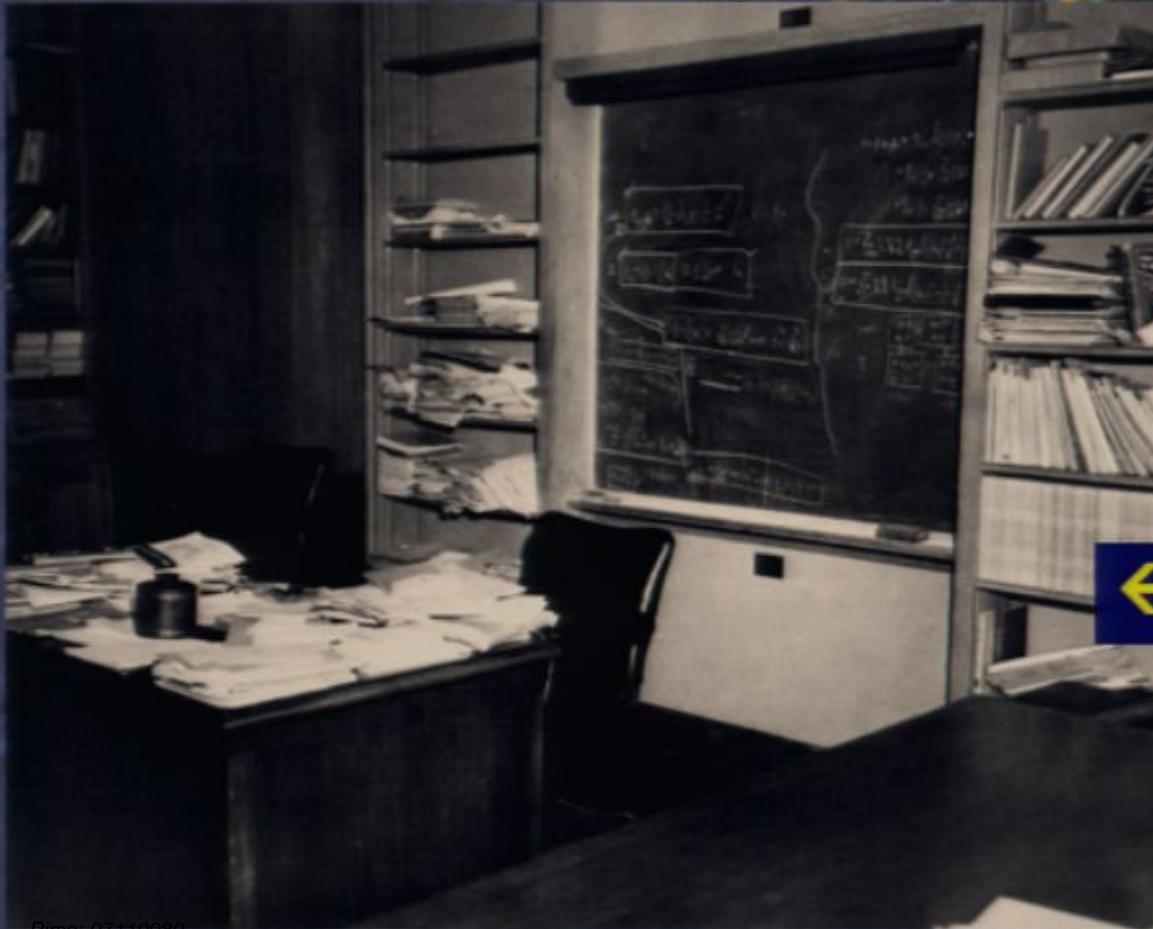


Matter and antimatter not quite equal and opposite: WHY?

Why does the Universe mainly contain matter, not antimatter?

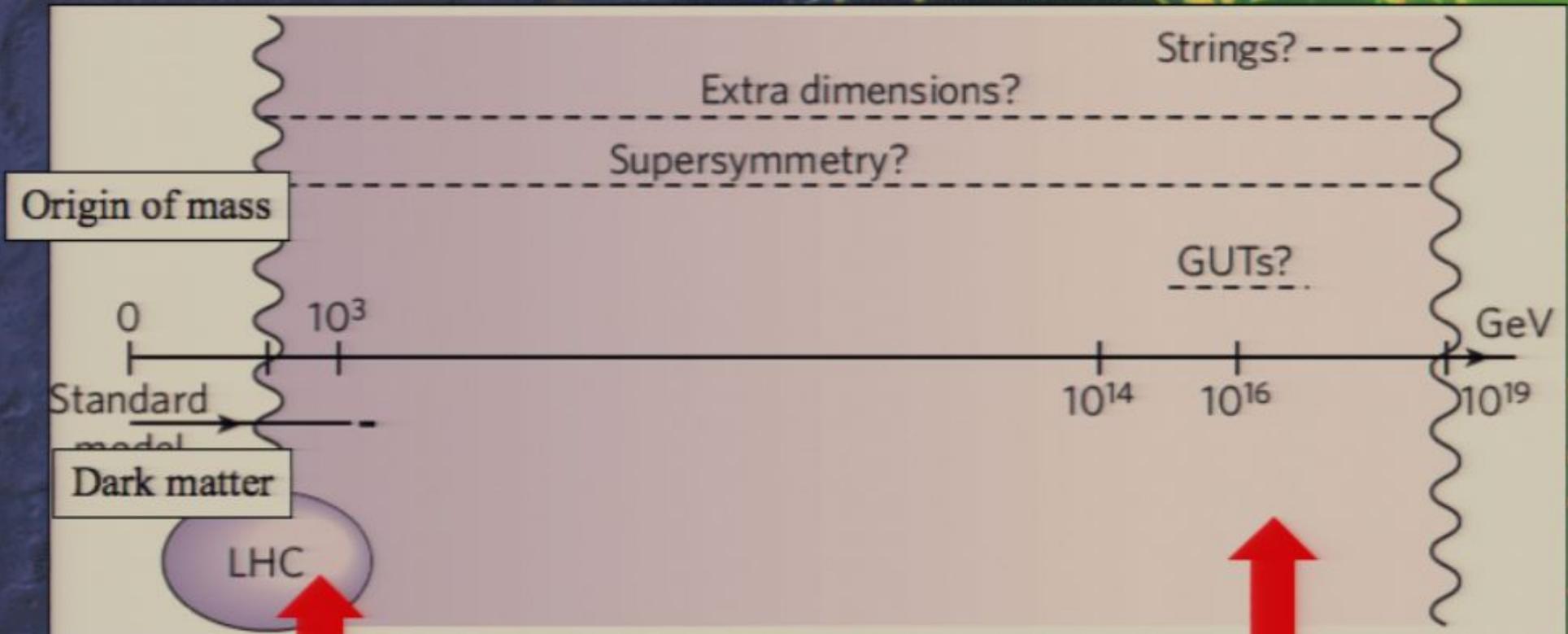
Experiments at LHC and elsewhere looking for answers

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



← ... but he never succeeded

At what Energy is the New Physics?



A lot accessible directly to the LHC

Some accessible only indirectly: via cosmology?

The Large Hadron Collider (LHC)

Proton- Proton Collider

7 TeV + 7 TeV



1,000,000,000 collisions/second

Each collision releases enough energy
to create 14000 protons

Primary targets:

- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

Some LHC Facts

LHC circumference = 26.6 kms

Average depth ~ 100 metres

Temperature = 1.9 degrees above absolute zero

Proton energy of 7 TeV = energy of 5 trillion AA batteries

= energy of 7 flying mosquitos

= over 7000 proton masses

Proton speed = 0.9999999991 velocity of light

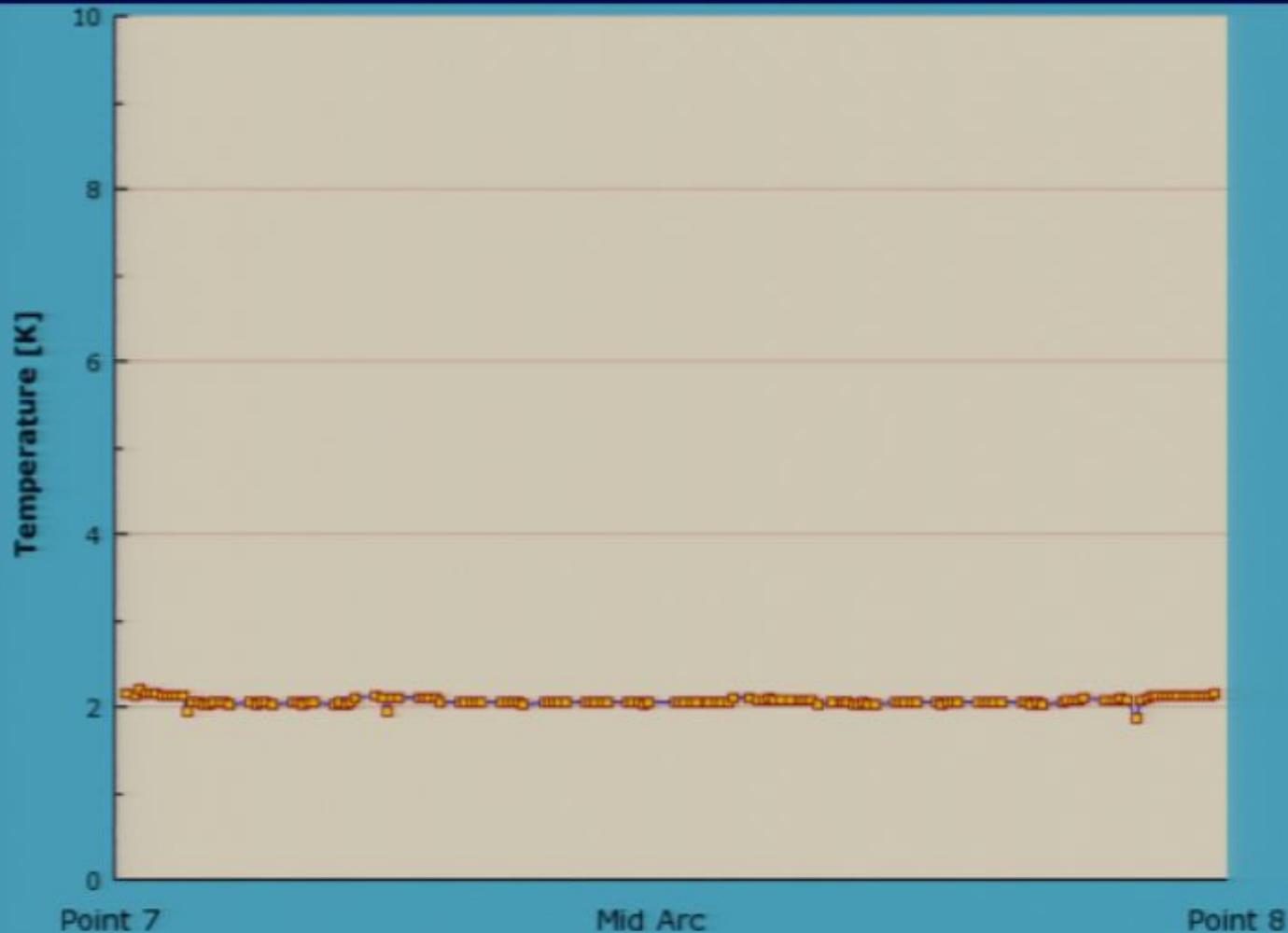
Total energy of beams ~ high-speed TGV train

When they collide, beams are narrower than human hair

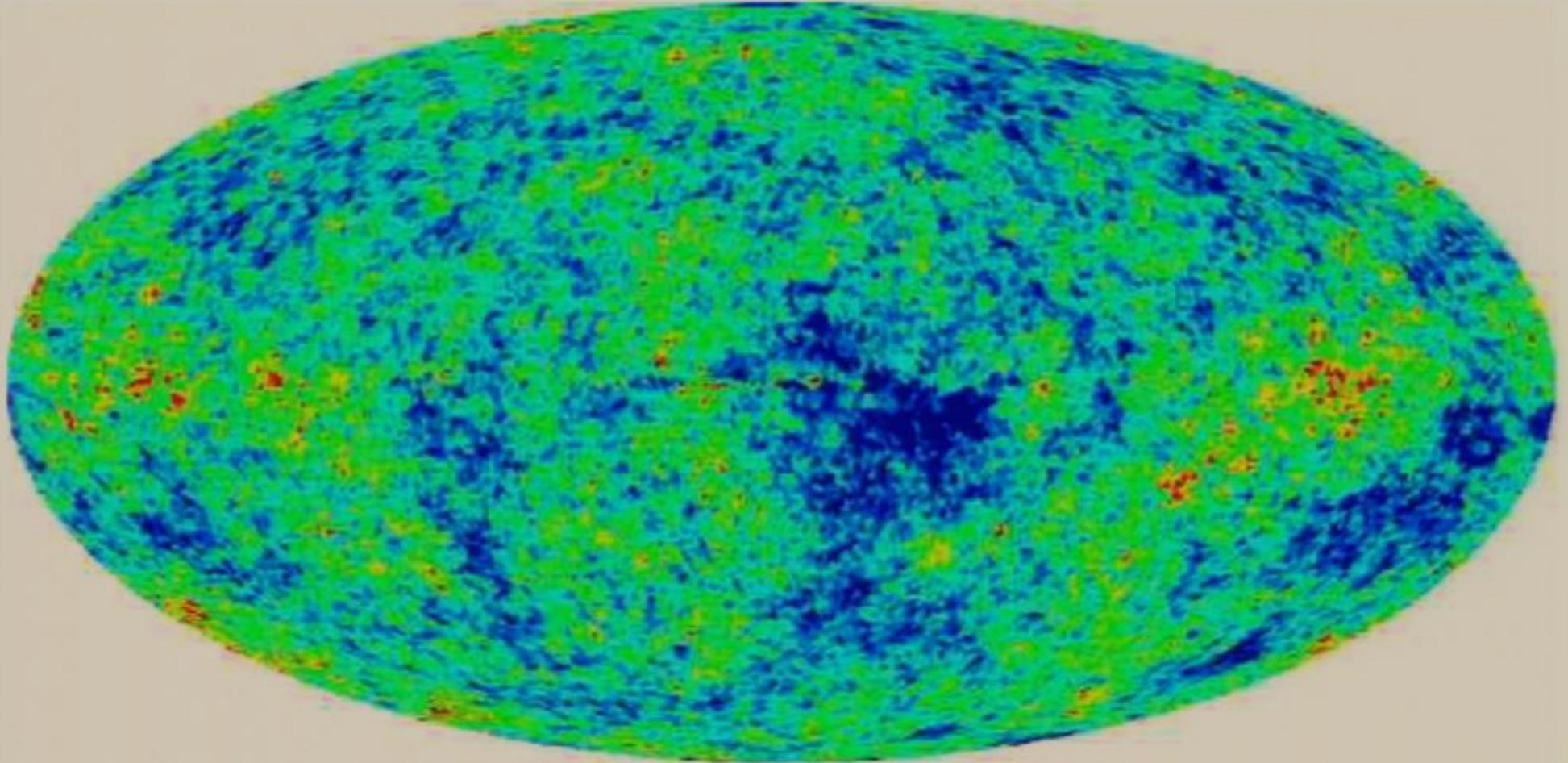
Cost of accelerator ~ 4.6 billion Swiss Francs

Colder than Outer Space

1.9 degrees above absolute zero = -271.3 degrees Celsius

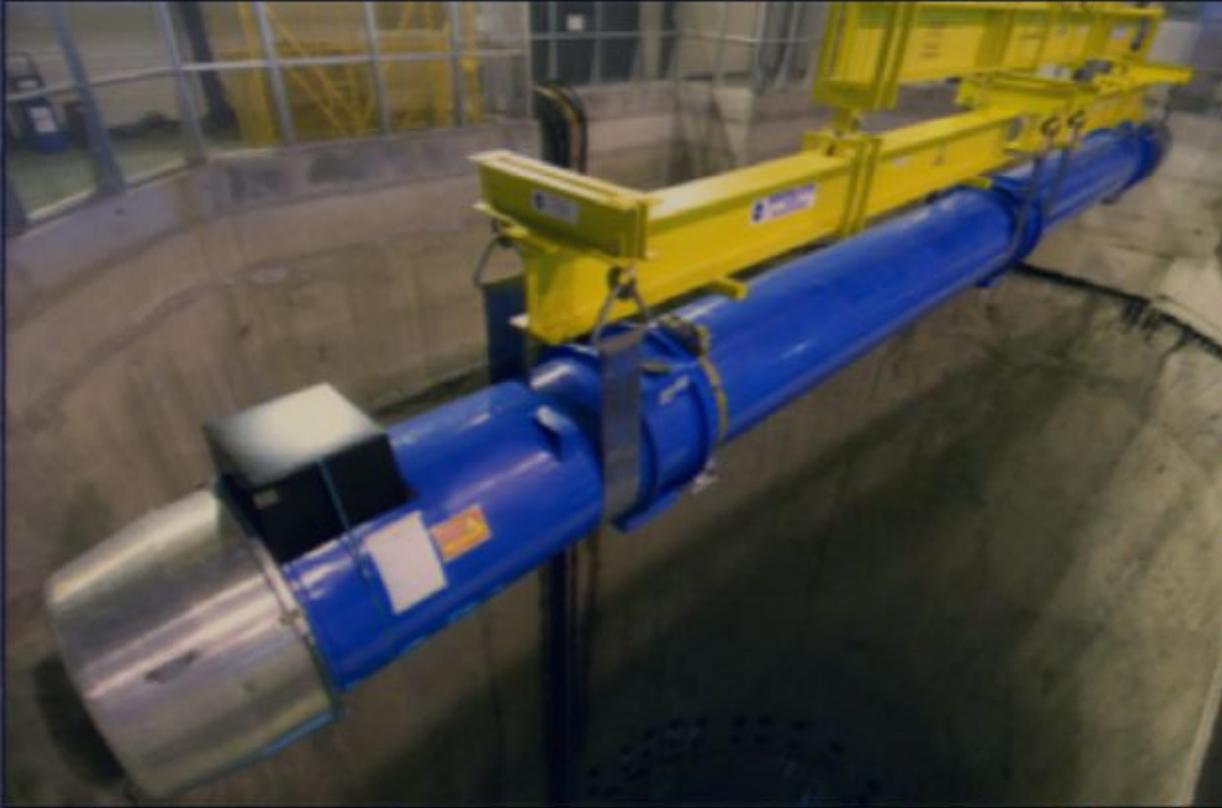


Warmer than the LHC

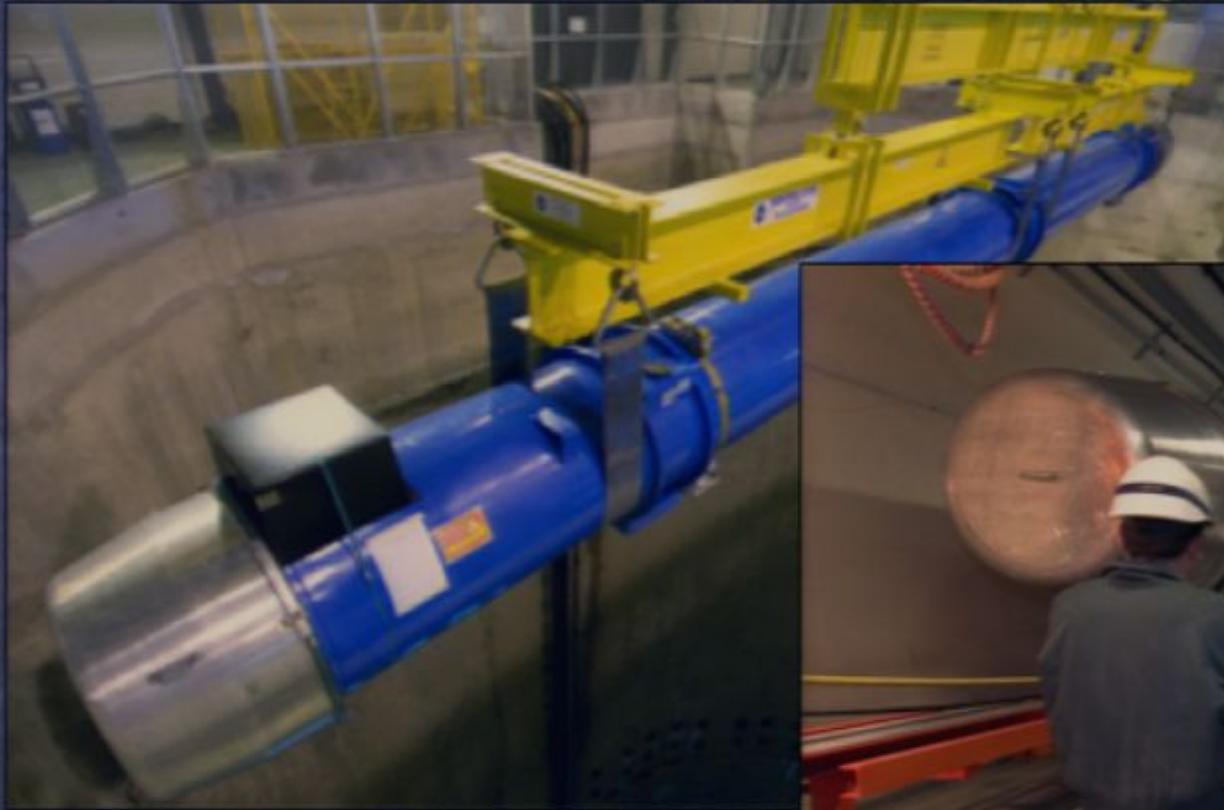


Cosmic background temperature ~ 2.7 degrees above absolute zero
 ~ -270.5 degrees Celsius

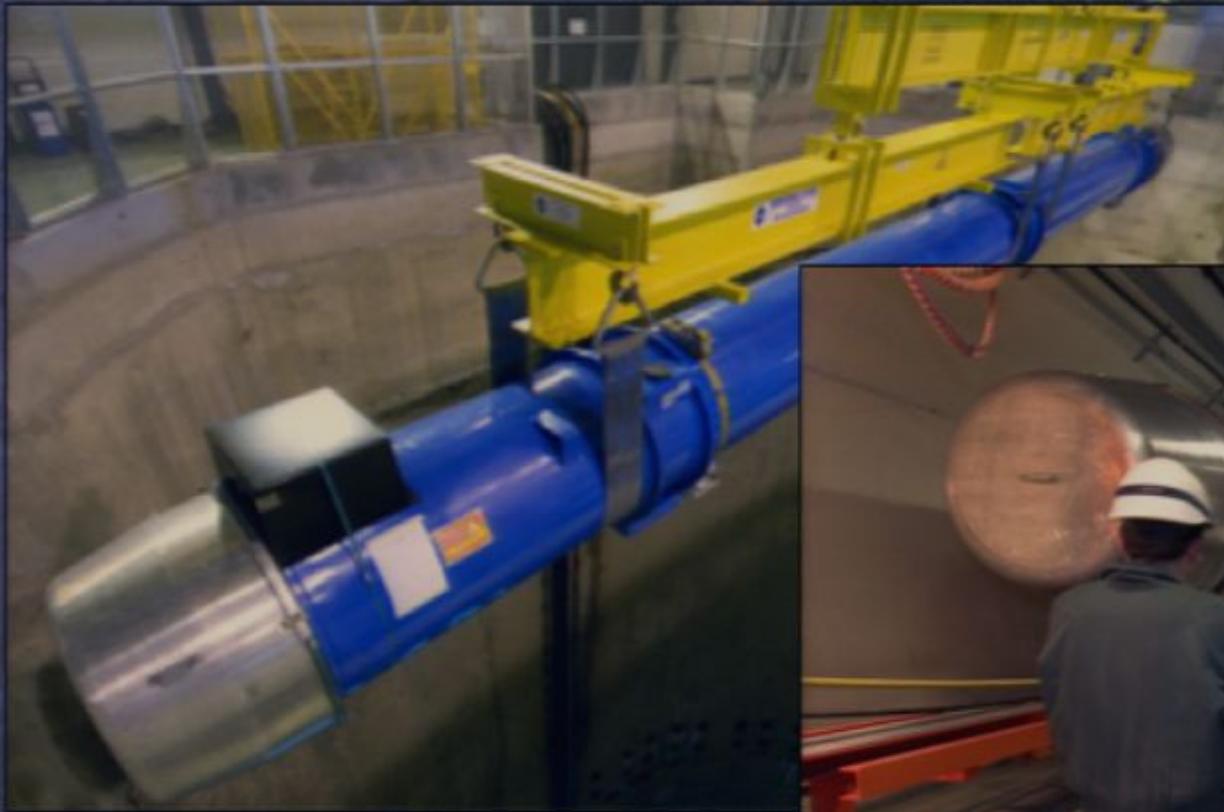
Installation of LHC Magnets



Installation of LHC Magnets



Installation of LHC Magnets



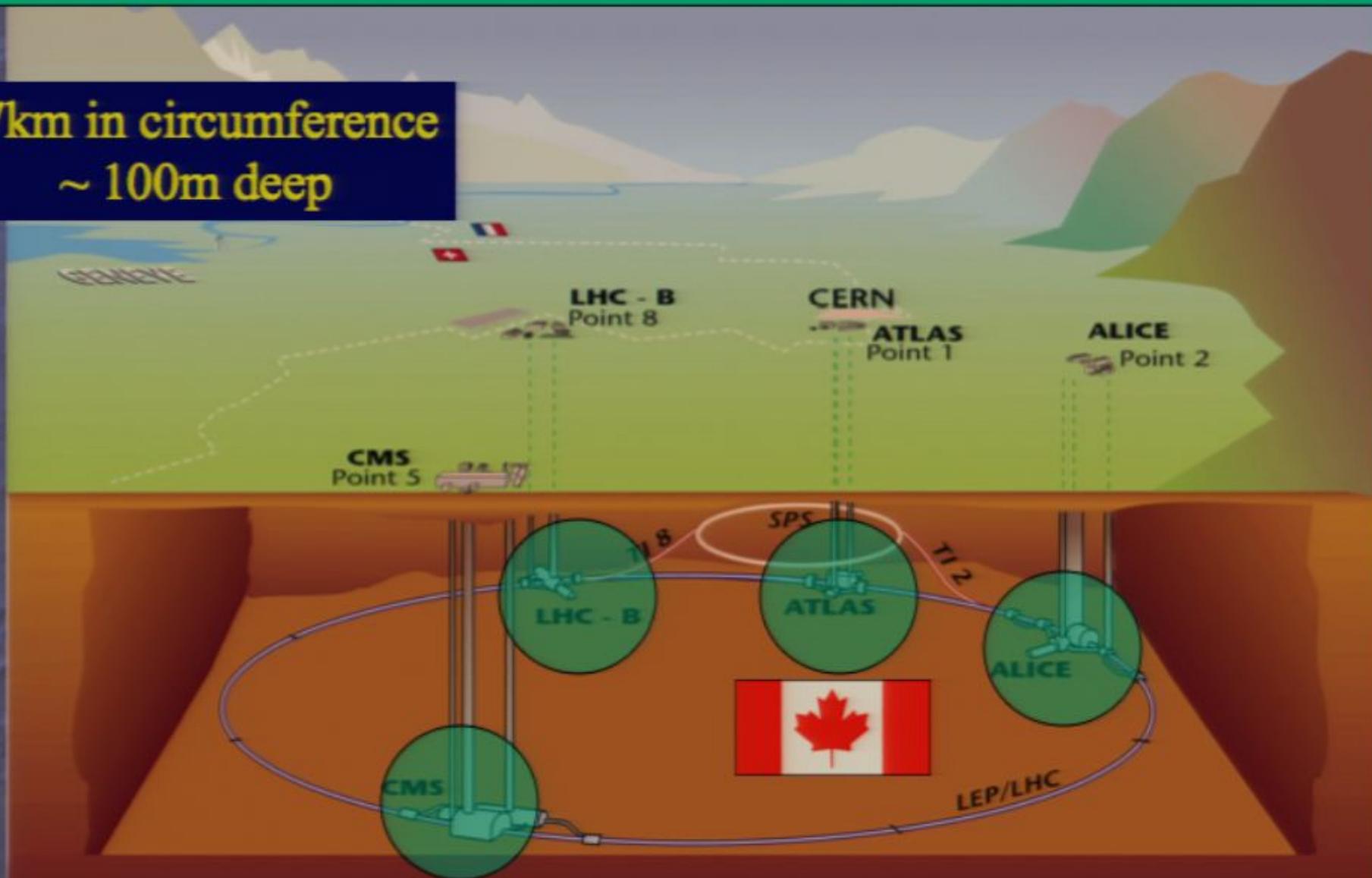
Installation complete: collisions in 2008

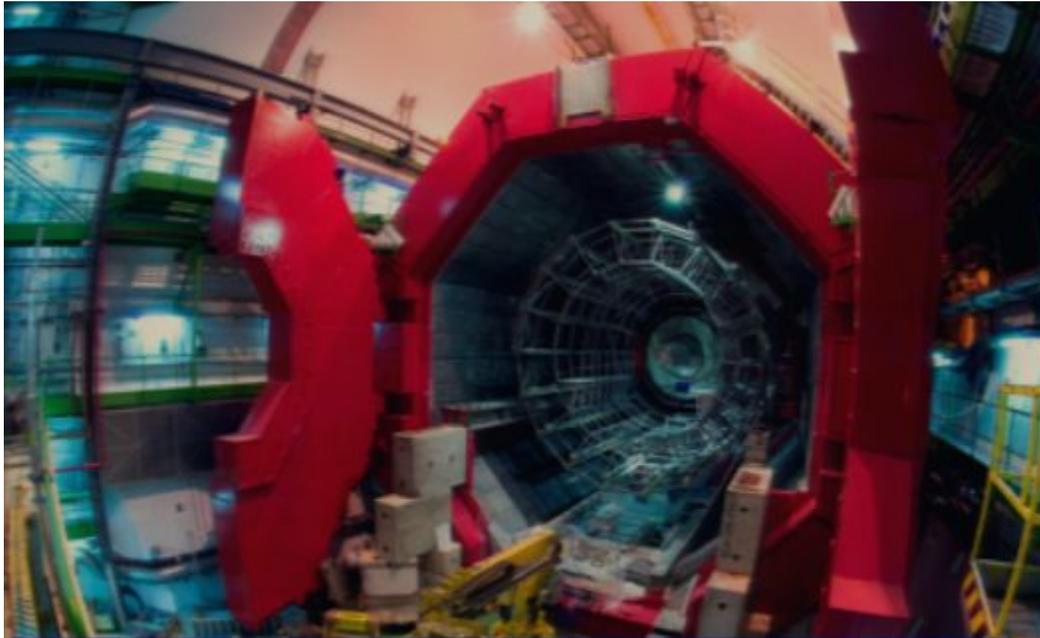
Contributions to LHC accelerator from:

Canada India Japan Russia US Pakistan

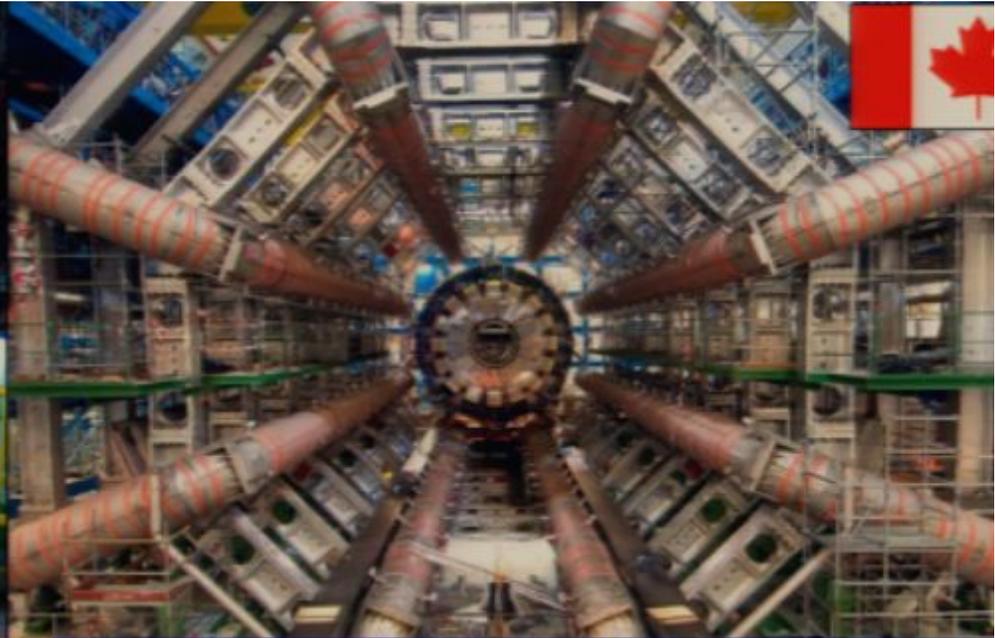
General View of LHC & its Experiments

27km in circumference
~ 100m deep

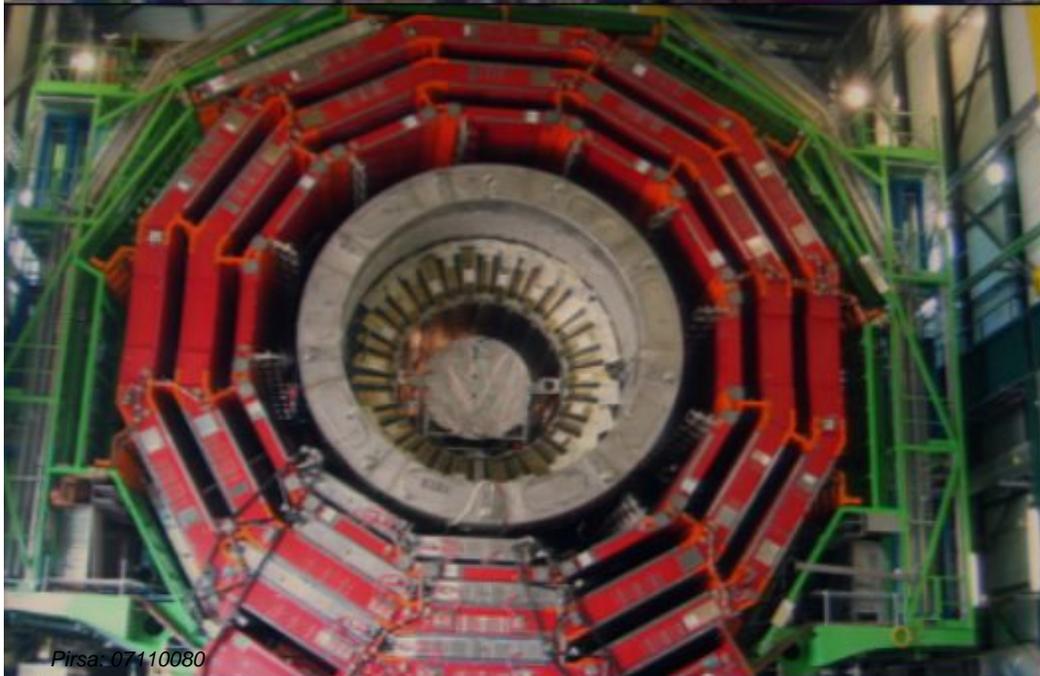




ALICE: Primordial cosmic plasma



ATLAS: Higgs and supersymmetry



Pirsa: 07110080

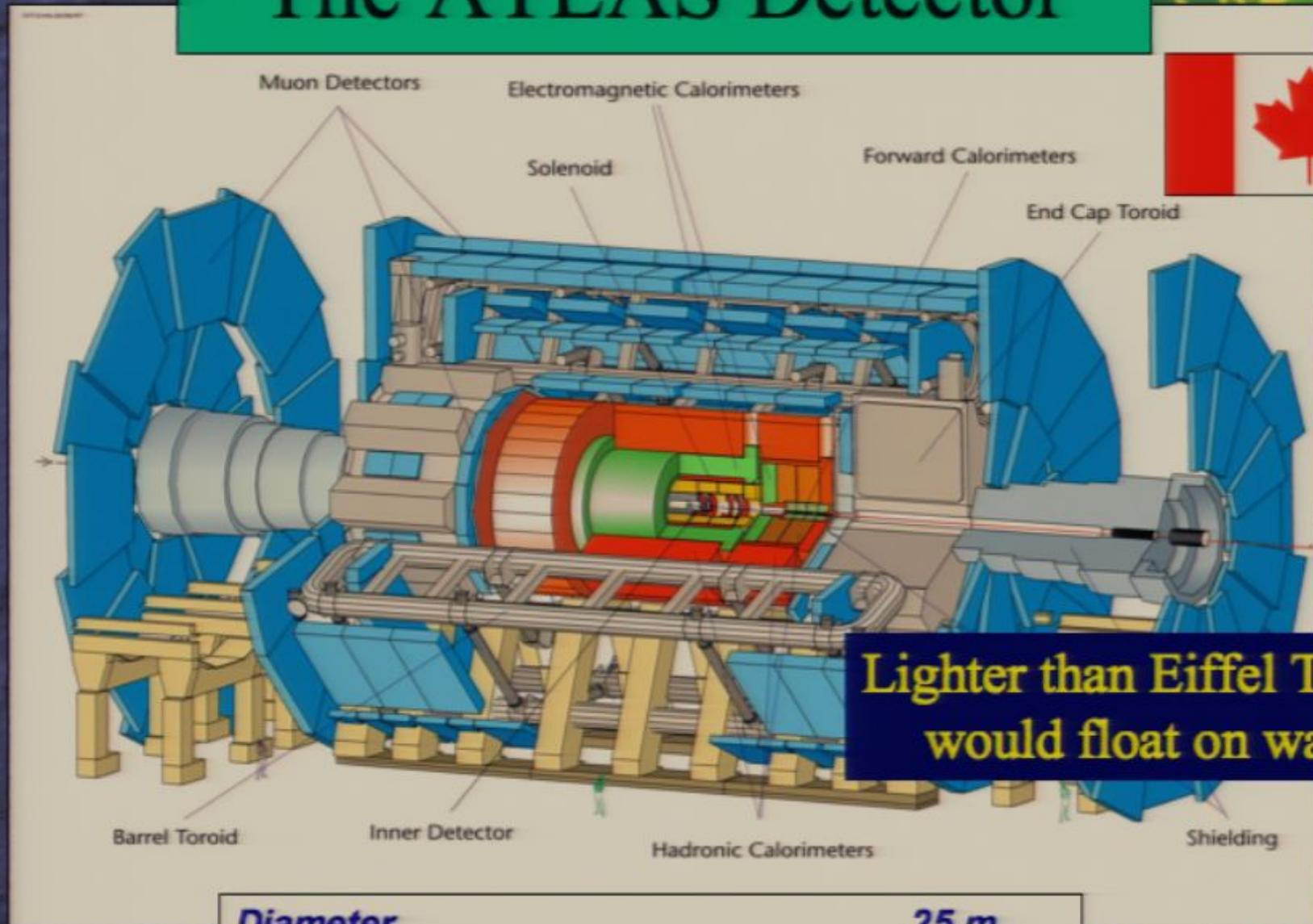
CMS: Higgs and supersymmetry



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LHCb: Matter-antimatter differences

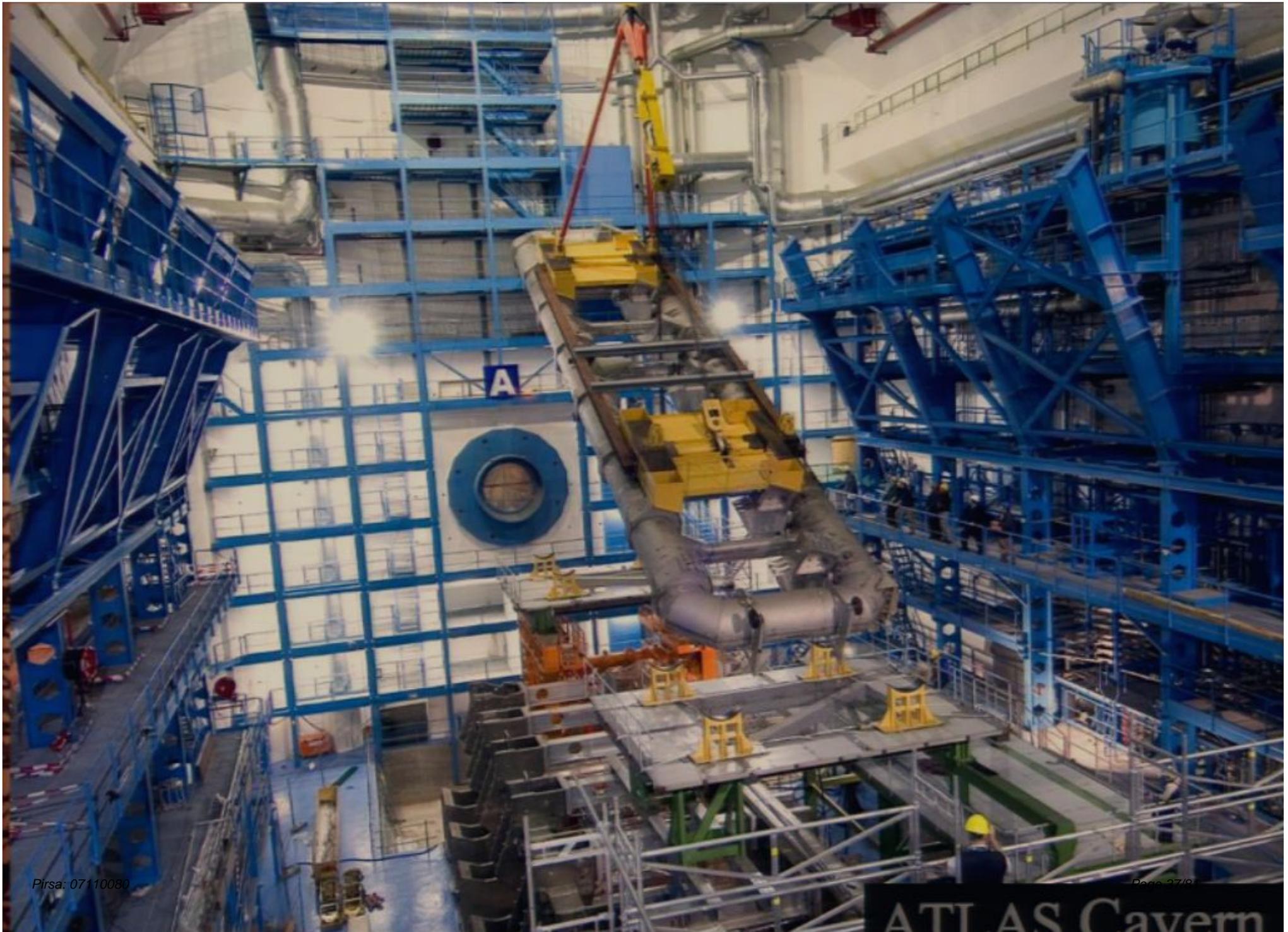
The ATLAS Detector

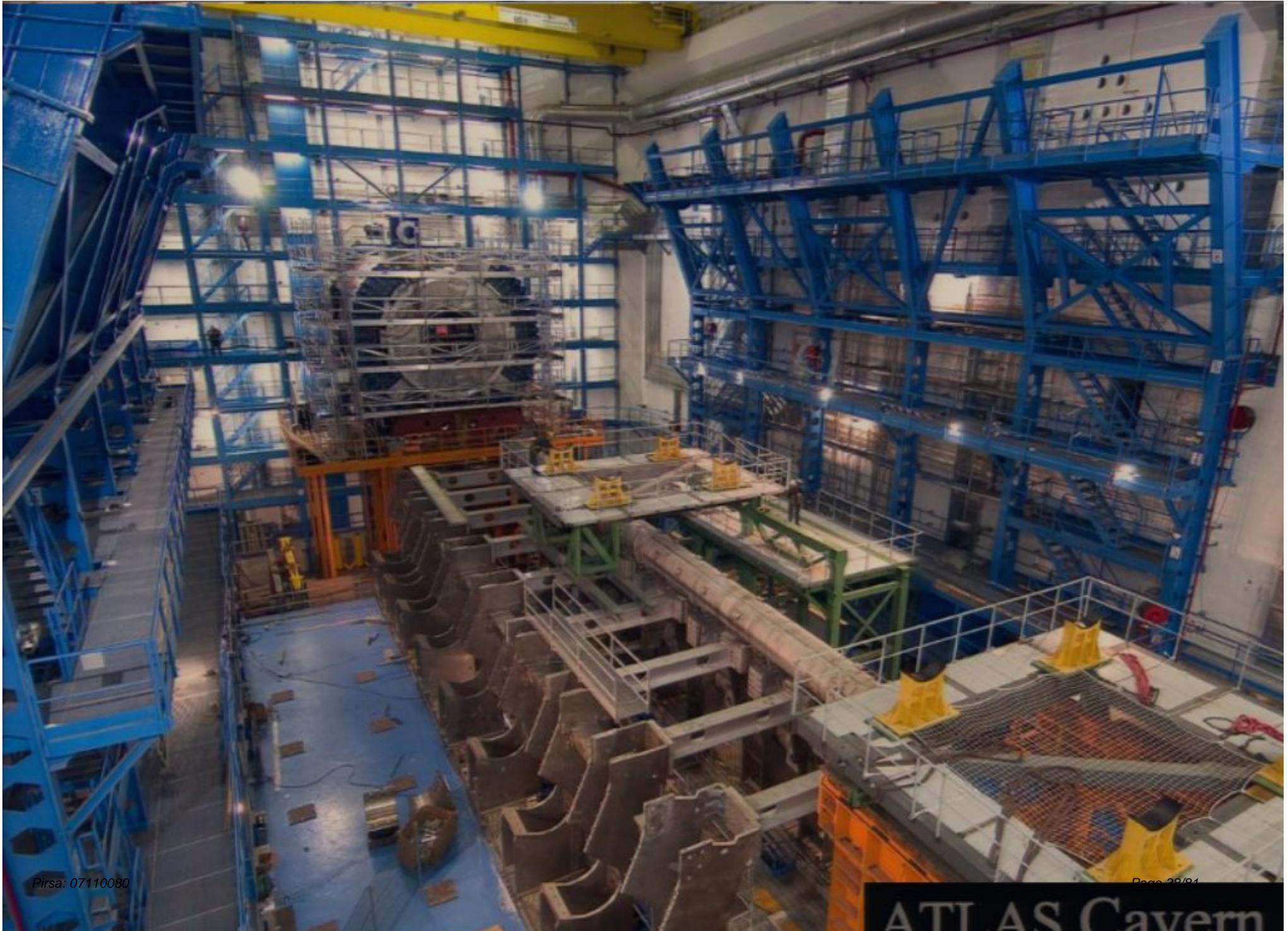


**Lighter than Eiffel Tower:
would float on water**

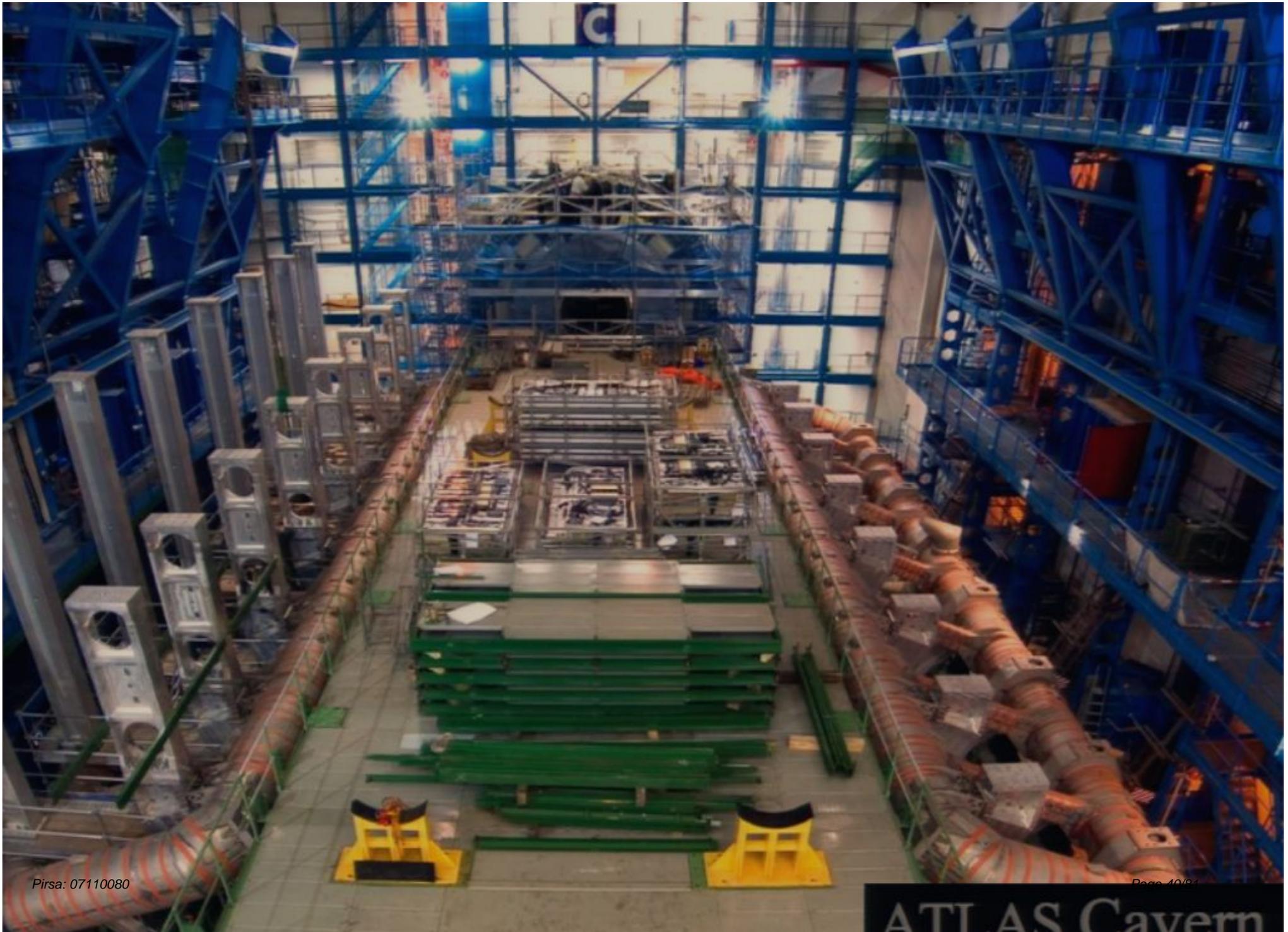
Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 Tons





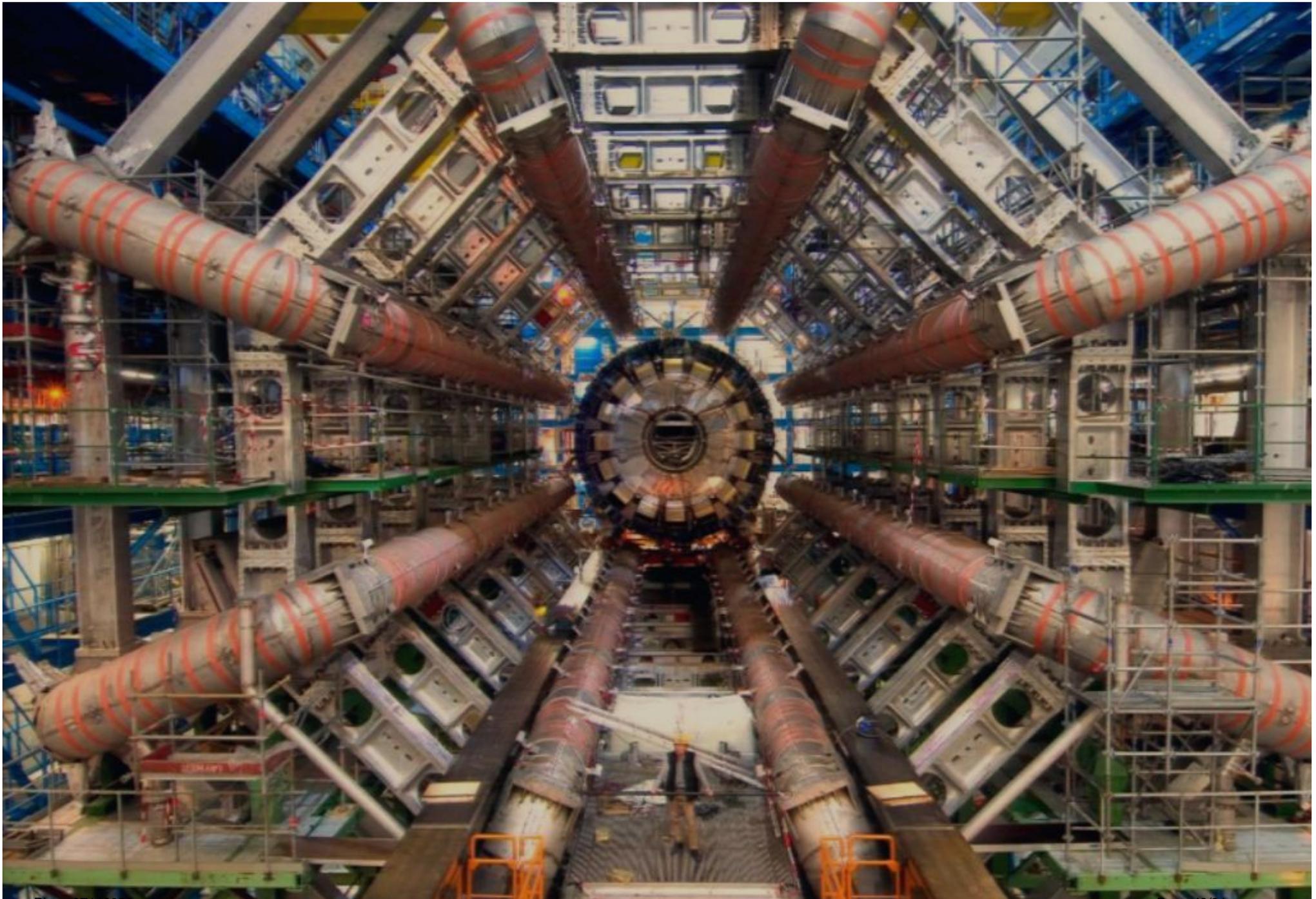












CMS Experiment

TRIGGER & DATA ACQUISITION

Austria, CERN, Finland, France, Greece, Hungary, Italy, Korea, Poland, Portugal, Switzerland, UK, USA

TRACKER

Austria, Belgium, CERN, Finland, France, New Zealand, Germany, Italy, Japan*, Switzerland, UK, USA

CRYSTAL ECAL

Belarus, CERN, China, Croatia, Cyprus, France, Ireland, Italy, Japan*, Portugal, Russia, Serbia, Switzerland, UK, USA

PRE SHOWER

Armenia, Belarus, CERN, Greece, India, Russia, Taipei, Uzbekistan

RETURN YOKE

Barrel: Czech Rep., Estonia, Germany, Greece, Russia
Endcap: Japan*, USA, Brazil

SUPER CONDUCTING MAGNET

All countries in CMS contribute to Magnet financing in particular:
Finland, France, Italy, Japan*, Korea, Switzerland, USA

HCAL

Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HO: India

FEET

Pakistan
China

FORWARD CALORIMETER

Hungary, Iran, Russia, Turkey, USA

MUON CHAMBERS

Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain
Endcap: Belarus, Bulgaria, China, Korea, Pakistan, Russia, USA

Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.5 m
Magnetic field : 4 Tesla

CMS Experiment

TRIGGER & DATA ACQUISITION

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PRESHOWER

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**Heavier than Eiffel Tower:
would sink in water**

CMS Experiment

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MUON CHAMBERS

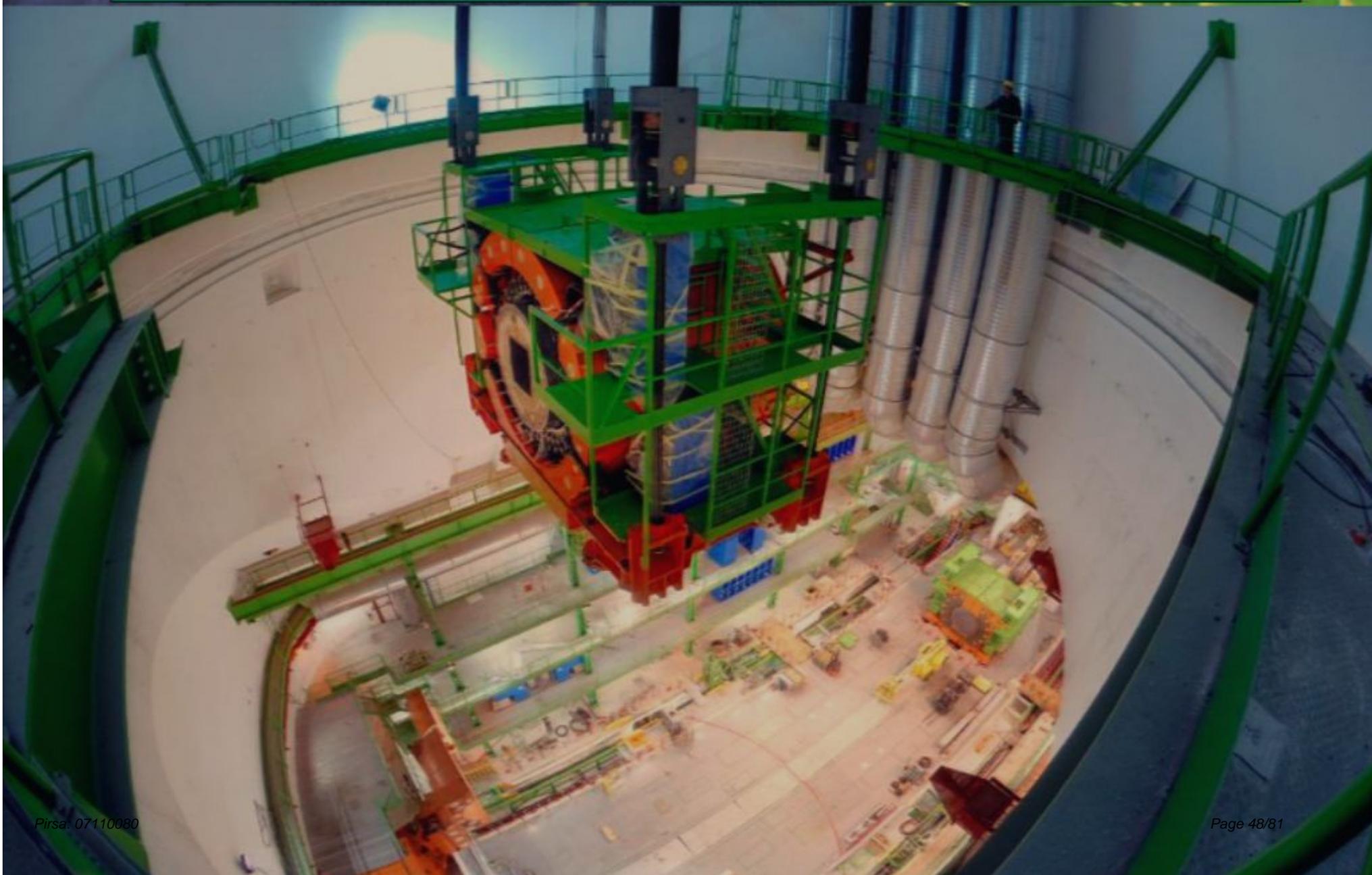
Barrel: Austria, Bulgaria, CERN, China, Germany, Hungary, Italy, Spain
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Construction of CMS



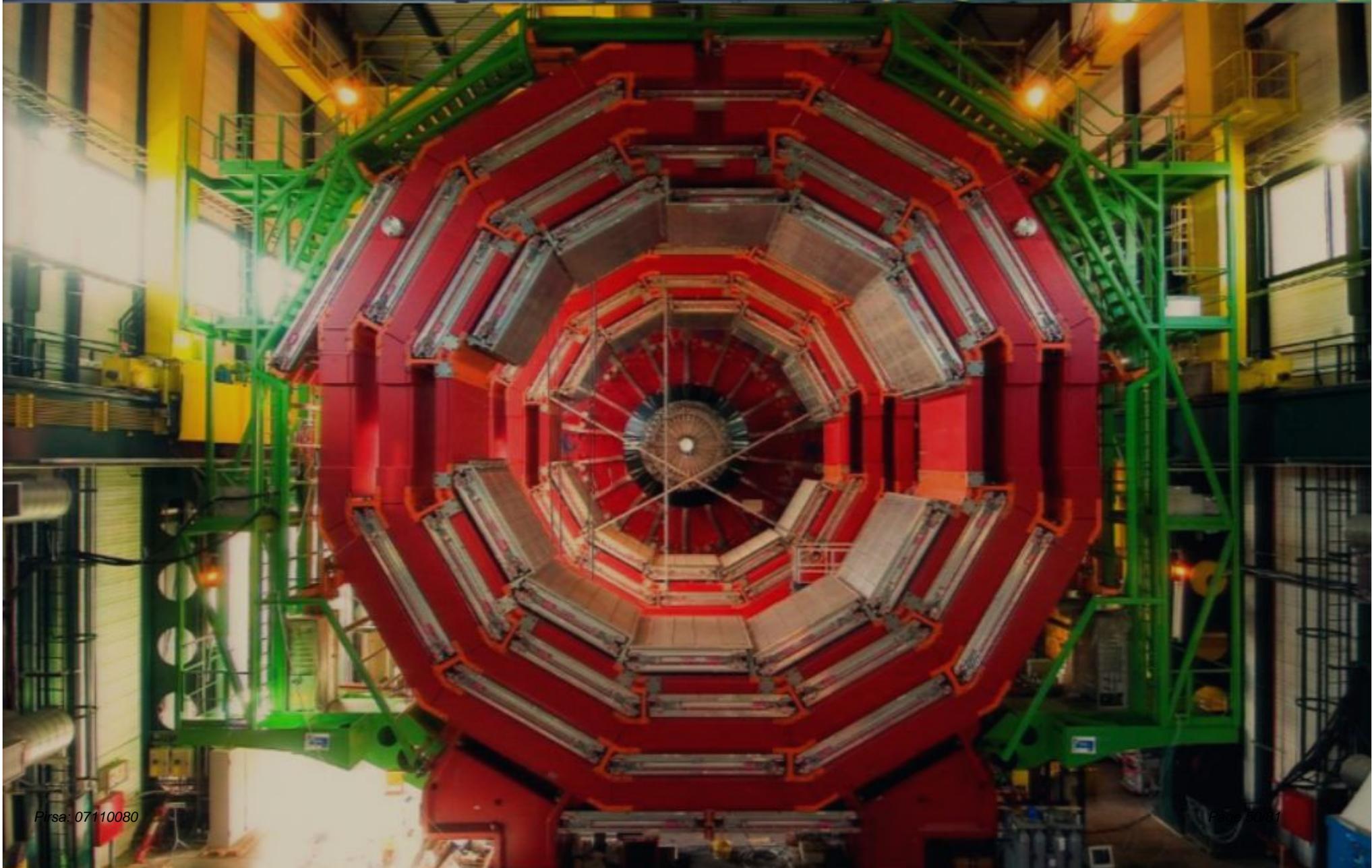
Construction of CMS



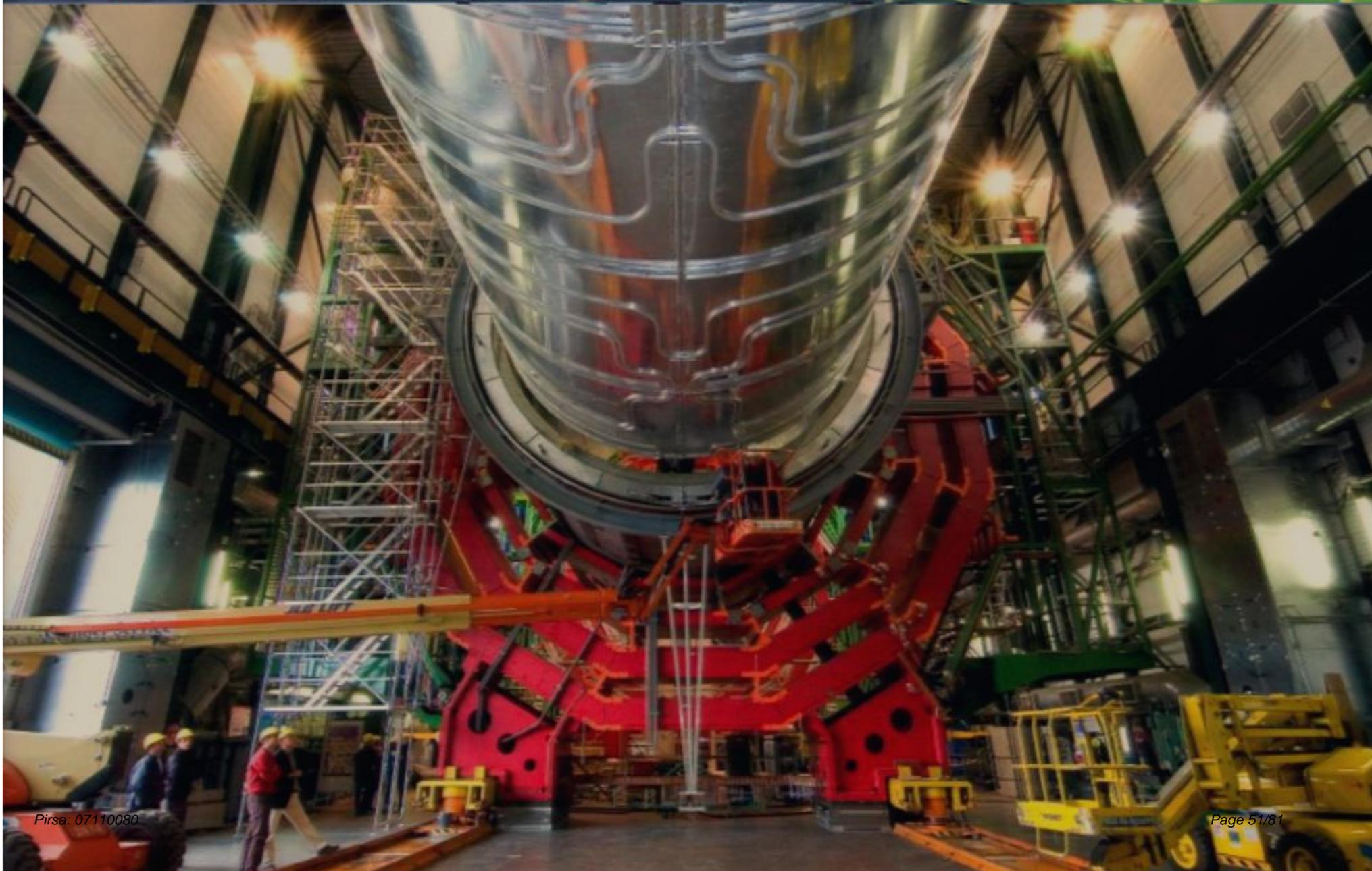
Construction of CMS



Construction of CMS



Construction of CMS



Construction of CMS



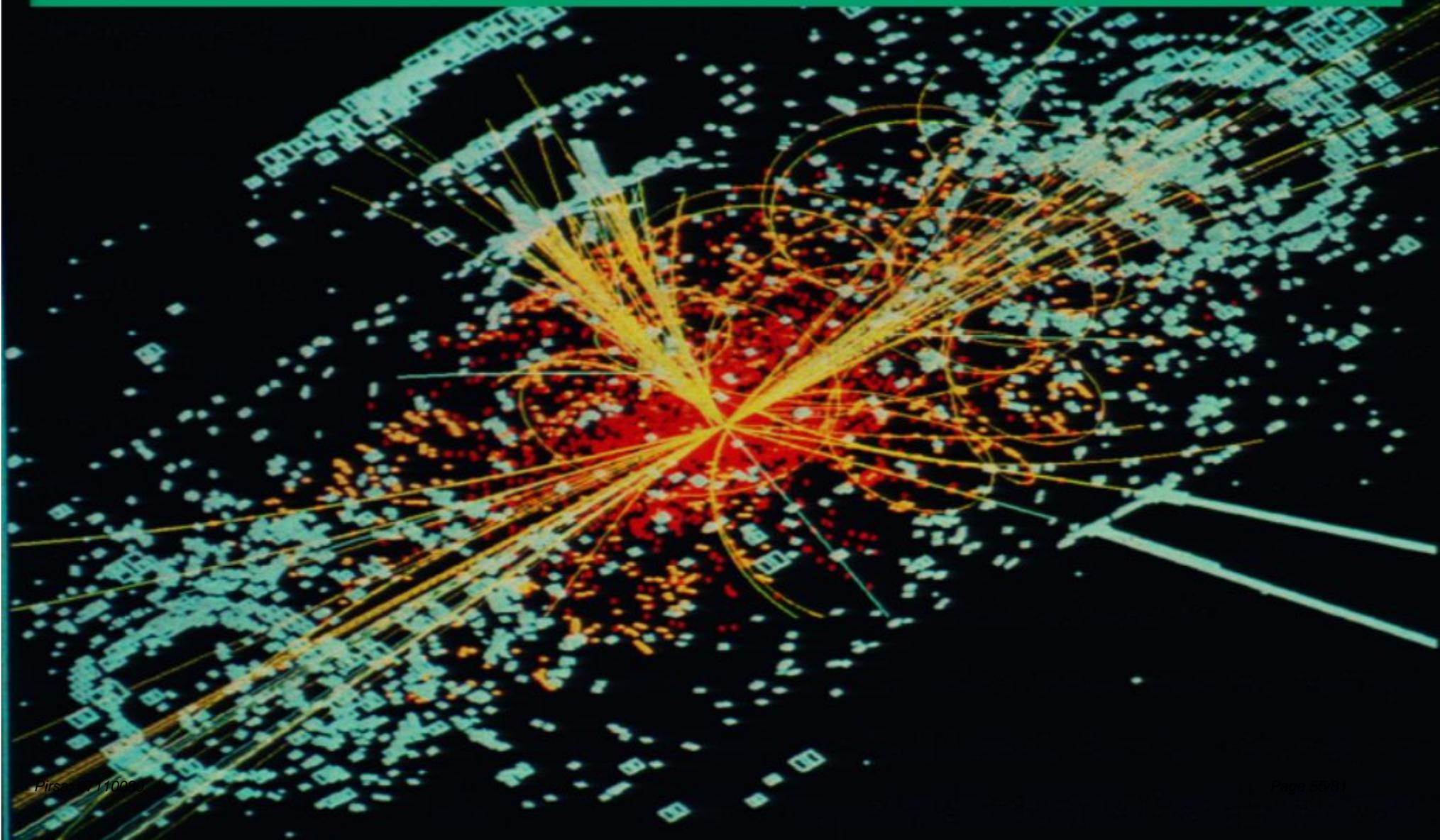
Construction of CMS



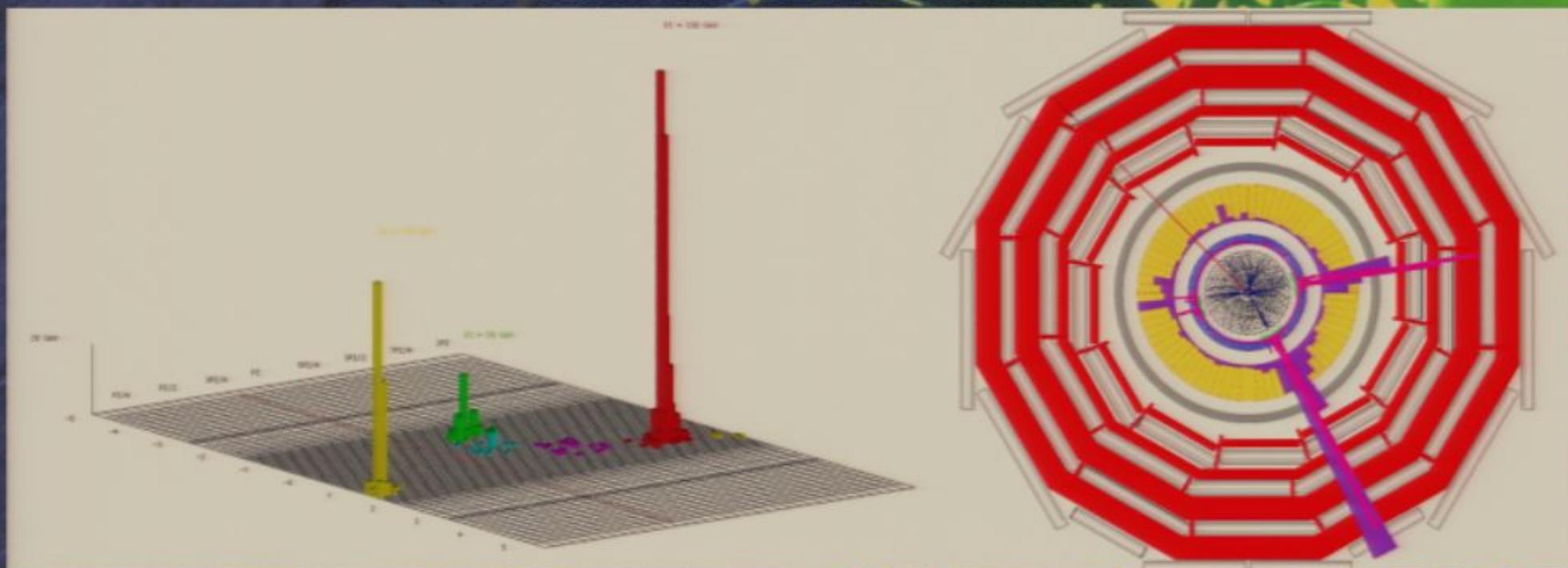
Construction of CMS



A Simulated Higgs Event in CMS



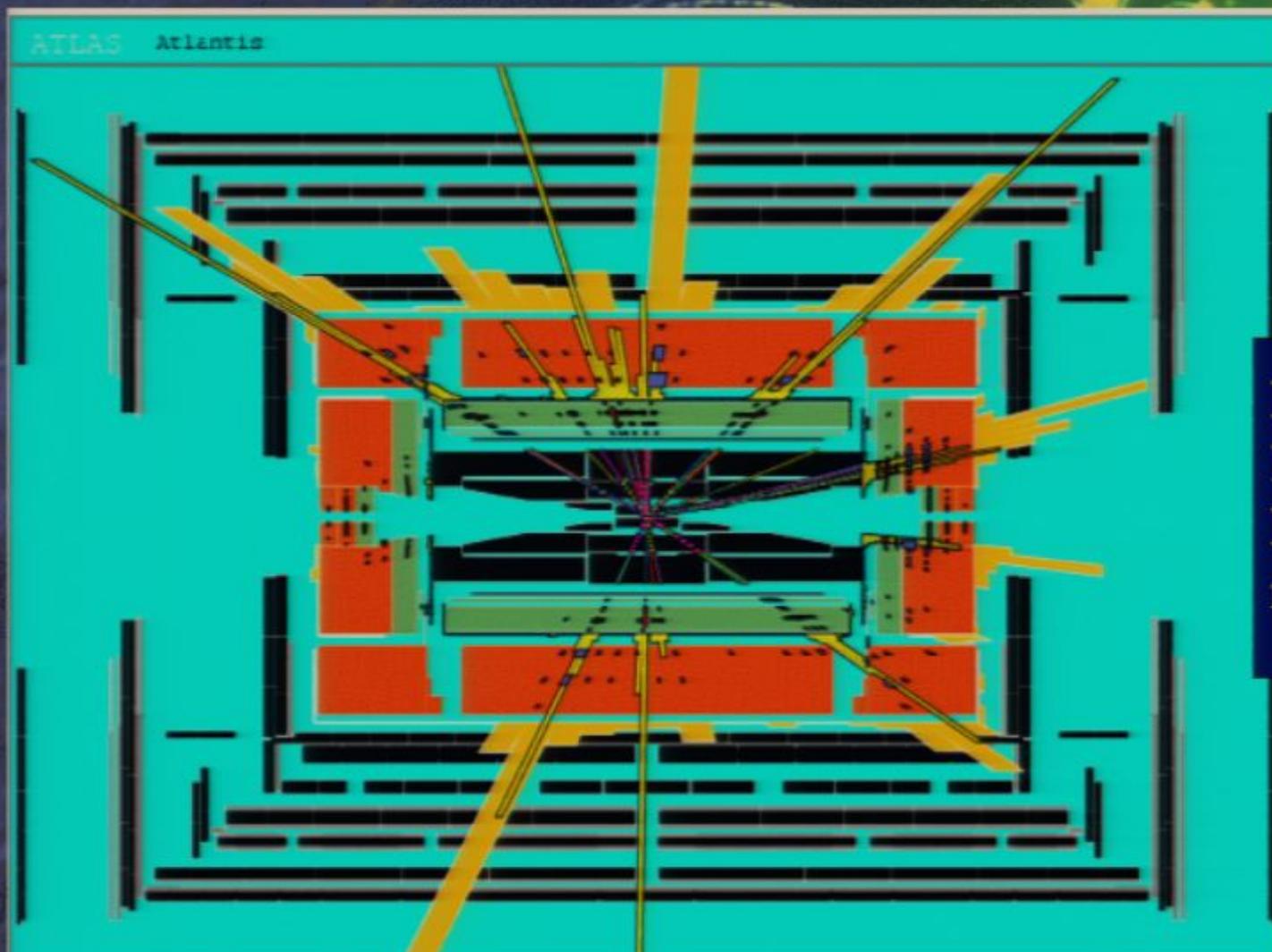
Classic Supersymmetric Signature



Missing transverse energy
carried away by dark matter particles

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

Black Hole Production at LHC?



Multiple jets,
leptons from
Hawking
radiation

Big Bang \leftrightarrow Little Bangs

- The matter content of the Universe

Nature of vacuum

Dark matter

Origin of matter

- Experiments at particle colliders

Higgs boson

Supersymmetry

Matter-antimatter
asymmetry

Learn particle physics from the Universe
Use particle physics to understand the Universe



**The LHC is a telescope
as well as a microscope**

<http://www.cern.ch>

<http://atlas.ch/>

rdg.lbl.gov/2007/html/outreach.htm

ATLAS Canada

Alberta
Carleton
McGill
Montréal
Regina
Simon Fraser
Toronto
TRIUMF
UBC
Victoria
York



41 University/Lab.physicists Over
120 people, including Engineers,
Technicians, Students

Educational Role

20 UG Summer Students
41 Graduate Students
23 Post Docs

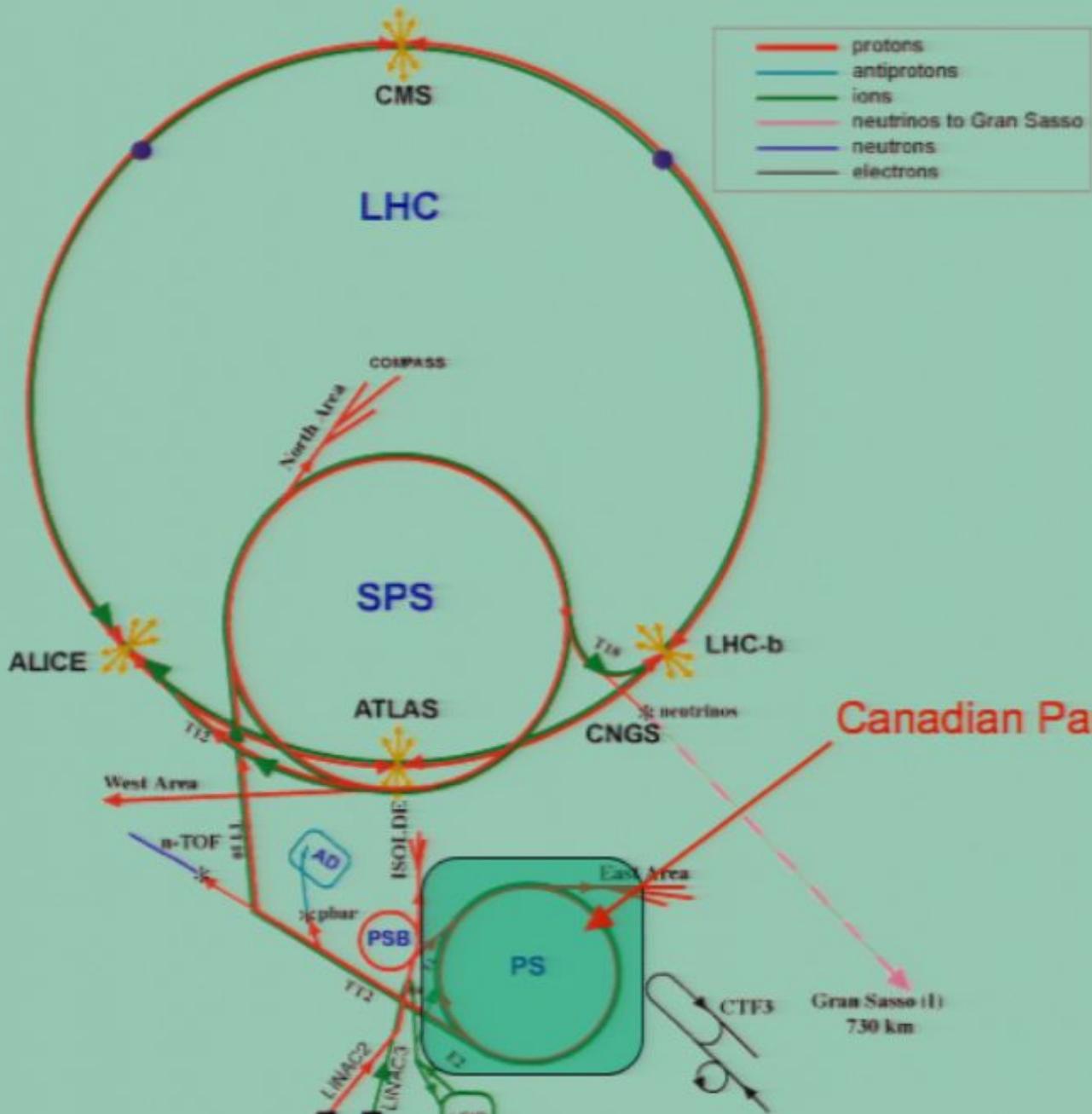
The Large Hadron Collider

- What did Canada provide?

The ATLAS Detector

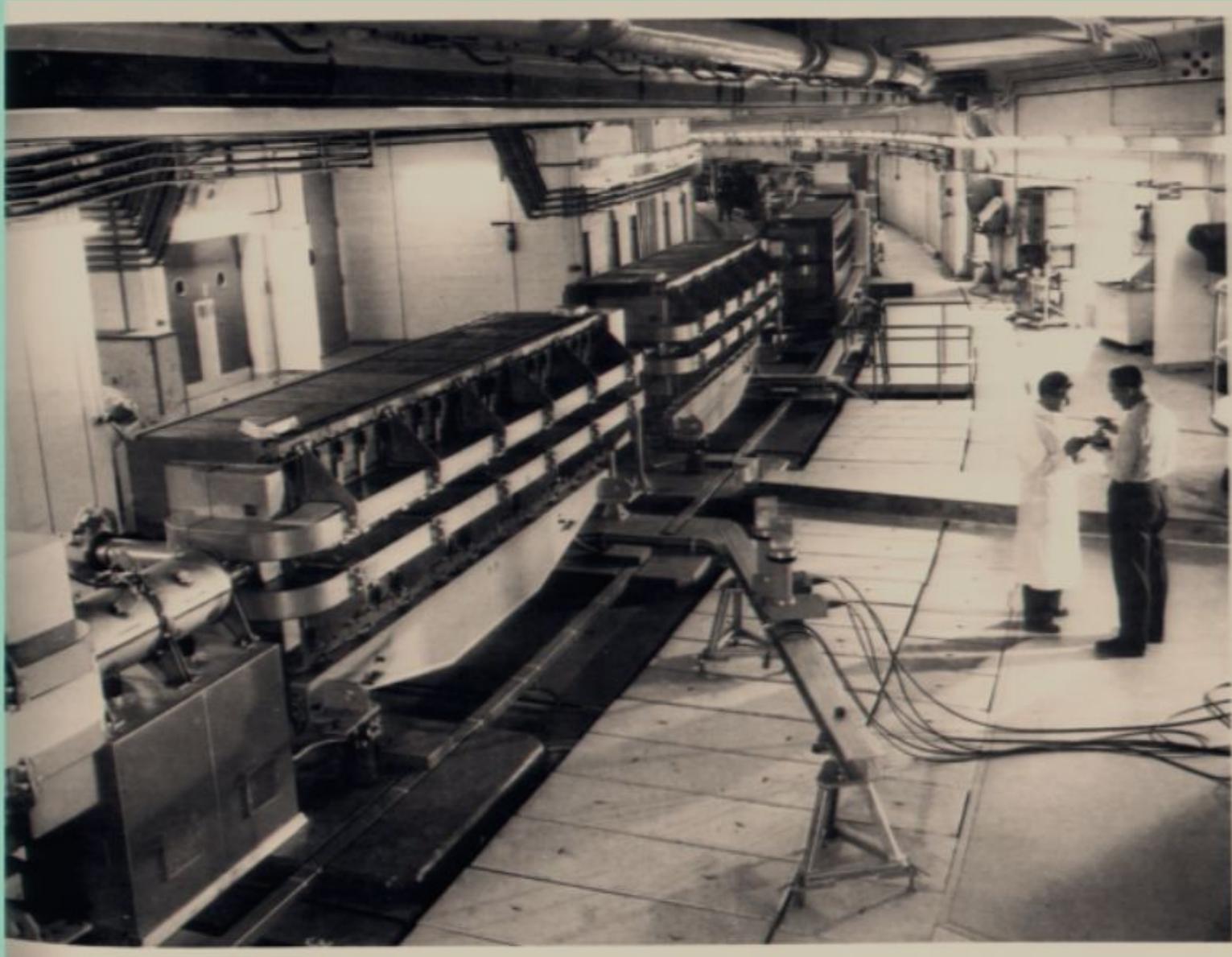
- What did Canadians Build?

CERN Accelerator Complex



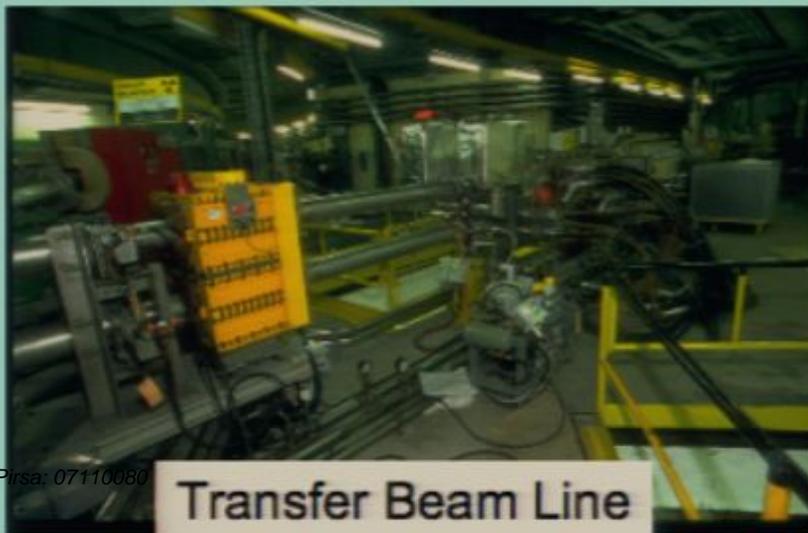
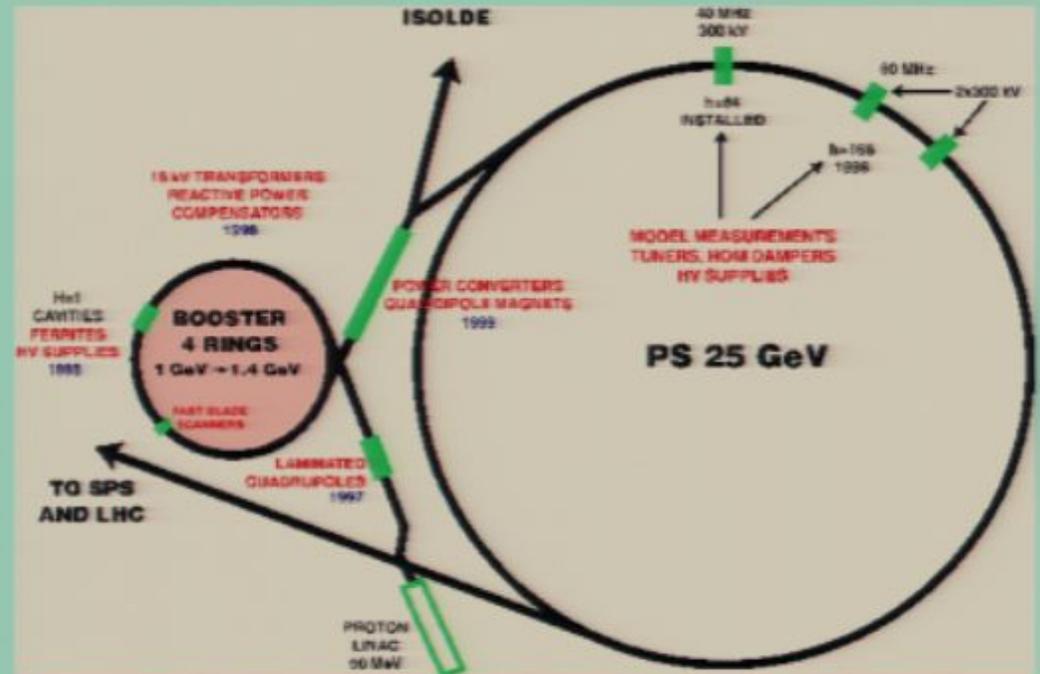
CERN Proton Synchrotron first operated in 1959

Needed refurbishment



Canadian Participation in LHC – PS Upgrade

**TRIUMF \$14M Equipment
1995-2000 \$ 6M Salaries**



Canadian Participation in LHC – 52 Twin Aperture Quadrupole Magnets



MQW line-up



MQWs in storage area



Used in the beam cleaning insertions in LHC.

2000-2005 Additional Contribution

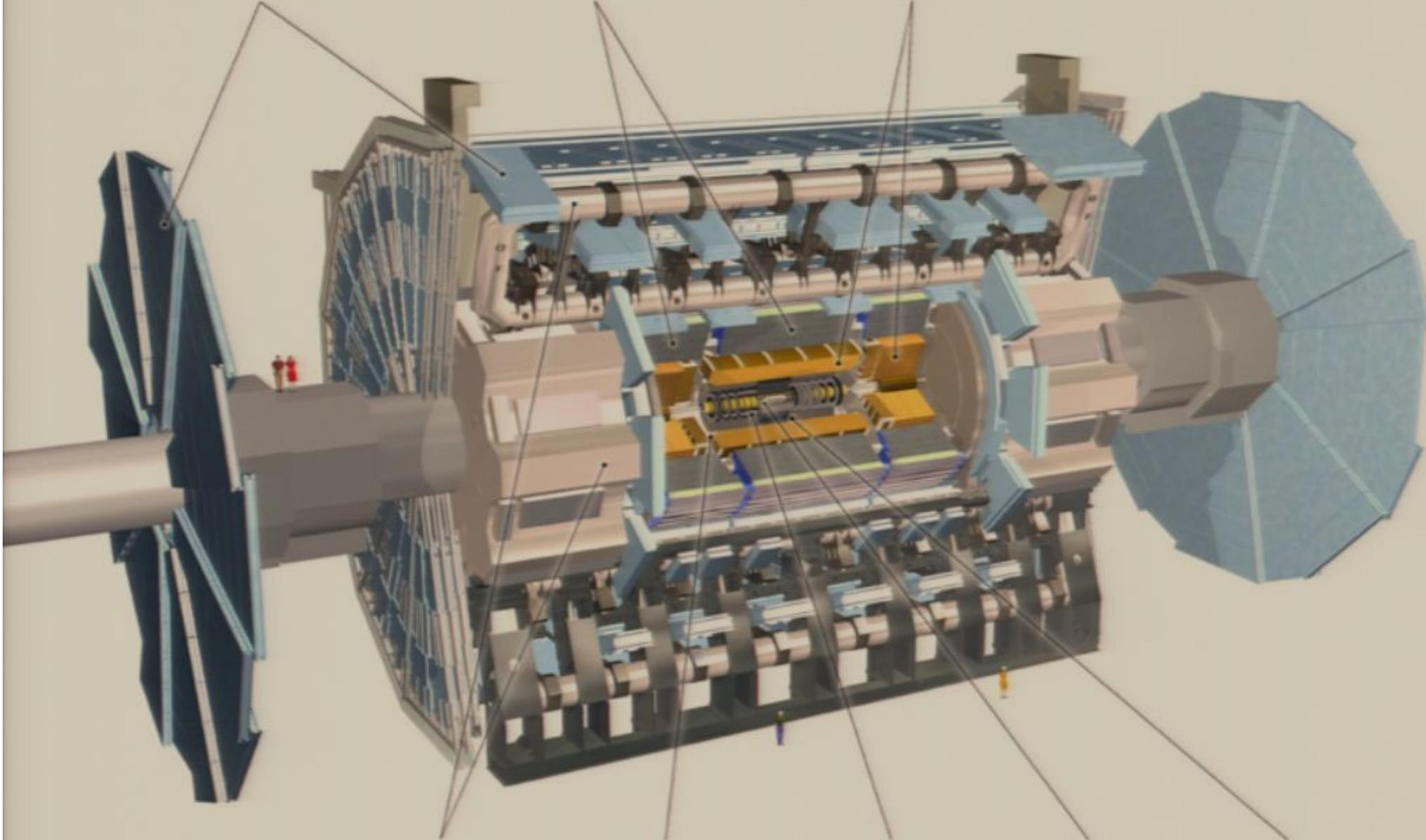
\$12.8M Capital

\$ 5.0M Salaries

Muon Detectors

Tile Calorimeter

Liquid Argon Calorimeter



Toroid Magnets

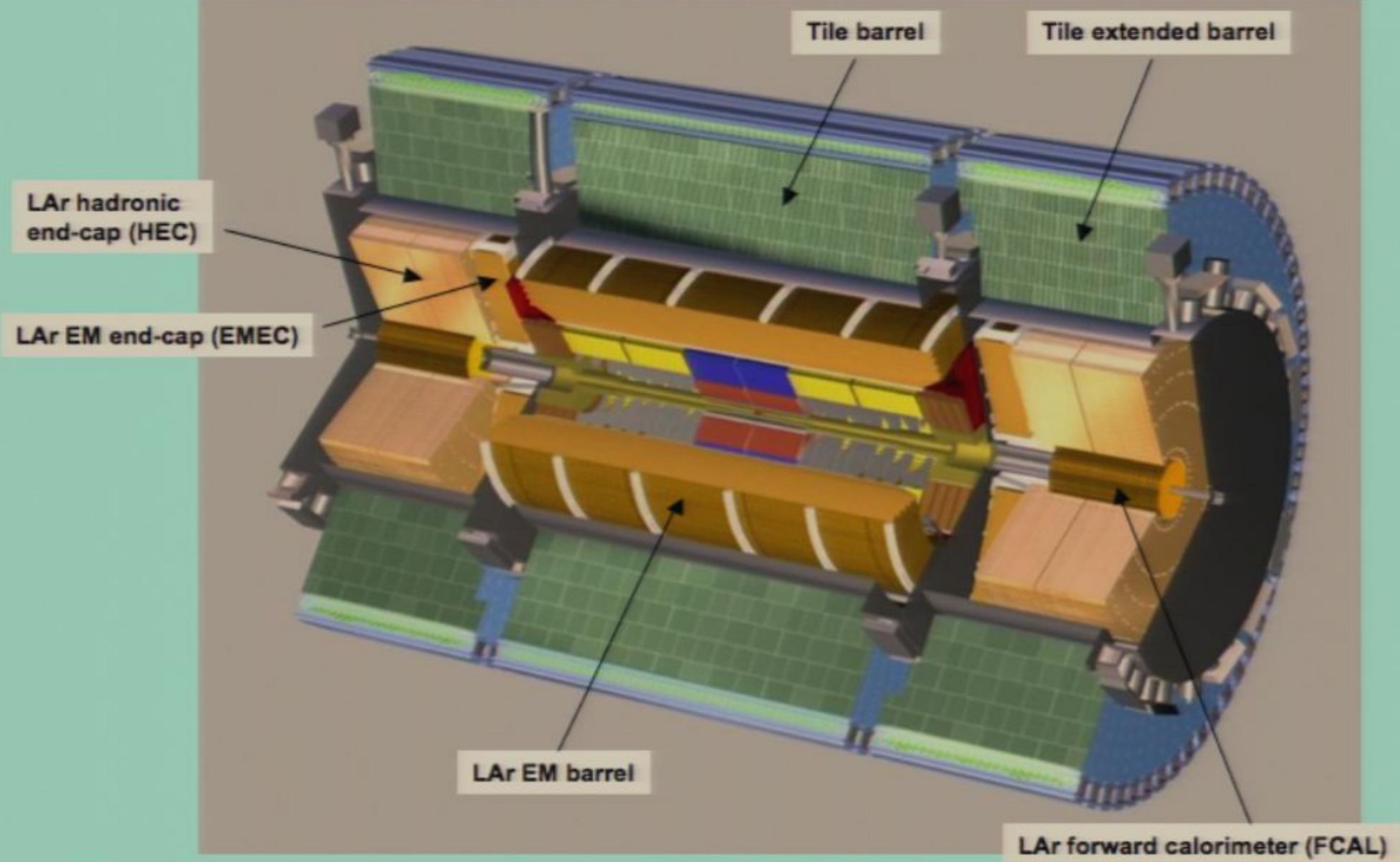
Solenoid Magnet

SCT Tracker

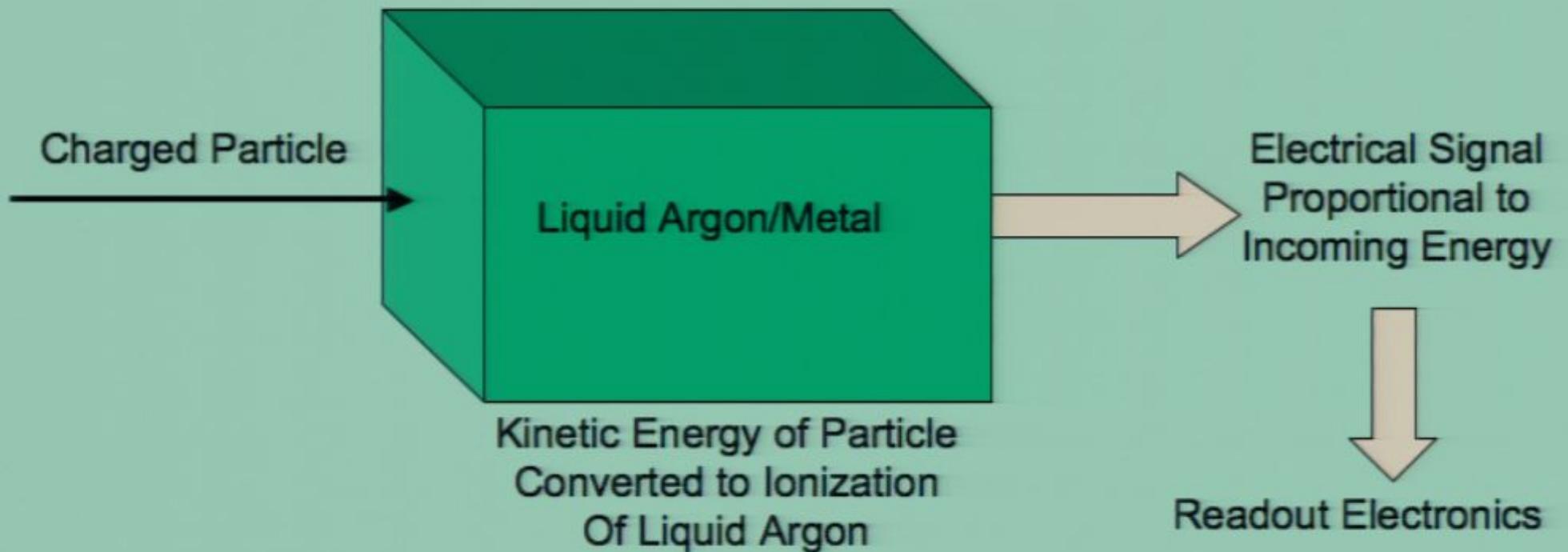
Pixel Detector

TRT Tracker

Liquid Argon (LAr) and Tile Calorimeters



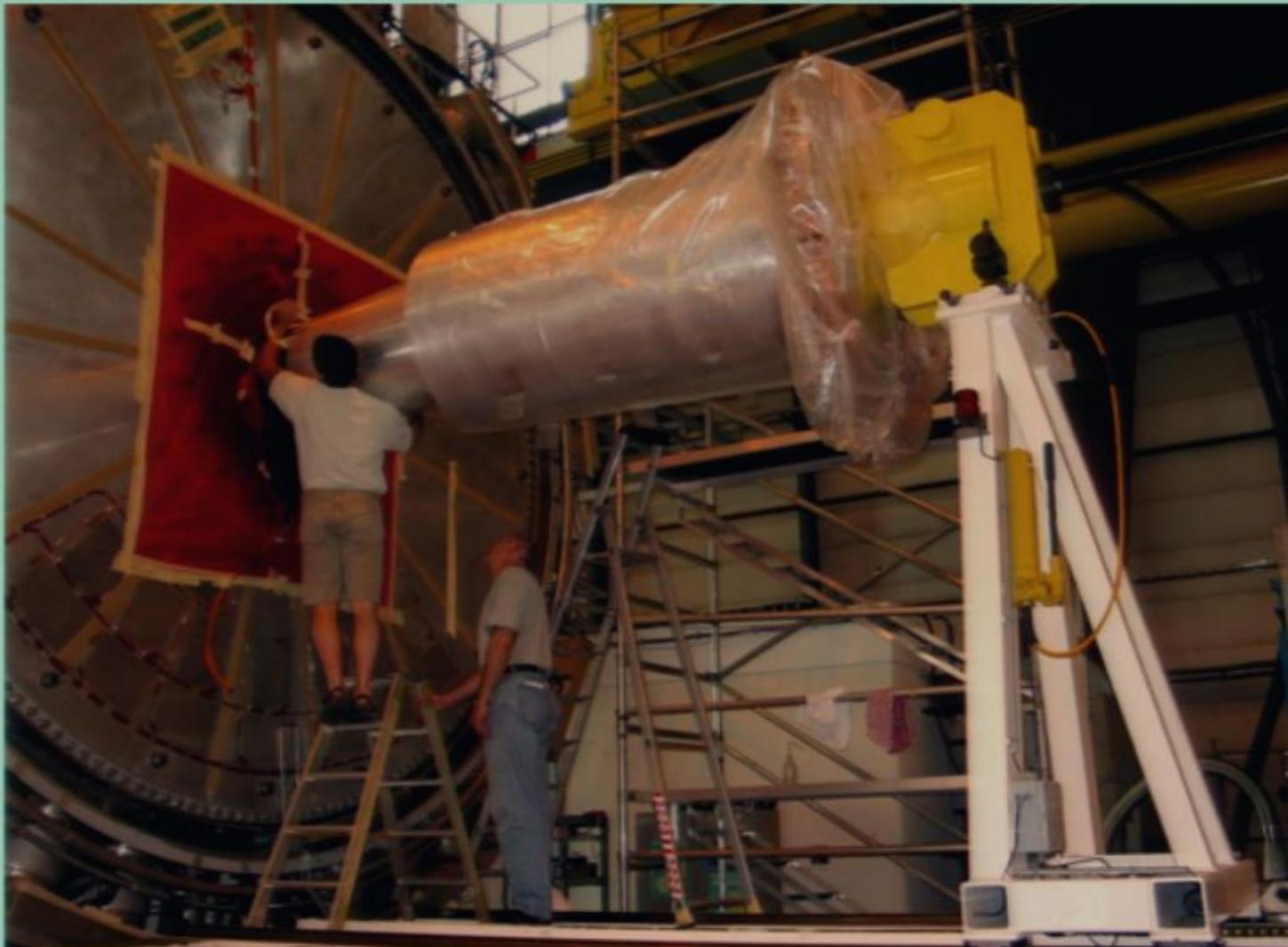
Why Is It Called a Calorimeter?



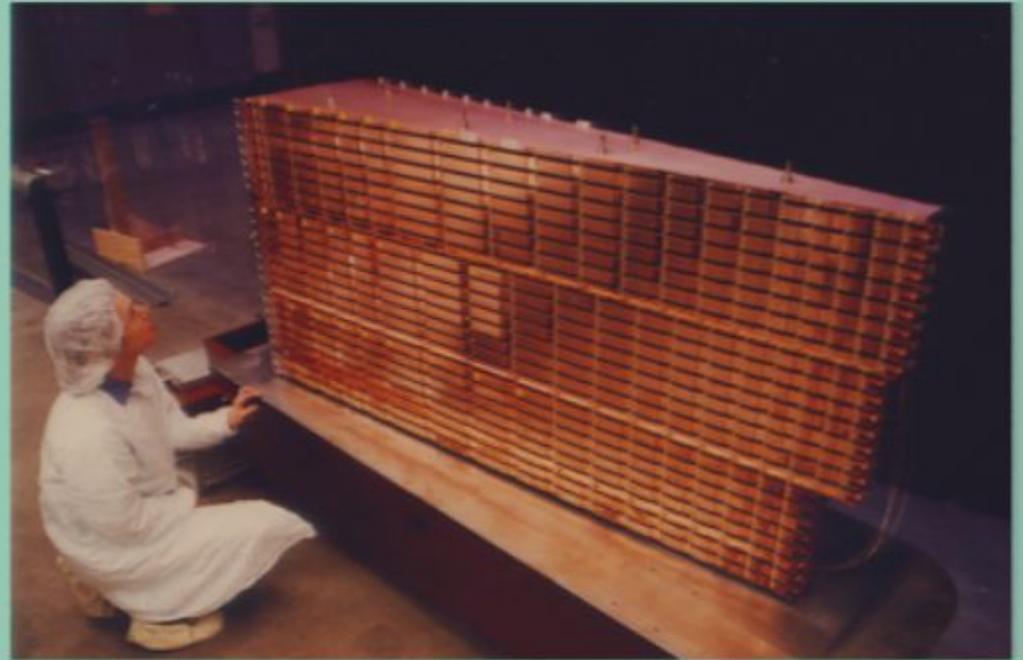
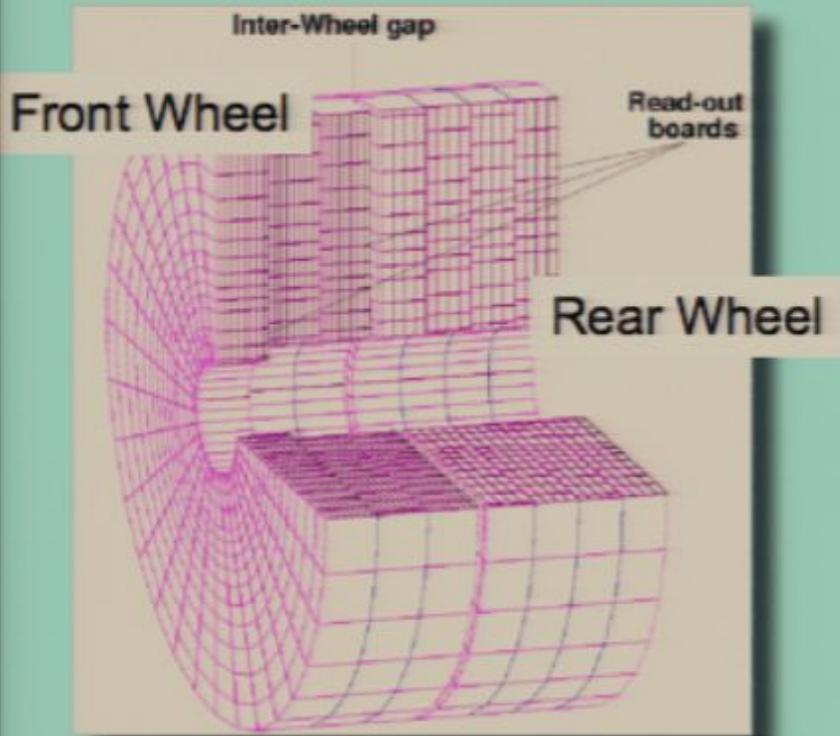
Liquid Argon End Caps

Detectors (Calorimeters) close to the LHC Beams

NSERC Capital \$15M

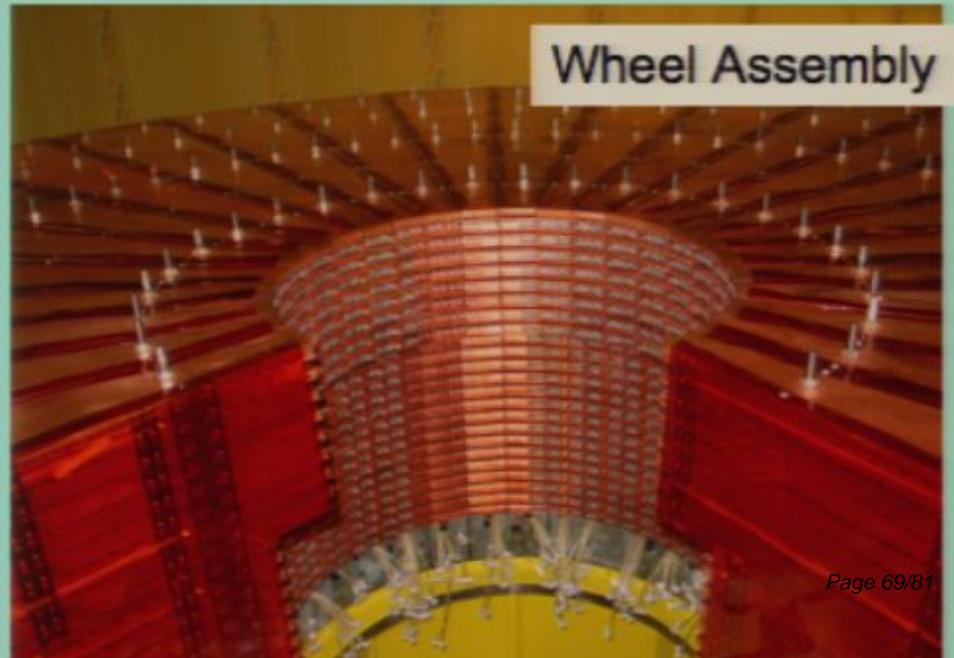


Hadronic Endcap Calorimeter (HEC)



Composed of 2 wheels per end
Front wheel: 67 t 25 mm Cu plates
Back wheel: 90 t 50 mm Cu plates

TRIUMF, Alberta

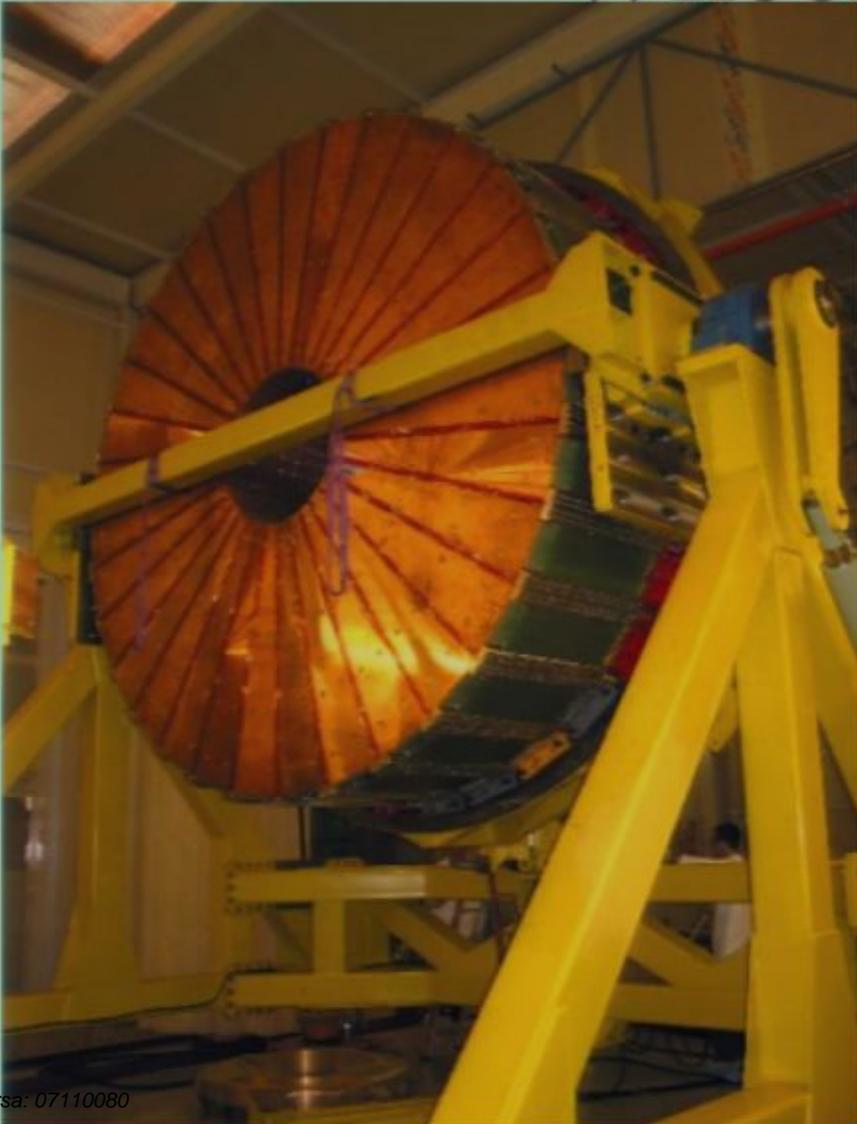


Oct 2002





Wheel Rotation



LAr Forward Calorimeters

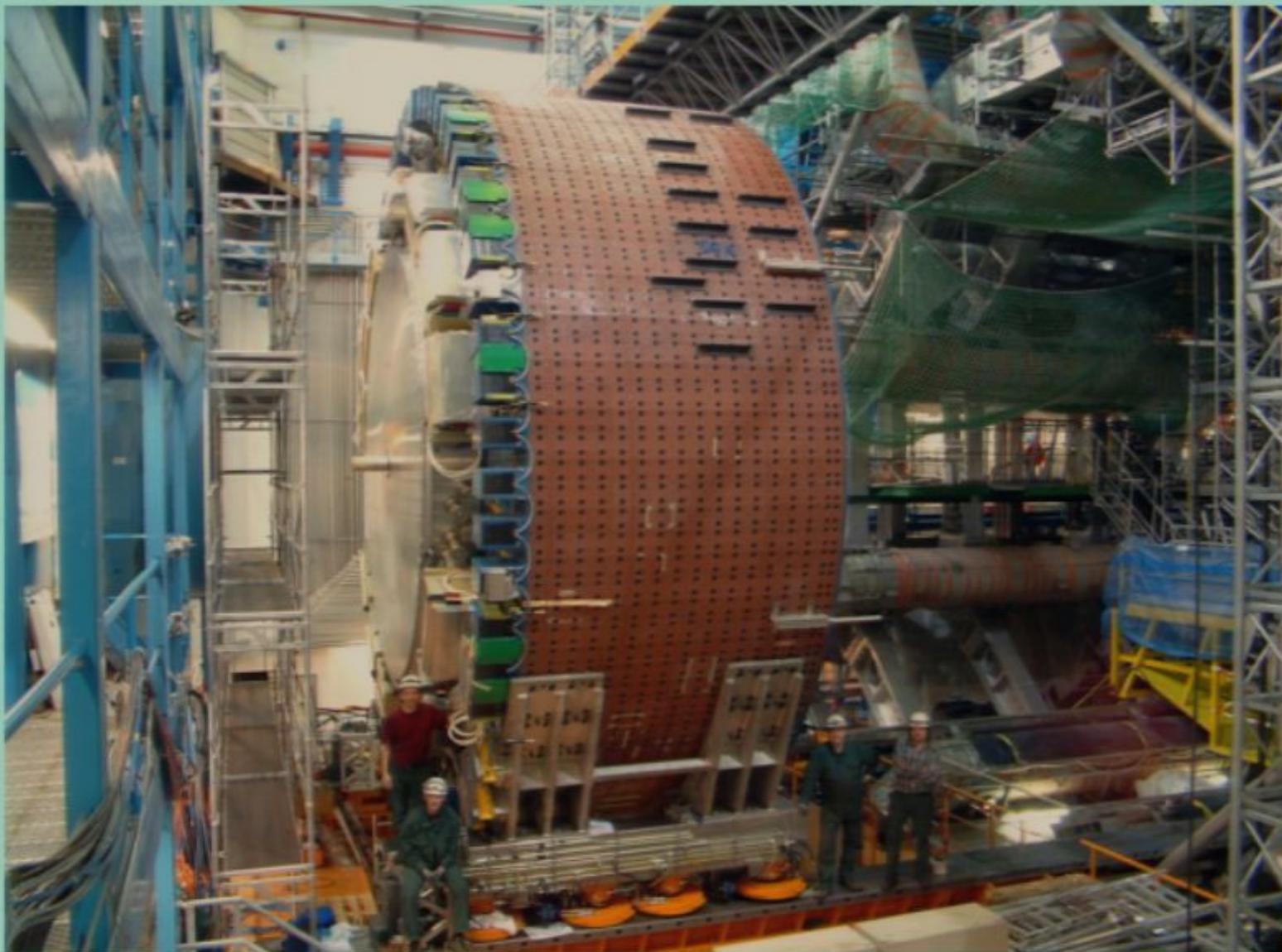


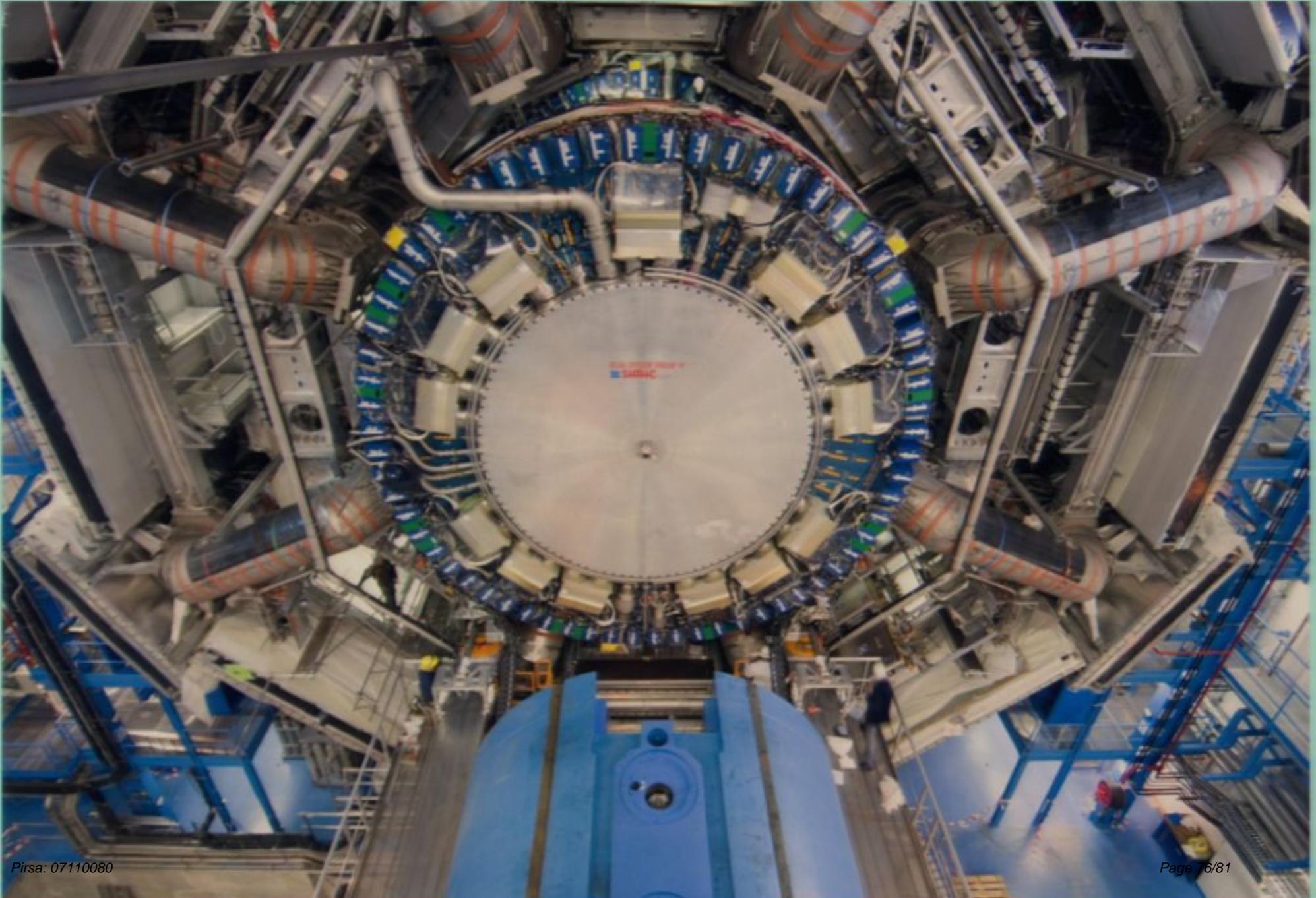
Toronto, Carleton

HEC – FCAL Assembly

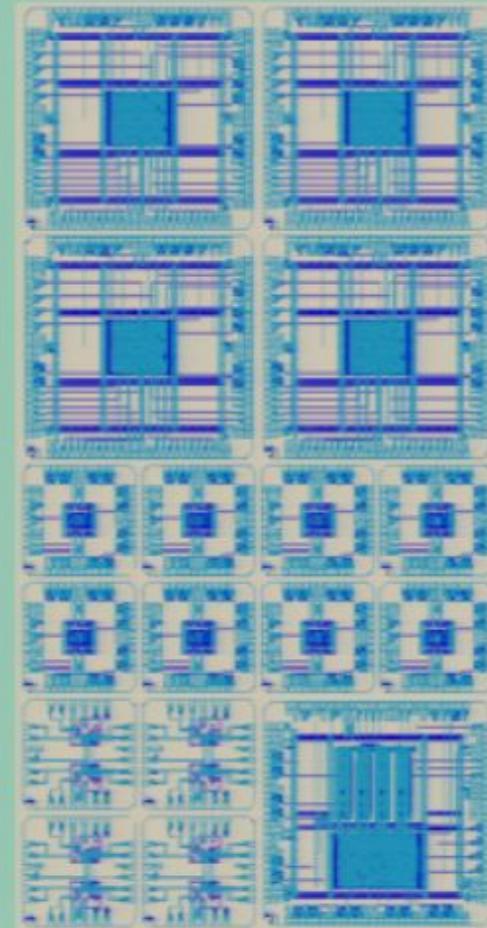
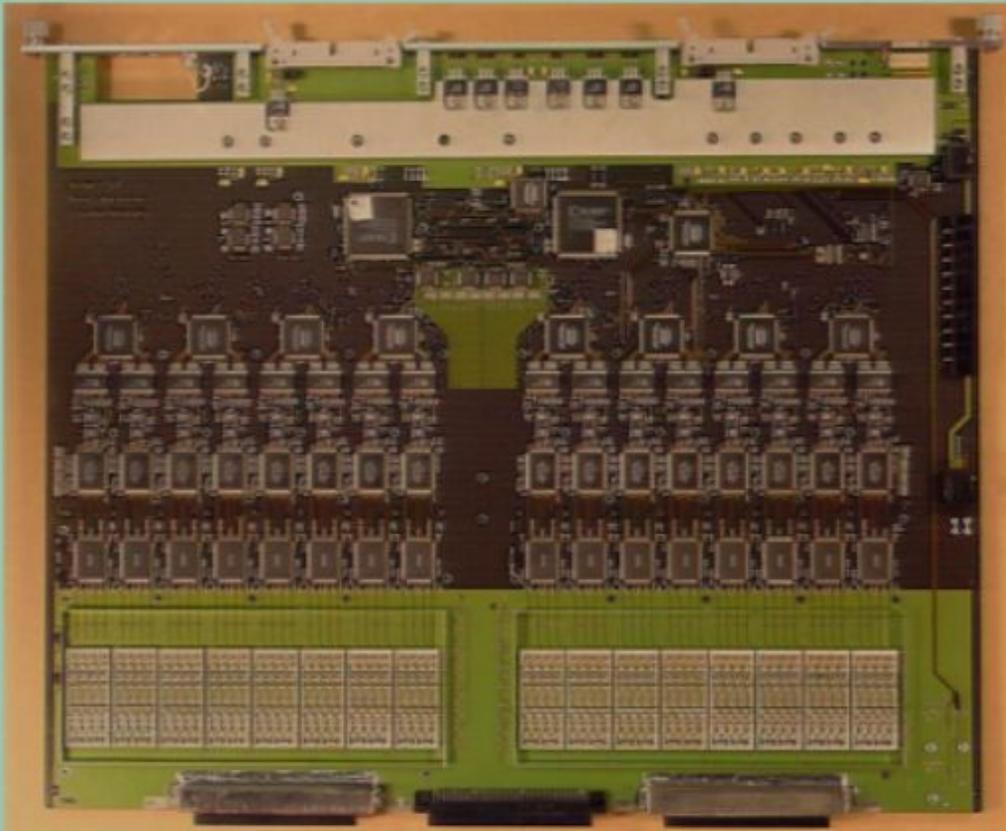


End-Cap LAr Calorimeters Ready to Slide In



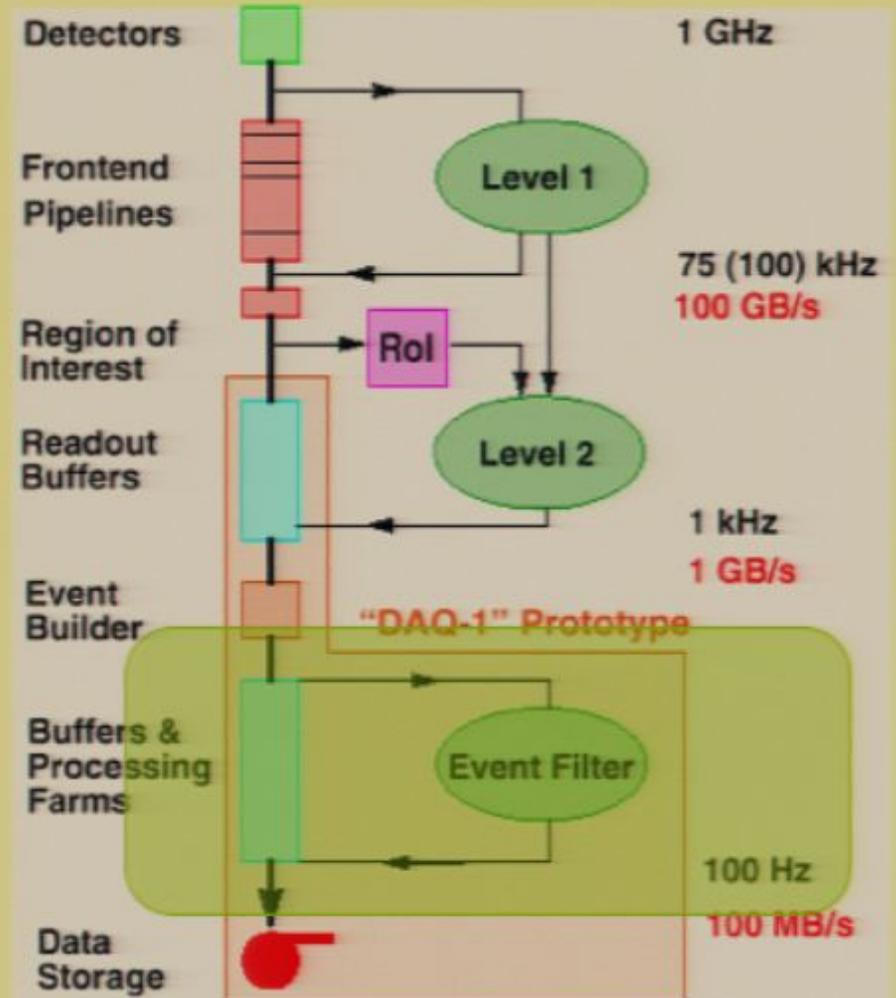
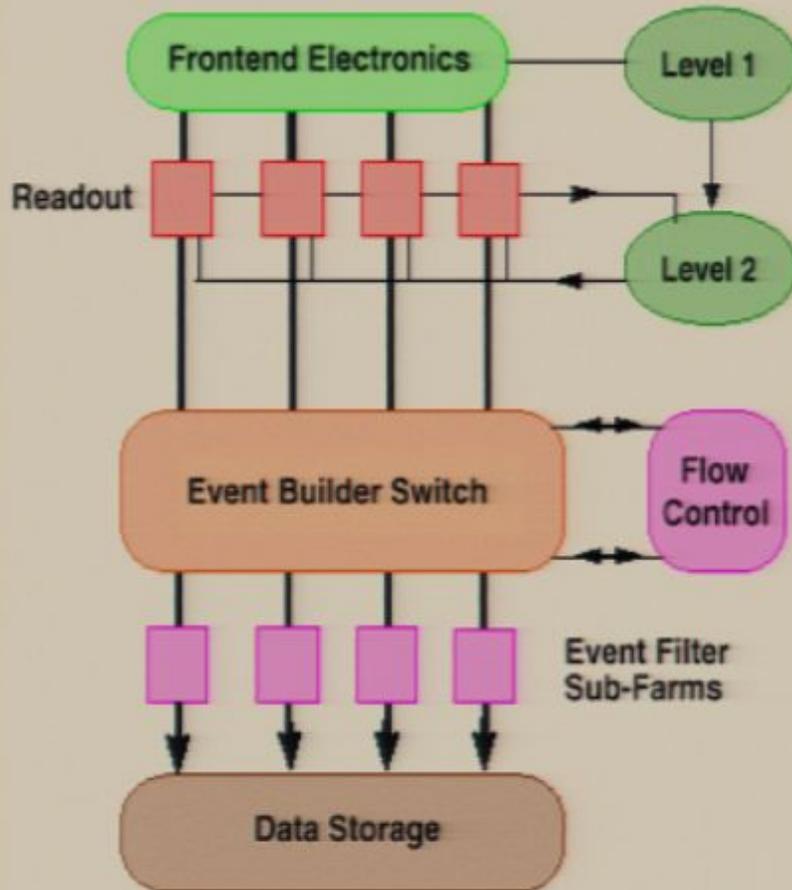


Calorimeter Front-End-Board Electronics



Radiation Hard Logic to Control Calorimeter Signal Readout
Design, Testing, Implementation

The Event Filter

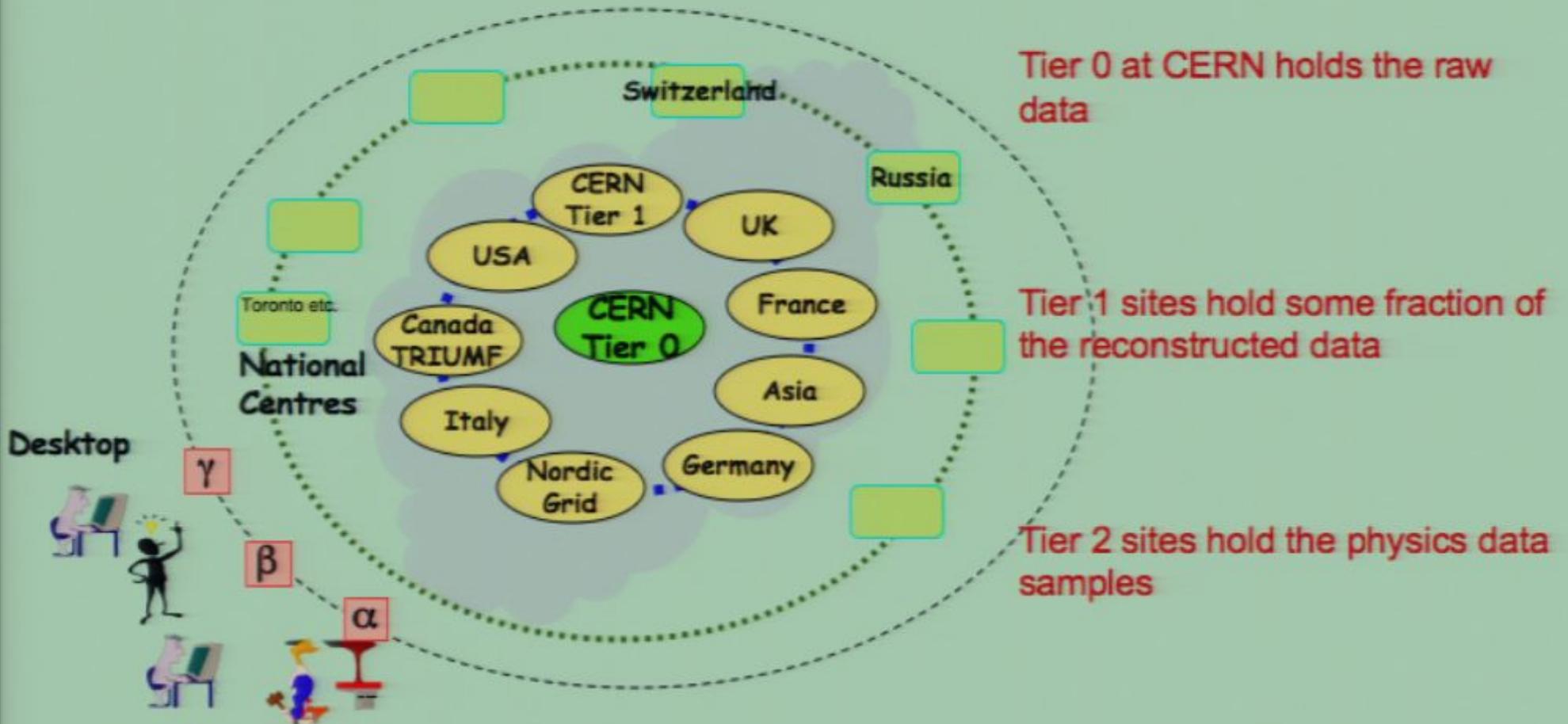


Online Computer Farm to Select Events Recorded by Experiment

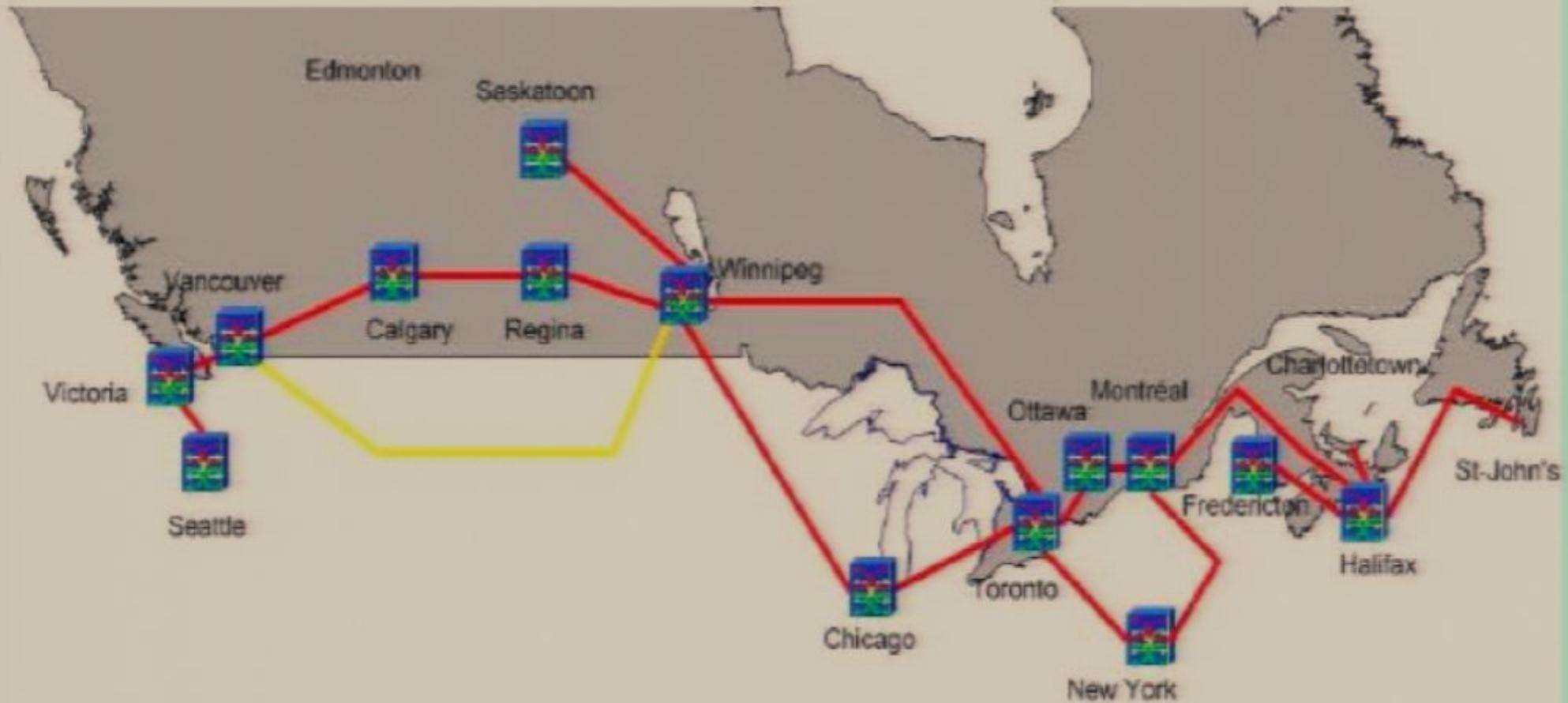
ATLAS Computing Model

ATLAS Computing Facility is a grid of CERN based and distributed facilities

Hierarchy of Facilities defined by the services they offer



CA*net *Canada's world class network*



ATLAS-LHC & Canada

- We have been active participants in realizing this enormous project.
- We are keenly looking forward to participating in the exciting discoveries that John has talked about
- **Watch out for the News!**