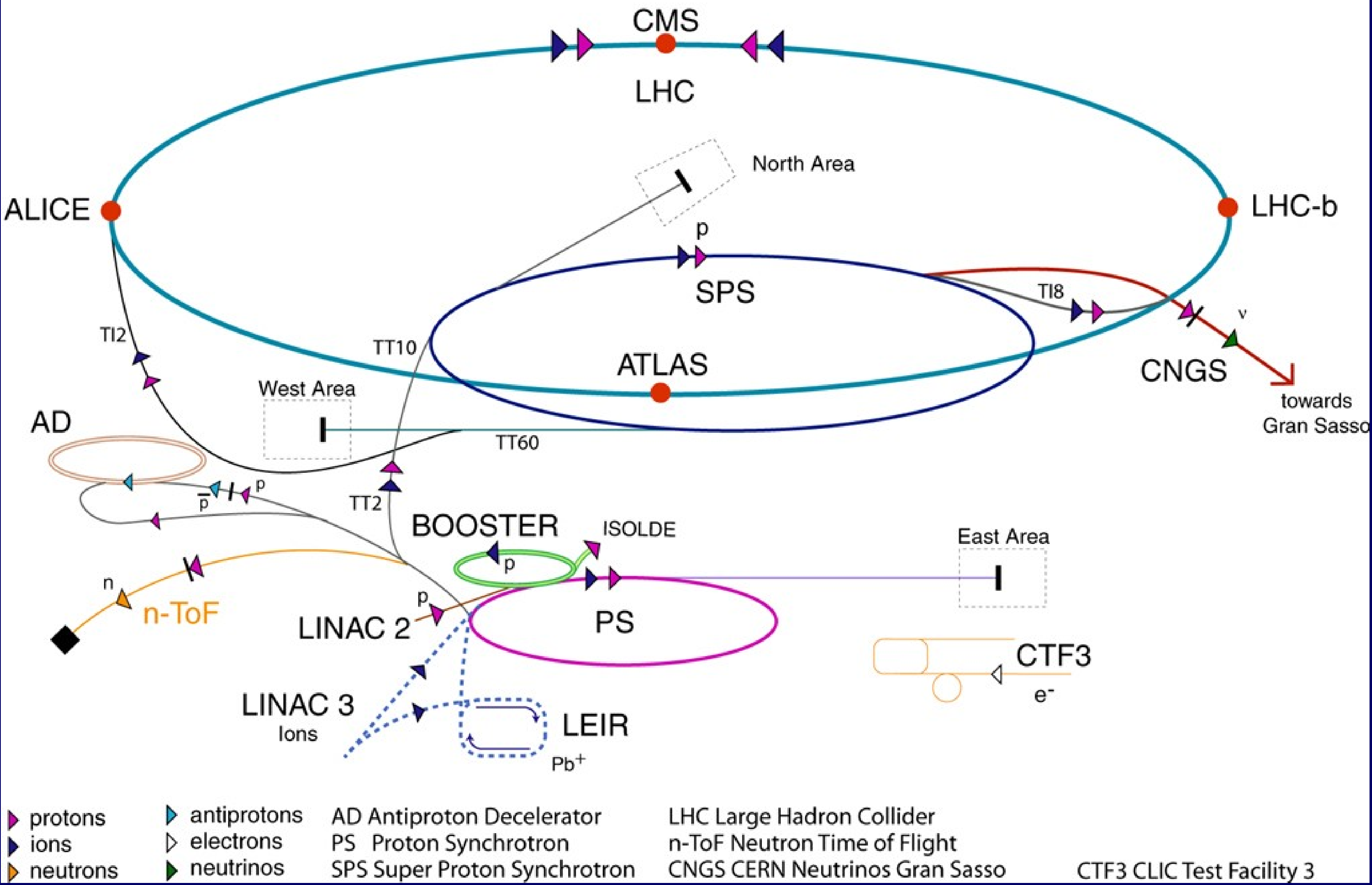
Introduction to CERN

Jos Engelen

Main Missions

CERN: the World's Most Complete Accelerator Complex

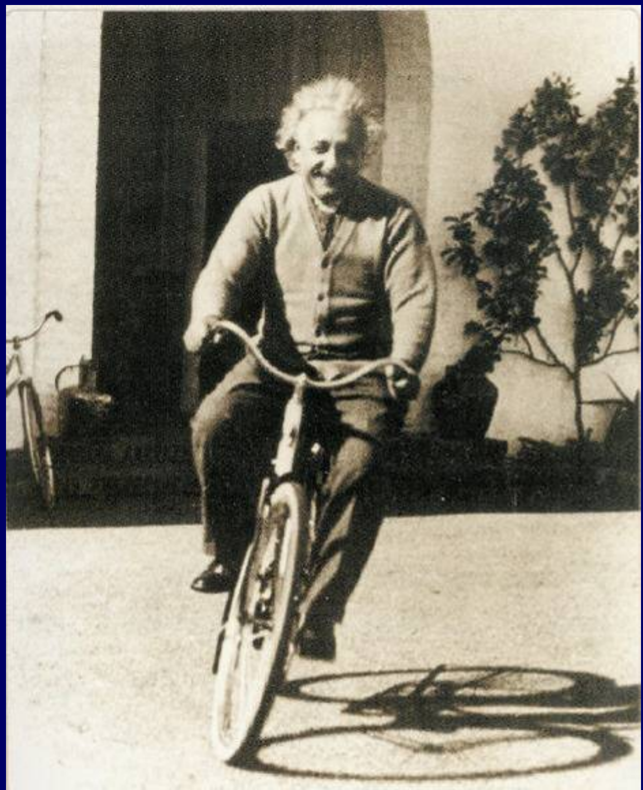
(drawing not to scale)



Research

"The study of elementary particles and fields and their interactions"

$E=Mc^2$



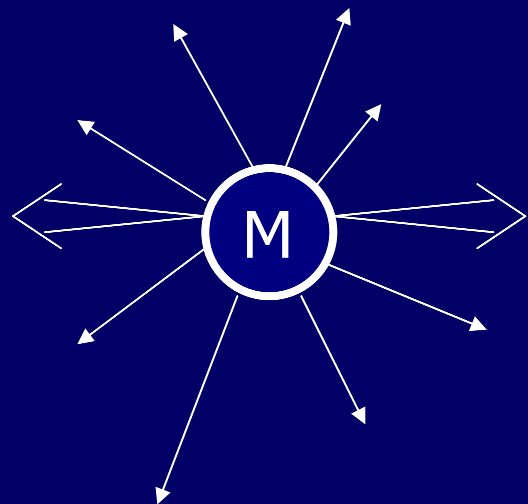
At Large Hadron Collider:

Before collision

proton
E=7 TeV

proton
E=7 TeV

After collision

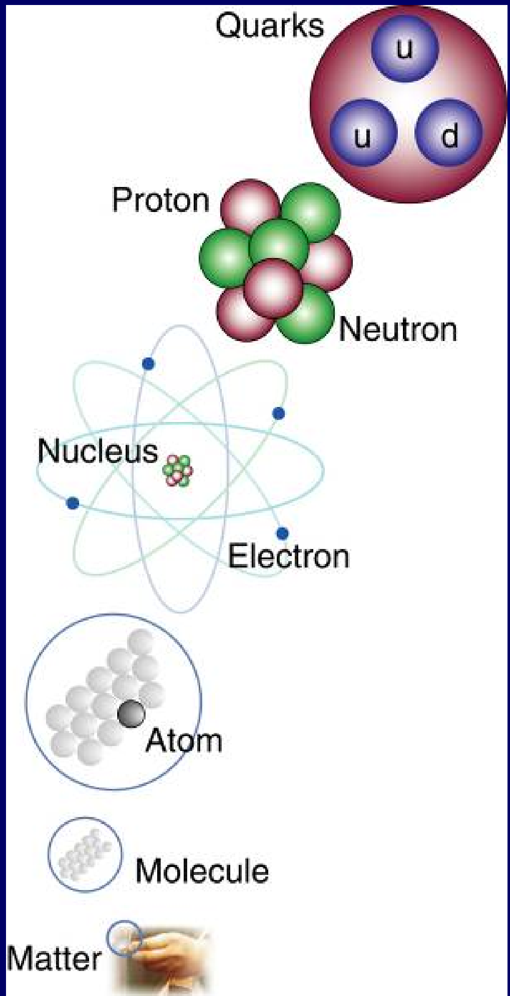


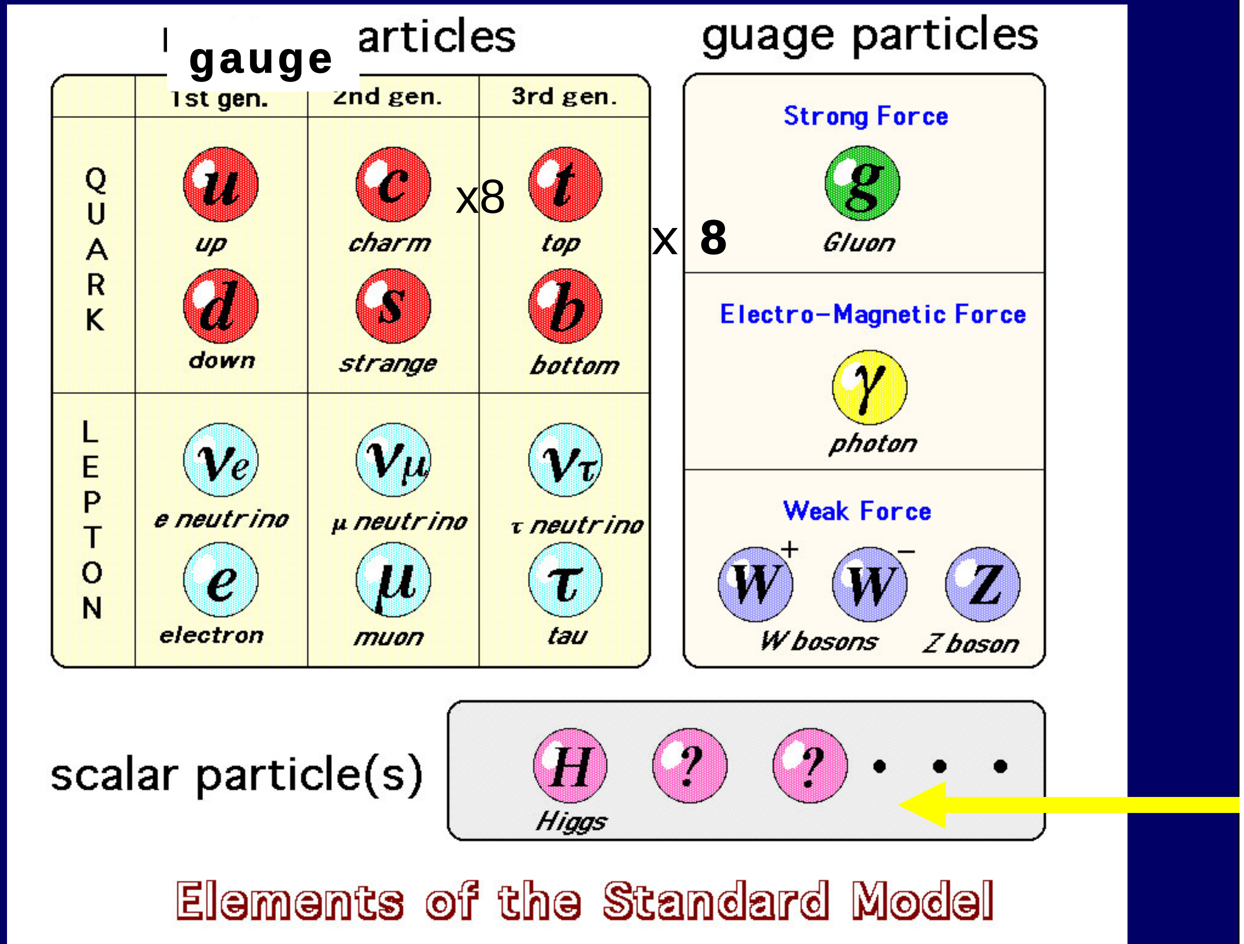
$\lambda = 1/M$

The Compton wavelength of a particle of mass M is
$\lambda = 1/M$
is $2\ 10^{-18}$ m for M=100 GeV (roughly the mass of the W and Z bosons)

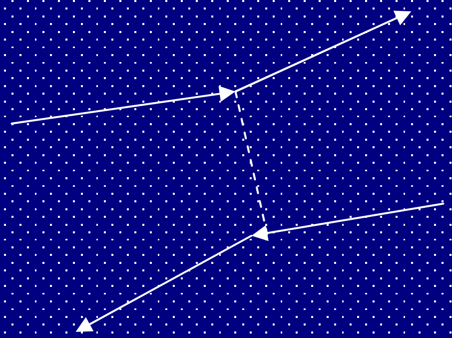
Elementary particle physics: high energies and small distances – theoretical framework is relativistic quantum field theory

The elementary particles and fields

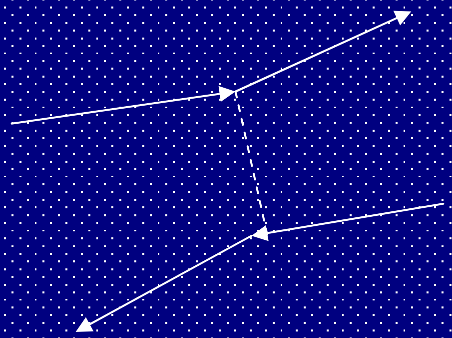




Gauge Invariance and the Higgs field



Two charged particles interact ('collide') through their electromagnetic fields: they exchange a **massless** photon; the theory works – it is gauge invariant



Those same particles also interact through their 'weak' fields: they exchange a **massive** W or Z particle – in order for the theory to work we need to 'embed' the interaction in a field that pervades all of space. Empty space, 'the vacuum', carries this field: the 'Higgs field' – the quantum of this field is the Higgs particle.

For electromagnetism:

$$L_{em} = e\left\{\sum_l \bar{l}\gamma_\mu l - \frac{2}{3}\sum_q \bar{q}\gamma_\mu q + \frac{1}{3}\sum_{q'} \bar{q}'\gamma_\mu q'\right\}A^\mu$$

Gauge invariant U(1)

The full GSW Lagrangian, including the Higgs sector

$$L_{GSW} = L_0 + L_H + \sum_l \left\{ \frac{g}{2}\bar{L}_l\gamma_\mu\vec{\tau}L_l\vec{A}^\mu + g'\left[\bar{R}_l\gamma_\mu R_l + \frac{1}{2}\bar{L}_l\gamma_\mu L_l\right]B^\mu \right\} +$$
$$+ \frac{g}{2}\sum_q \bar{L}_q\gamma_\mu\vec{\tau}L_q\vec{A}^\mu +$$
$$+ g'\left\{\frac{1}{6}\sum_q\left[\bar{L}_q\gamma_\mu L_q + 4\bar{R}_q\gamma_\mu R_q\right] + \frac{1}{3}\sum_{q'}\bar{R}_{q'}\gamma_\mu R_{q'}\right\}B^\mu$$

SU(2)xU(1)

The Higgs sector

$$L_H = \frac{1}{2}(\partial_\mu H)^2 - m_H^2 H^2 - h\lambda H^3 - \frac{h}{4} H^4 +$$

$$+ \frac{g^2}{4}(W_\mu^+ W^\mu + \frac{1}{2\cos^2\theta_W} Z_\mu Z^\mu)(\lambda^2 + 2\lambda H + H^2) +$$

$$+ \sum_{l,q,q'} (\frac{m_l}{\lambda}\bar{l}l + \frac{m_q}{\lambda}\bar{q}q + \frac{m_{q'}}{\lambda}\bar{q}'q')H$$

makes theory gauge invariant (renormalizable) with massive gauge fields;
Higgs couples to mass: wants to decay in heavy particles

The Higgs sector has not been directly accessible so far: this is the domain of the LHC !

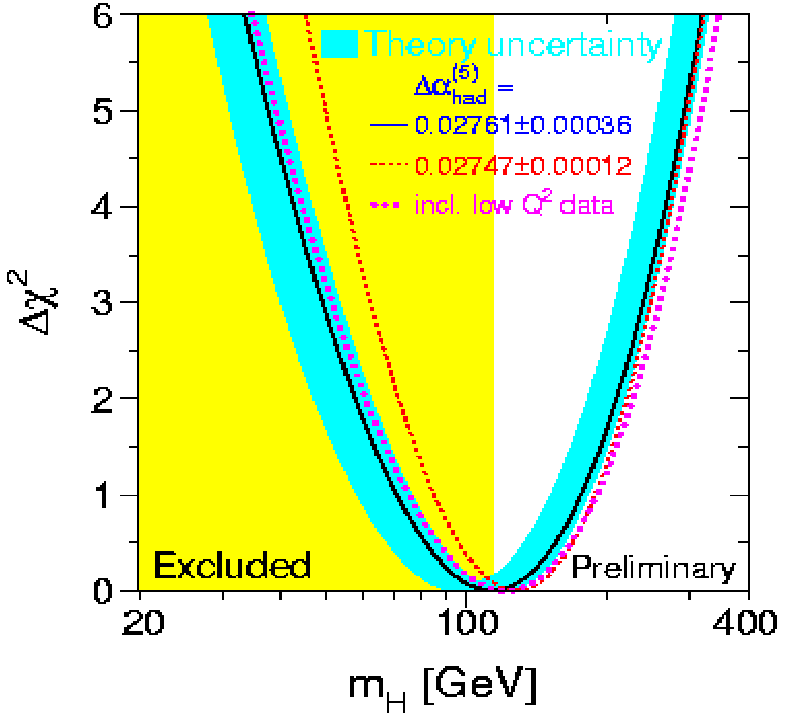
The Higgs particle

Gives mass to all other particles
Makes the theory gauge invariant

We need to find this particle to have a theory for really high energy

Apparently its mass is high – that makes it hard to find; we need particle collisions at higher energy than ever (technological, experimental challenge); that high energy will lead to more discoveries than 'just' the Higgs.

The Higgs mass limits



Direct limit from LEP data: m_H>114.4 GeV (95% CL)

Electroweak fits (also using Tevatron and other data) m_H<237 GeV (95% CL)

The odds for the LHC are not so bad...

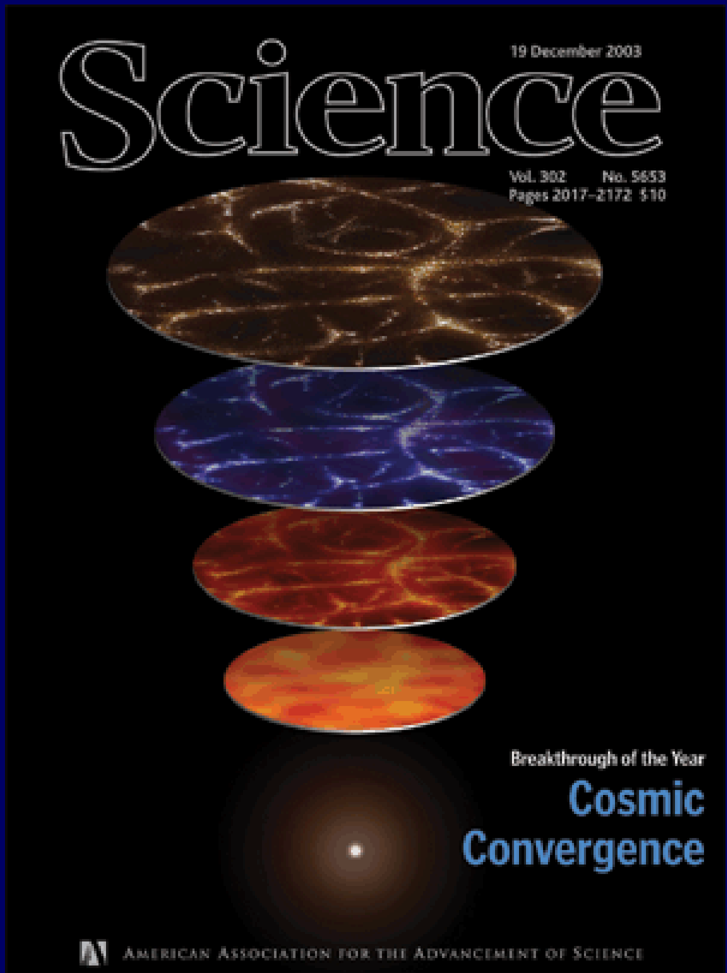
The Strong Interaction

Gauge theory of the interactions of quarks and gluons; SU(3):
3 colors, 8 generators, i.e. 8 gauge bosons

so: quarks form color triplets

mesons: quark-antiquark combinations (colorless)
baryons: quark-quark-quark combinations (colorless)

Couverture
Magazine Science 2003



And then there is this other thing:
dark matter...

What has particle physics got to do with it?

Supersymmetry..?
Will come back to it

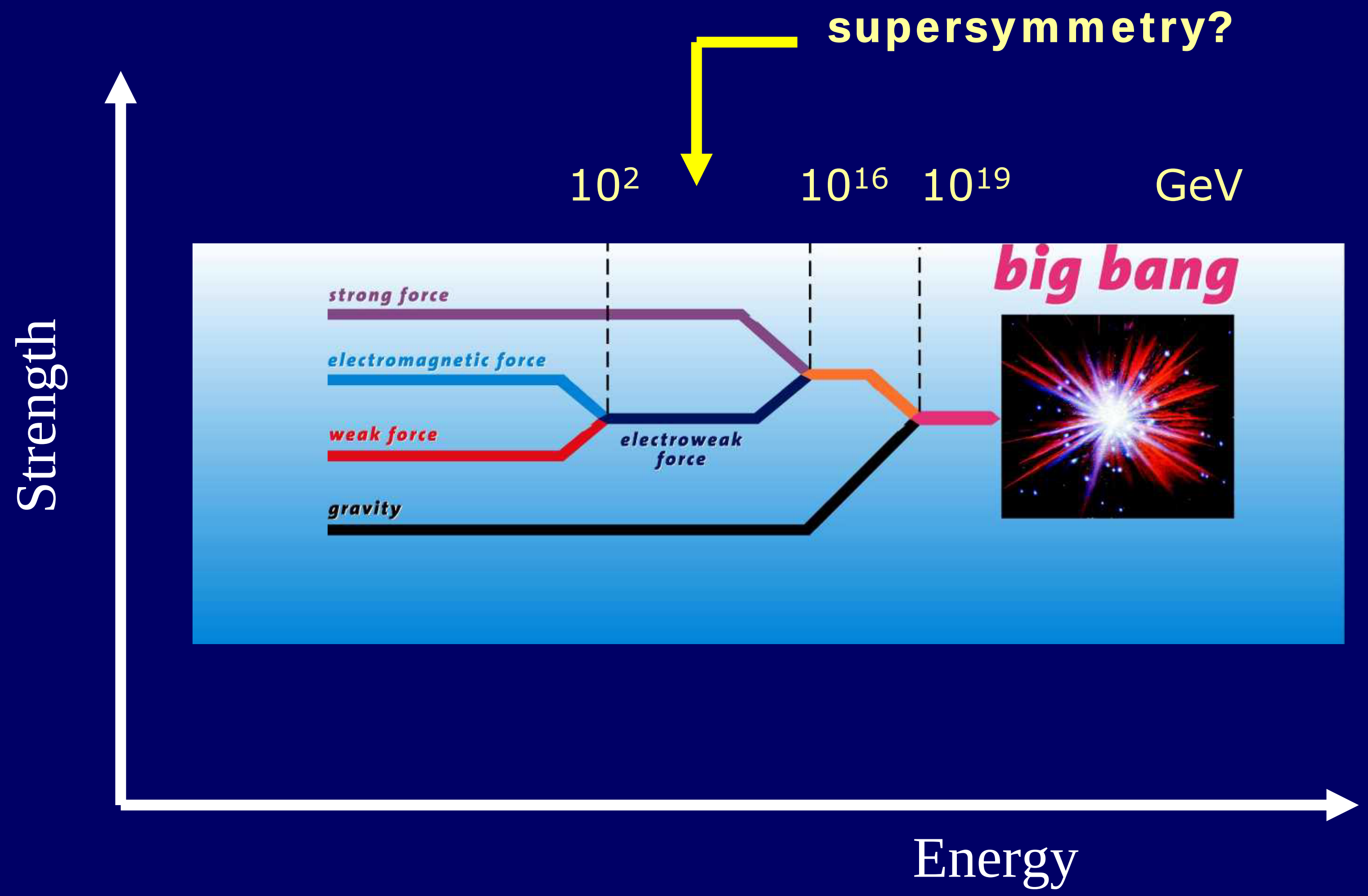
Dark Matter

First evidence from rotation of visible objects as function of R:
for small R
v~R (solid disc)
at larger R:
v=constant, meaning that M increases ~ R
→Dark Matter

(Kepler: $v \sim 1/R^{1/2}$)

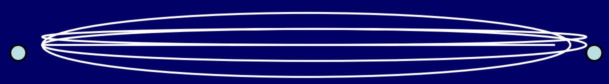
Now: corroborated by other (CMB) observations

Unification of the various interactions



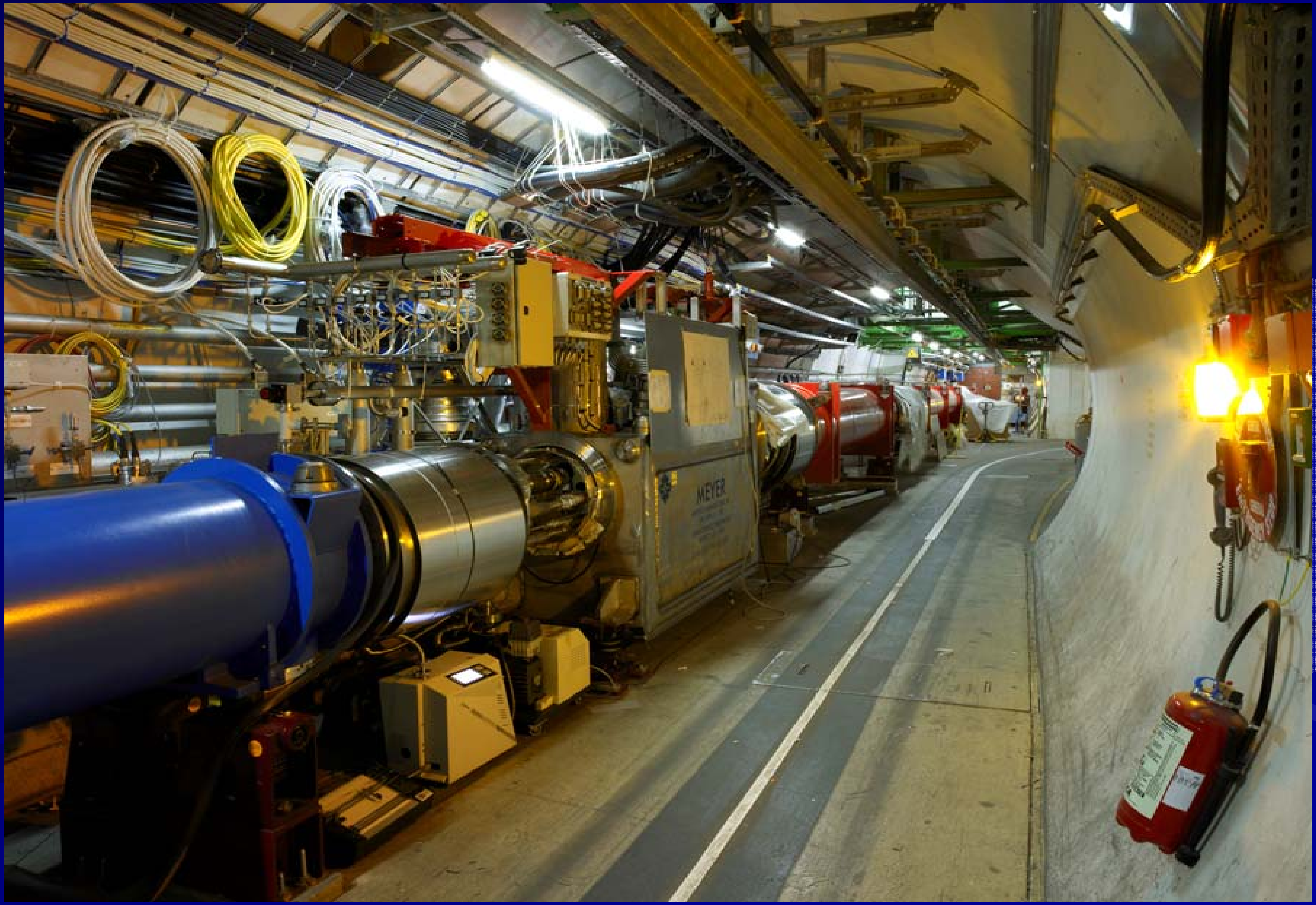
Extra dimensions

Constant field in a hypothetical one dimensional world

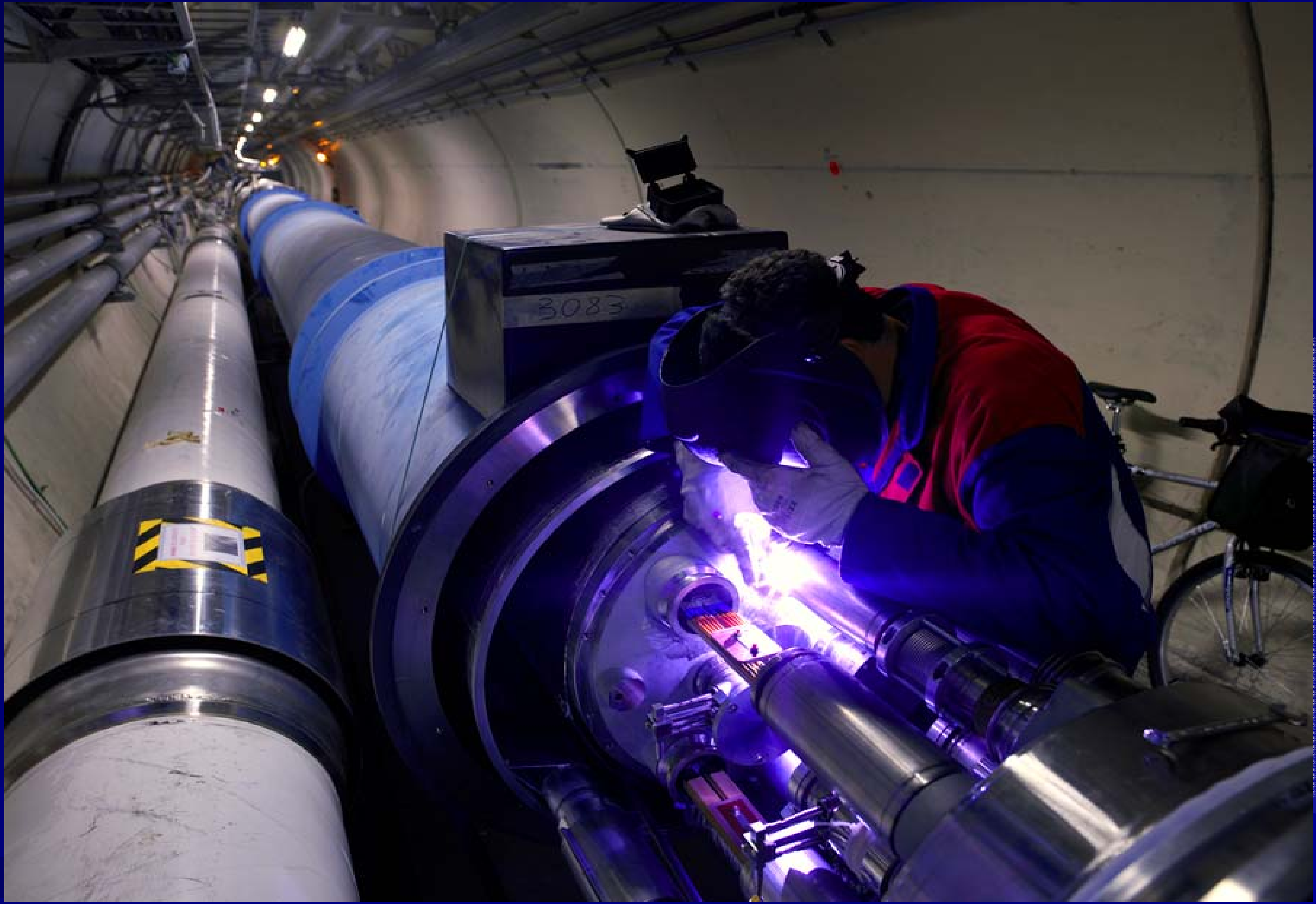


That same hypothetical world with one extra dimension in which the field can spread: at distances from the source comparable to the size of the extra dimension or smaller, the field increases rapidly

The LHC Collider



Tunnel interconnect



Milestones

Last magnet delivered	October 2006
Last magnet tested	December 2006
Last magnet installed	March 2007
Machine closed	August 2007
First collisions	November 2007

The Detector Challenge of the LHC

Quote (mid 1980's): *' we think we know how to build a high energy, high luminosity hadron collider – **we don't have the technology to build a detector for it***

for a high energy, high luminosity electron–positron collider the situation is just the opposite '

The LHC detectors are radically different from their predecessors at the SppS collider, LEP, SLC, HERA, Tevatron, etc.

They are designed for a luminosity of 10^{34} $cm^{-2}s^{-1}$ for pp collisions at an energy of 14 TeV

Detectors need to be fast, radiation hard (also the electronics) and big

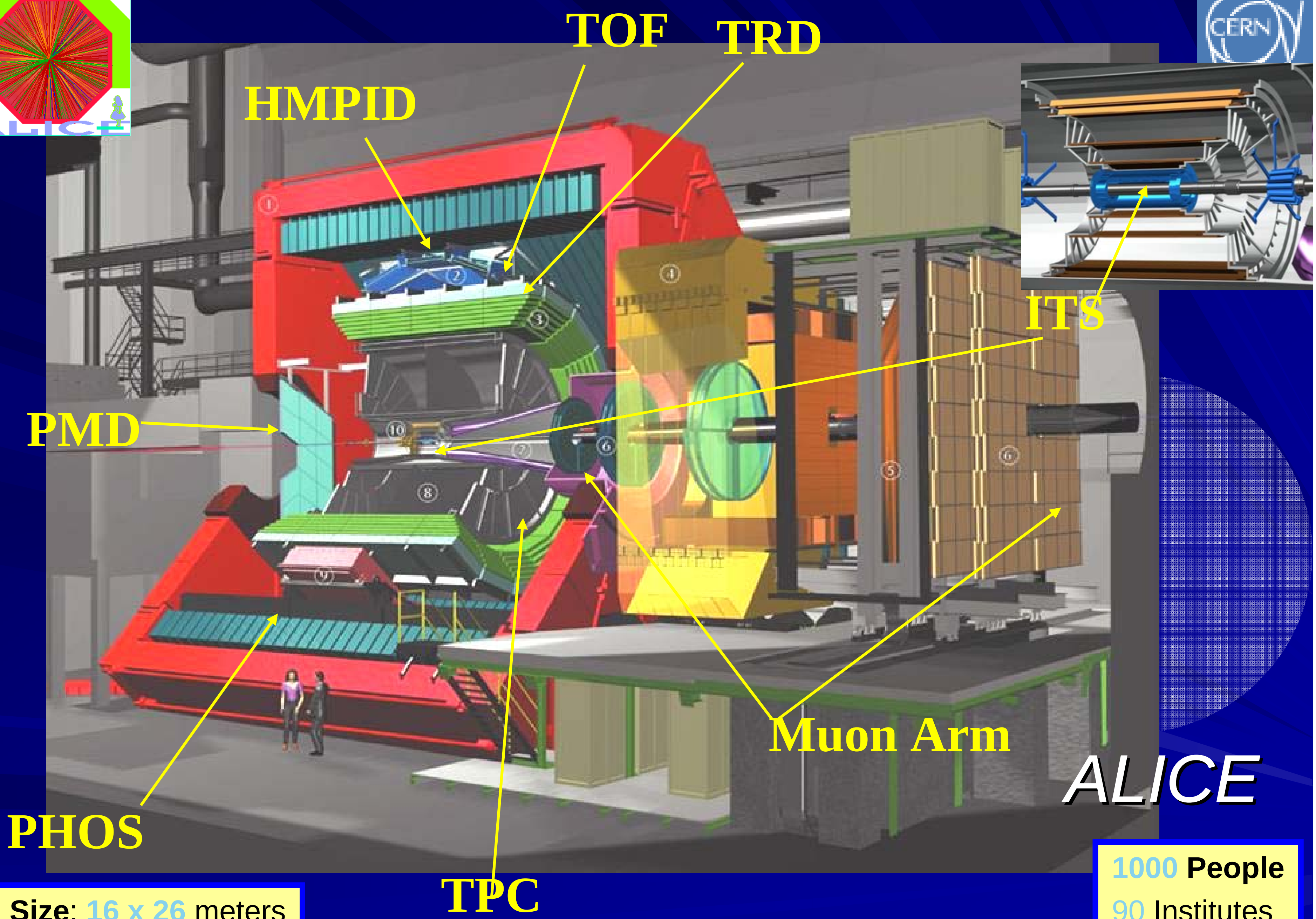
The Detectors

Event rate 20 – 25 per bunch crossing (every 25 ns)
--> 10^9 events / s --> 10^{11} – 10^{12} tracks /s

Very remarkable: experiments will, in this environment:

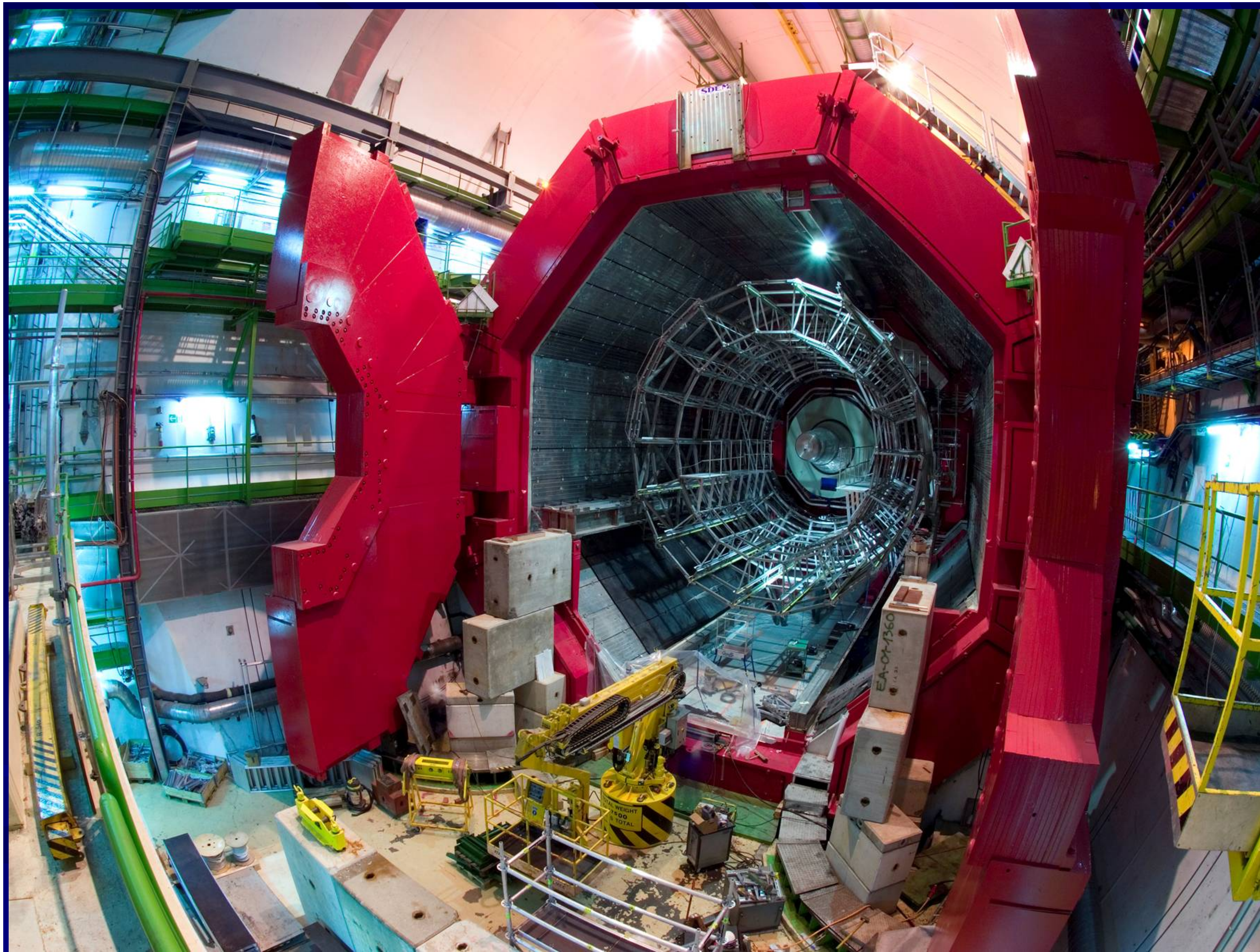
- reconstruct secondary vertices from B mesons, only mm's away from the primary vertex.
- reconstruct individual photons with sufficient energy and angular resolution for (light) Higgs detection

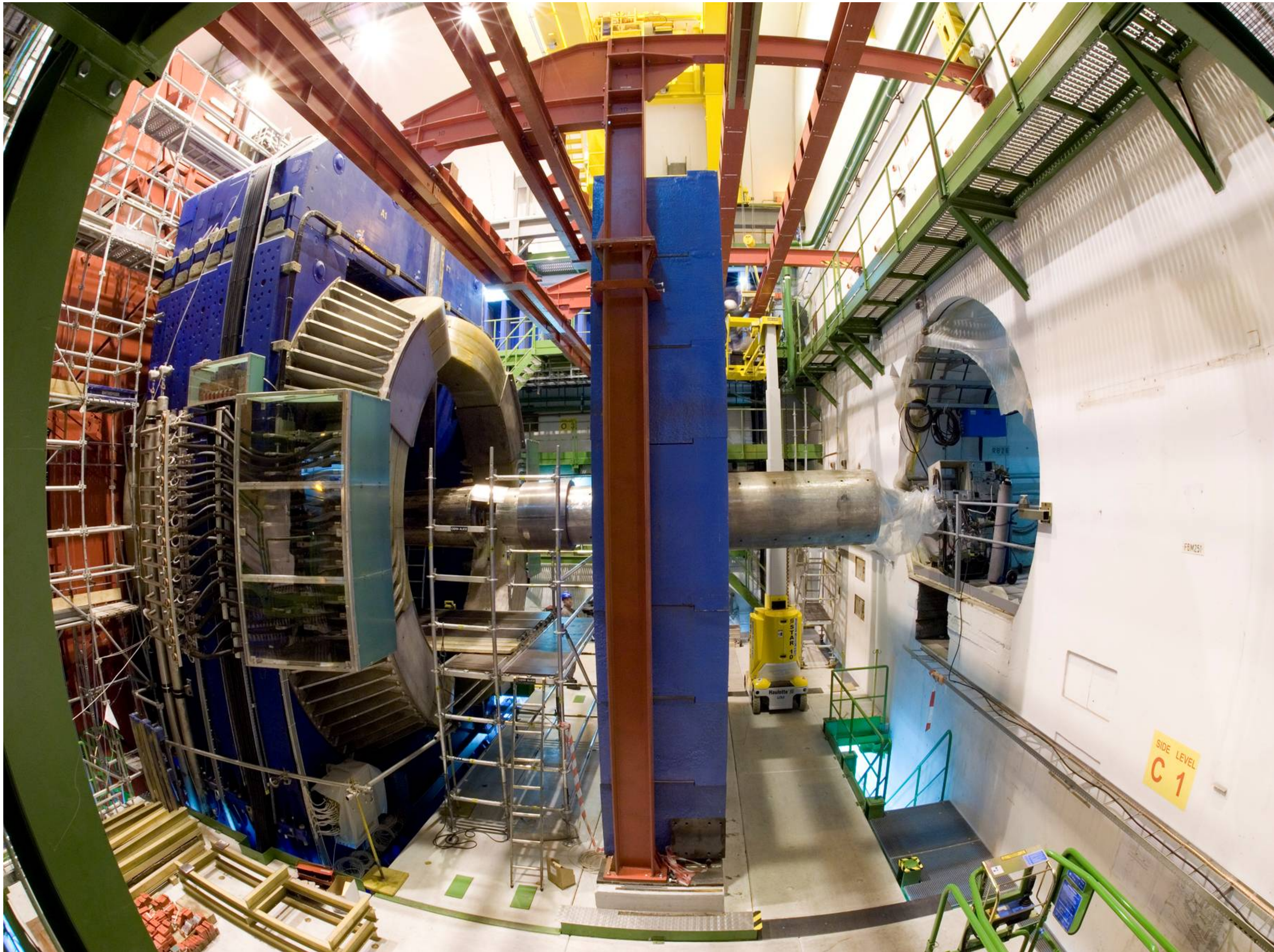
in addition to many more capabilities: they are 'general purpose – 4π' detectors, featuring tracking, magnetic momentum analysis, calorimetry, muon spectrometry, in an, almost, **hermetic** setup



Size: 16 x 26 meters
Weight: 10,000 tons

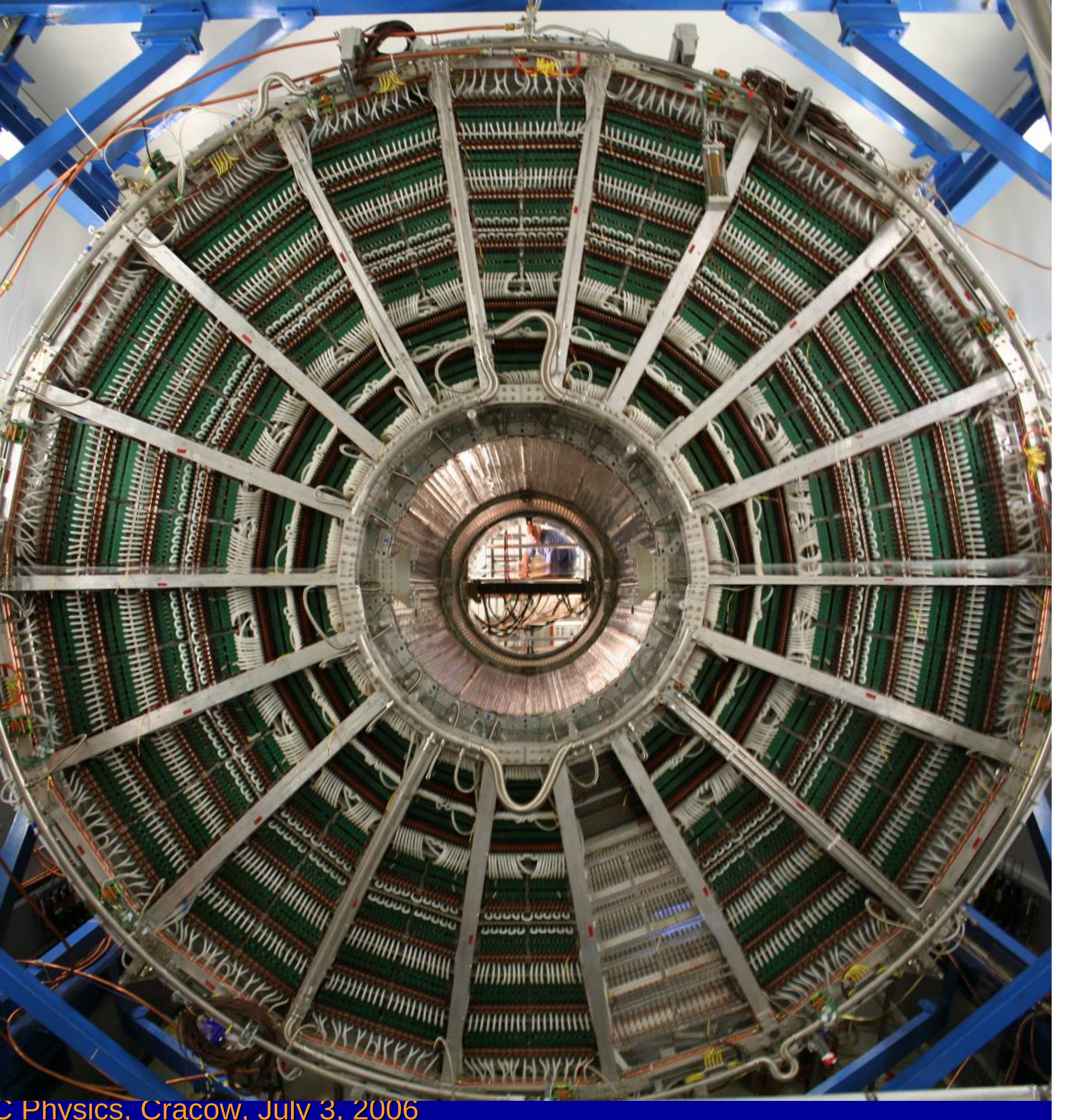
1000 **People**
90 Institutes
30 Countries


EA-04-1360

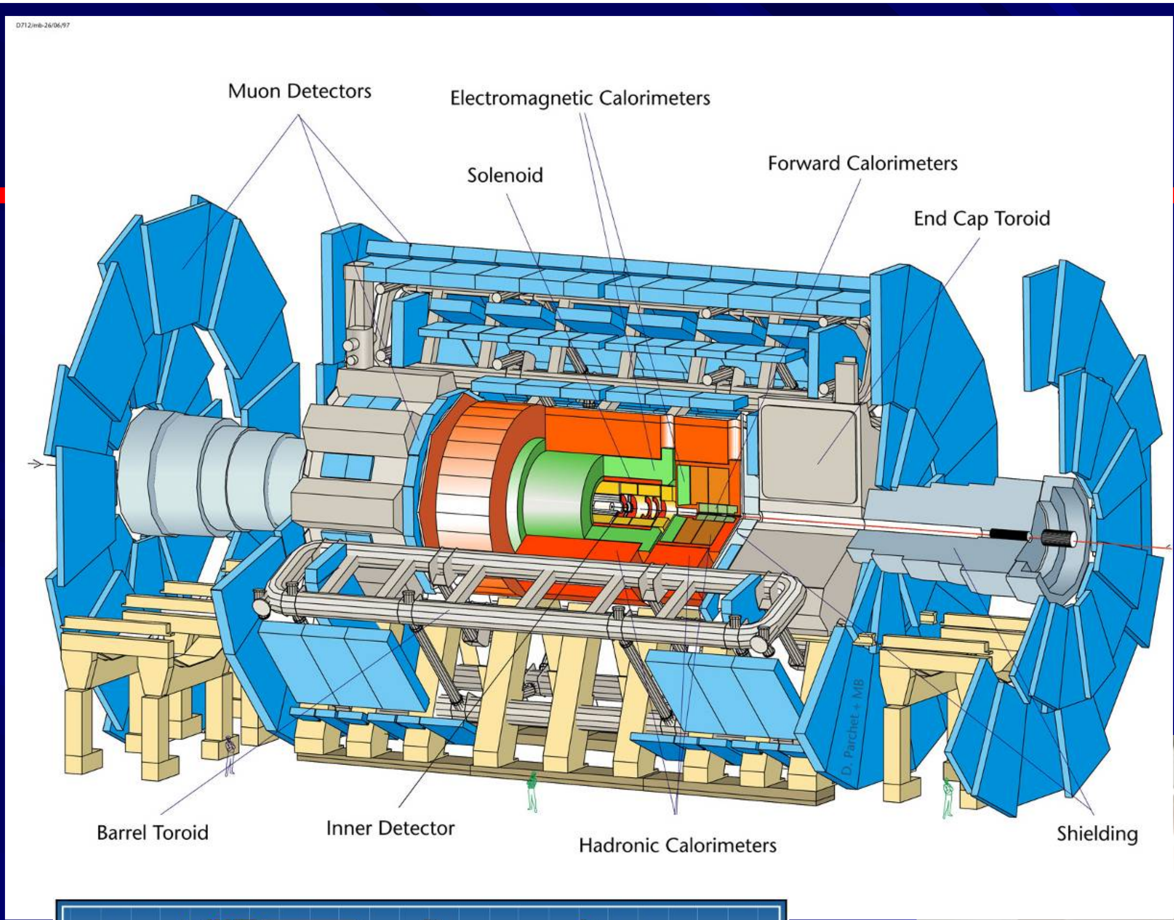

SIDE LEVEL
C 1

The ALICE TPC has entered the commissioning phase

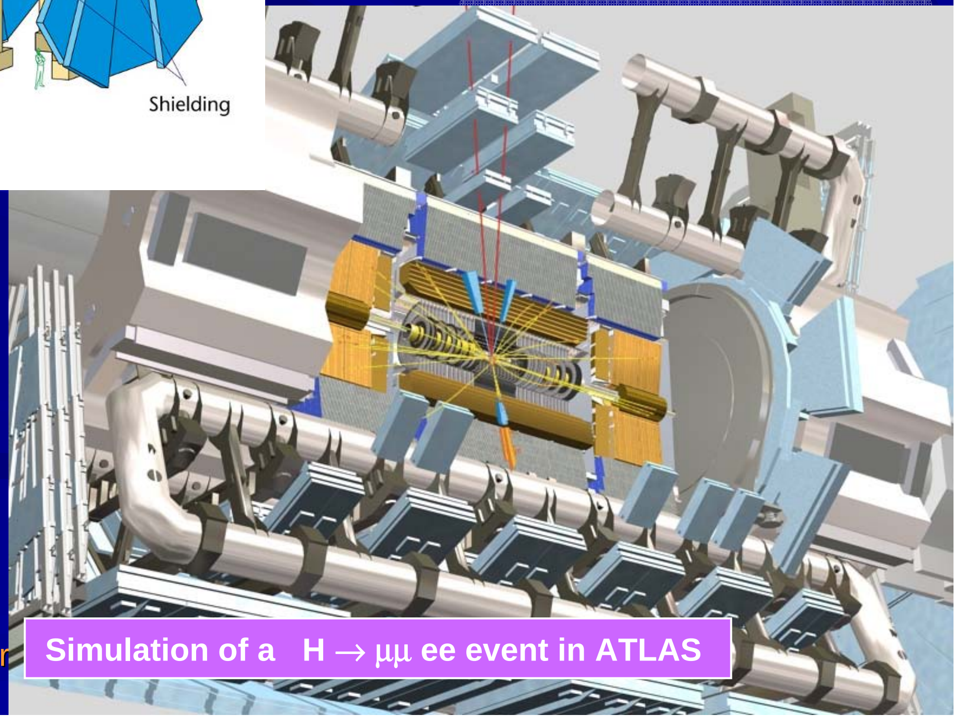
- 2006/Q1: Frontend electronics installation
  - 72 readout chambers
  - 4356 FEE cards
  - 557,568 channels
  - up to 1000 time bins each
- Pre-commissioning above ground since May
  - Gas system: 95 m^3 $Ne/CO_2/N_2$ (90/10/5), now few ppm O_2
  - 2 sectors at a time
  - Full data chain
  - Cosmics tracks
  - Laser tracks
  - Noise σ ~ 0.7 ADC cts
- Move to cavern in fall



ATLAS



Construction status: on track for collisions towards the end of 2007



Simulation of a H $\rightarrow \mu\mu$ ee event in ATLAS

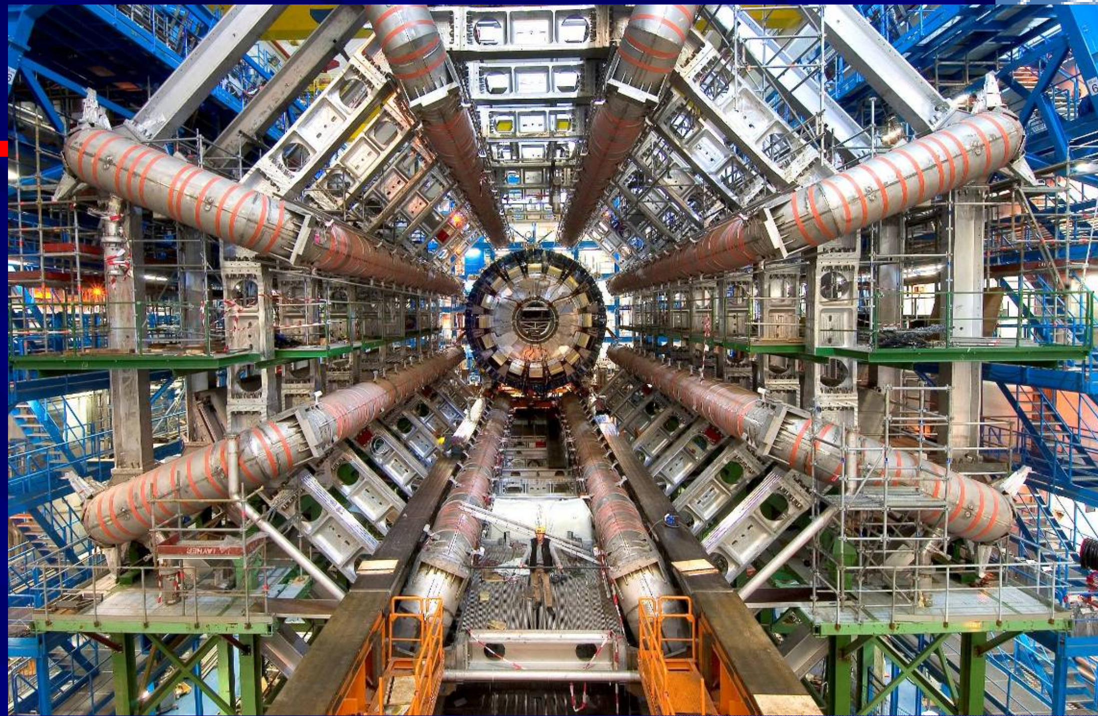
Magnet System

The Barrel Toroid is installed, and is being pumped down, followed by full excitation tests in July/Aug 06

The End-Cap Toroids are in the final integration phase, on time for the cavern (end of 2006)

The solenoid has been tested already *in situ* at reduced current, awaiting the closure of the calo end-caps

→ The full magnet system is on time to be operational in spring 07



Barrel Toroid before insertion of the barrel calorimeter on 4th November 2005

Muon Chambers

All chambers are built, installation in the barrel region is in full swing (complete before end 2006), and end-cap sectors are being pre-assembled in Hall 180 (on the critical path for installation by summer 2007)

Installation of barrel muon chambers

The CMS Detector

CALORIMETERS

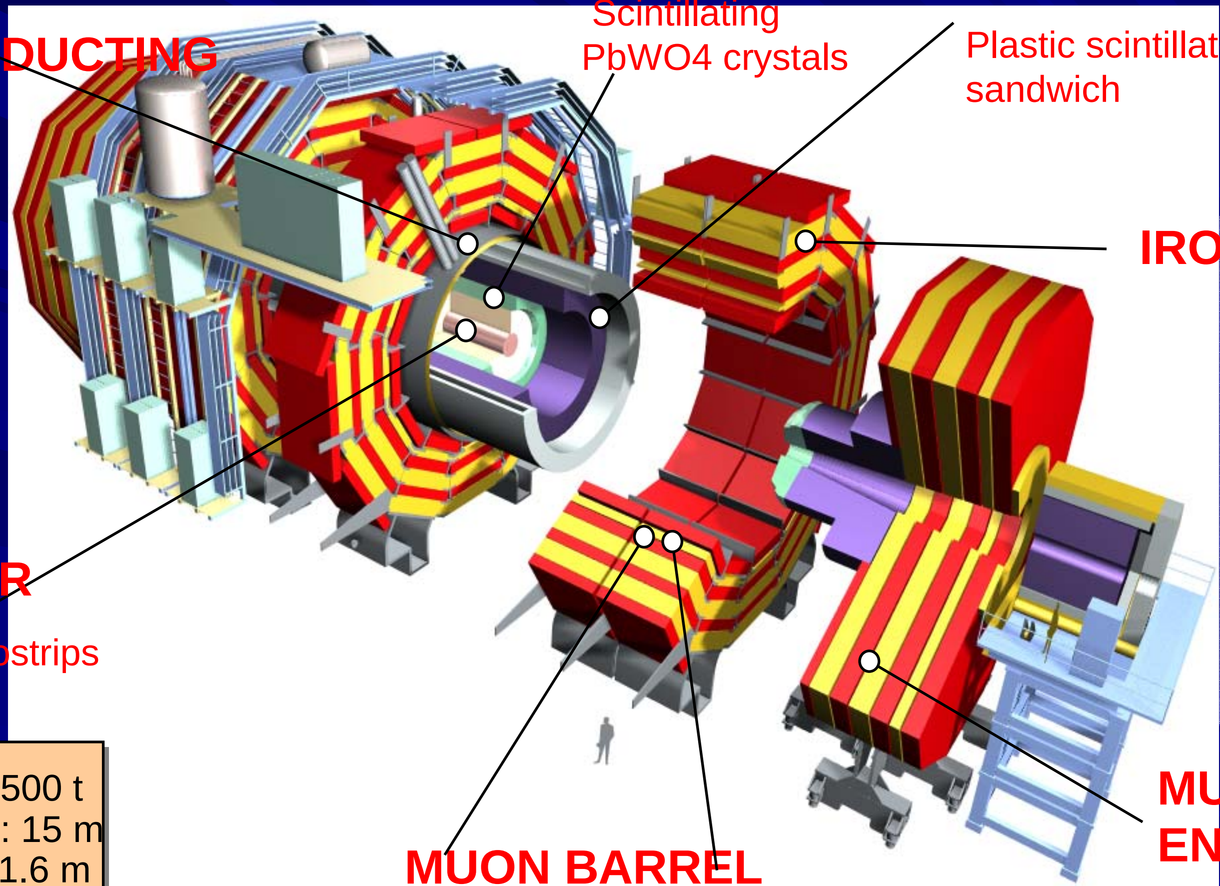
ECAL

Scintillating PbWO4 crystals

HCAL

Plastic scintillator/brass sandwich

SUPERCONDUCTING COIL



IRON YOKE

TRACKER

Silicon Microstrips
Pixels

MUON BARREL

Drift Tube Chambers

Resistive Plate Chambers

MUON ENDCAPS

Cathode Strip Chambers
Resistive Plate Chambers

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

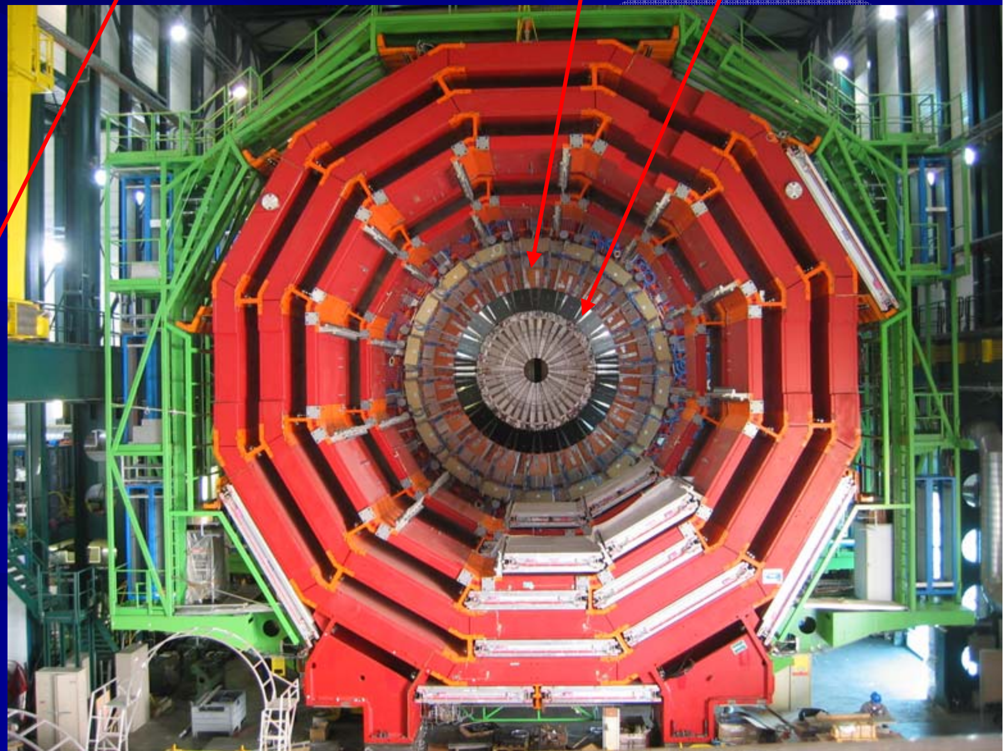
3 g/cm^3

CMS Assembly at Point 5 for Slice Test

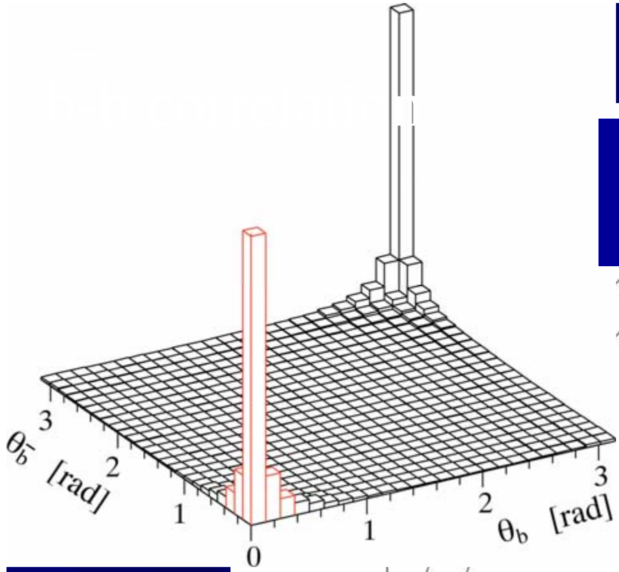
Magnet Test and Detector Test - Jul-Aug06

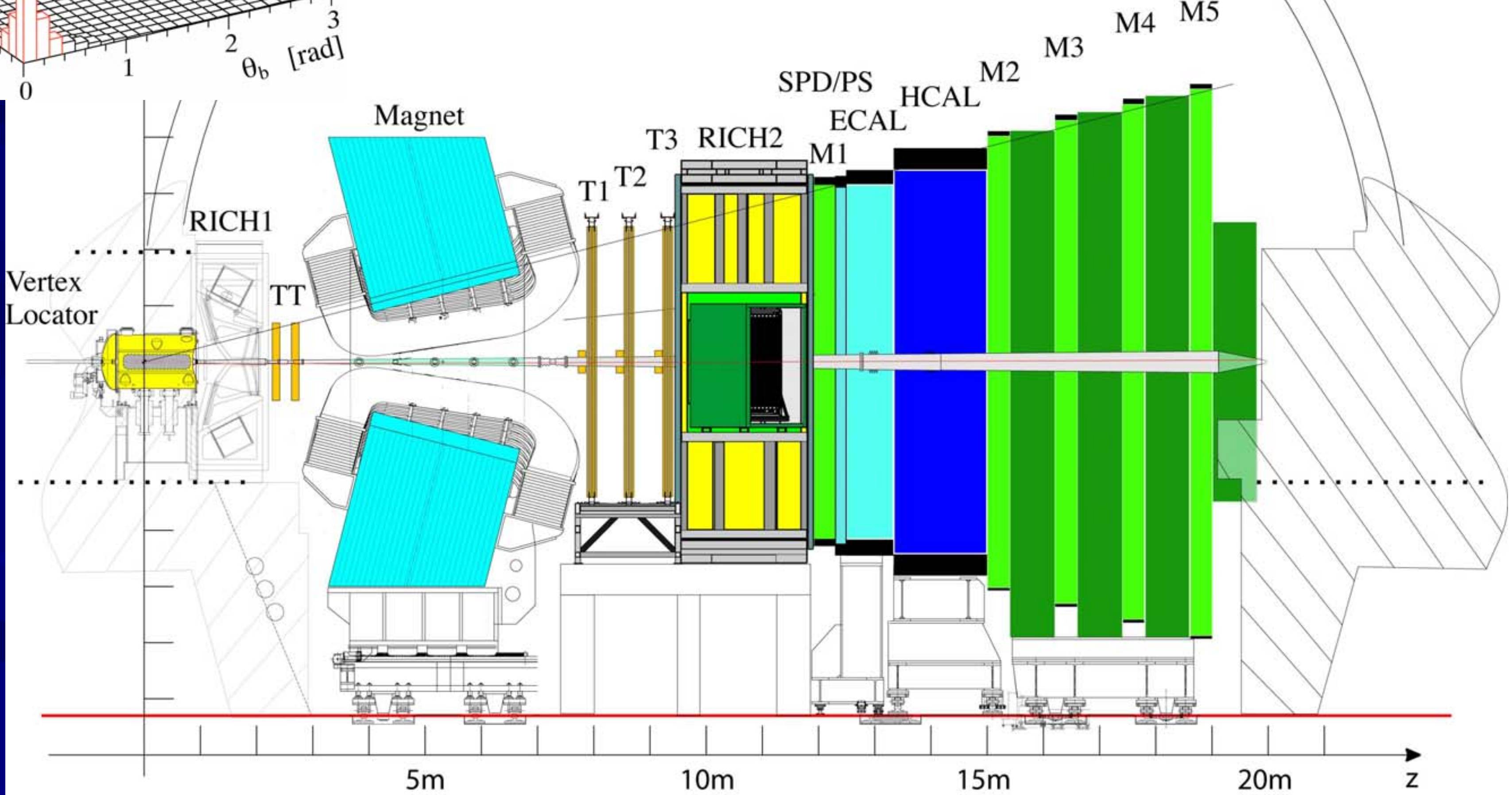
- Solenoid is cold
- HB inserted in coil
- 2 ECAL SM
- Tracker Components
- DT + RPCs

HCAL Endcap
CSCs



LHCb detector at IP8





LHCb pit

Computing

LHC data

- 40 million * 20 collisions per second
- After filtering, 100 collisions of interest per second
- A Megabyte of data digitised for each collision
= recording rate of 0.1 Gigabytes/sec
- several 10^9 collisions recorded each year
= up to 10 Petabytes/year of data

1 Megabyte (1MB)
A digital photo

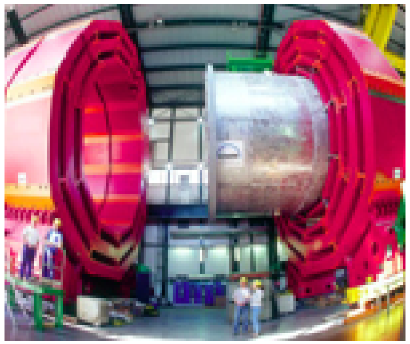
1 Gigabyte (1GB)
= 1000MB
A DVD movie

1 Terabyte (1TB)
= 1000GB
World annual book production

1 Petabyte (1PB)
= 1000TB
Annual production of one LHC experiment

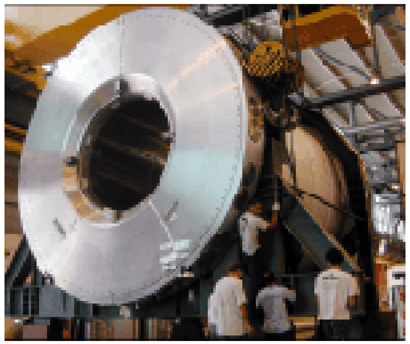
1 Exabyte (1EB)
= 1000 PB
World annual information production

CMS

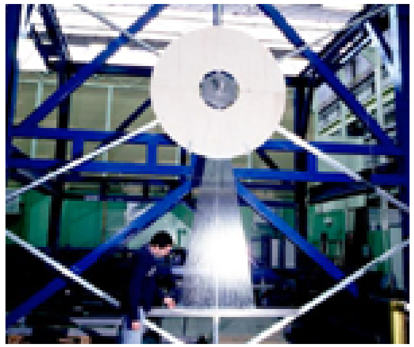


LHCb

ATLAS



ALICE



LHC Computing Grid (LCG)

Mission:

• Grid deployment project aimed at installing a functioning Grid to help the LHC experiments collect and analyse the data coming from the detectors

Strategy:

• Integrate thousands of computers at dozens of participating institutes worldwide into a global computing resource

• Rely on software being developed in advanced grid technology projects, both in Europe and in the USA

How will it work?

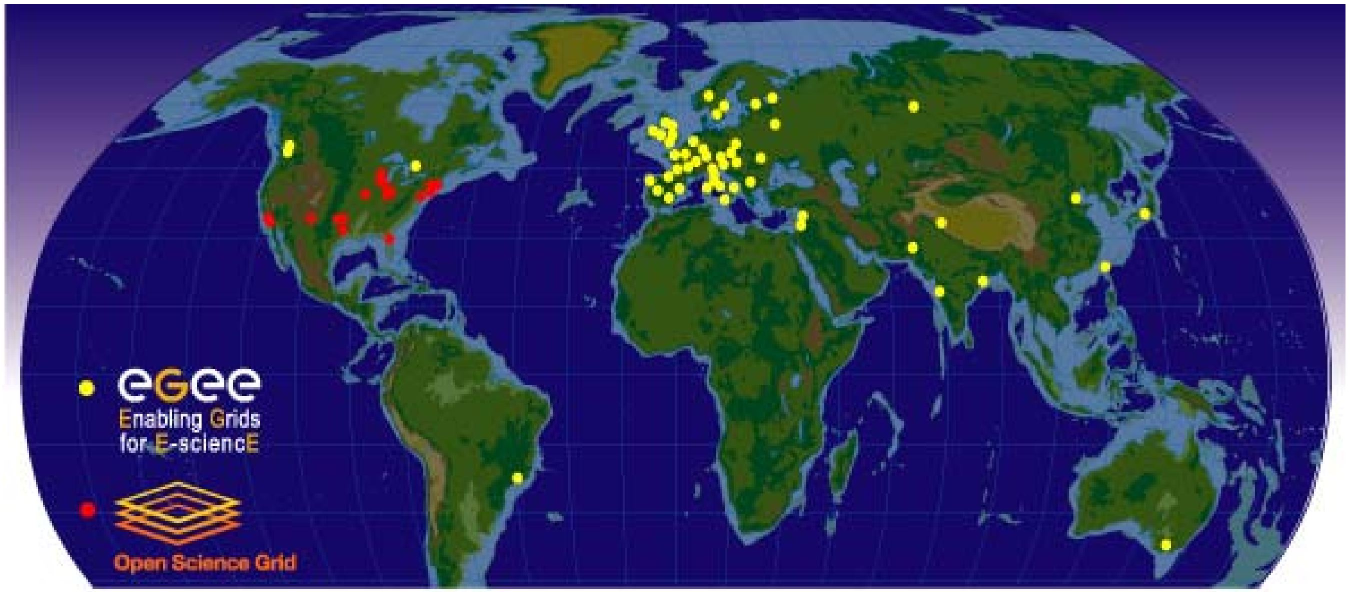
• The Grid relies on advanced software, called middleware, which ensures seamless communication between different computers and different parts of the world

• The Grid search engine will not only find the data the scientist needs, but also the data processing techniques and the computing power to carry them out

• It will distribute the computing task to wherever in the world there is spare capacity, and send the result to the scientist

Interoperation between Grid Infrastructures

- Good progress EGEE-OSG interoperability
- Cross job submission – in use by CMS
- Integrating basic operation – 4th workshop at CERN 19-20 June



A map of the worldwide LCG infrastructure operated by EGEE and OSG.

- Early technical studies on integration with Nordic countries

Conclusions

CERN is the right place to be!