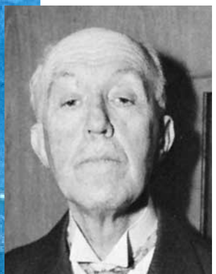
# CERN: A EUROPEAN LABORATORY FOR THE WORLD

G.K. Mallot
CERN

# THE BEGINNINGS



1949: Proposal by de Broglie to the Eur. Cult. Conf.

*"the creation of a laboratory or institution where it would be possible to do scientific work, but somehow beyond the framework of the different participating states"*

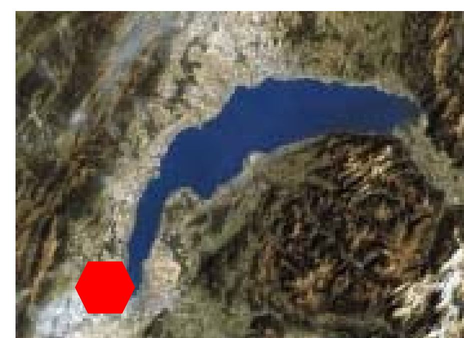
*"undertake tasks, which, by virtue of their size and cost, were beyond the scope of individual countries"*

1952: Interim council:

*Conseil Européen pour la Recherche Nucléaire*

*left council members :* Pierre Auger, Edoardo Amaldi and Lew Kowarski

1953: Geneva chosen as location



# THE BEGINNINGS

*foundation stone laying 10 June 1955 by DG Felix Bloch*

## 1954: *European Organization for Nuclear Research*

## 12 founding European Member States

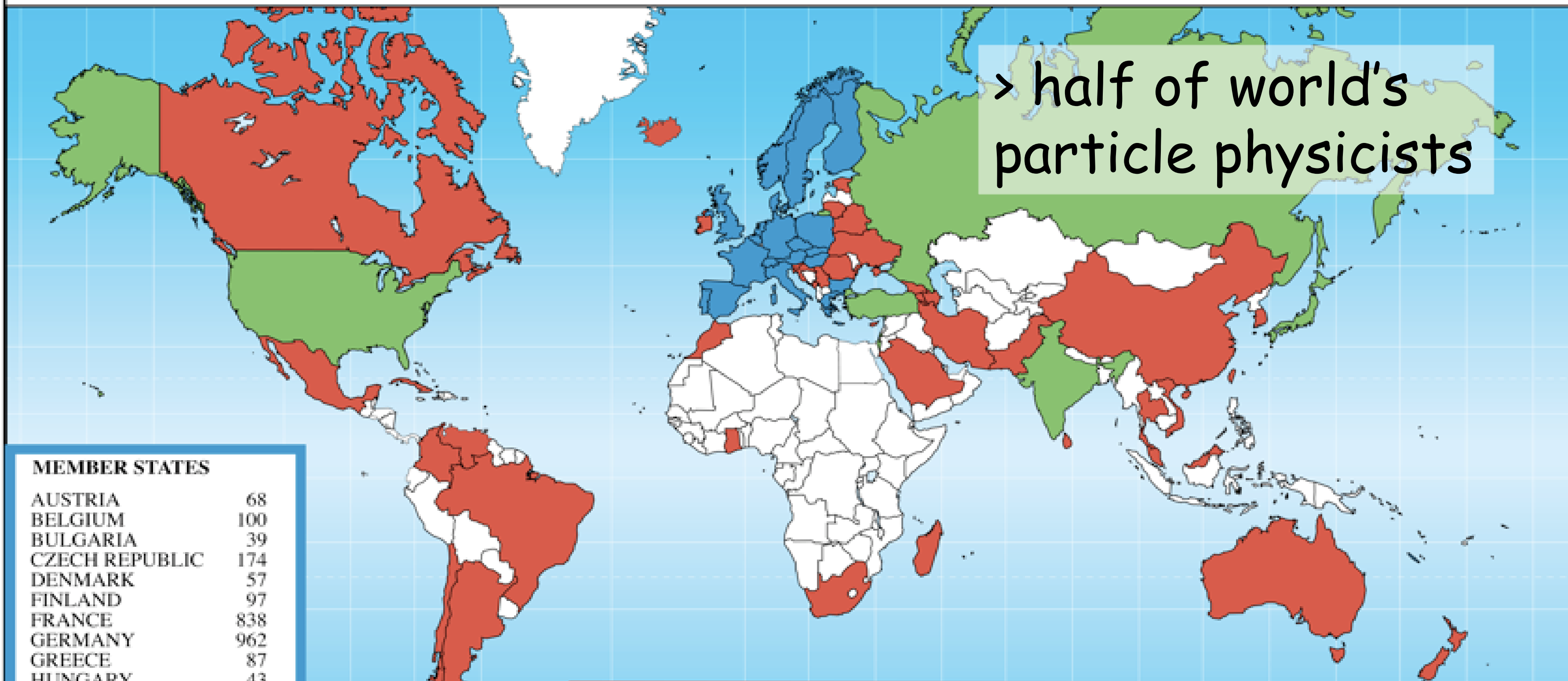
Belgium, Denmark, France, the Federal Republic of Germany, Greece, Italy, the Netherlands, Norway, Sweden, Switzerland, the United Kingdom, and Yugoslavia

**Mission:**

- *provide for collaboration among European States in nuclear research of a pure scientific and fundamental character*
- *have no concern with work for military requirements*
- *the results of its experimental and theoretical work shall be published or otherwise made generally available .*

# A GOBAL ENDEAVOUR

## Distribution of All CERN Users by Nation of Institute on 15 July 2008




**MEMBER STATES**

| | |
|---|---|
| AUSTRIA | 68 |
| BELGIUM | 100 |
| BULGARIA | 39 |
| CZECH REPUBLIC | 174 |
| DENMARK | 57 |
| FINLAND | 97 |
| FRANCE | 838 |
| GERMANY | 962 |
| GREECE | 87 |
| HUNGARY | 43 |
| ITALY | 1475 |
| NETHERLANDS | 171 |
| NORWAY | 74 |
| POLAND | 168 |
| PORTUGAL | 104 |
| SLOVAKIA | 46 |
| SPAIN | 278 |
| SWEDEN | 72 |
| SWITZERLAND | 341 |
| UNITED KINGDOM | 666 |

**5860**

**OBSERVER STATES**

| | |
|---|---|
| INDIA | 94 |
| ISRAEL | 57 |
| JAPAN | 192 |
| RUSSIA | 905 |
| TURKEY | 61 |
| USA | 1447 |

**2756**

**OTHER STATES**

| | |
|---|---|
| ARGENTINA | 10 |
| ARMENIA | 17 |
| AUSTRALIA | 15 |
| AZERBAIJAN | 4 |
| BELARUS | 18 |
| BRAZIL | 68 |
| CANADA | 127 |
| CHILE | 8 |
| CHINA | 68 |
| COLOMBIA | 12 |
| CROATIA | 22 |
| CUBA | 6 |
| CYPRUS | 7 |
| ESTONIA | 12 |
| GEORGIA | 11 |
| GHANA | 1 |
| ICELAND | 2 |
| IRAN | 13 |
| IRELAND | 10 |
| KOREA | 51 |
| LITHUANIA | 10 |
| MADAGASCAR | 1 |
| MALAYSIA | 1 |
| MALTA | 4 |
| MEXICO | 36 |
| MONTENEGRO | 1 |
| MOROCCO | 5 |
| NEW ZEALAND | 8 |
| PAKISTAN | 29 |
| PALESTINIAN TERR. | 1 |
| ROMANIA | 49 |
| SAUDI ARABIA | 2 |
| SERBIA | 15 |
| SLOVENIA | 17 |
| SOUTH AFRICA | 8 |
| SRI LANKA | 1 |
| TAIWAN | 46 |
| THAILAND | 1 |
| UKRAINE | 20 |
| U.A.E. | 4 |
| VIETNAM | 3 |

**744**

# CERN IN NUMBERS

2500 staff
9000 users (192 from Japan)
800 fellows and associates
580 universities, 85 nations
Budget 987MCHF (93 GJPY)

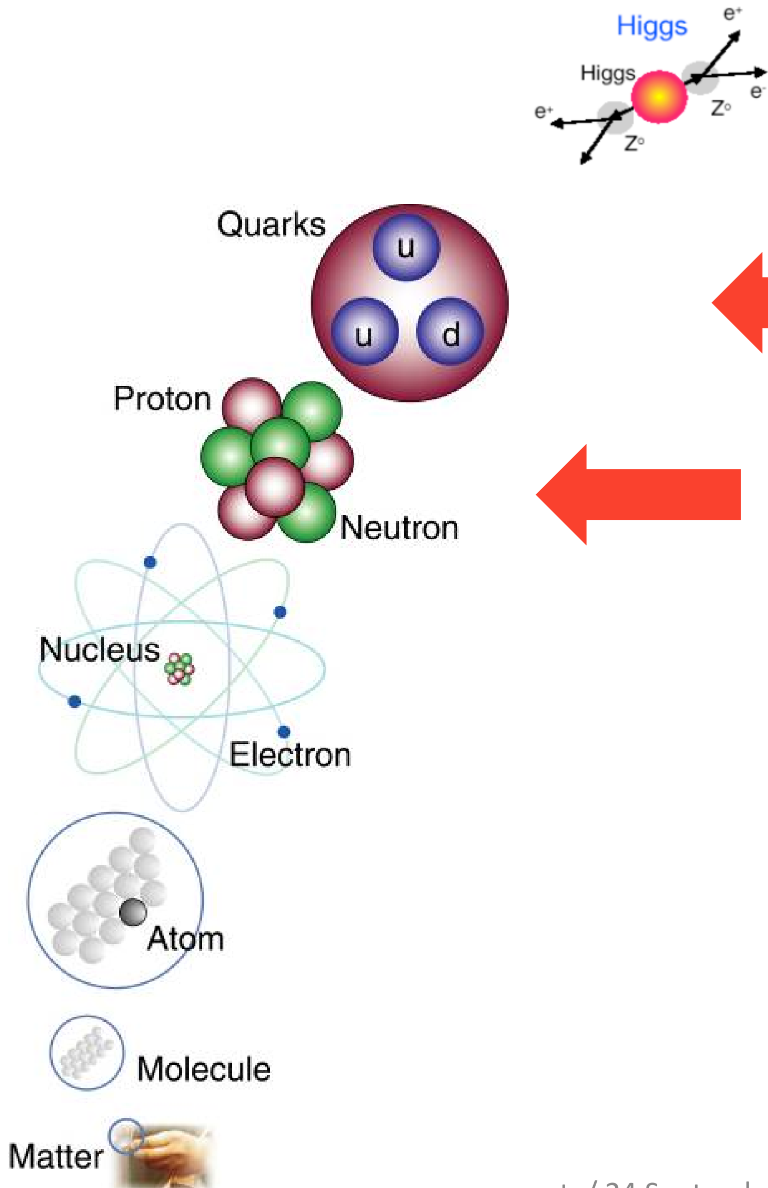
## 20 Member States:

Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom.

## 7 Observers:

India, Israel, Japan, the Russian Federation, Turkey, the United States of America, the European Commission and Unesco

# MATTER

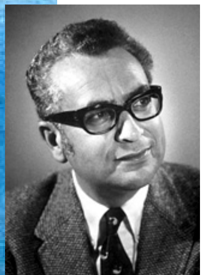



fields, forces, cosmology

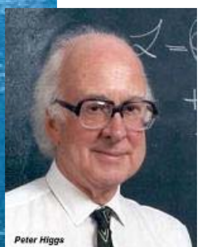
particle physics

nuclear physics

# THE RISE OF THE SM



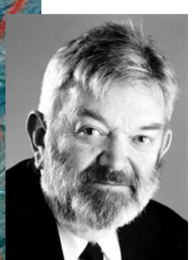
1964: Quark Model
Gell-Mann, Zweig




1964: Higgs mechanism

1967: Electroweak unification
Weinberg, Salam, Glashow

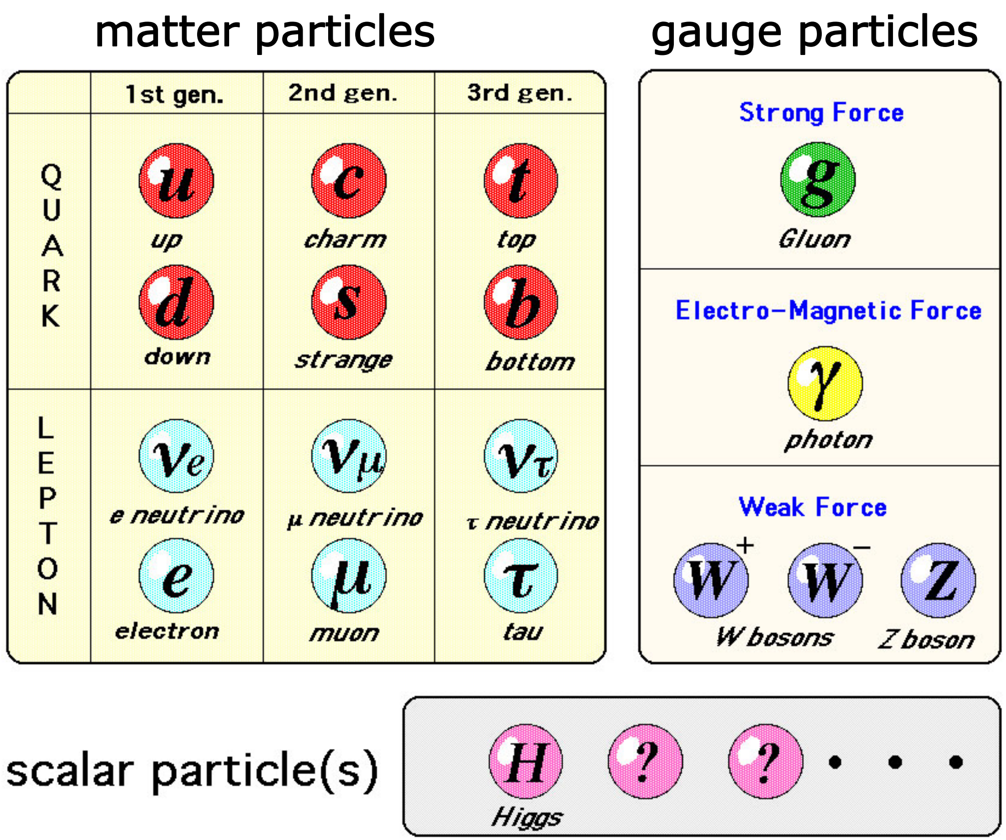
1969: Partons, DIS
Friedman, Kendal, Taylor



1971: Renormalization
Veltman, t'Hooft

# THE STANDARD MODEL

- incorporates three of the four known forces
- greatest achievement of the last decades
- mathematical tool: Quantum Field Theory




# TEST THE STANDARD MODEL

- By now we know that the SM describes strong, electromagnetic and weak interactions over a huge range of energy with amazing precision.
- Requires 'charged' (cc) and 'neutral' (nc) weak interactions (currents) (cc: $W^{\pm}$, nc: $Z^0$)
- Requires a 4th particle, the scalar Higgs Boson H, coupling to particles proportional to their mass

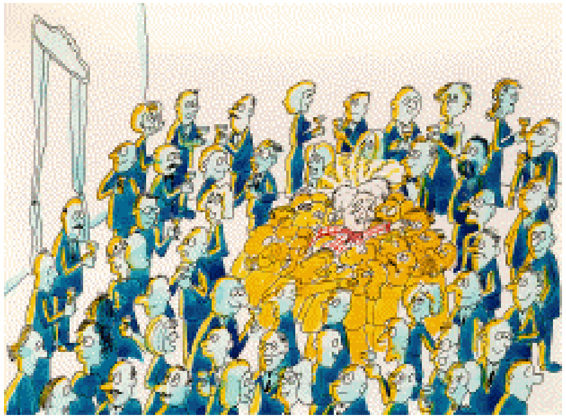
- The first crucial question was whether nc exist (neutron β-decay involves cc)
- If yes, find the $W^{\pm}$ and $Z^0$ particles and measure their masses and couplings

# THE HIGGS MECHANISM

D. Miller
UC London

The Higgs field

A particle enters the
Higgs field

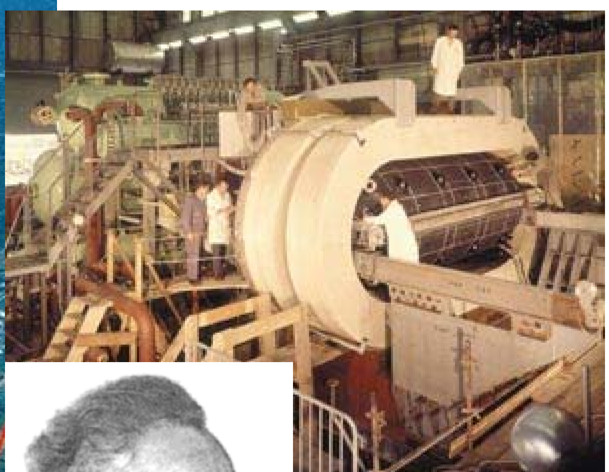


It's gains mass proportional
to the interest in it

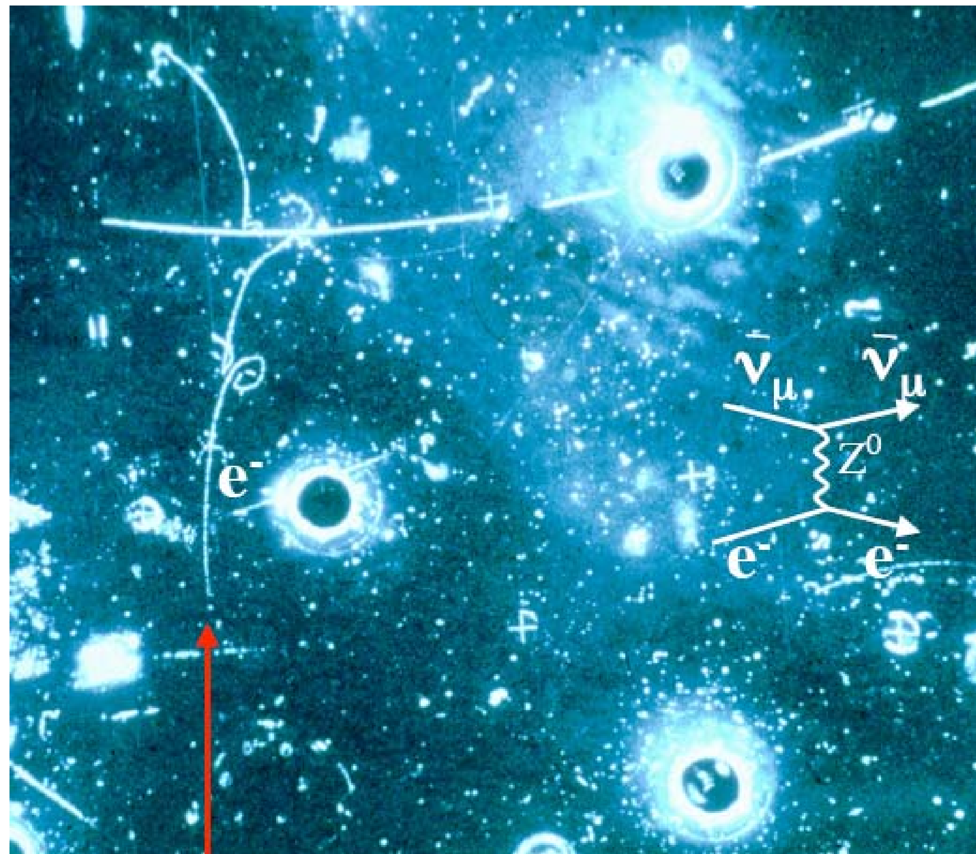
# NEUTRAL CURRENTS: YES OR NO?

## 1973: The discovery of neutral currents at CERN

Gargamelle Bubble chamber at the PS neutrino beam



A. Lagarrigue



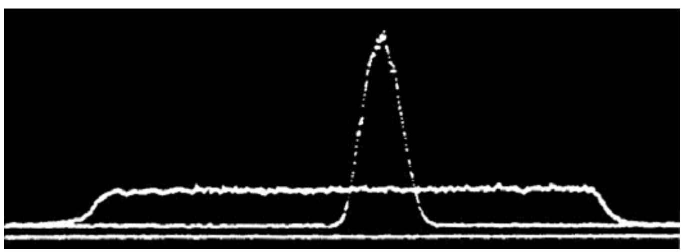

$\bar{\nu}_\mu e^- \rightarrow \bar{\nu}_\mu e^-$

# A PROTON-ANTIPROTON COLLIDER

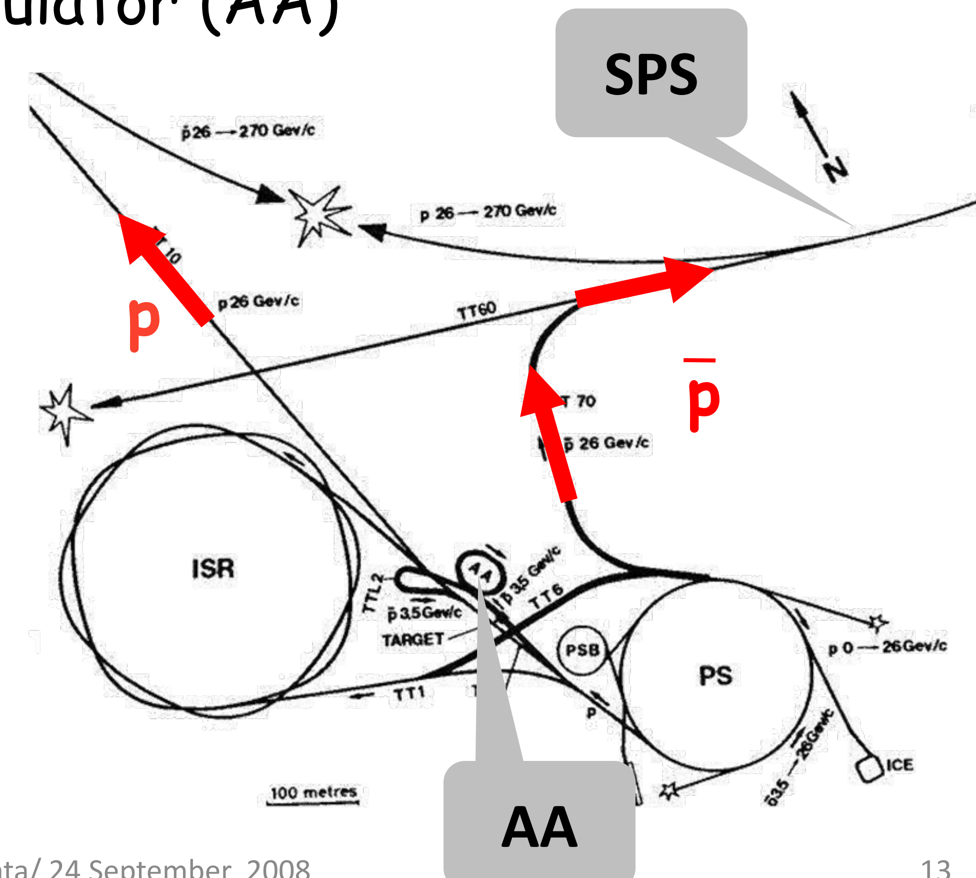
- The Gargamelle result showed that the $W^{\pm}$ and $Z^0$ masses were large ~ 100 GeV.
- Since 1976 a new 450 GeV proton accelerator (SPS) was in operation at CERN with a cm energy of 30 GeV in fixed-target mode
- Colliding two beams of 450 GeV would yield up to 900 GeV
- The available cm energy is actually much lower, because quarks and gluons collide and not the entire protons
- The idea was to circulate proton and anti-protons in oppsite sense in the SPS and collide them!
- The alternative: The large electron positron ring (LEP)

# HUNT FOR THE W± AND Z⁰ BOSON

- since 1976 a new 450 GeV proton accelerator (SPS)
- use the Super Proton Synchrotron as $p\bar{p}$ collider
- built antiproton accumulator (AA)
- UA1 & UA2 detectors
- stochastic cooling

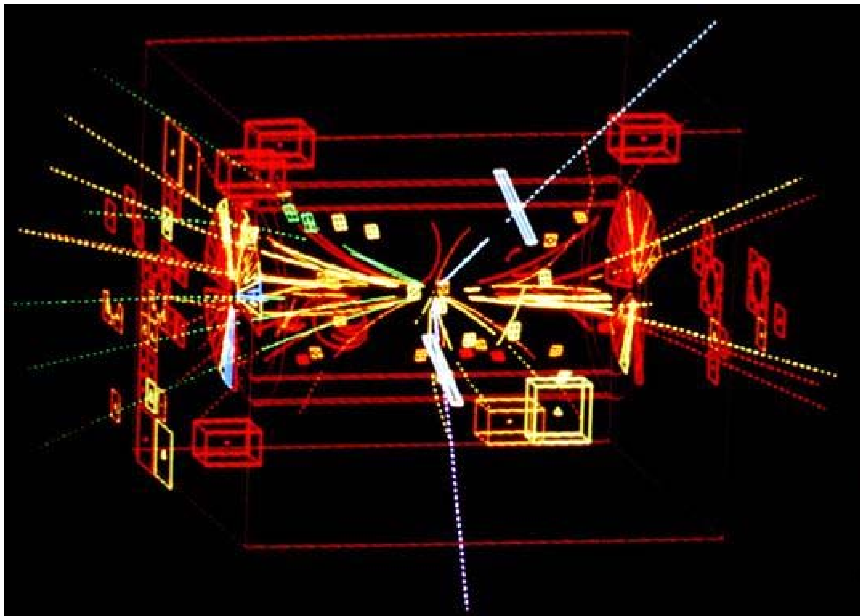


ICE demonstration of cooling



# DISCOVERY OF W AND Z (1983)

C. Rubbia

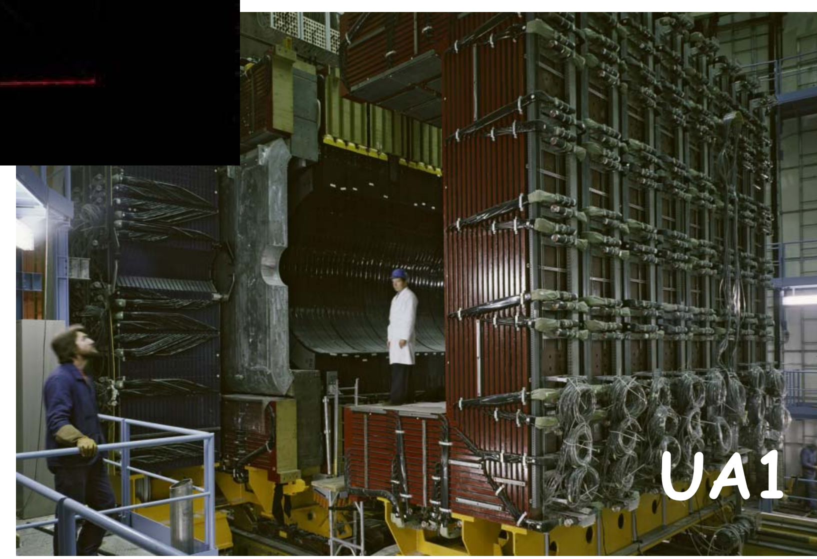


first $Z^0$ event

$$p\bar{p} \rightarrow Z^0 + X \rightarrow e^+e^-$$

S. van der Meer

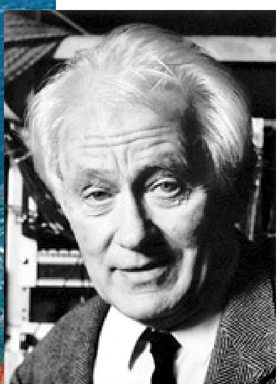
CERN's first
Nobel prize 1984



# A NOBEL INVENTION

Gaseous detectors:

- Multiwire Proportional Chamber  (1968)
- Drift chambers
- Micromegas



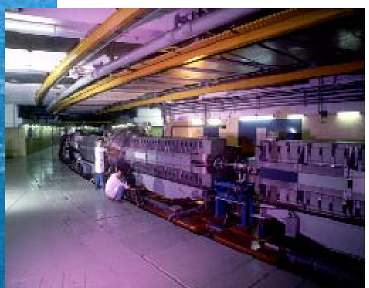
G. Charpak

CERN's second
Nobel prize 1992

# CERN ACCELERATORS (BEFORE 1988)

(incomplete)

1955: SC, Synchro-Cylotron,
600 MeV



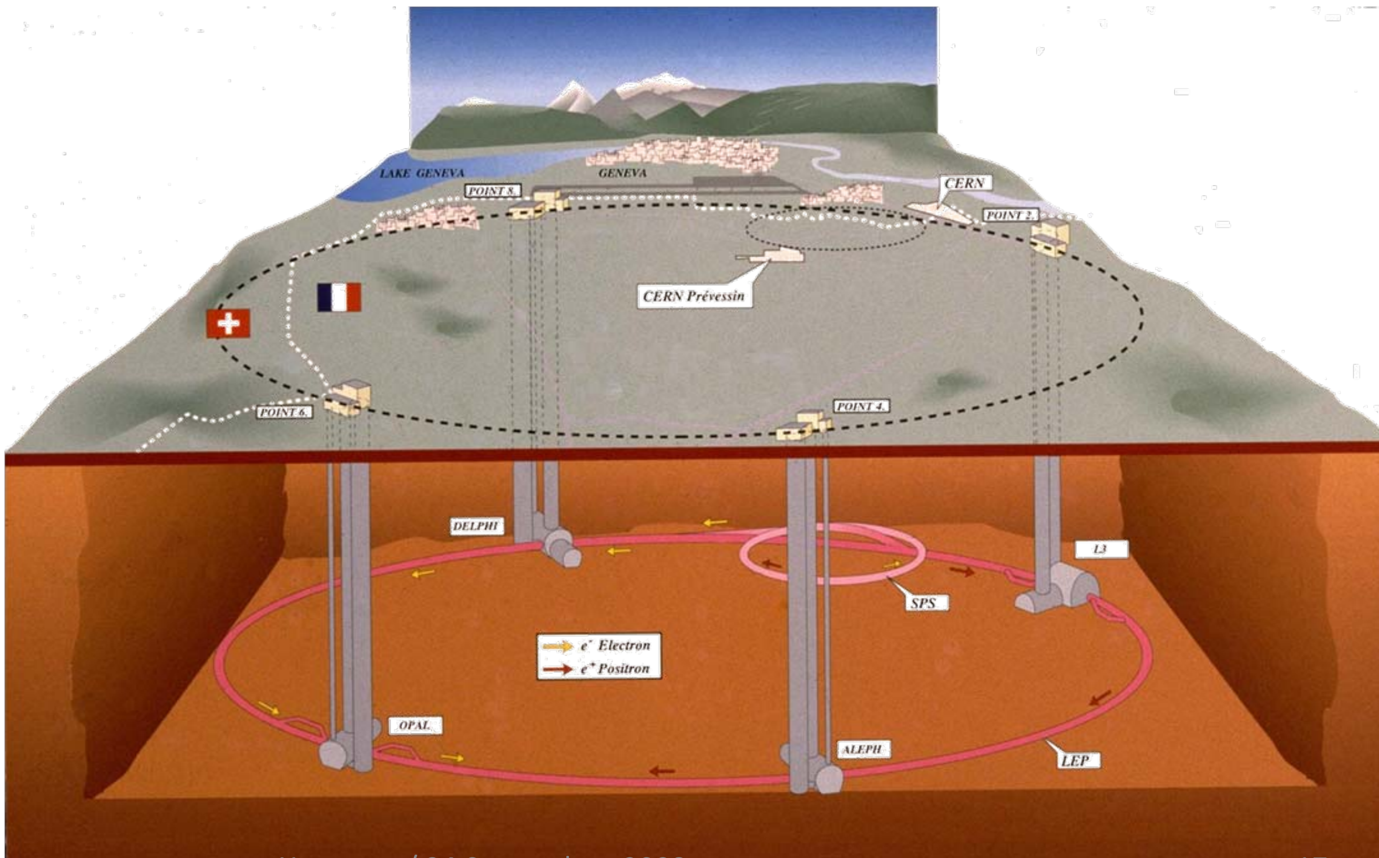
1959: PS, Proton Synchotron,
28 GeV, 628 m

1971: ISR, Intersecting Storage Ring,
31 GeV, pp collider, 943 m

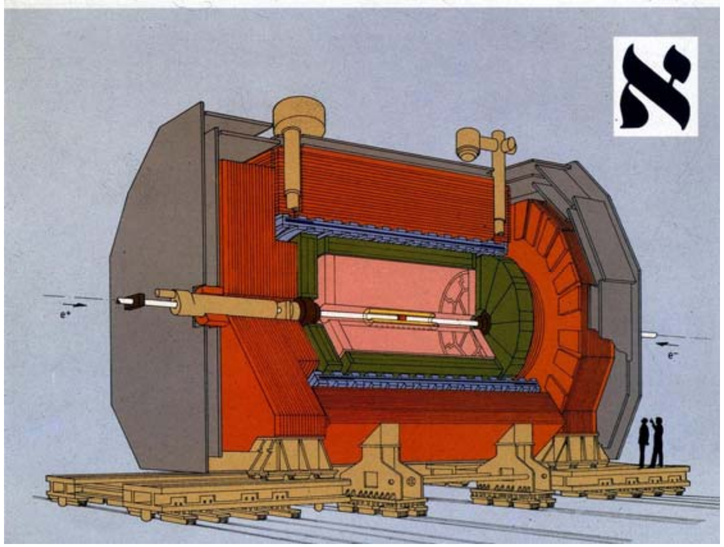
1976: SPS, Super Proton Synchotron
450 GeV, 6912 m, 1982-1991 SP$\bar{\text{P}}$S

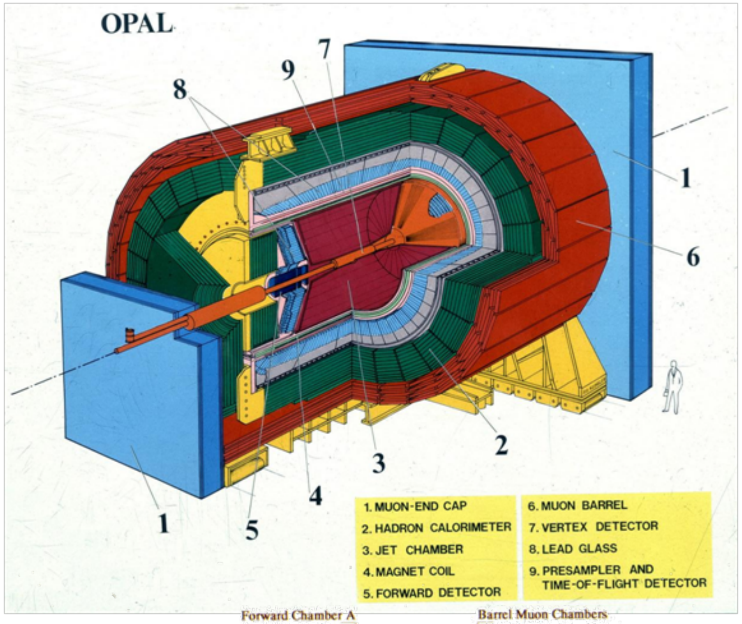
# LEP: A $Z^0$-FACTORY

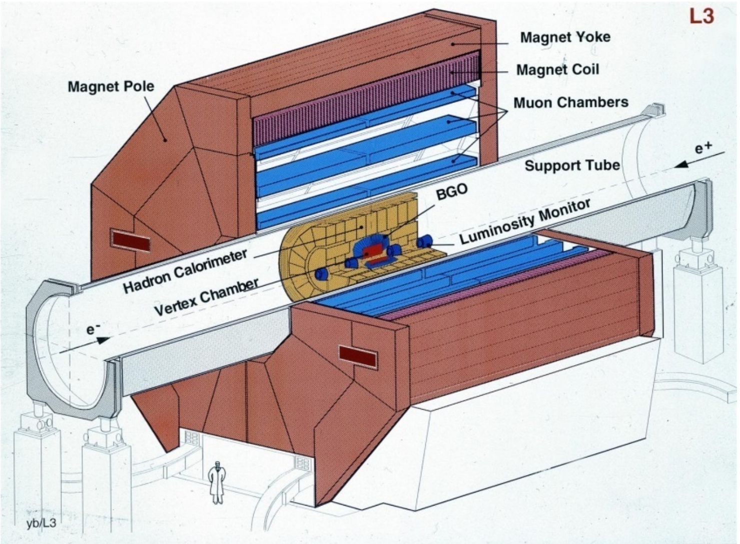
- 1989: LEP: Large-Electron-Positron Ring,
  55 GeV (per beam), 27 km
- 1996: LEP200
  100 GeV

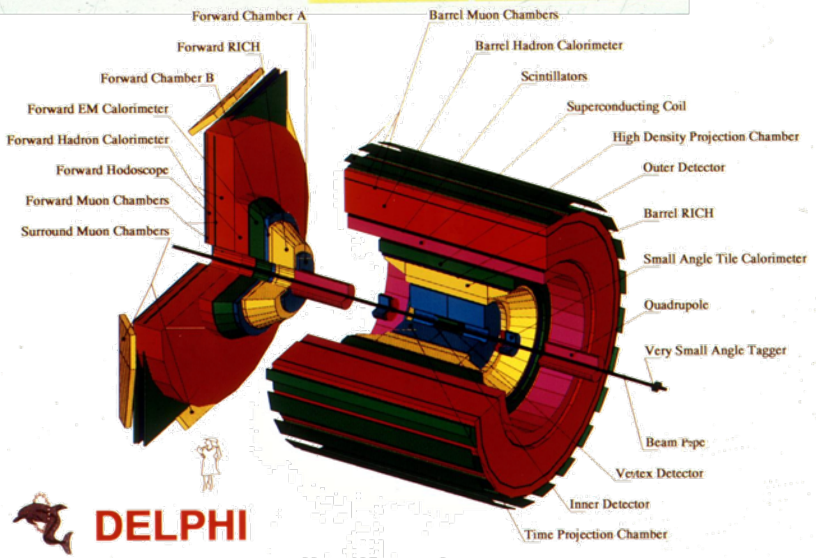


# LEP DETECTORS



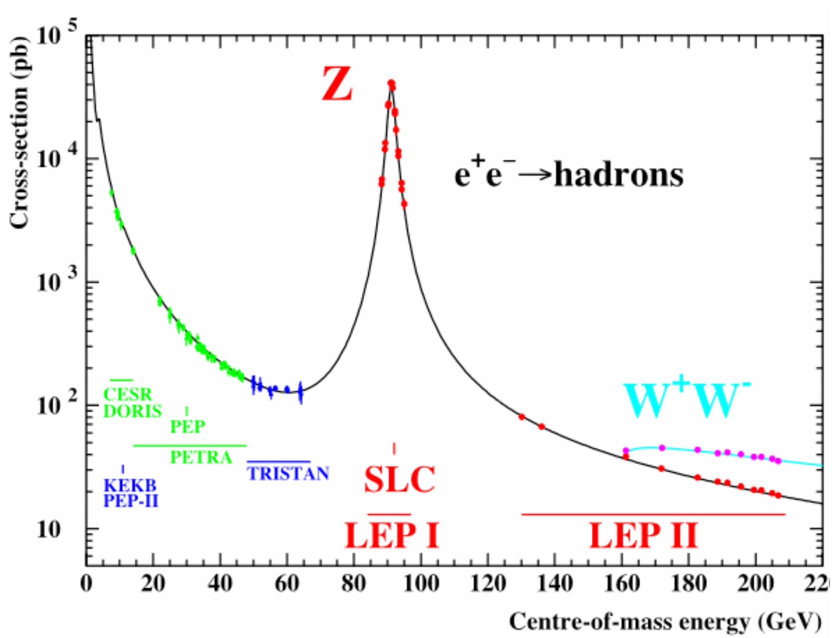



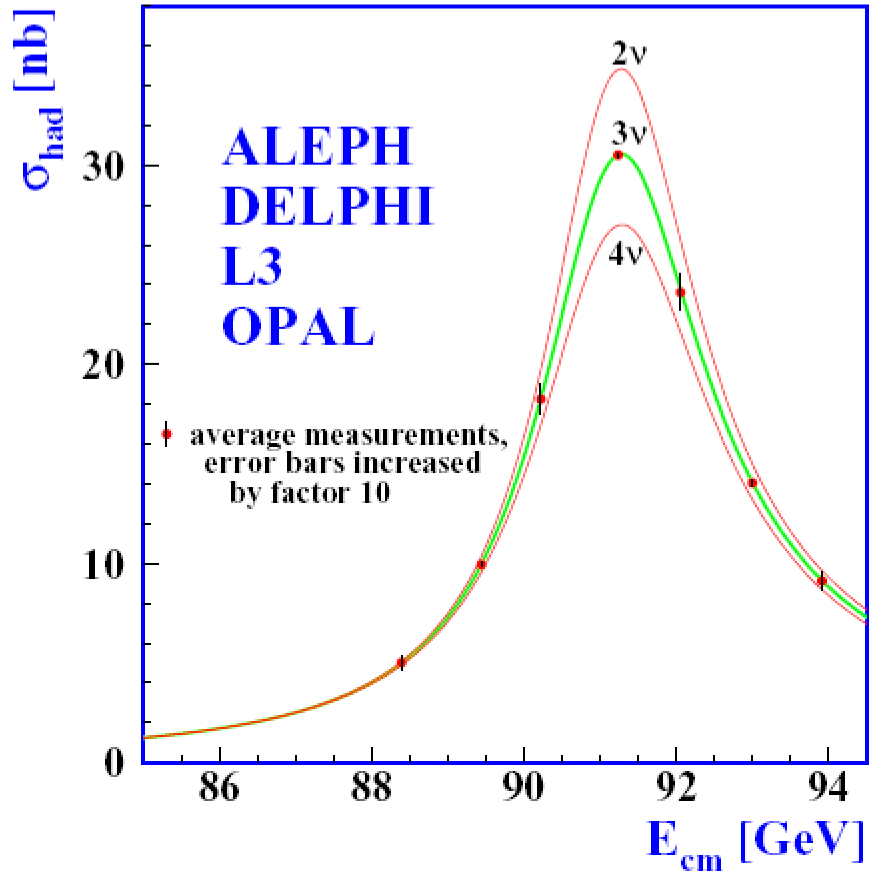



# LEP HIGHLIGHTS

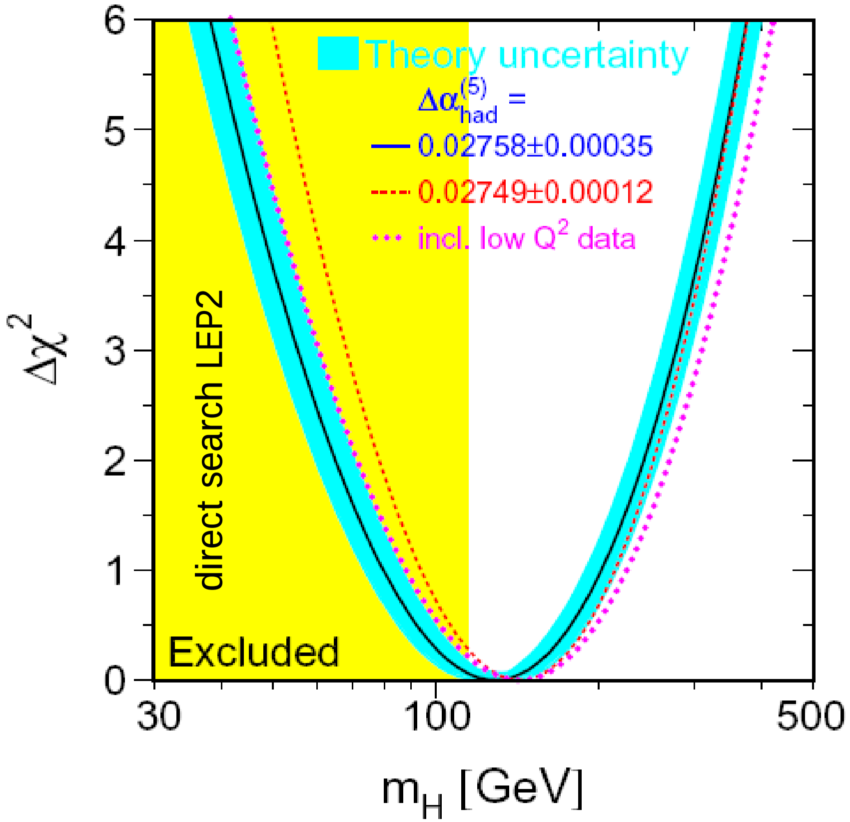
- There are only three generations of neutrinos
- precise determination of Z and W mass
  $m_Z = 91.1875 \pm 0.0021$ GeV
- confirmation of the SM

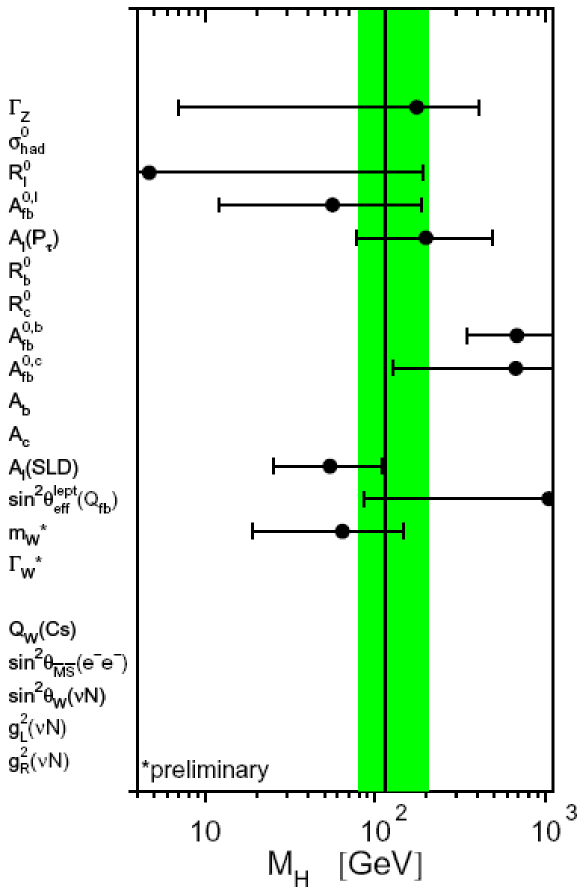


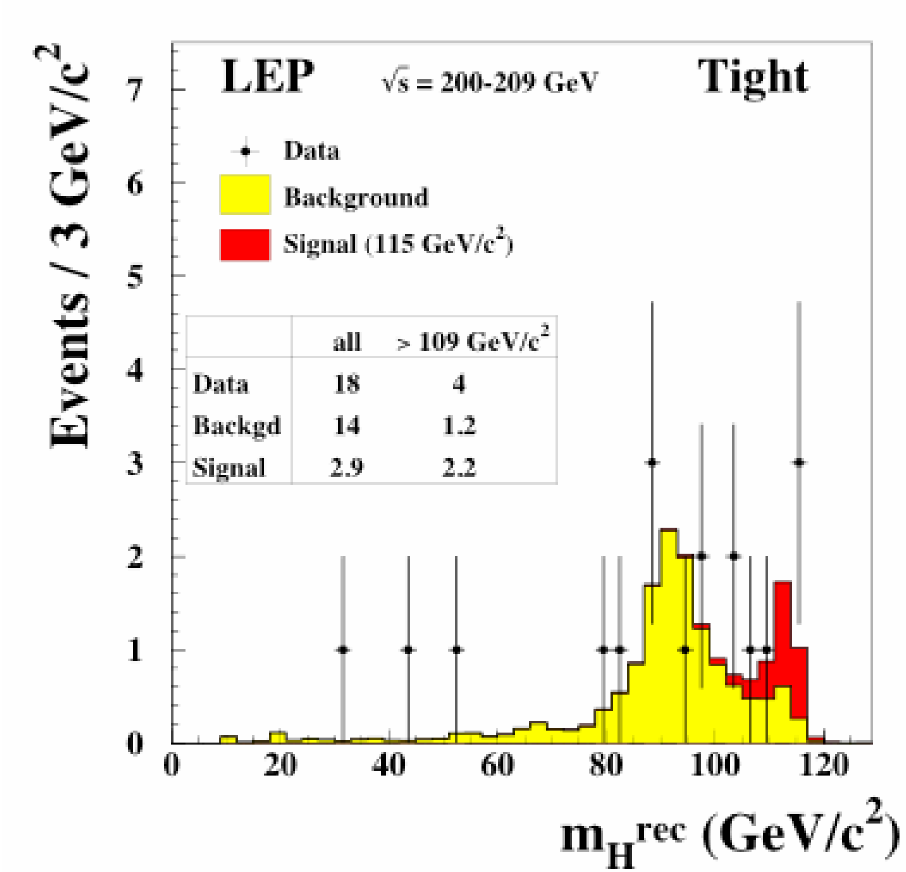
# SM HIGGS MASS

$$m_H = 103^{+76}_{-45}\,\text{GeV}$$



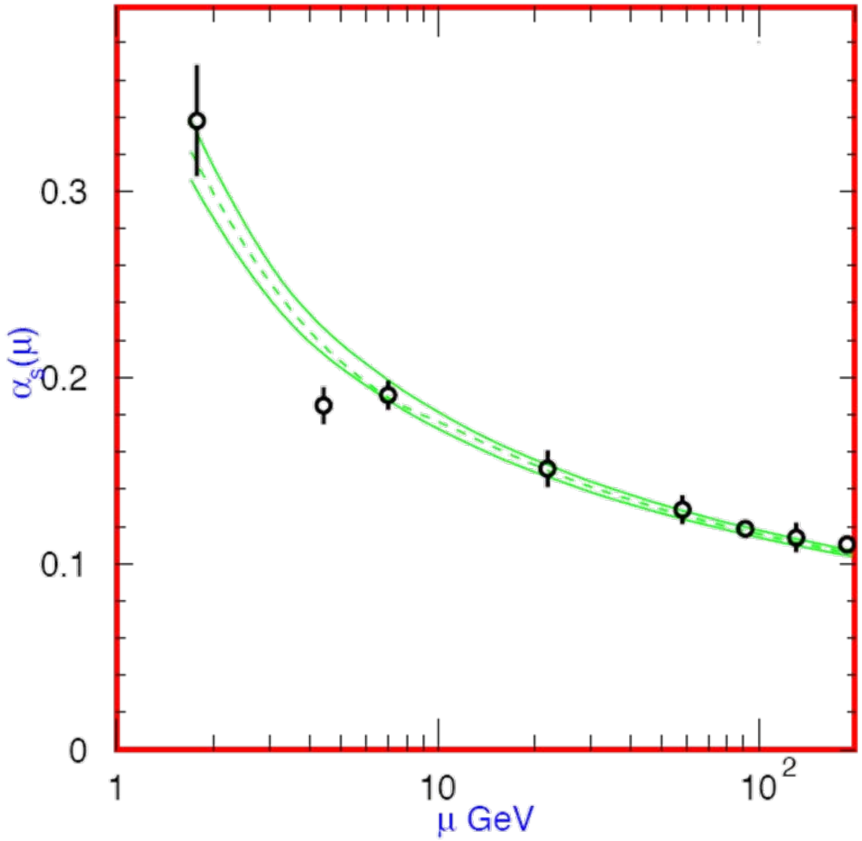
# HIGGS ALREADY SEEN @ LEP2?



# RUNNING STRENGTH OF FORCES

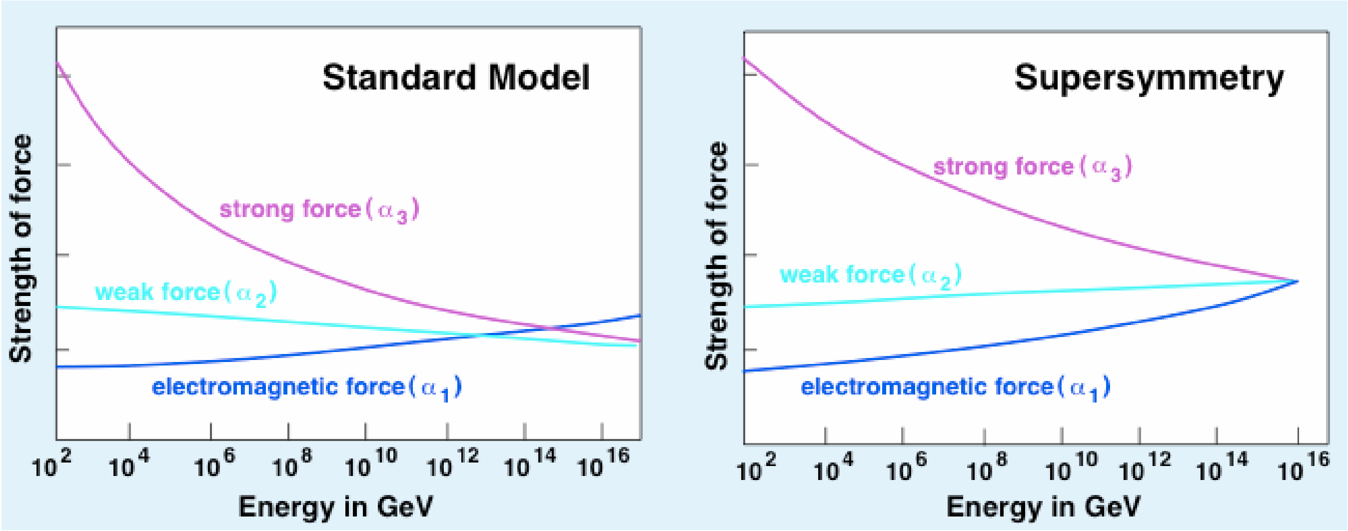
The strength of forces vary with energy

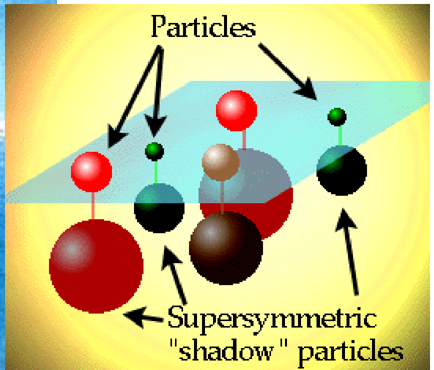
- This is due contributions from creation and annihilation of virtual particles
- variation of $\alpha_s$ measured in decays, DIS, at LEP
- asymptotic freedom of quarks at high energies, $\alpha_s \rightarrow 0$,



# RUNNING COUPLING

- All forces manifestations of the same force?
- Strength must then be the same at some energy
- The running depends on the available particle zoo and the masses
- In the SM unification is slightly missed
- In supersymmetry it can be perfect!

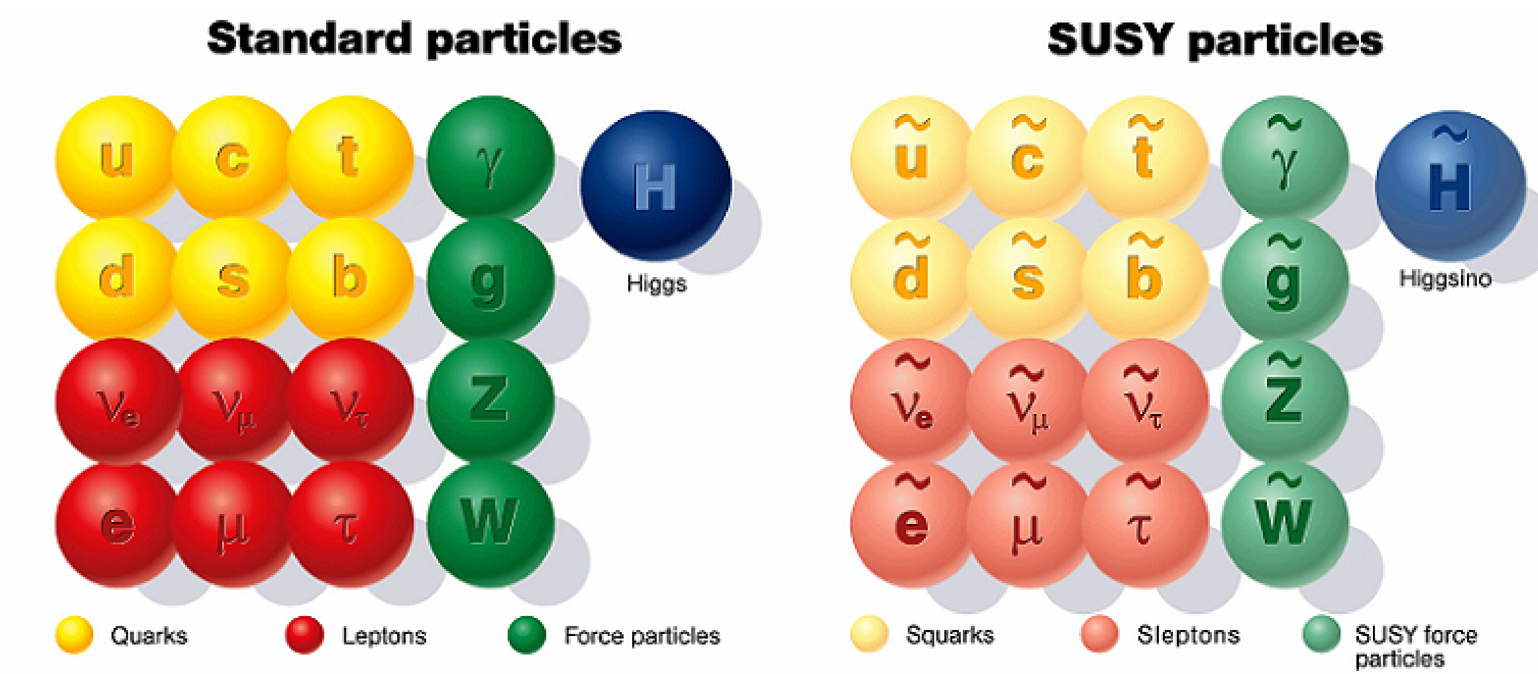





# SUPERSYMMETRY

A new symmetry between
Spin ½ matter particles (fermions) ⇔
Spin 1 force carriers (bosons)

Every SM matter particle has a heavy susy force particle partner
every SM force particle has a heavy susy matter particle partner

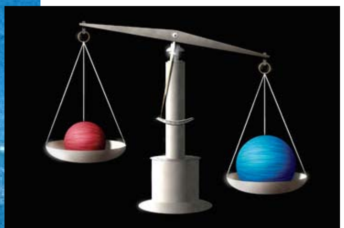


# SUPERSYMMETRY

- Unifies matter and force particles
- Solves divergences in theory (fermion-boson)
  - SUSY masses in the 1 TeV region needed (LHC)
- Allows unification of forces
- Provides a candidate for dark matter:
  - the lightest SUSY particle **(LSP)**

**SUSY could be found at an early stage of LHC!**

# MYSTERIES WAITING TO BE SOLVED

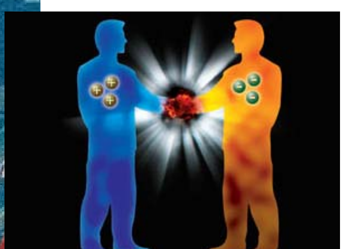


What is the origin of mass?

Higgs?

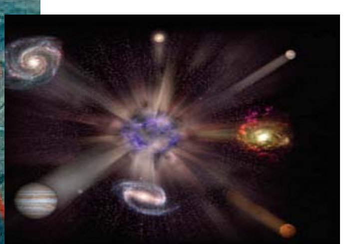
What is dark  matter?

LSP?



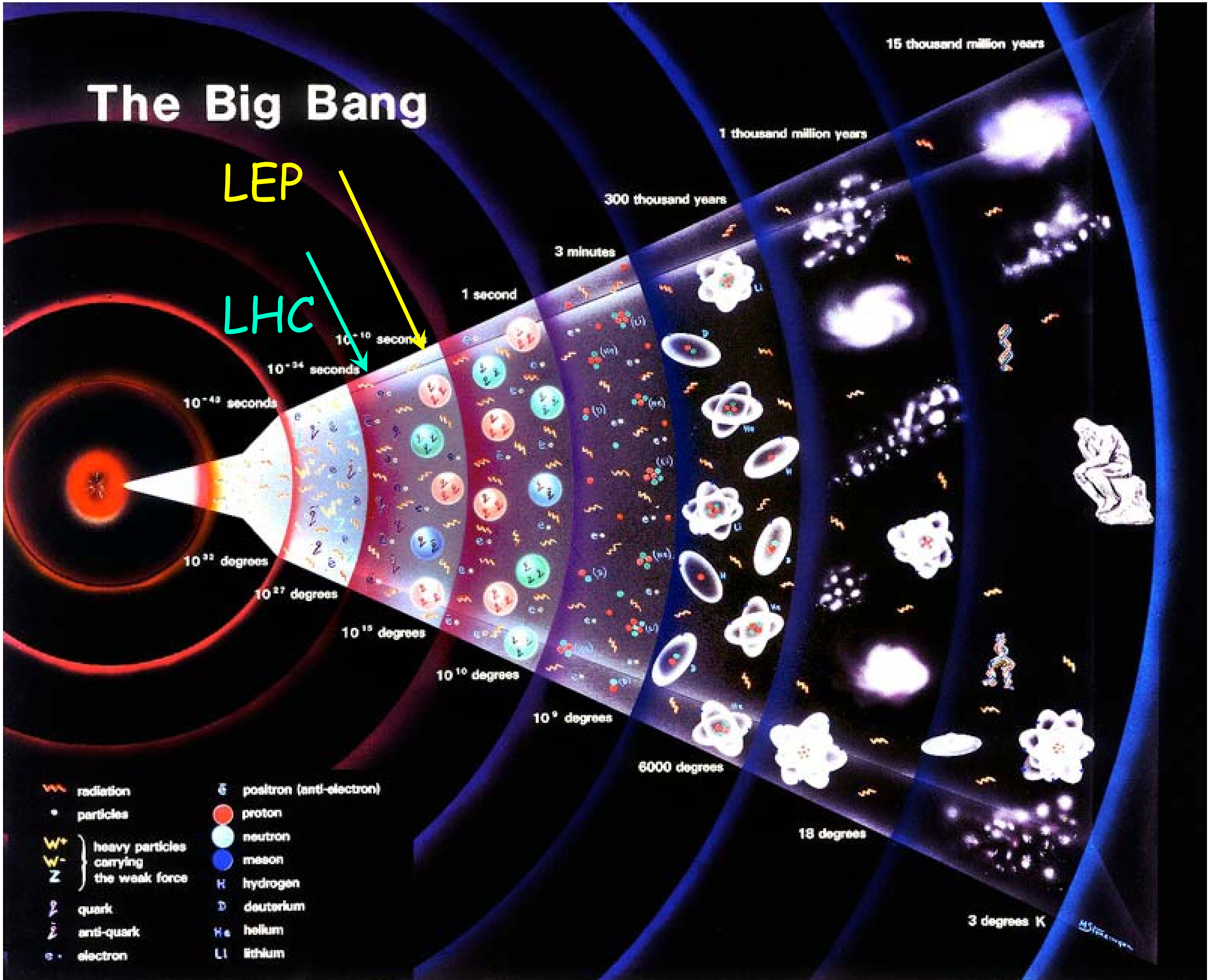
Why is no anti-matter left from big bang?

CP violation, LHCb



Why is dark energy, universe accelerating?

new force, extra dimensions?


The Big Bang
LEP
LHC
15 thousand million years
1 thousand million years
300 thousand years
3 minutes
1 second
$10^{-10}$ seconds
$10^{-34}$ seconds
$10^{-43}$ seconds
$10^{32}$ degrees
$10^{27}$ degrees
$10^{15}$ degrees
$10^{10}$ degrees
$10^{9}$ degrees
6000 degrees
18 degrees
3 degrees K
radiation
particles
W+ W- Z heavy particles carrying the weak force
quark
anti-quark
electron
positron (anti-electron)
proton
neutron
meson
hydrogen
deuterium
helium
lithium

# ENOUGH THEORY AND HISTORY!!

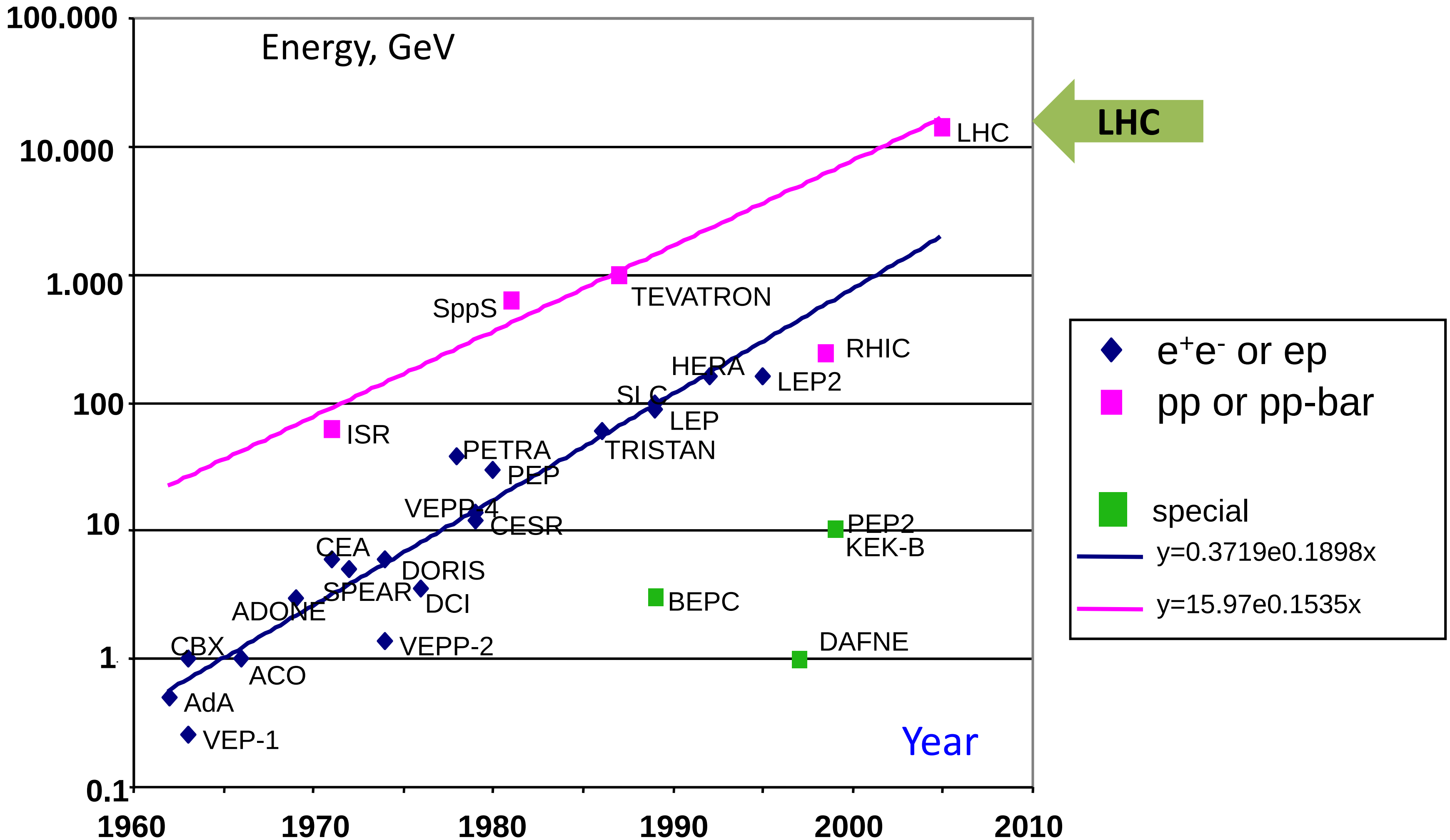
# THE LARGE HADRON COLLIDER

Milesstones :

- 1976 First idea
- 1984 R&D starts
- 1987 Proto-Collaborations
- 1989 First public presentation by DG
- 1994 Approval of LHC project
- 1996 Approval of experiments
  -1998 ATLAS, CMS, ALICE, LHCb
- 2007 Construction complete
- 2008 first circulation of beam

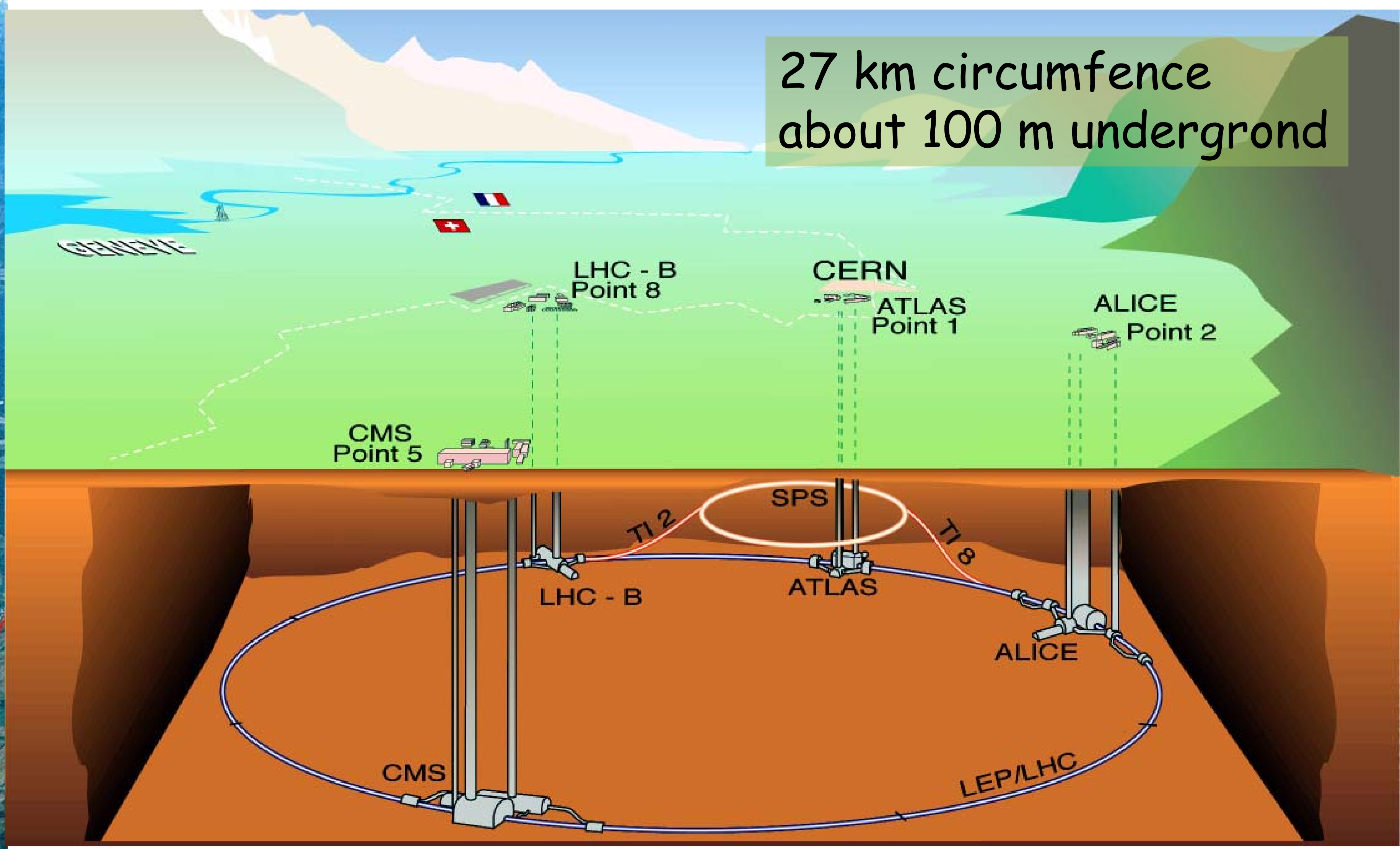
It took $\frac{1}{4}$ of a century or more!

# THE COLLIDER ZOO: A BIG LEAP

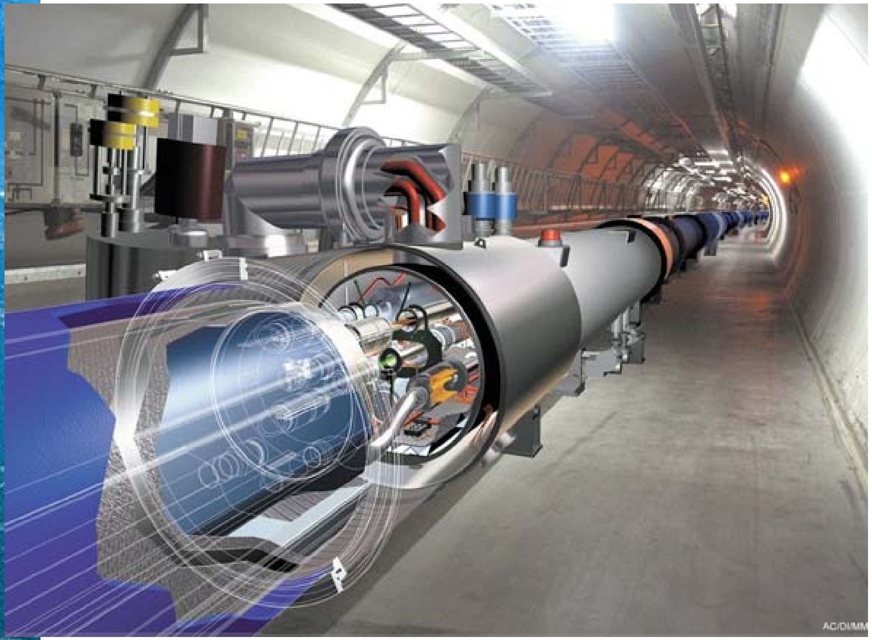


# LHC GENERAL VIEW

27 km circumfence
about 100 m undergrond

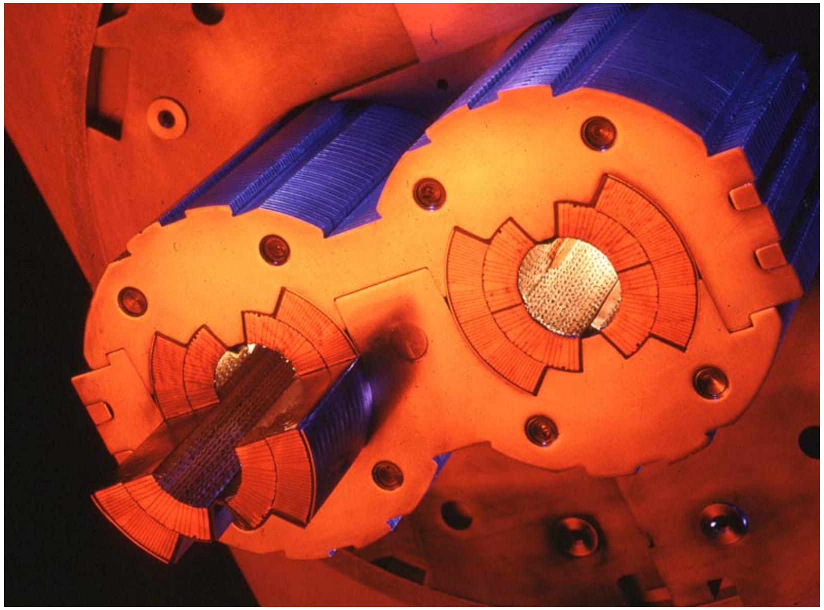


# LARGE HADRON COLLIDER



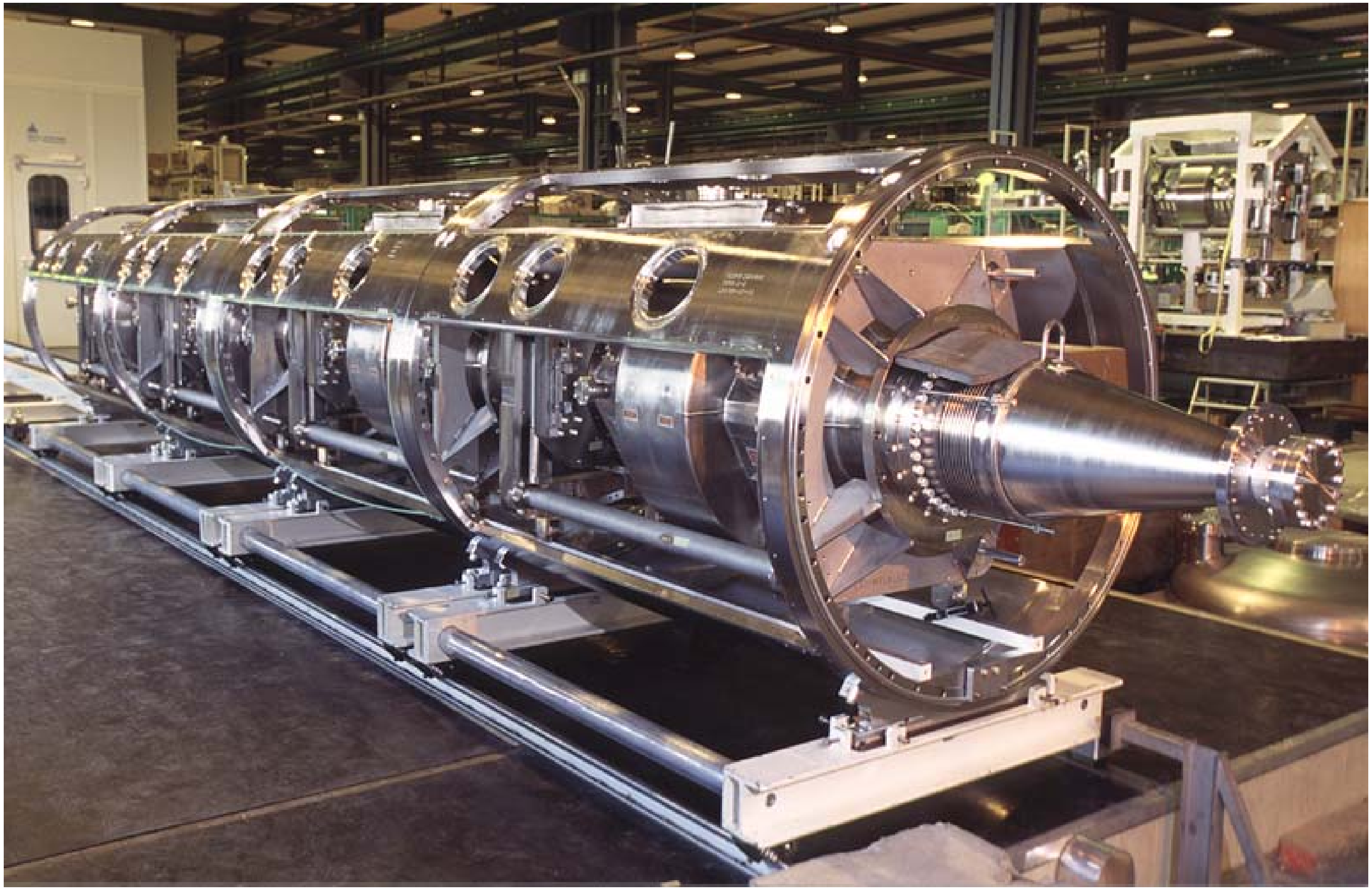

9300 magnets (total)
1232 dipoles
max. mag field 8.33 T
at 11700 A

- two-in-one design

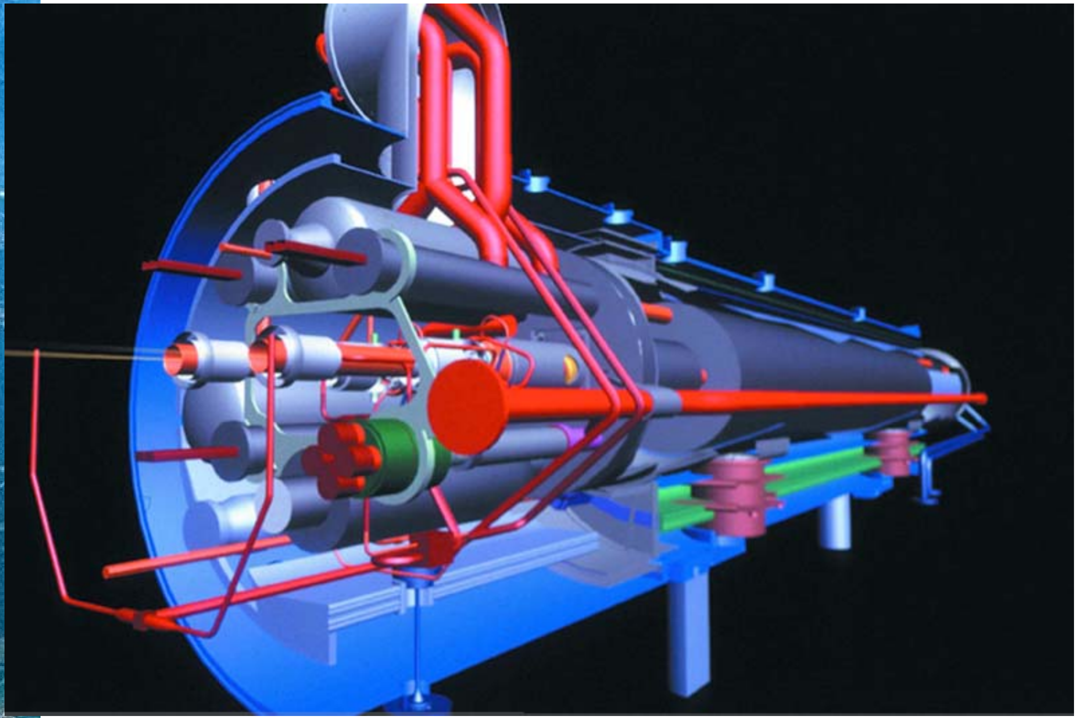


# LHC CAVITIES

2x8 RF Cavities for acceleration

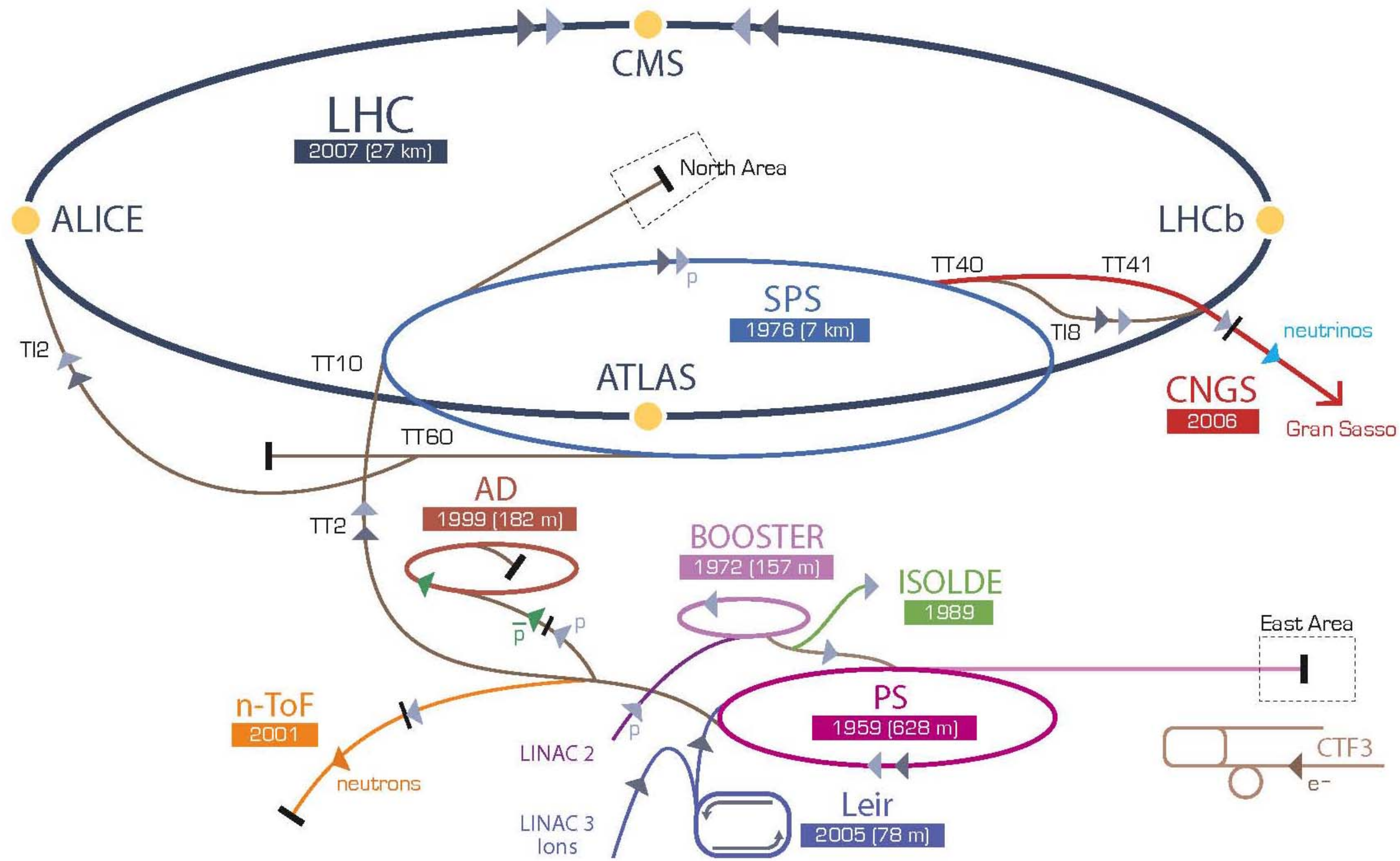


# LHC DIPOLE (1232)



- two beams running in opposite direction in the same magnet
- superfluid He at 1K
  96 tons
- vacuum $10^{-13}$ bar
  6500 $m^3$
- Mag. field 8.33T, @ 11700 A
- length 14.3 m
- weight 35 tons

# THE CERN ACCELERATOR COMPLEX



# SOME NUMBERS

- Max Energy:
  - Protonen 7 + 7 TeV
  - Lead-Ions 575 + 575 TeV
- Number of stored particles:
  2808 bunches x 1011 protons
- Collisions per second: 600 000 000
- Beamenergy: 100 MJoule
- Electrical power: 120 MW

| COST: | |
|---|---|
| Construction cost | 4’700 MCHF |
| Experiments | 1’100 MCHF |
| Computing | 250 MCHF |
| Total | 600’000 GJPY |

# JAPANESE CONTRIBUTION

Japan's early entry into the LHC arena in 1995 provided a memorable boost for the project.

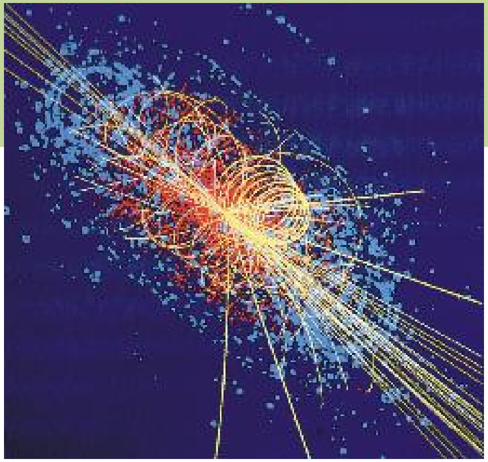
Japanese contributions currently total approximately ¥13,850 million (some SFr 160 million).

Of this sum, some SFr 25 million was earmarked for constructing of the solenoid magnet for the ATLAS experiment.

A further significant Japanese contribution to the LHC is the 16 quadrupoles used to squeeze the colliding beams and boost the interaction rate. Also on the list of equipment are compressors for cooling superfluid helium.

# INTERACTION RATE

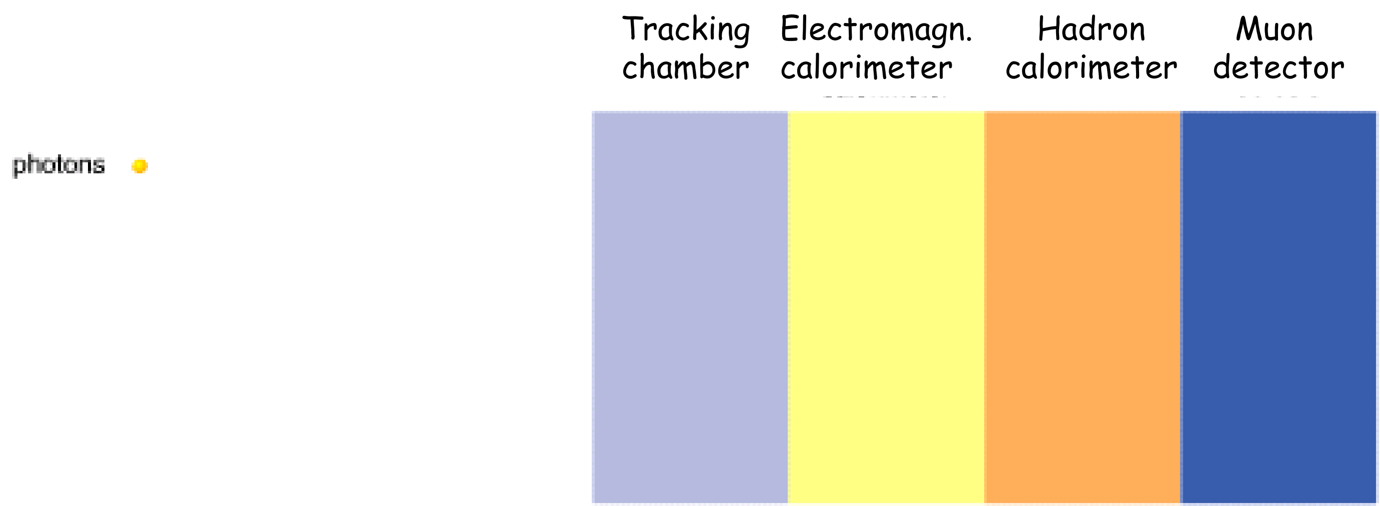
- Luminosity $10^{34}$ $cm^2s^{-1}$
- 25 ns bunch crossing, 20 interactions/crossing
- about 1000 particles per crossing produced
- in one year about 30 x Tevatron x 10 years
- reduce 40 MHz interaction rate to about 100-200 Hz by selective triggers



# FIRST BEAM CIRCULATION IN LHC

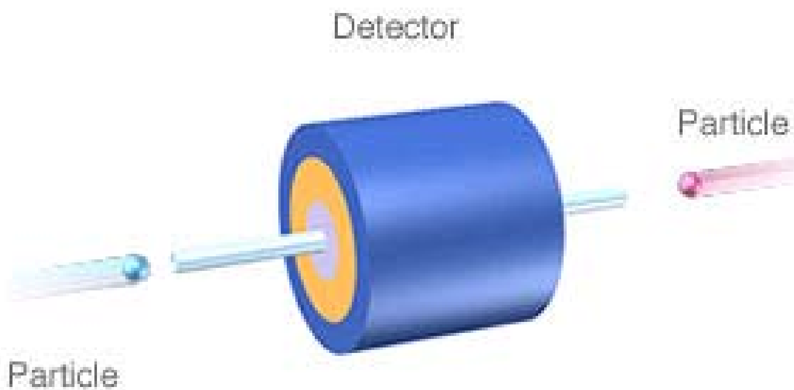
# PARTICLE DETECTION

- particle classes:
  - charged particles seen in tracking chambers
  - photons (and electrons) seen in electromagnetic calorimeters
  - hadrons (e.g. pion, neutron) seen in hadron calorimeters
  - muons penetrate all absorbers

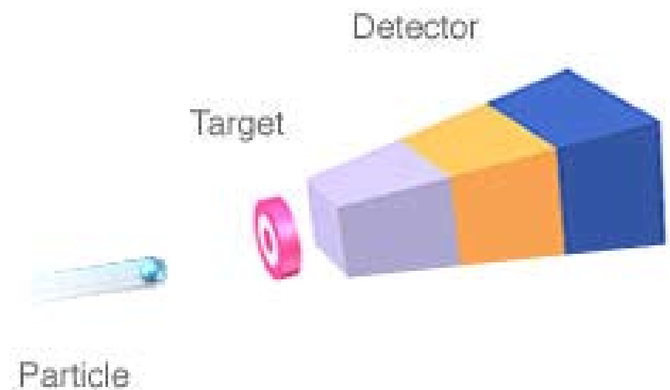


# DETECTOR DESIGN

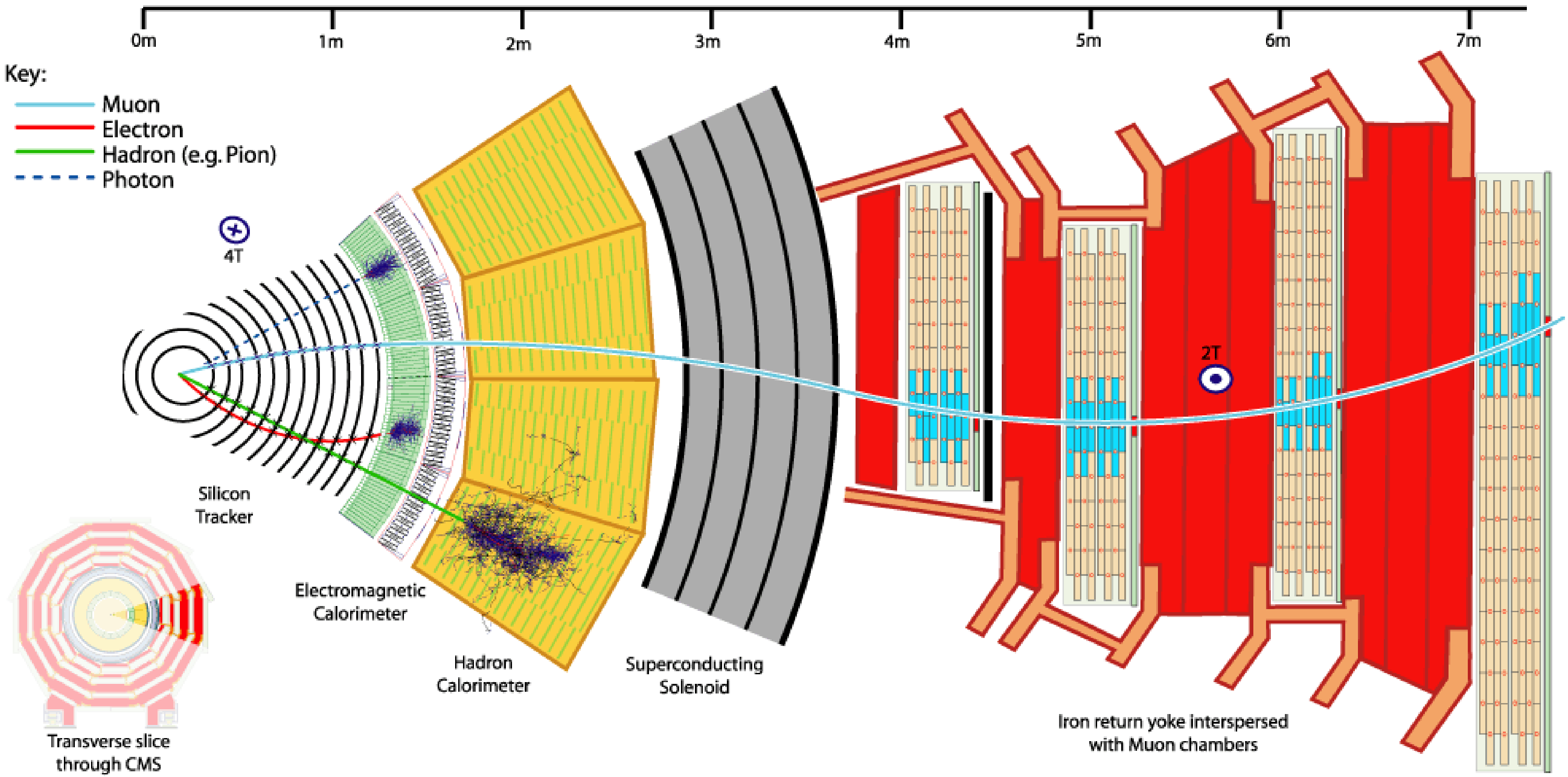
**Collider:**
two particle beams collide,
particle fly in all directions,
complete energy available




**Fixed-target:**
beam hits target at rest,
particles go forward,
fraction of energy available

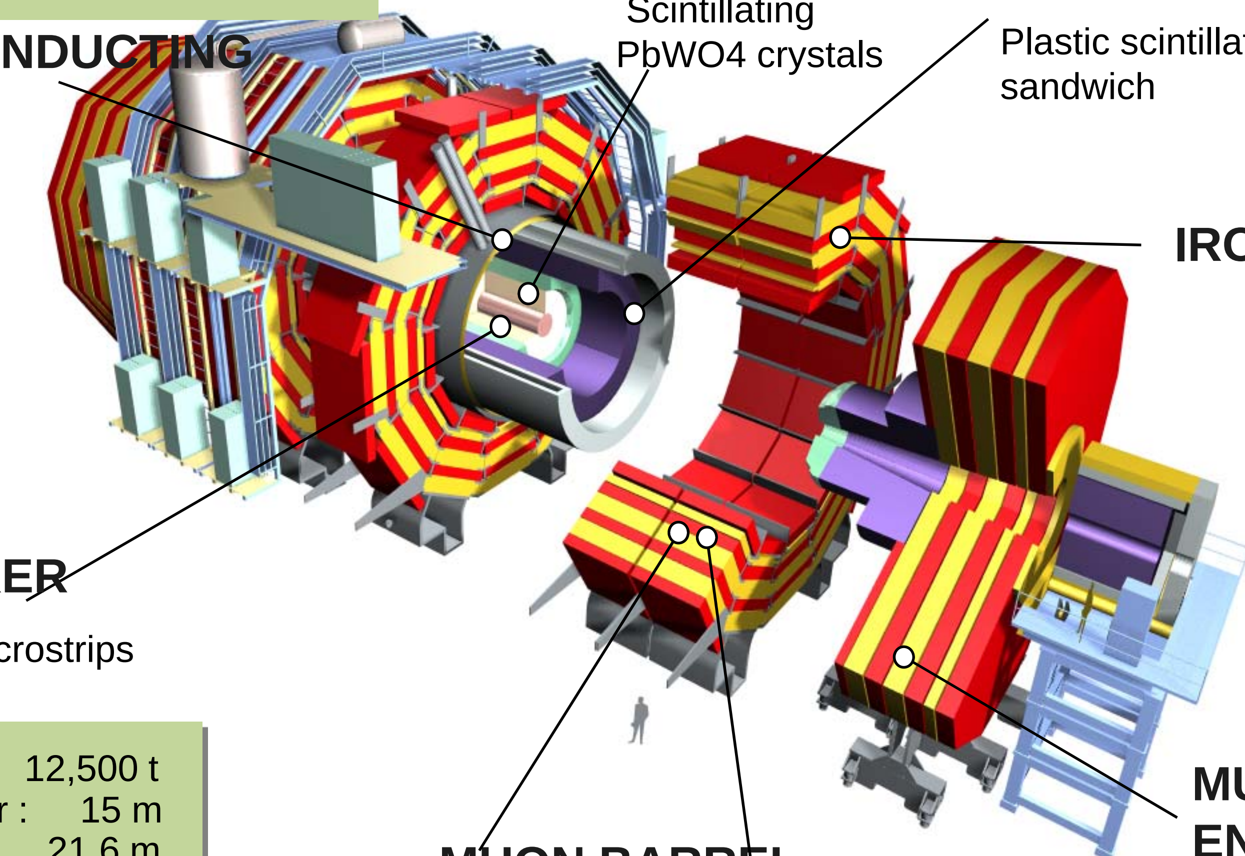


# ANATOMY OF A DECTECTOR: CMS



# THE CMS DETECTOR

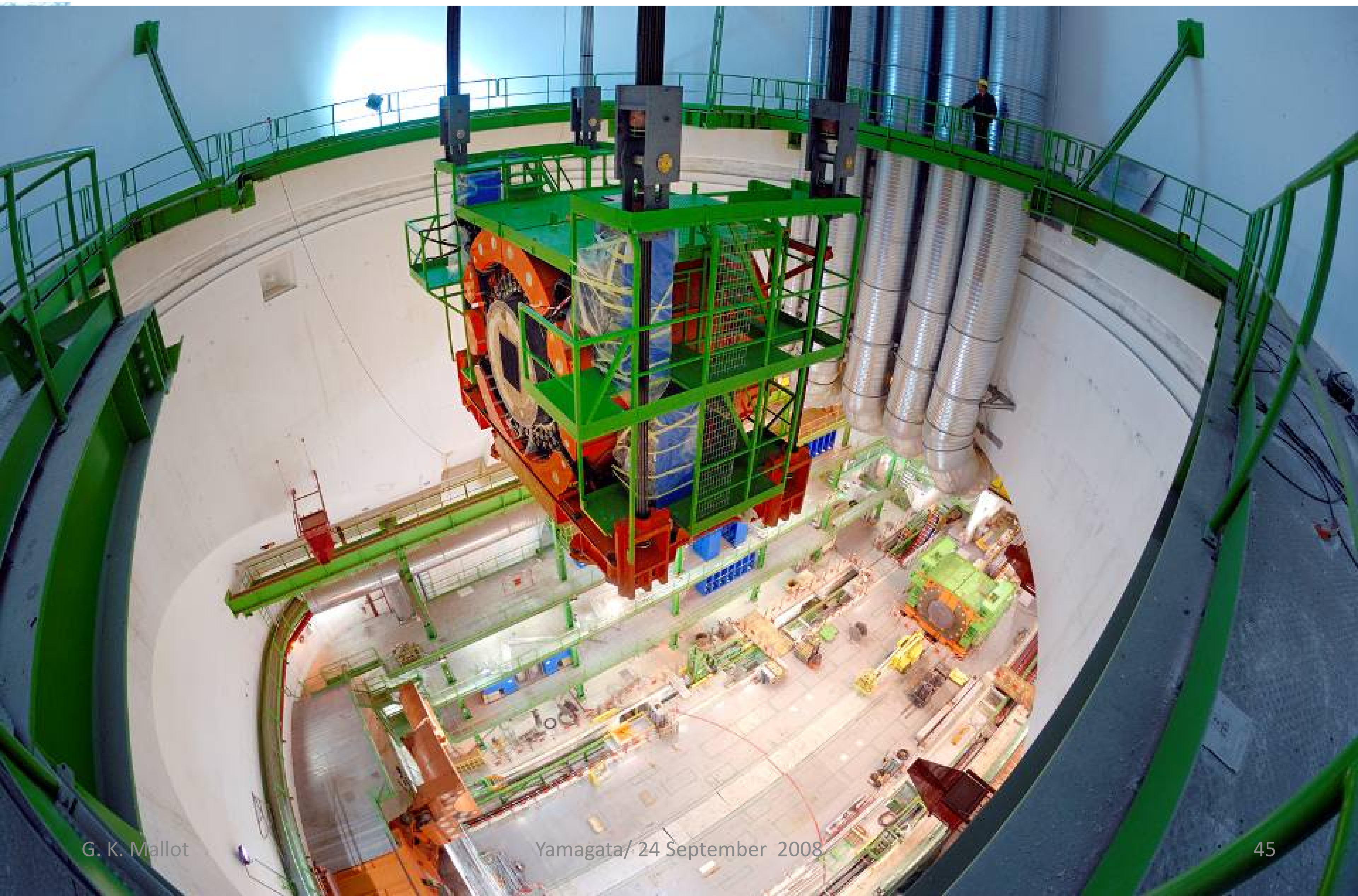
| | |
|---|---|
| Number of scientists: | 2350 |
| Number of institutes: | 180 |
| Number of countries: | 38 |



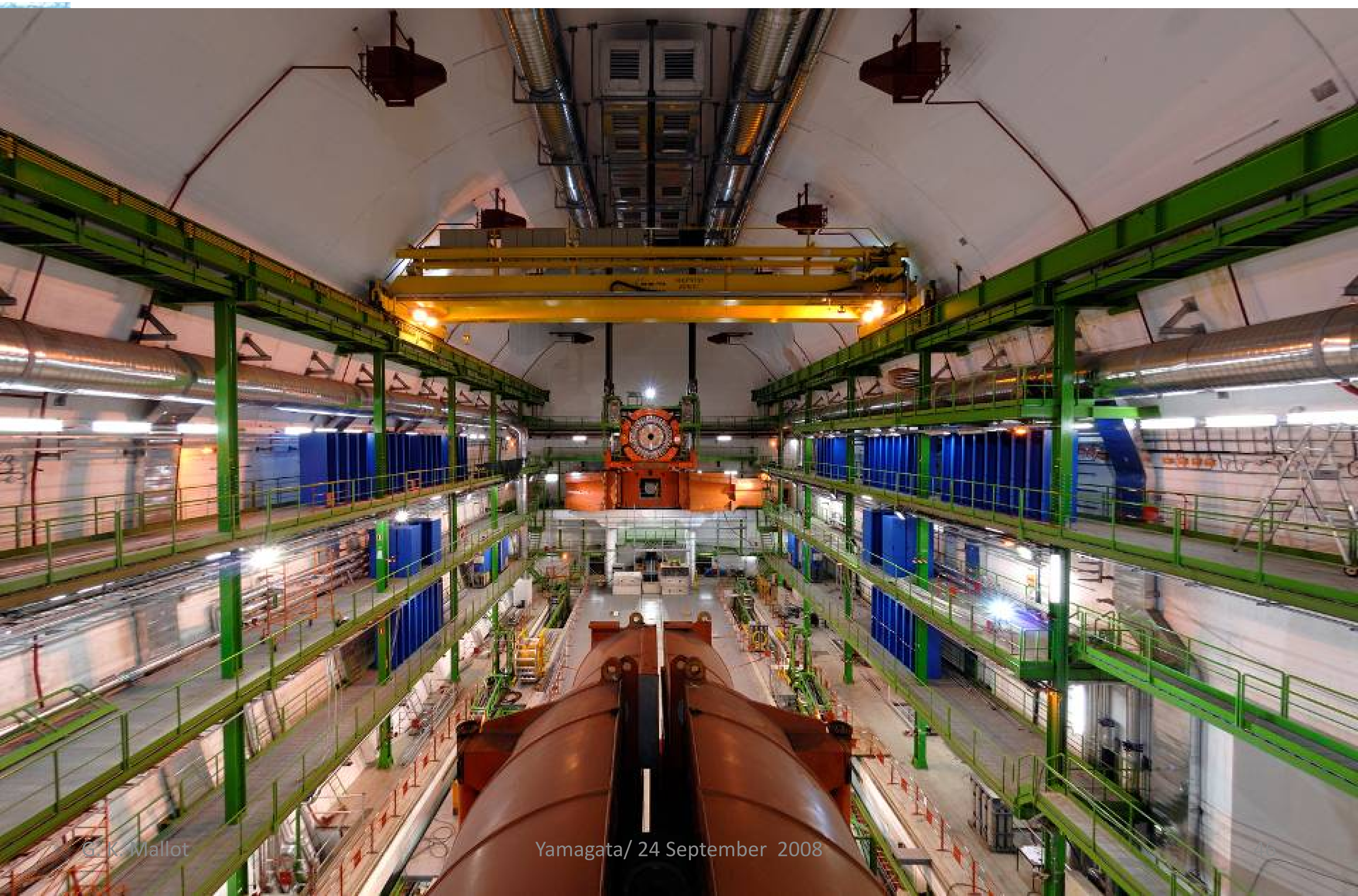

| | |
|---|---|
| Total weight : | 12,500 t |
| Overall diameter : | 15 m |
| Overall length : | 21.6 m |
| Magnetic field : | 4 Tesla |

# CMS

# CMS

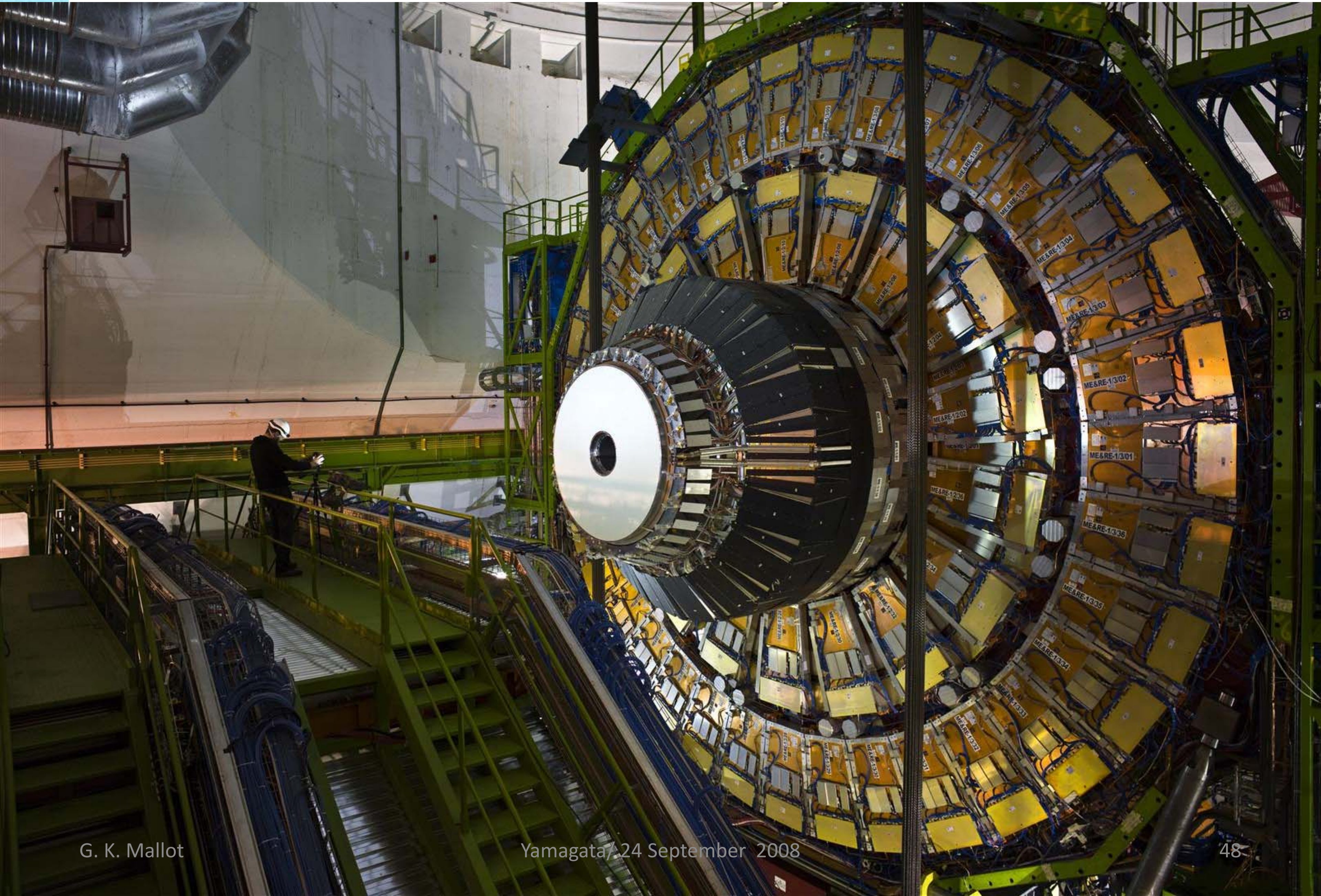


# CMS

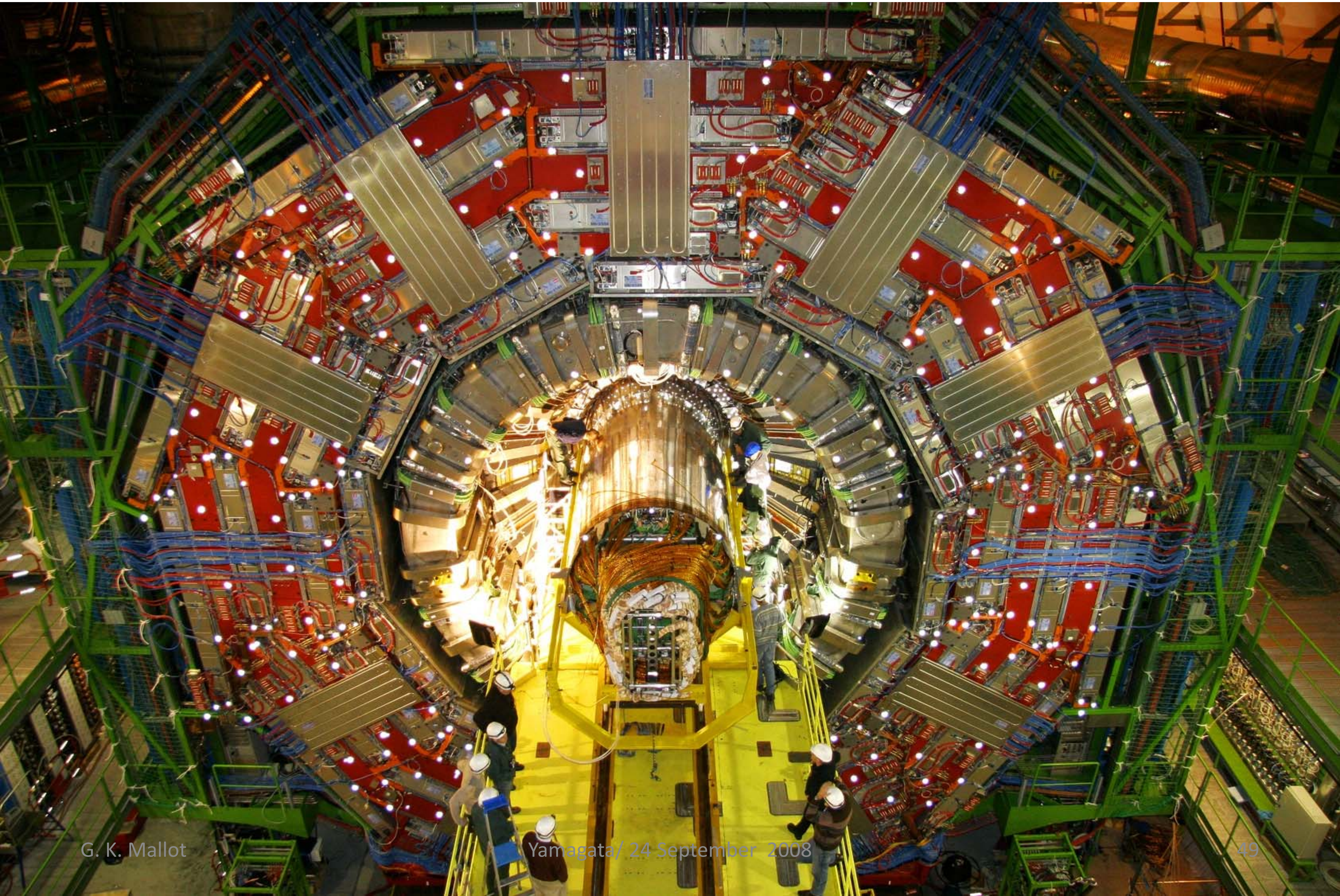


# CMS

# CMS

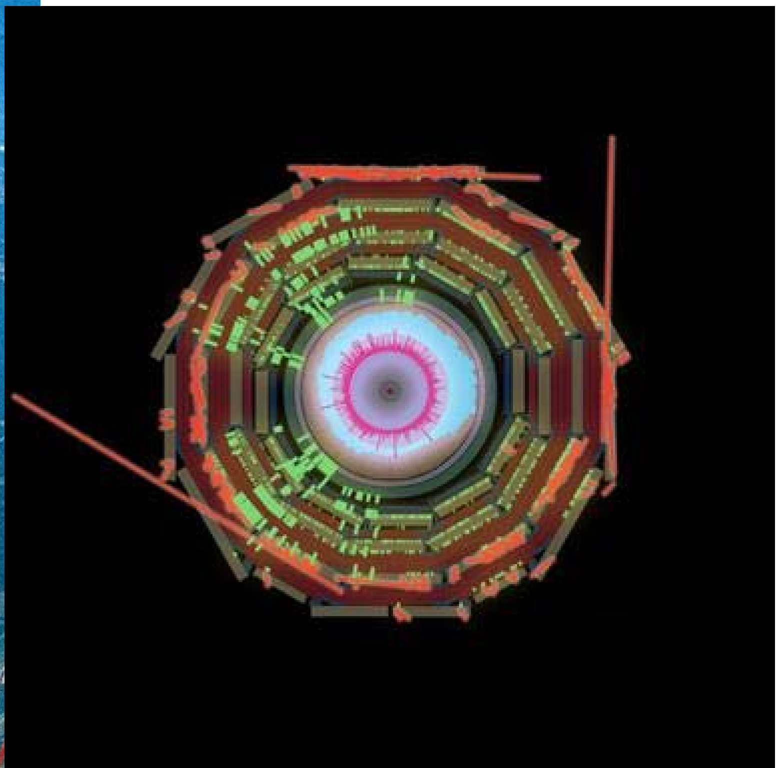


# CMS

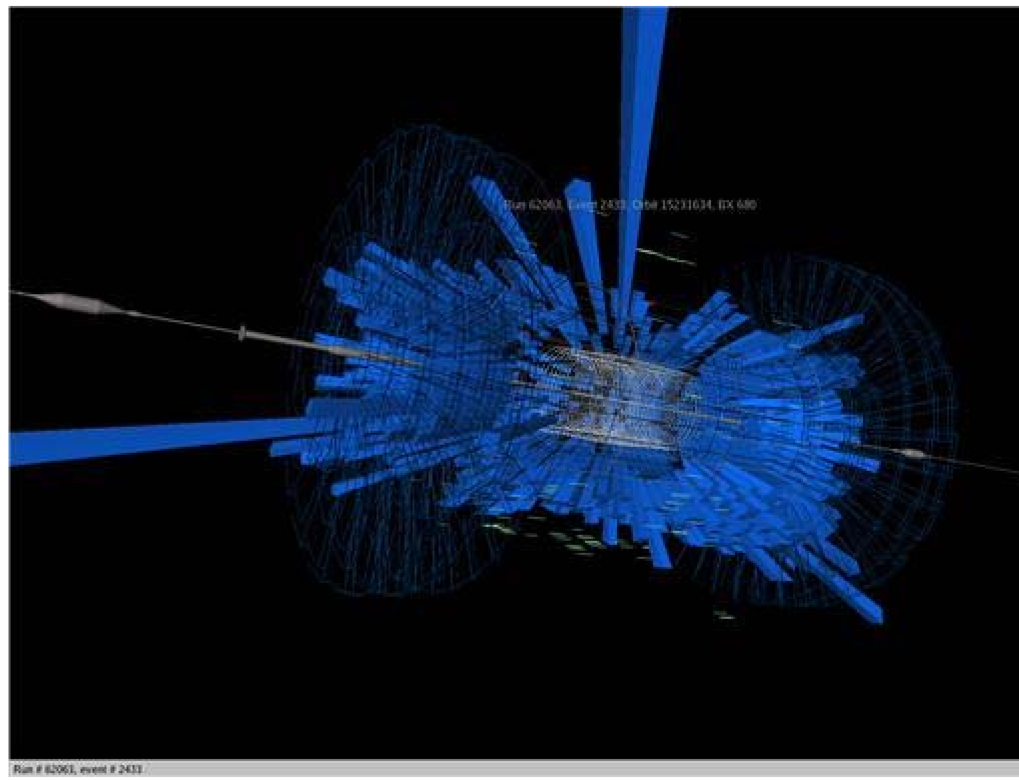


# CMS ELECTROMAGNETIC CALORIMETER

# FIRST EVENTS IN CMS



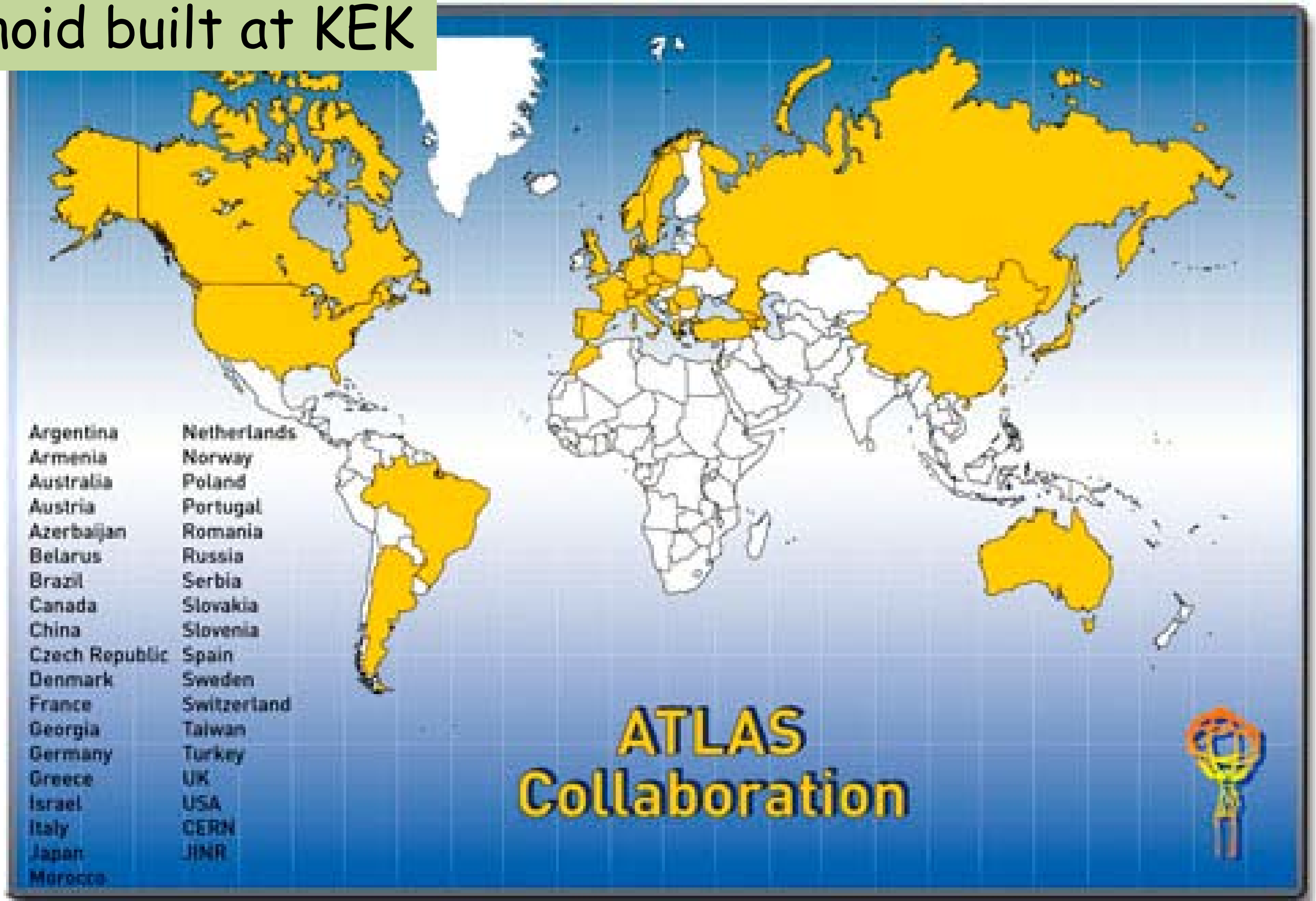
beam steered into collimator



# ALTAS

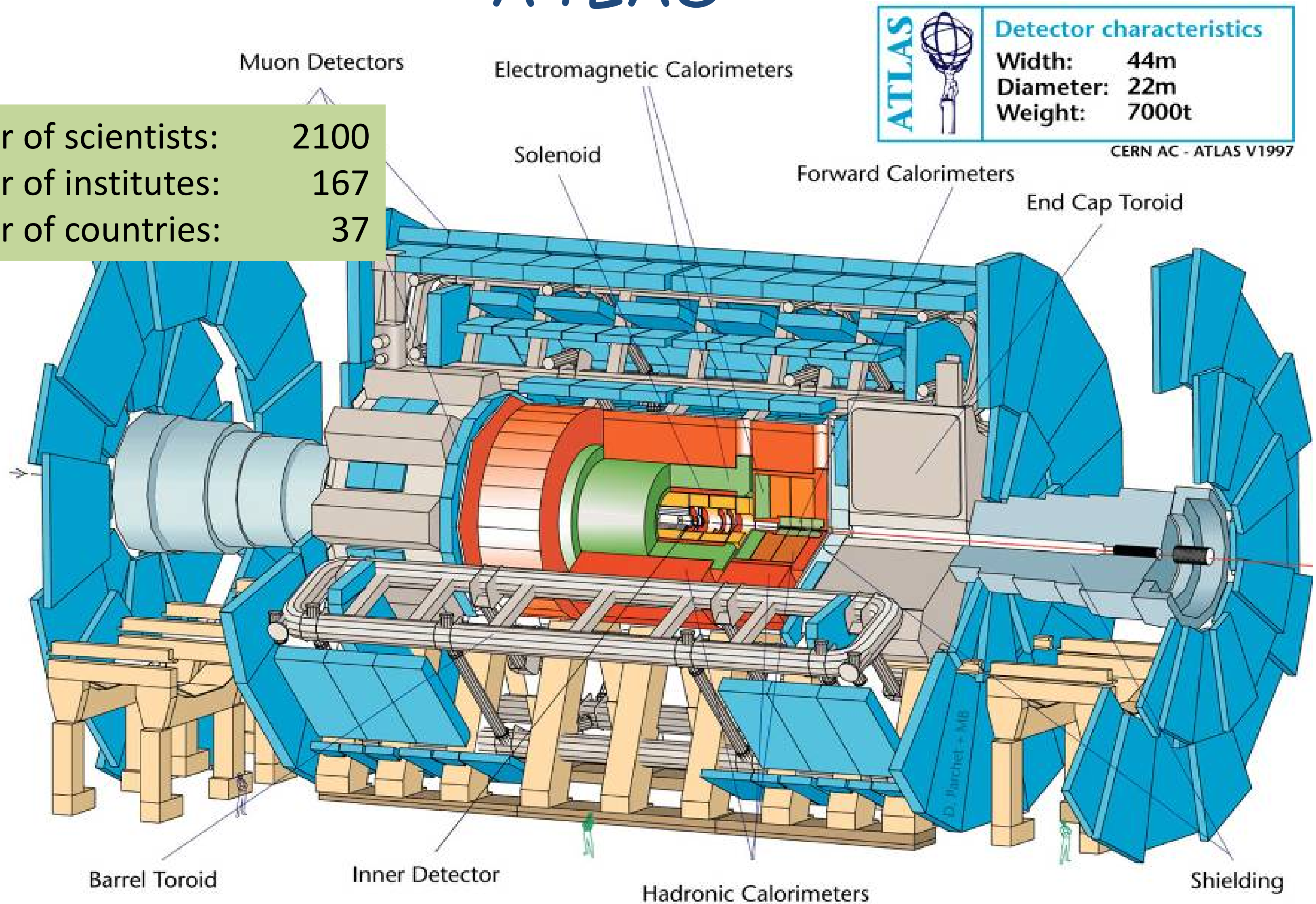
# ATLAS

Solenoid built at KEK

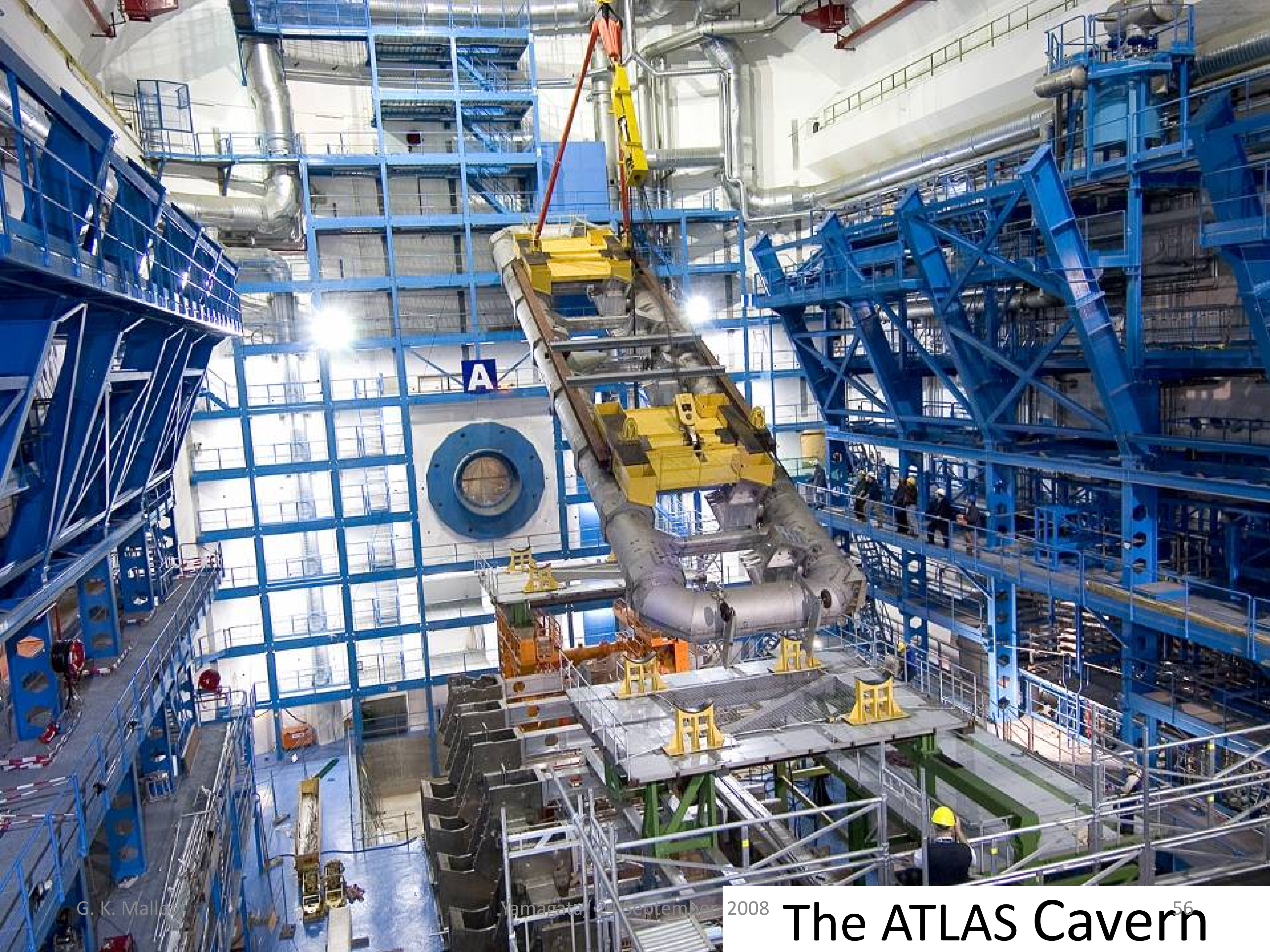


# ATLAS

| | |
|---|---|
| Number of scientists: | 2100 |
| Number of institutes: | 167 |
| Number of countries: | 37 |

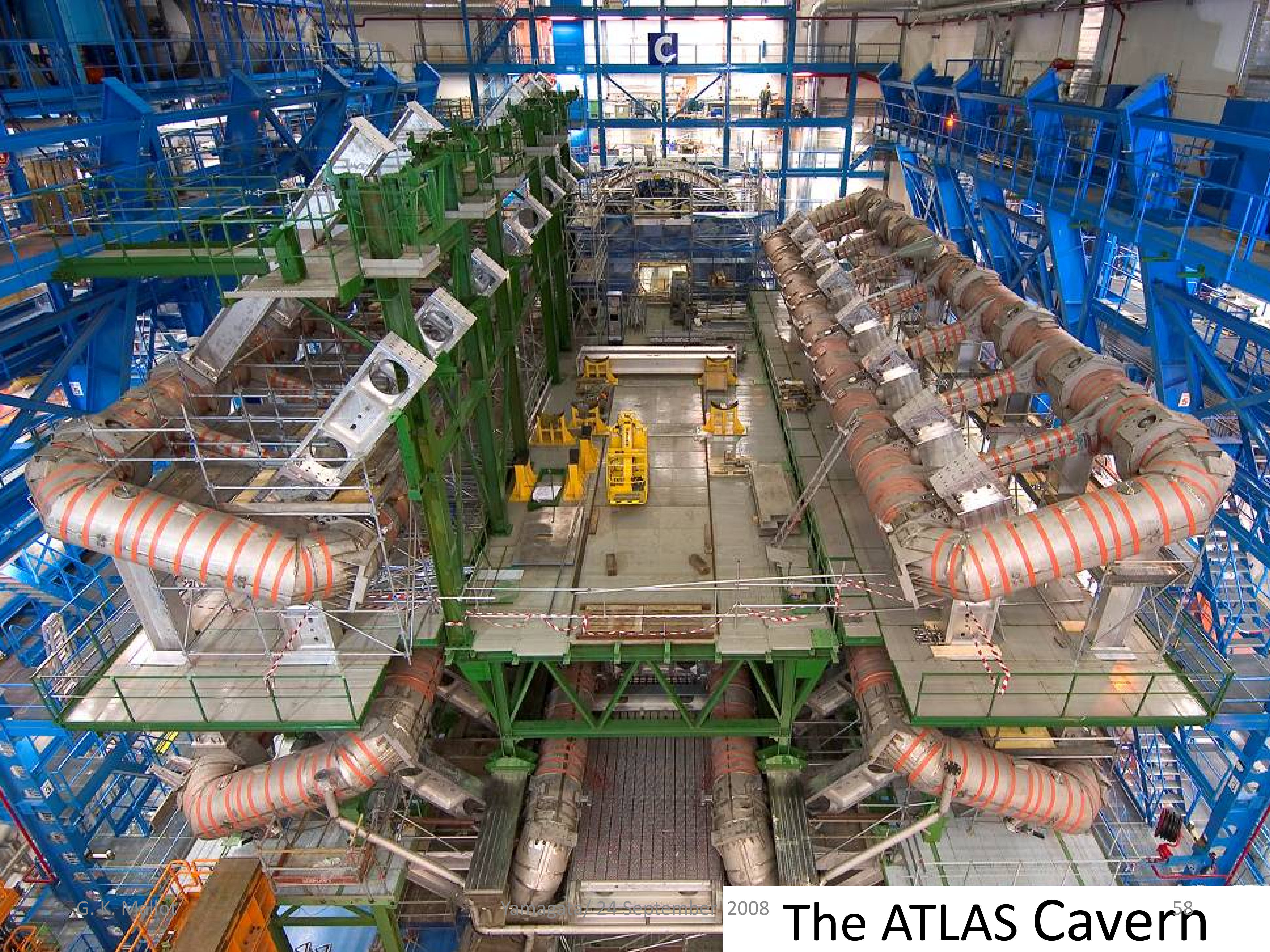


# THE ATLAS CAVERN

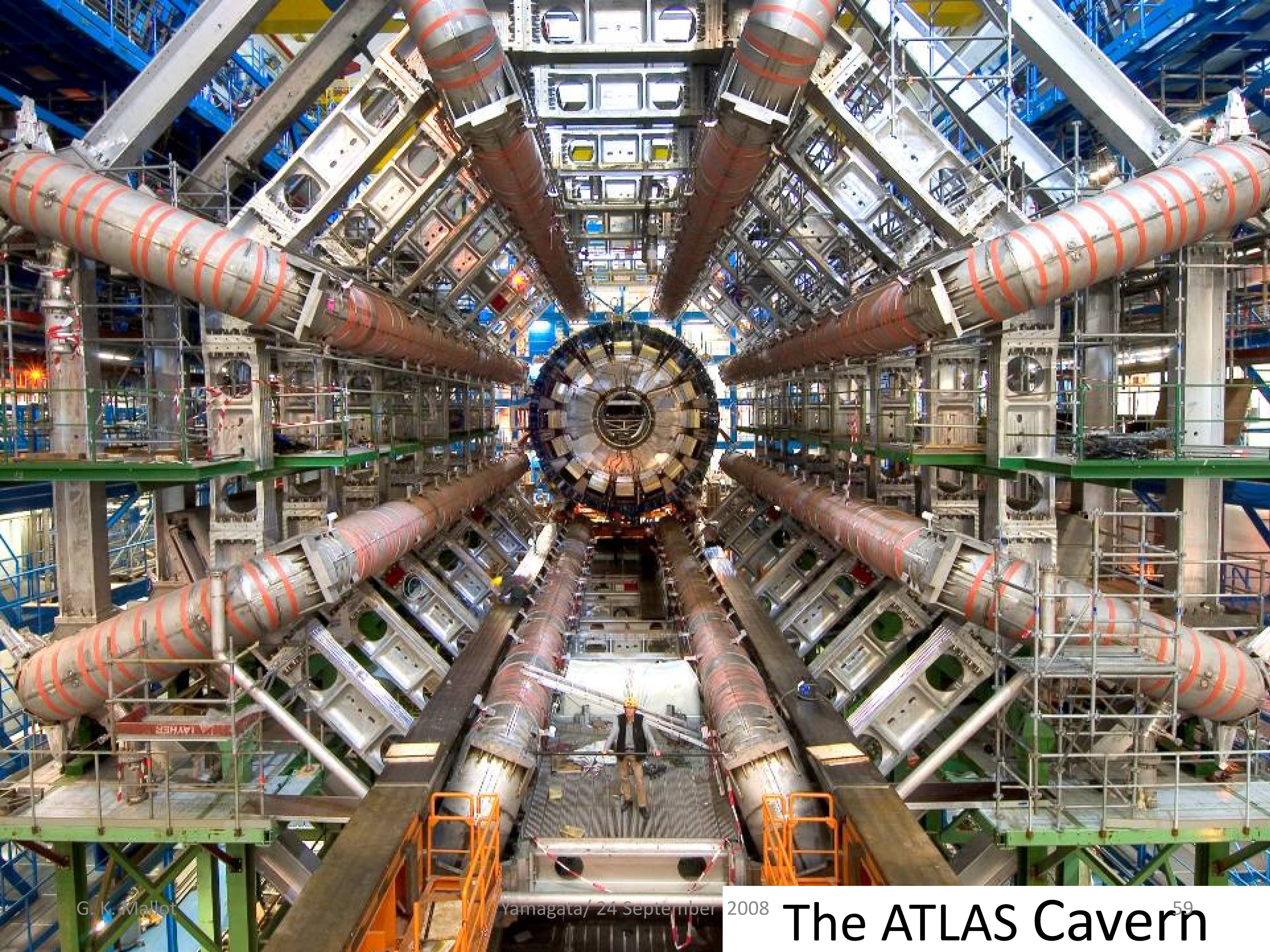



# The ATLAS Cavern

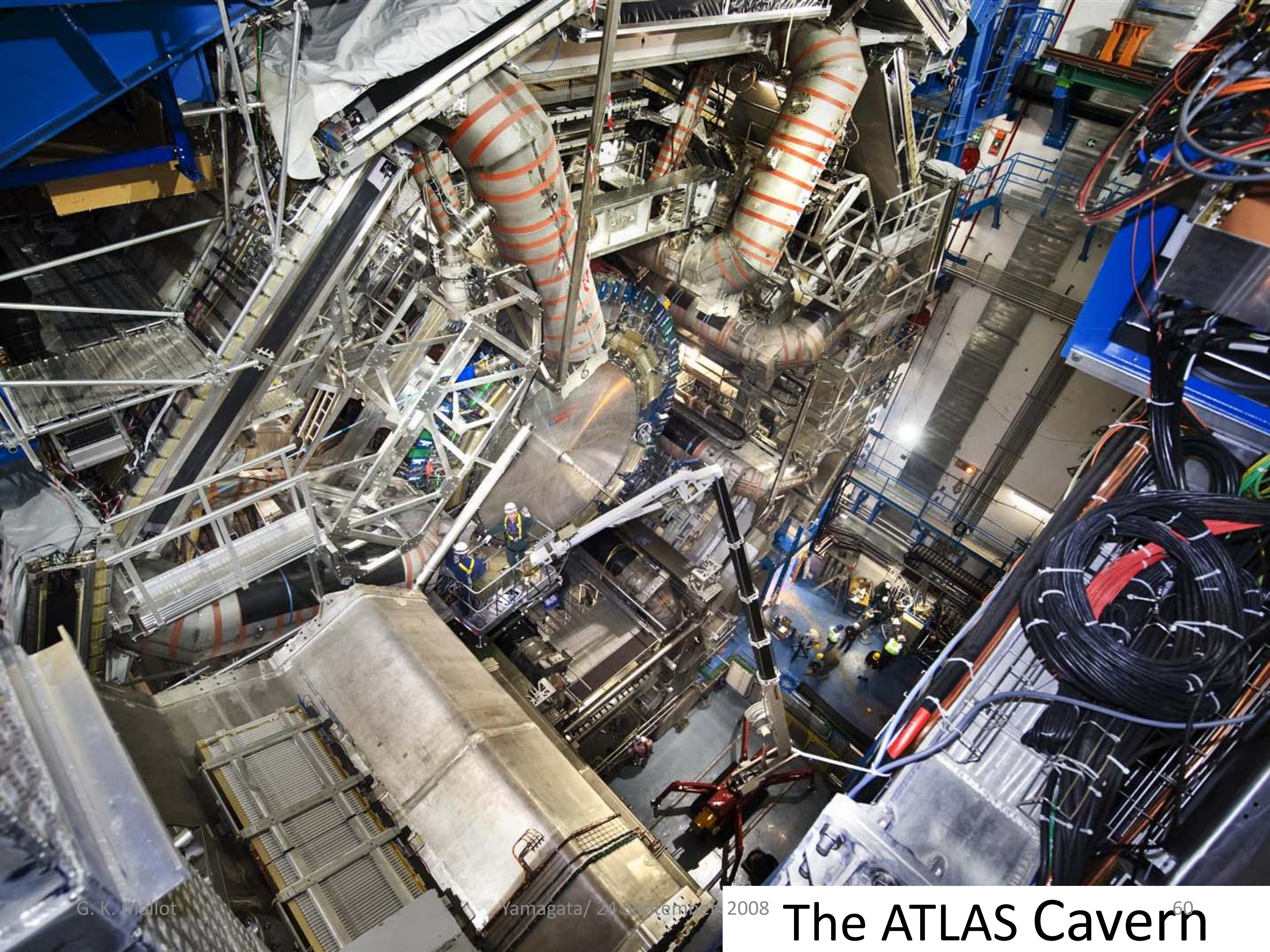
# The ATLAS Cavern



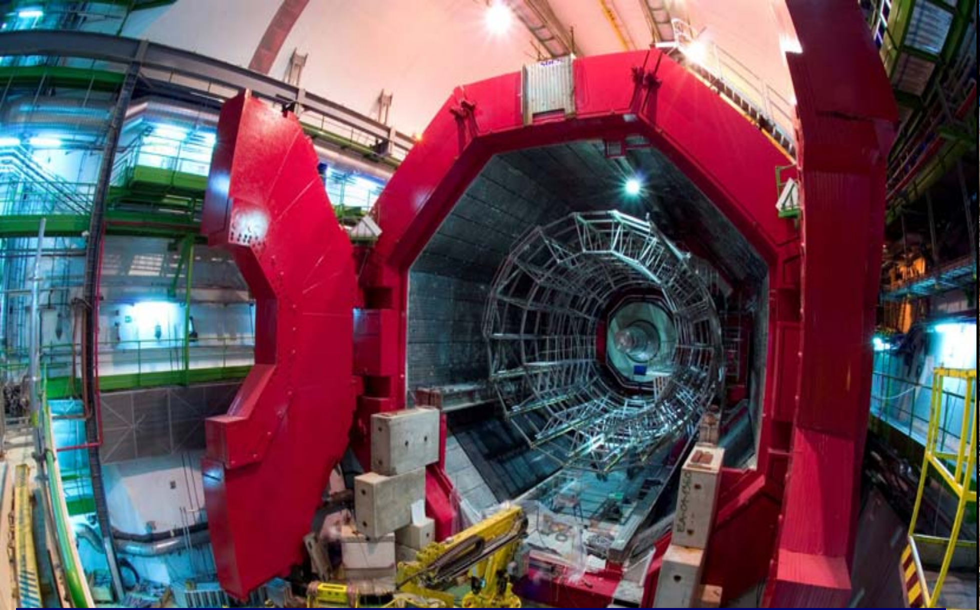

# The ATLAS Cavern



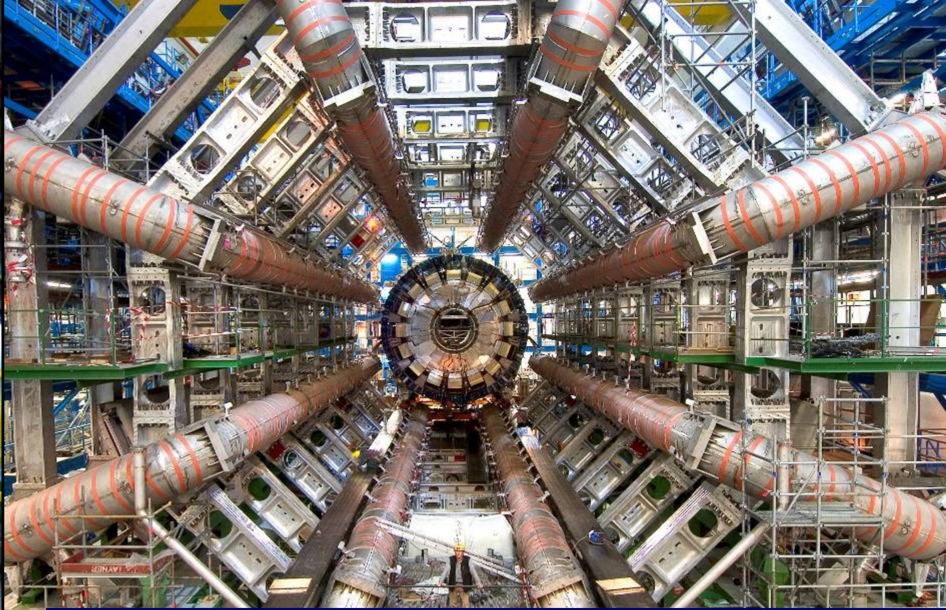
# The ATLAS Cavern



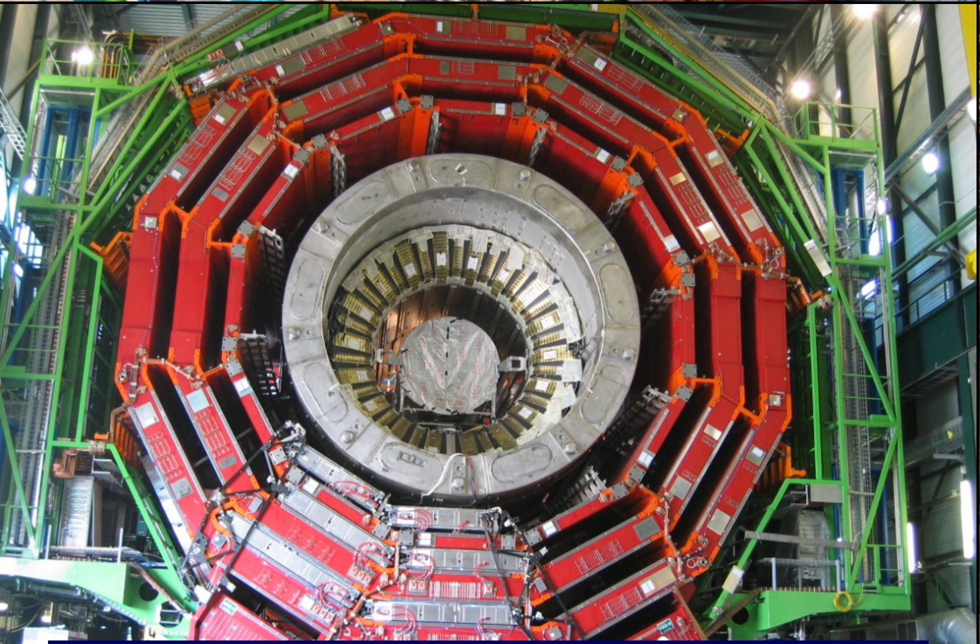
# The ATLAS Cavern



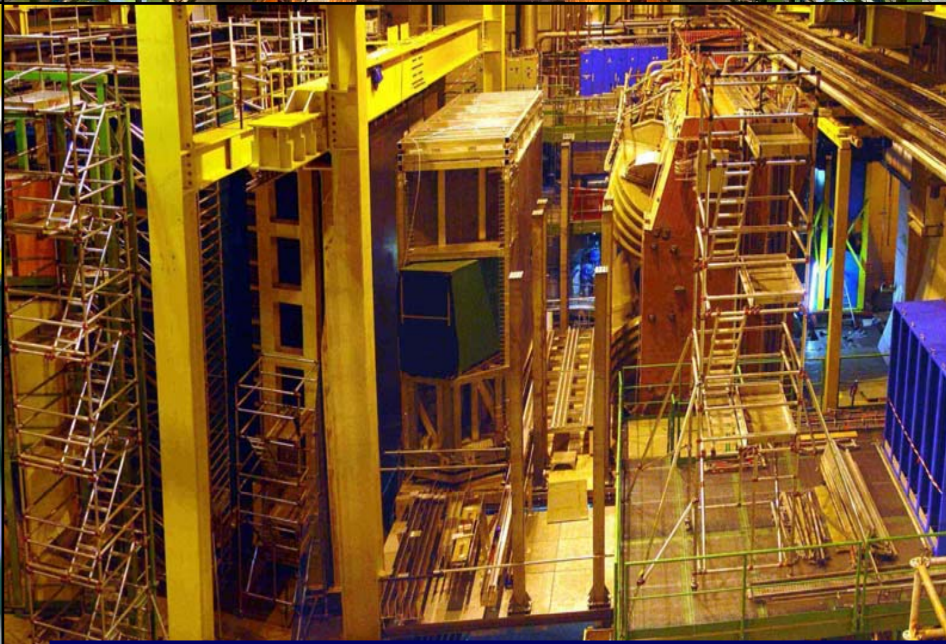
ALICE: Primordial cosmic plasma



ATLAS: Higgs and supersymmetry

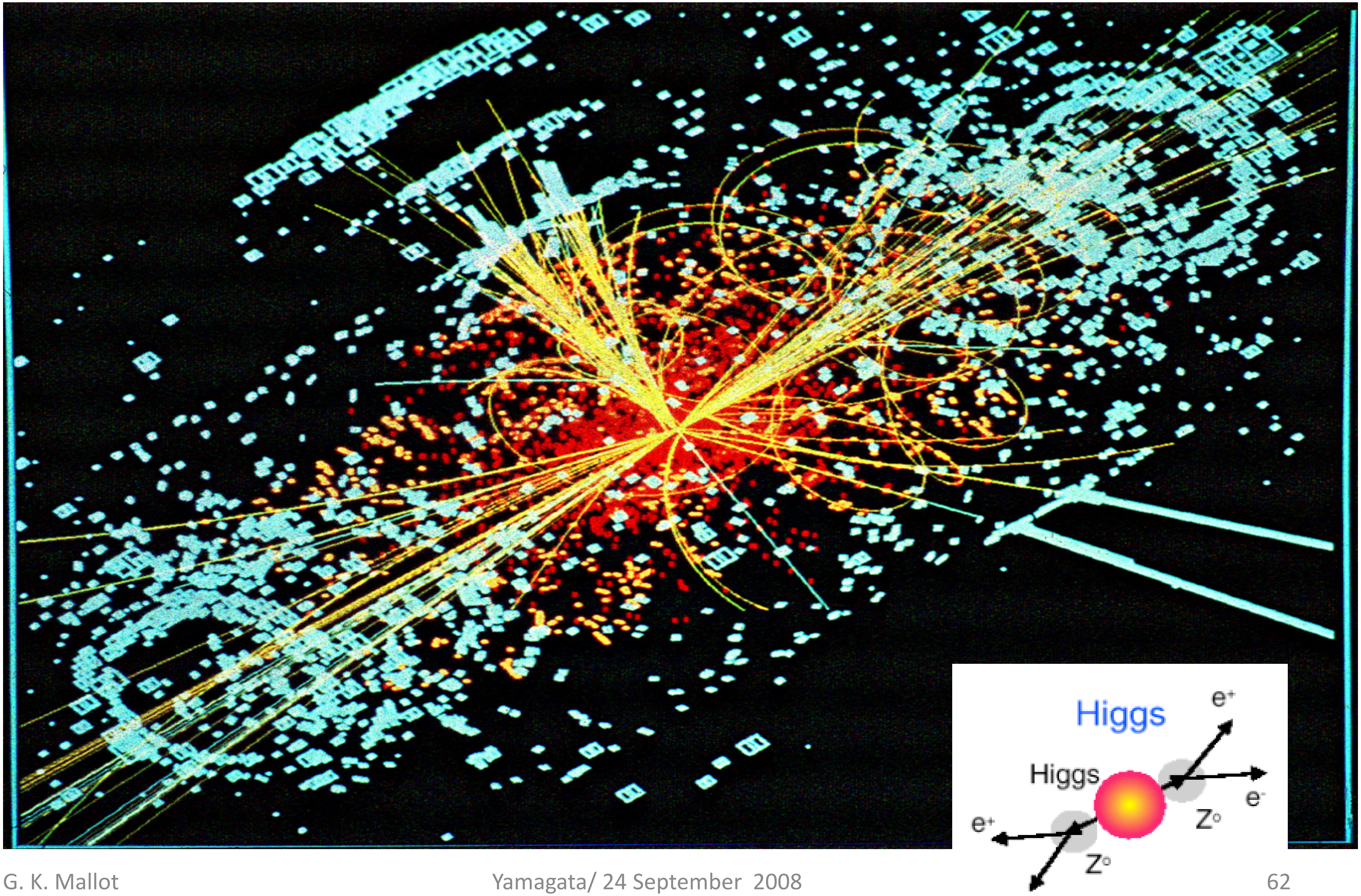


CMS: Higgs and supersymmetry



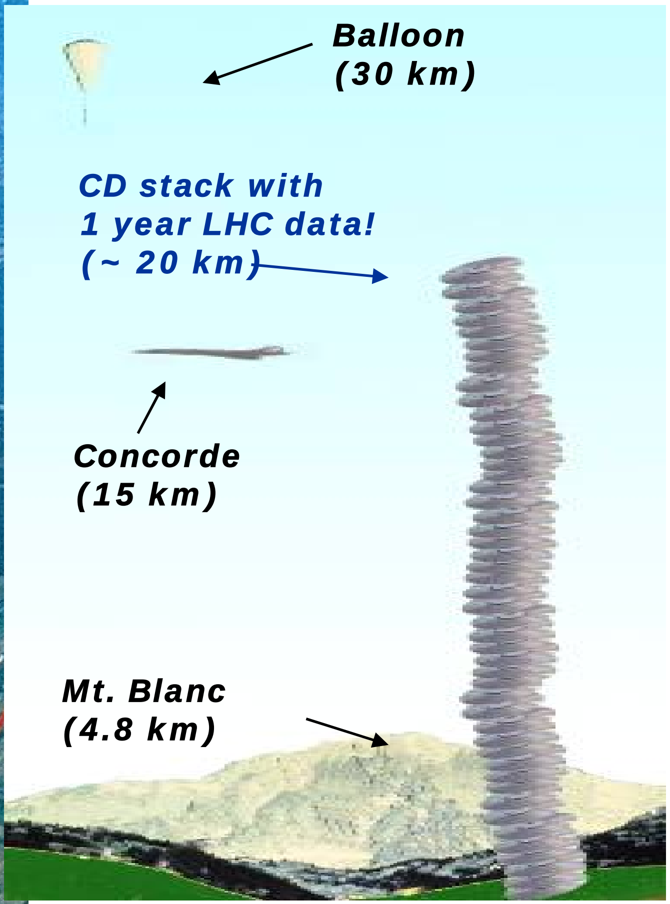
LHCb: Matter-antimatter differenc

# A SIMULATED HIGGS EVENT @ LHC



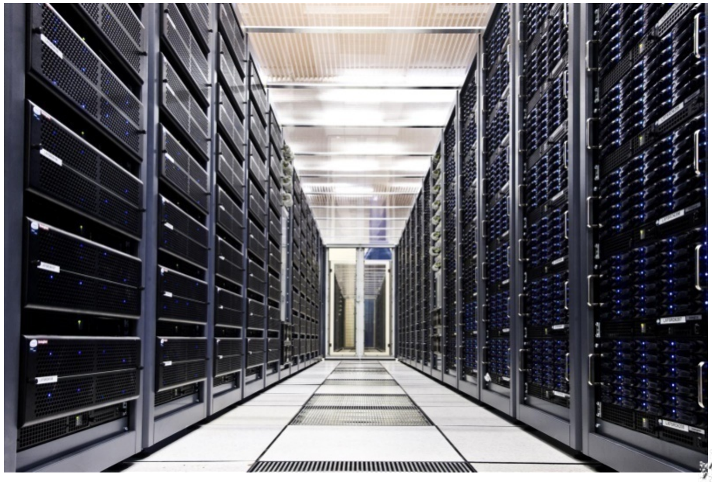
# LHC GRID COMPUTING

from P. Mendez

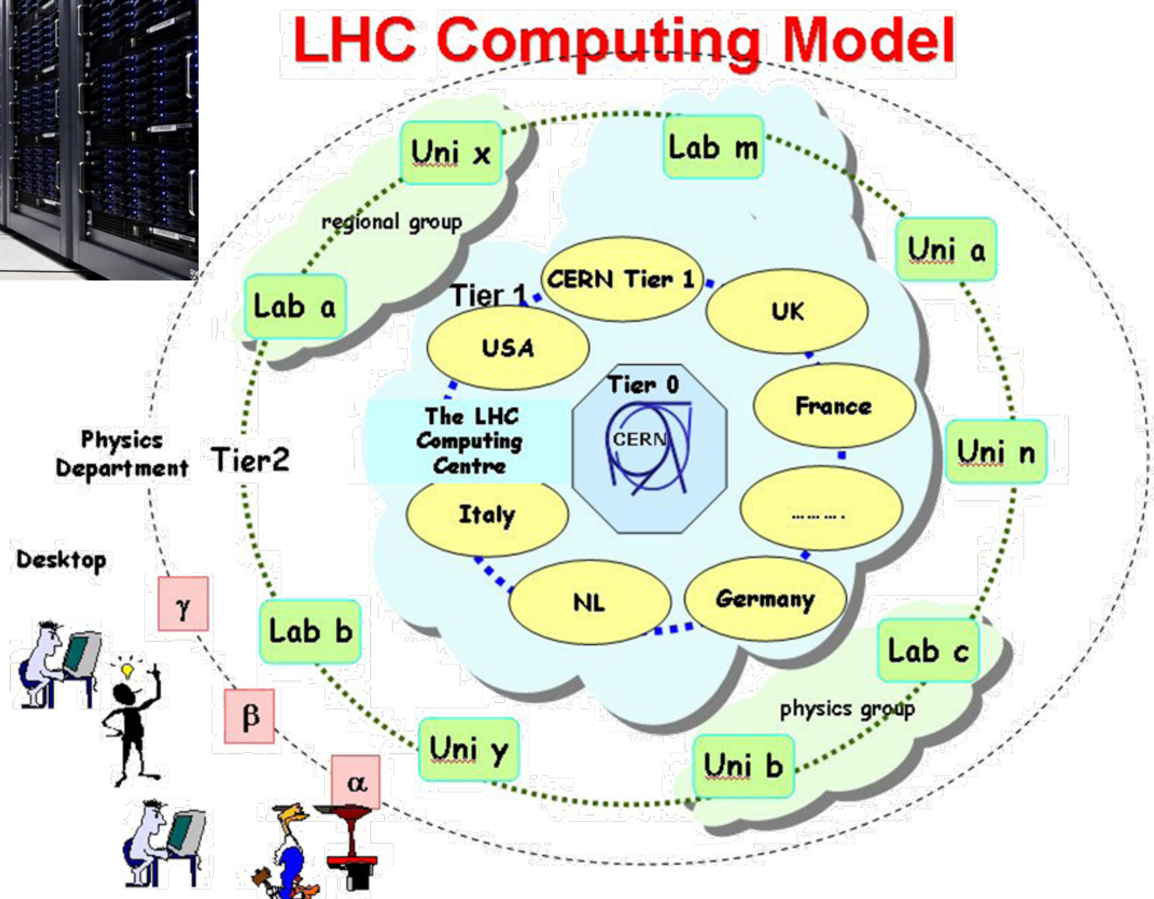



- **15 Million Gigabyte/year** (about 20 million CDs!)
- computing power equivalent to around **100'000 PCs**
- CERN can cover about 20%
- need computing network

# LHC COMPUTING MODEL



Tier 0 centre
@ CERN



# IS THAT ALL CERN IS DOING? NO!

many non LHC activities:

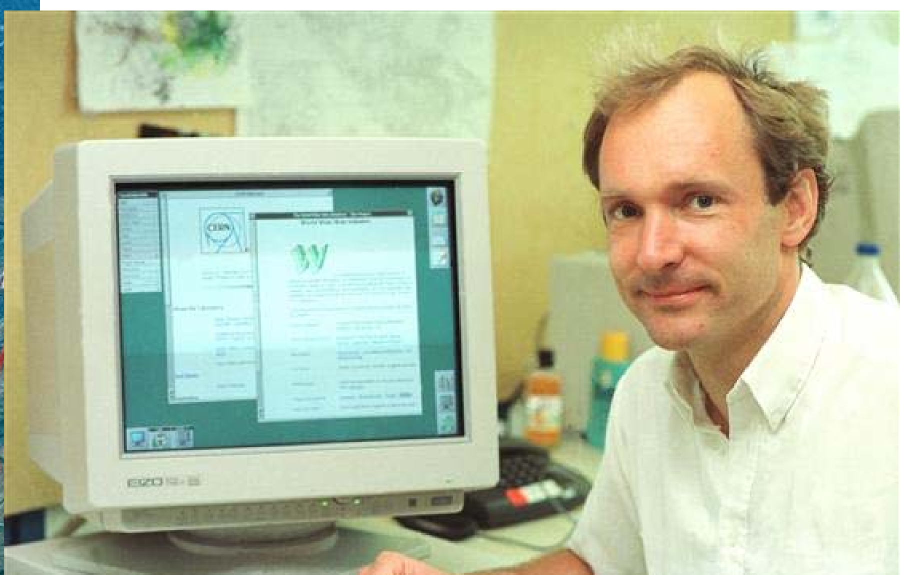
CNGS – CERN neutrinos to Gran Sasso
COMPASS - Structure and spectroscopy of hadrons
Antimatter studies - ACE, ALPHA, ASAKUSA, ATRAP
ISOLDE - radioactive beams for nuclear physics
nTOP - neutron facility
CAST – CERN Solar Axion Telescope
DIRAC – DImeson Relativistic Atomic Complex
CLOUD – Cosmics Leaving OUtdoor Droplets

R&D: CLIC compact linear collider study
Medical imaging
WWW

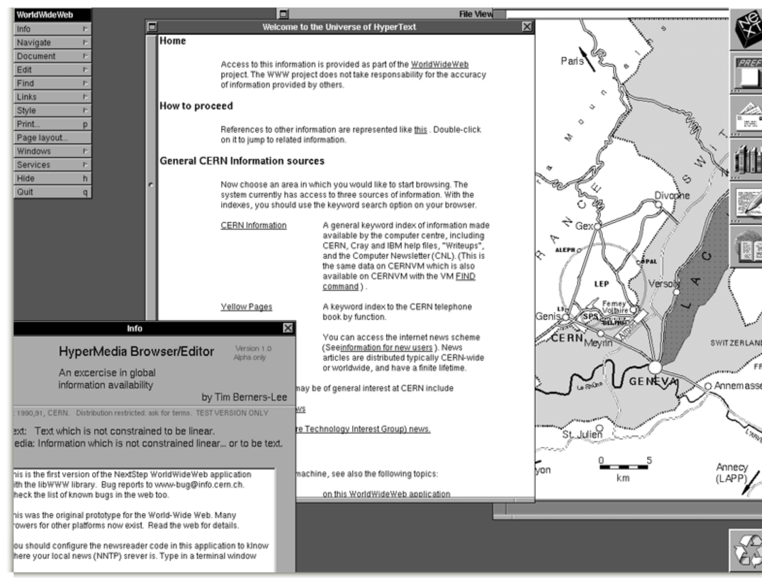
# THE WORLD WIDE WEB

http://www.cern.ch/

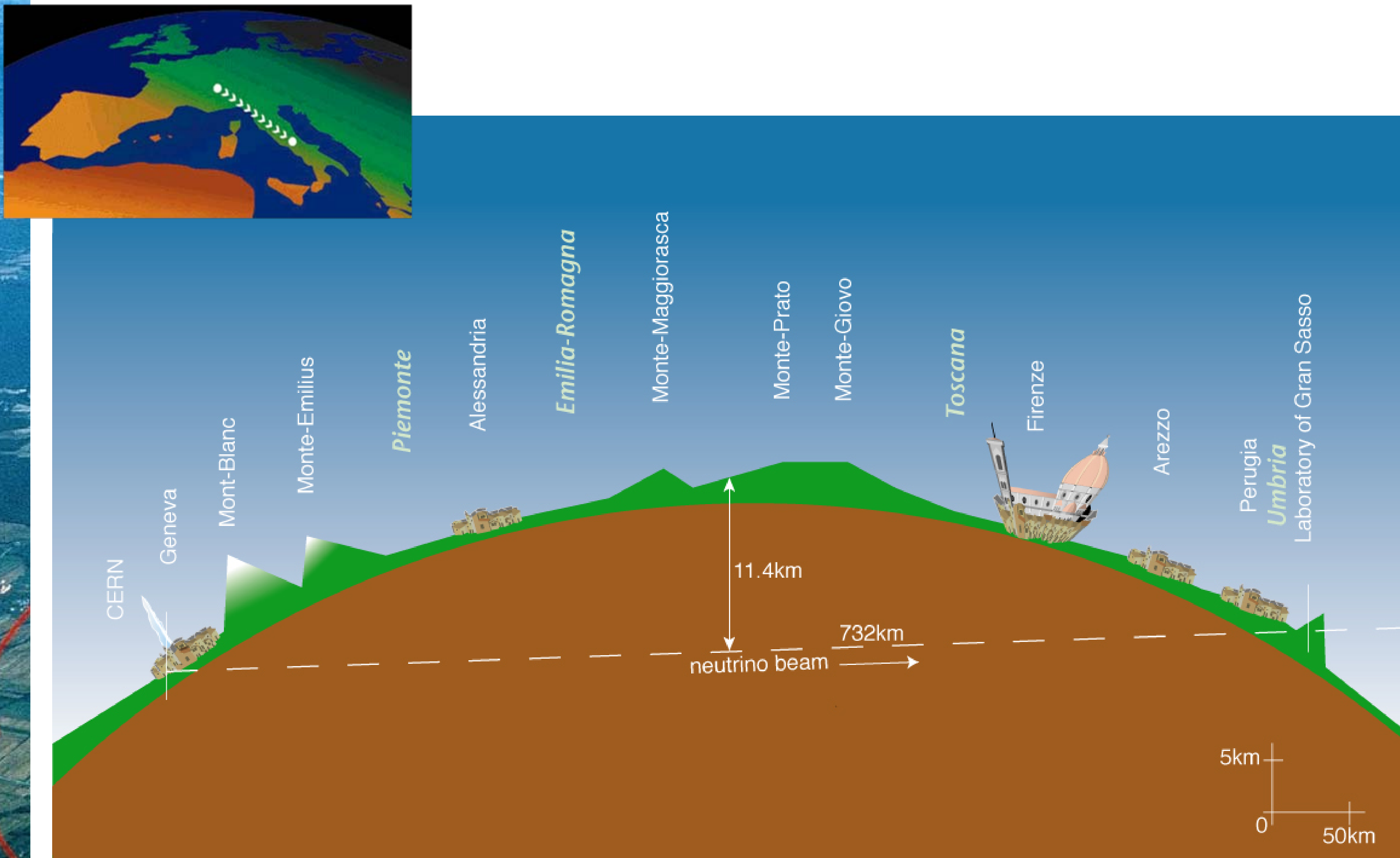
1989: proposed at CERN to exchange data world-wide (LEP)
1991: released in CERN program library
1992: in November 26 web servers, 200 by Oct 93
1993: Mosaic browser (NCSA)



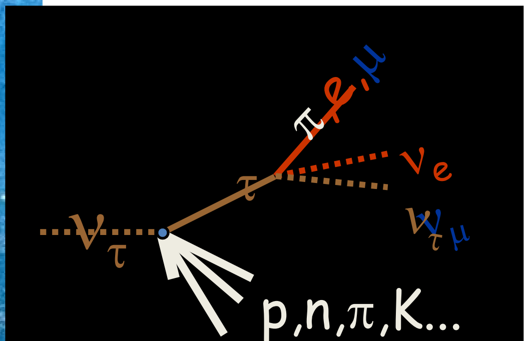
T. Berners-Lee

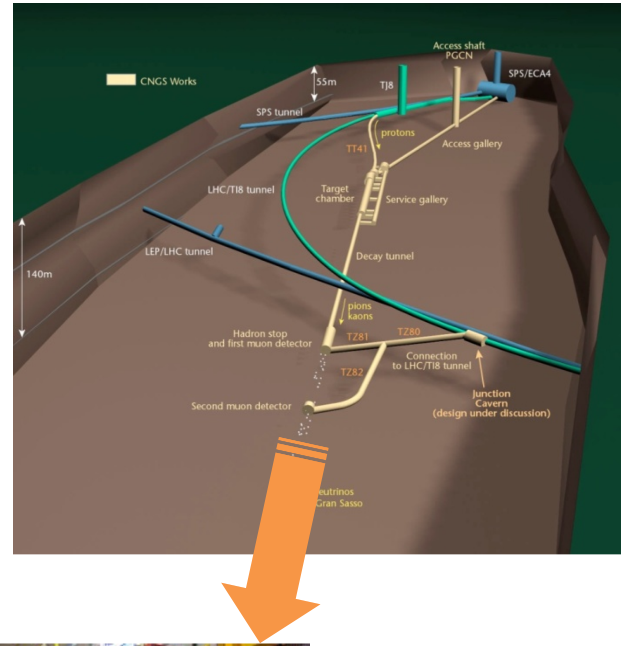


# CNGS: NEUTRINOS TO GRAN SASSO

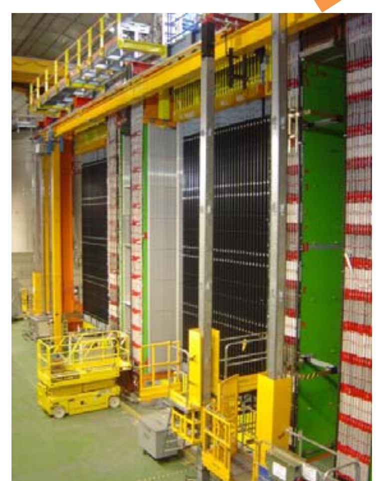


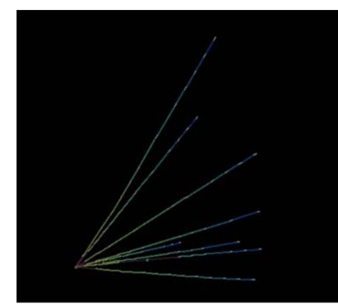
# CNGS/OPERA: TAU NEUTRINO APPEARANCE




search for the appearance of tau neutrino in a muon neutrino beam from CERN





first neutrino event

Expect ~10 evts after 5 yrs running

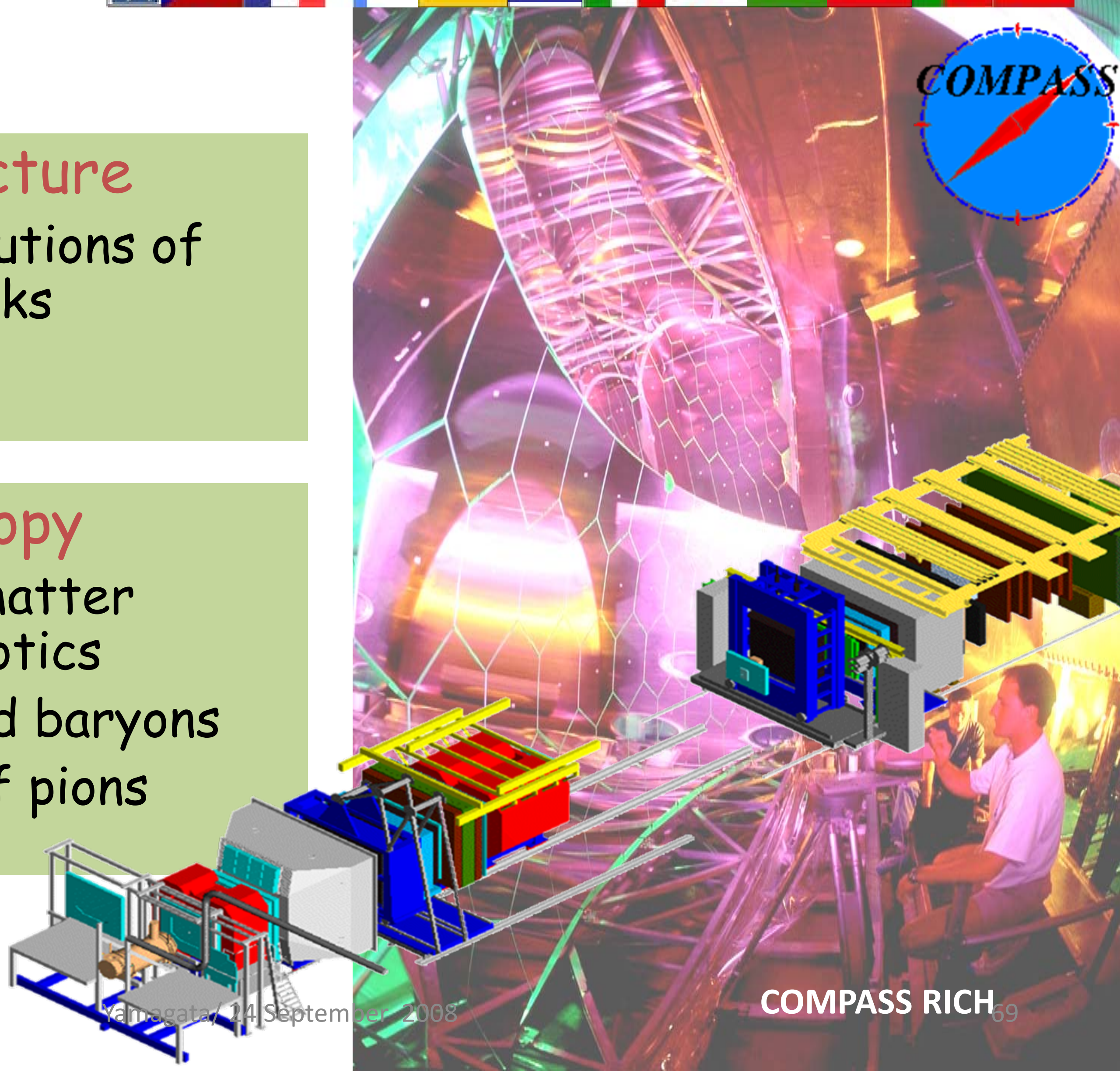
# COMPASS: QCD STRUCTURE OF HADRONS

## nucleon spin-structure

- helicity distributions of gluons and quarks
- transversity

## hadron spectroscopy

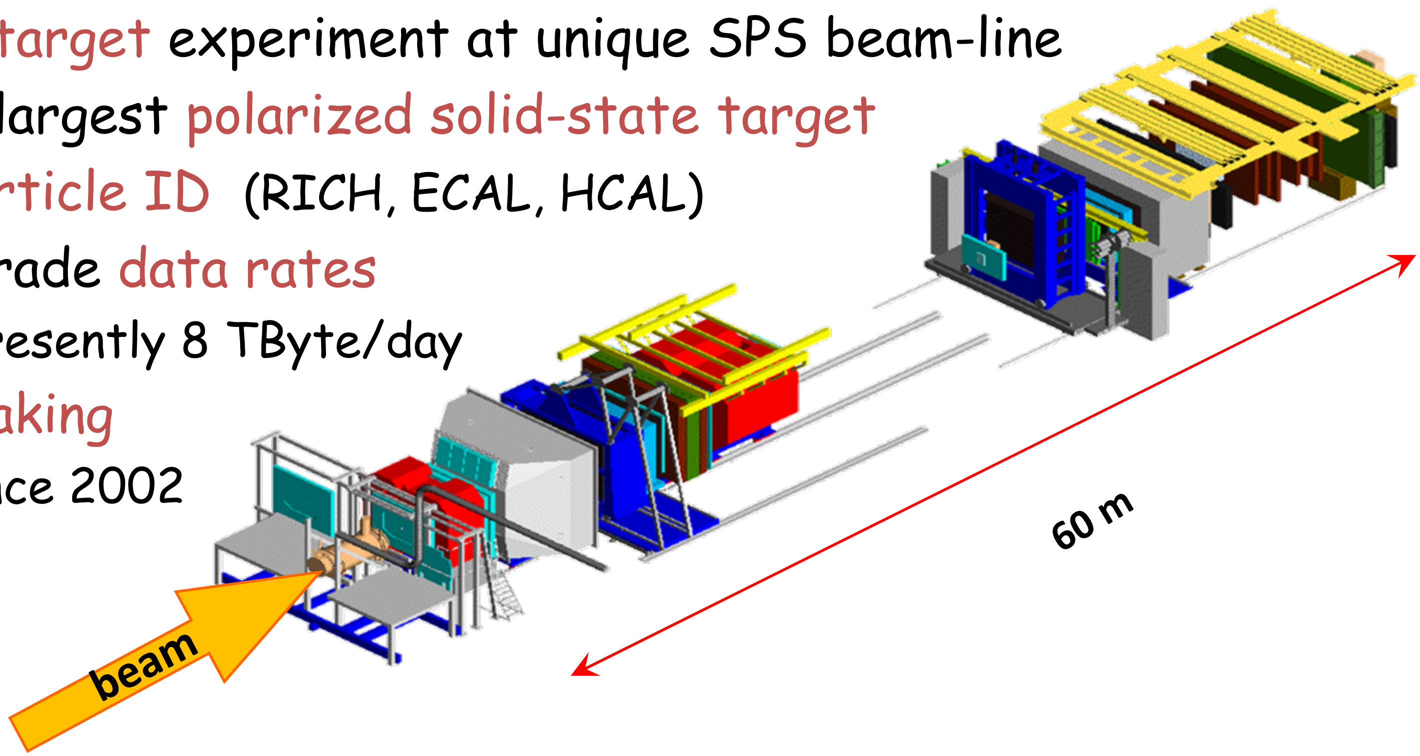
- new forms of matter glue-balls & exotics
- double-charmed baryons
- polarisability of pions and kaons



# THE COMPASS EXPERIMENT

http://wwwcompass.cern.ch

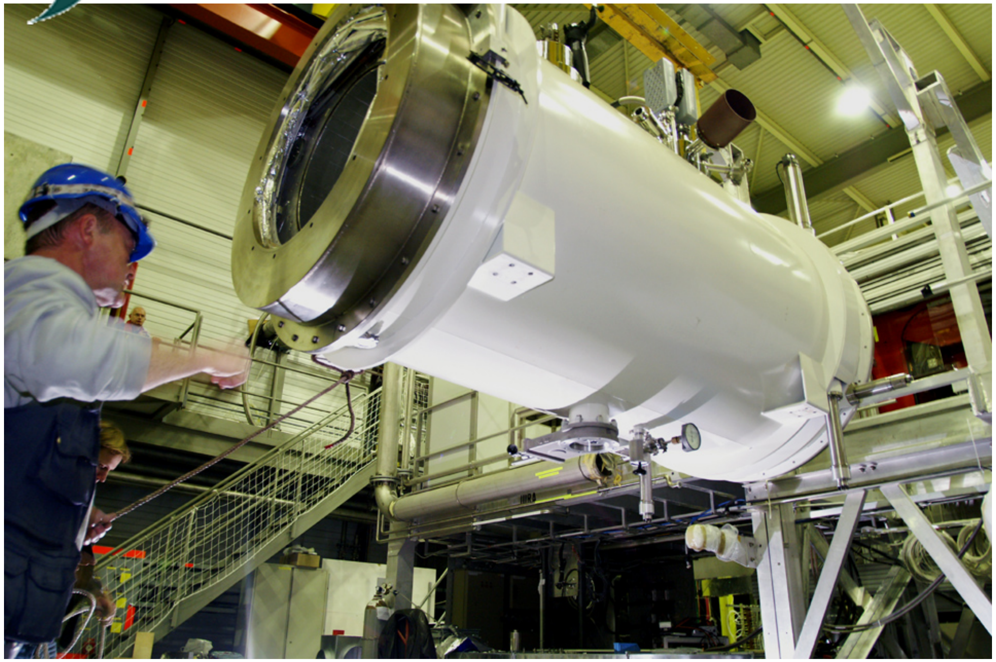
- 250 physicists from 10 countries
- fixed-target experiment at unique SPS beam-line
- world-largest polarized solid-state target
- full particle ID (RICH, ECAL, HCAL)
- LHC-grade data rates
  - presently 8 TByte/day
- data taking
  - since 2002

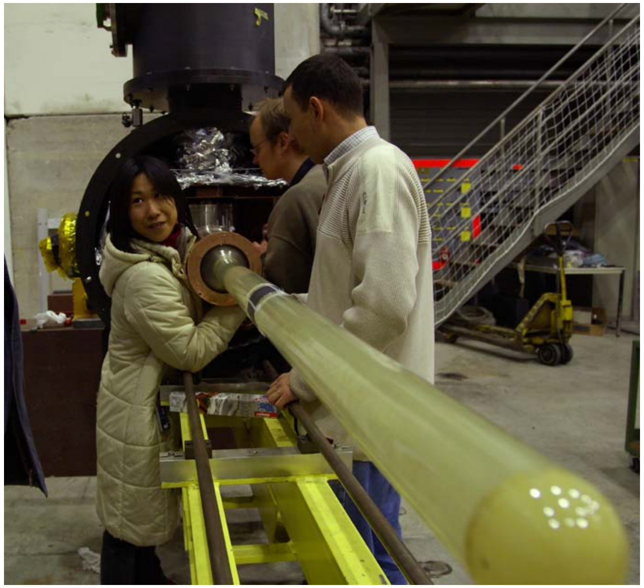


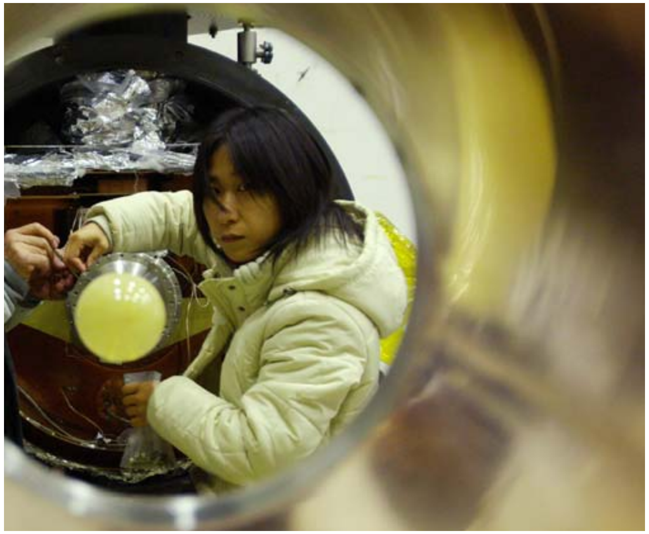

New proposal for beyond 2010 in preparation

# COMPASS POLARIZED TARGET

big support from Yamagata group







The coldest place @ CERN:

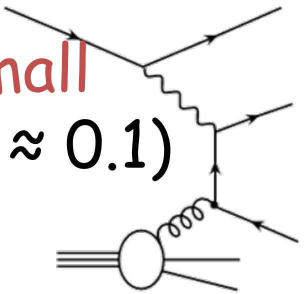
60mK, 1/30 of LHC magnets temperature

# GLUON CONTRIBUTION

- The nucleon's spin puzzle
  - long-standing problem in the quark-parton model
  - contribution of quark spins to nucleon spin is only about 30% 100% expected
  - rest hidden by large gluon polarization ? (axial anomaly)

COMPASS: gluon polarization is small

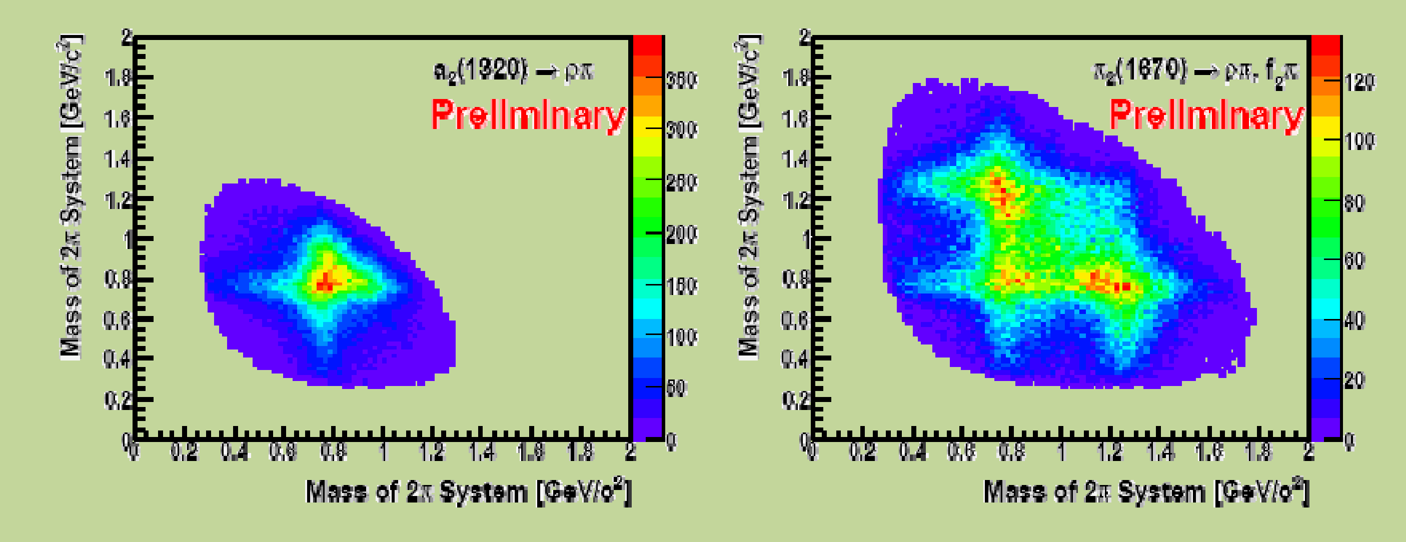
(at $x_{gluon} \approx 0.1$)



Large gluon polarisation unlikely solution of spin puzzle

# LIGHT MESON SPECTROSCOPY

$\pi^- p \rightarrow p\, \pi^- \pi^+ \pi^-$



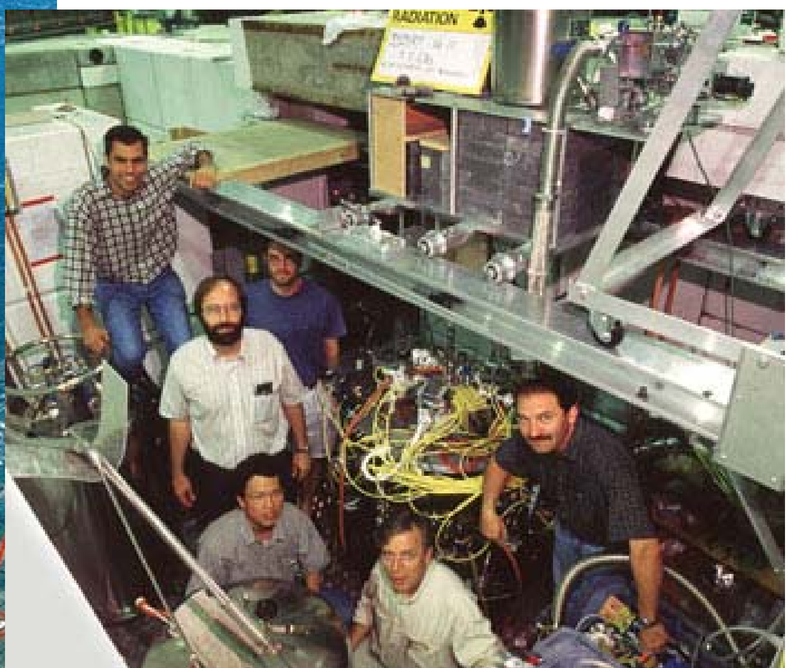

- Programme started 2008

- COMPASS offers pion, proton and kaons (few %) as production channel
- charged and neutral decay channels
- excellent particle ID
- PWA will allow to attribute quantum numbers to states

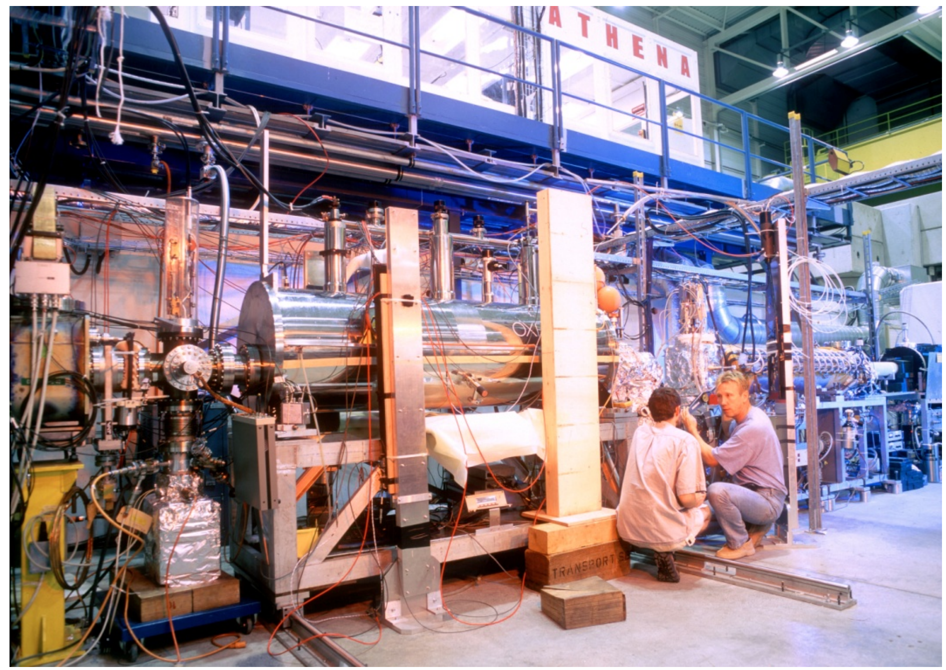
# COLD ANTIMATTER

Find a way to make cold antihydrogen (done)
Trap and cool antihydrogen
Precision measurements

ATRAP

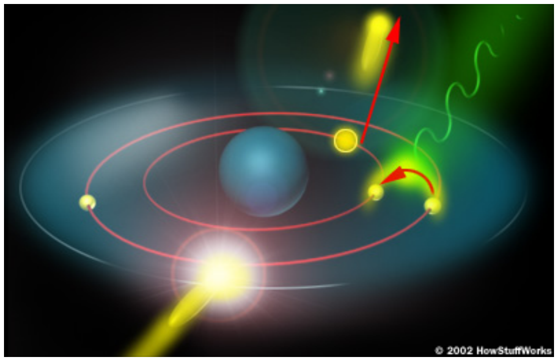


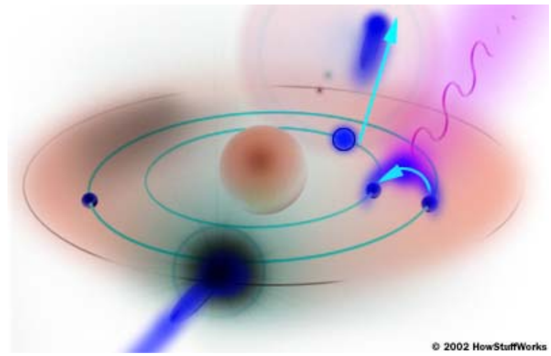

ATHENA

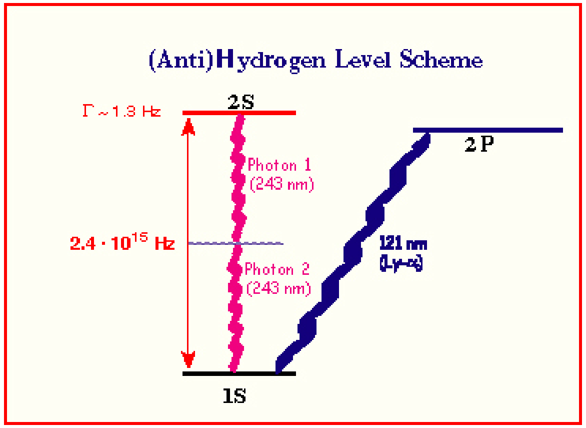



**More than 50000 anti-hydrogen atoms made!**

# ANTIHYDROGEN $\stackrel{?}{=}$ HYDROGEN



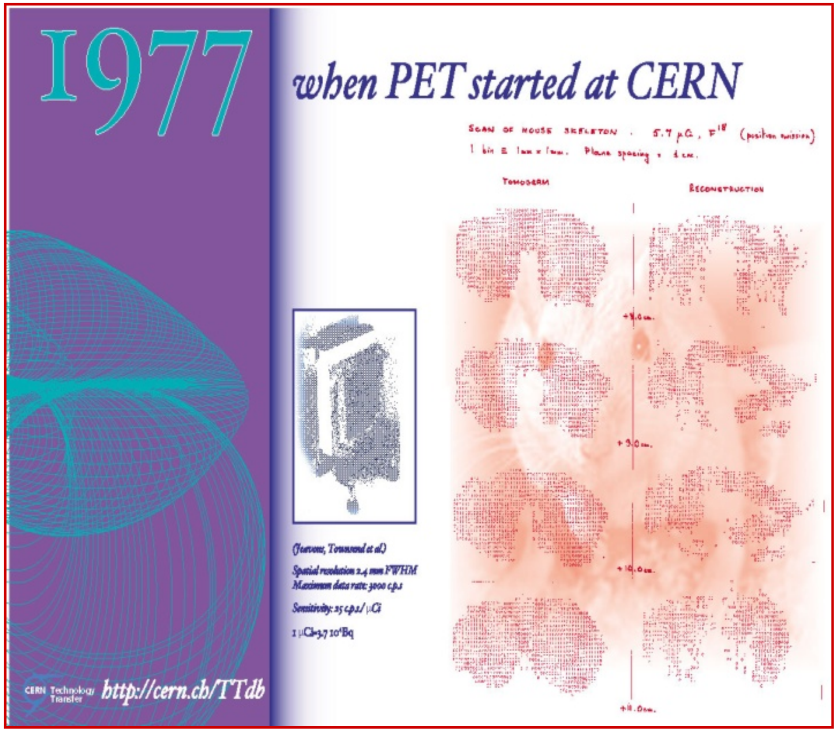




2S level is metastable (T ~ 120 ms)

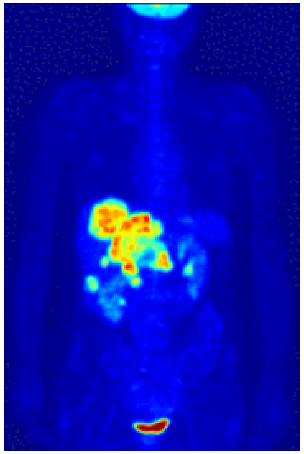
## Goal:

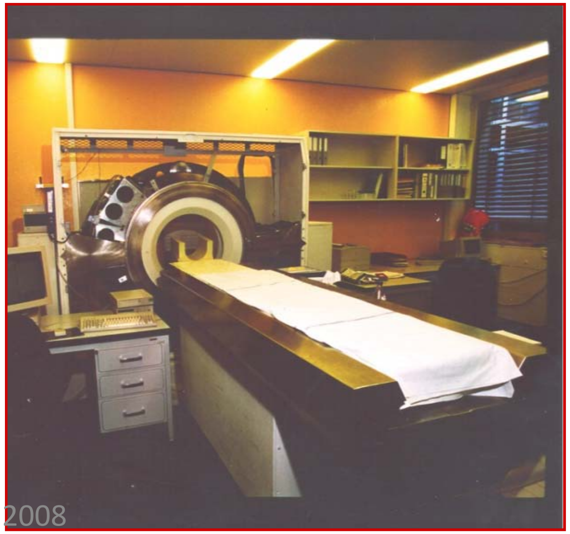
- Two photon laser-spectroscopy (1S-2S energy diff.)
- very narrow line width = high precision: $\Delta\nu/\nu \sim 10^{-15}$
- Long observation time - need trapped (anti)atoms

# SCIENCE FOR HEALTH: IMAGING

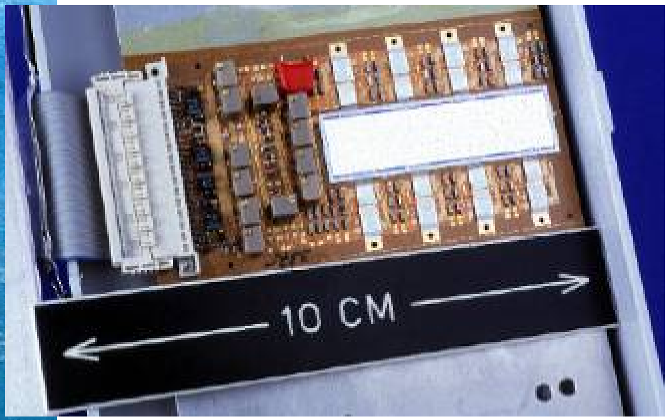



PET today



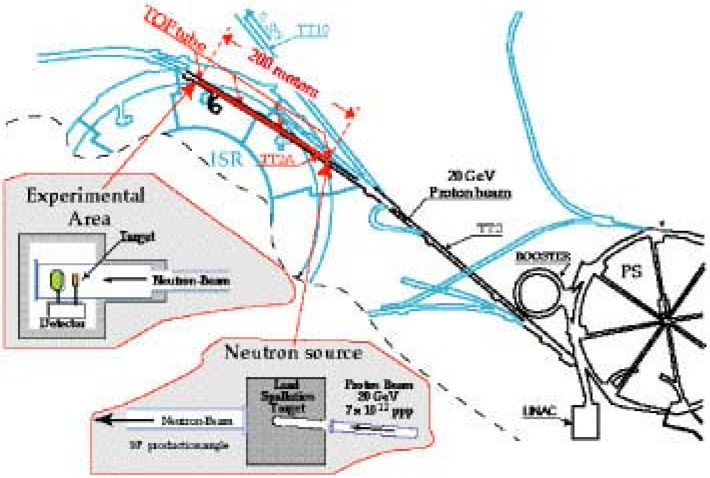


# TECHNOLOGY TRANSFER PROJECTS

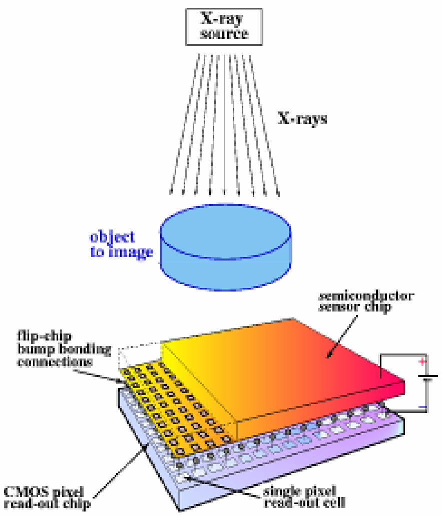



Silicon detector for a Compton camera in nuclear medical imaging

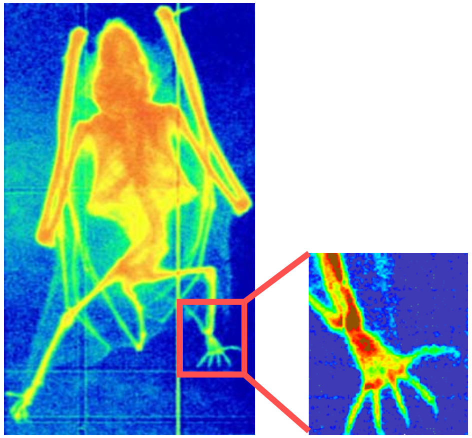
Thin films by sputtering or evaporation




Radio-isotope production for medical applications




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



Radiography of a bat, recorded with a GEM detector

# CERN…

- Seeking answers to questions about the Universe
- Advancing the frontiers of technology
- Training the scientists of tomorrow
- Bringing nations togethr through science