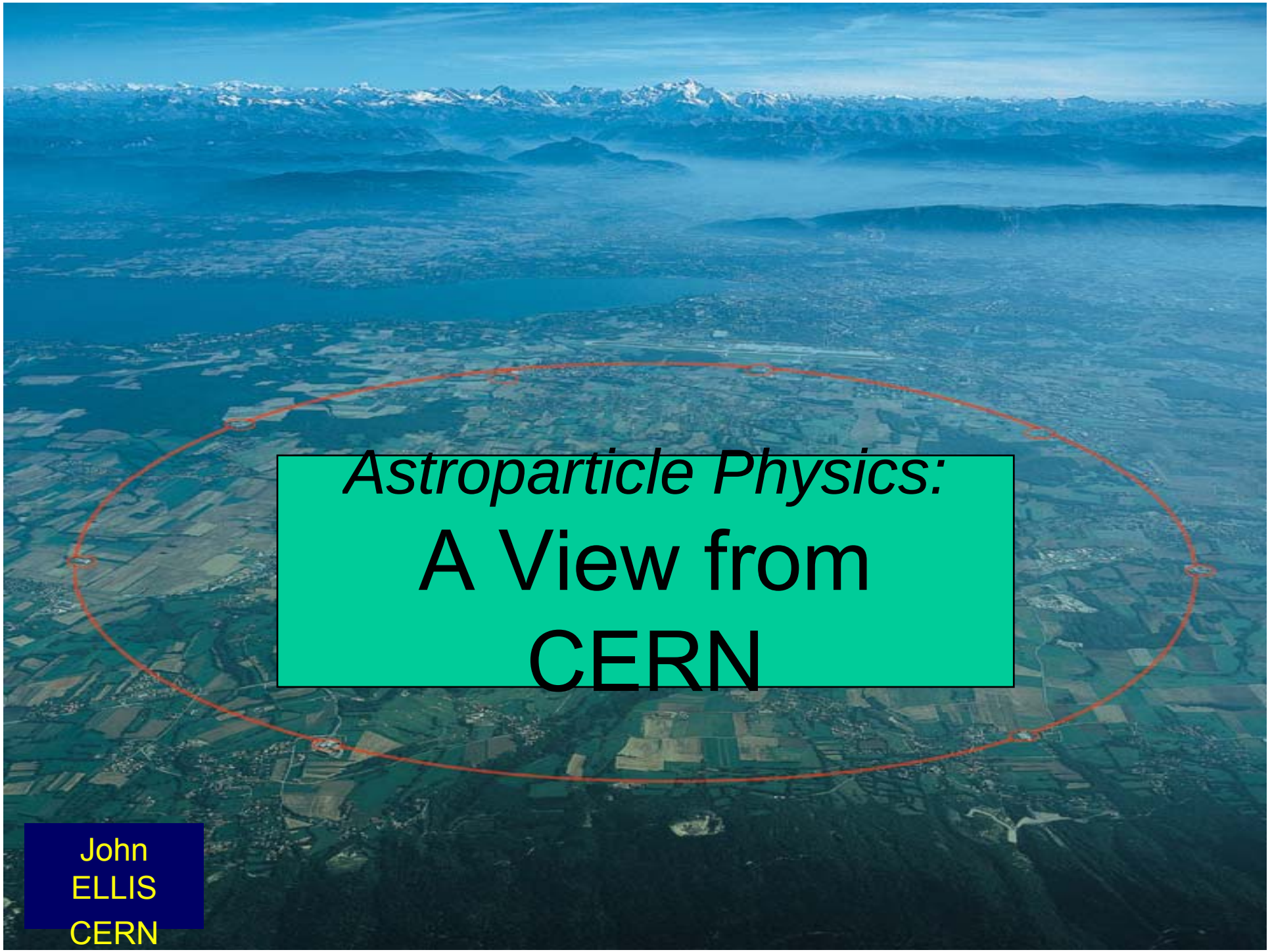
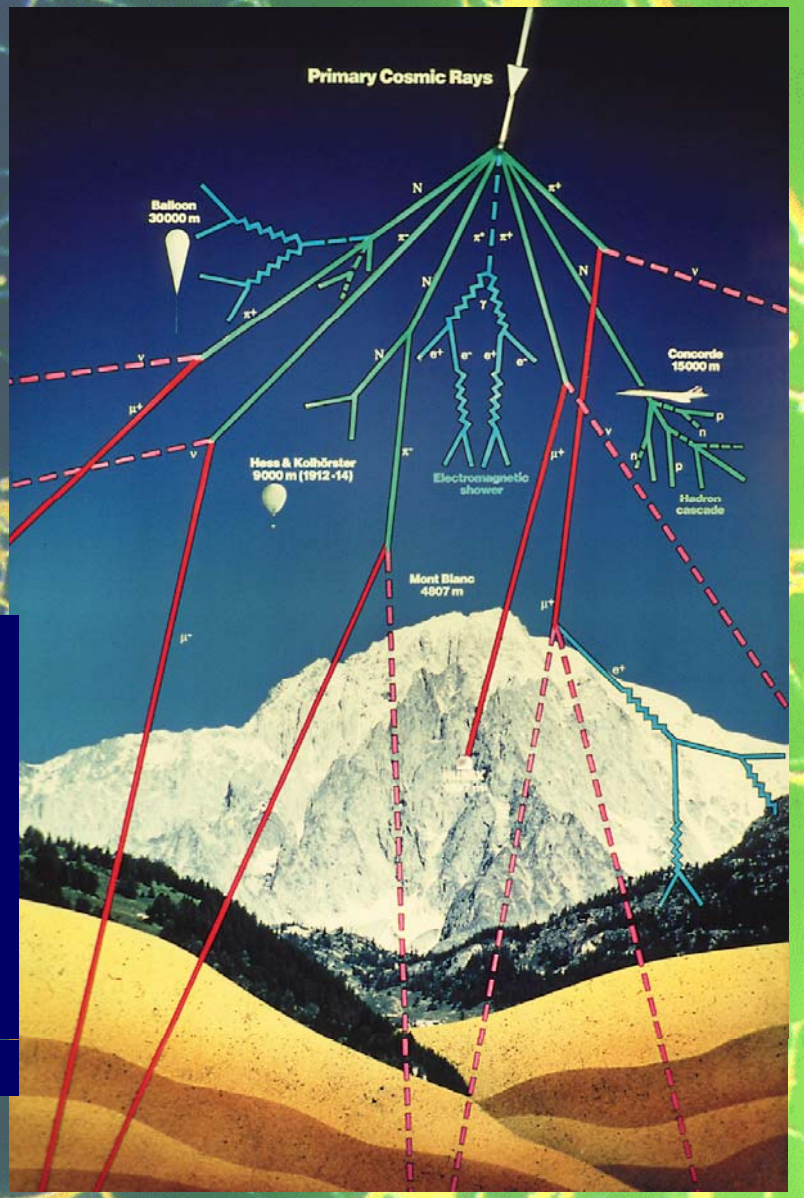


Astroparticle Physics: A View from CERN

John ELLIS
CERN

From the Cosmic Rays to Particle Physics

Much of particle physics originated from discoveries in cosmic rays



CERN was founded in 1954 to study these particles

Extracts from CERN Convention

1. The Organization shall provide for collaboration among European States in **nuclear research** of a pure scientific and fundamental character, and in research essentially related thereto ….
2. … the construction and operation of **one or more international laboratories** … for research on high-energy particles, **including work in the field of cosmic rays ….**
7. … **co-operate to the fullest possible extent with laboratories and institutes in the territories of Member States** within the scope of their programmes of activities. … the Laboratories shall seek to **avoid duplicating research work** which is being carried out the said laboratories or institutes

Possible General Interpretation

- Primary purpose: study structure of matter
- Focus on construction of particle accelerators
- Maintain interest in their astroparticle connections
- Open to hosting groups preparing astroparticle experiments elsewhere (remember ESO)
- Complement national activities
- Potential for more direct role, **IFF**
  - Hiatus in accelerator construction
  - Need for coordination of large-scale project
- Not the case for the foreseeable future

European Strategy for Particle Physics

- Agreed by the CERN Council on July 14th, 2006:

> 7. A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena; *Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest.*

- From accompanying discussion document

  "The areas of more direct interest to astrophysics and cosmology include
  - very-high-energy particles from the Universe
  - low-energy neutrinos from supernovae, sun and earth
  - gravitational waves
  - axions from the Sun or the early Universe …

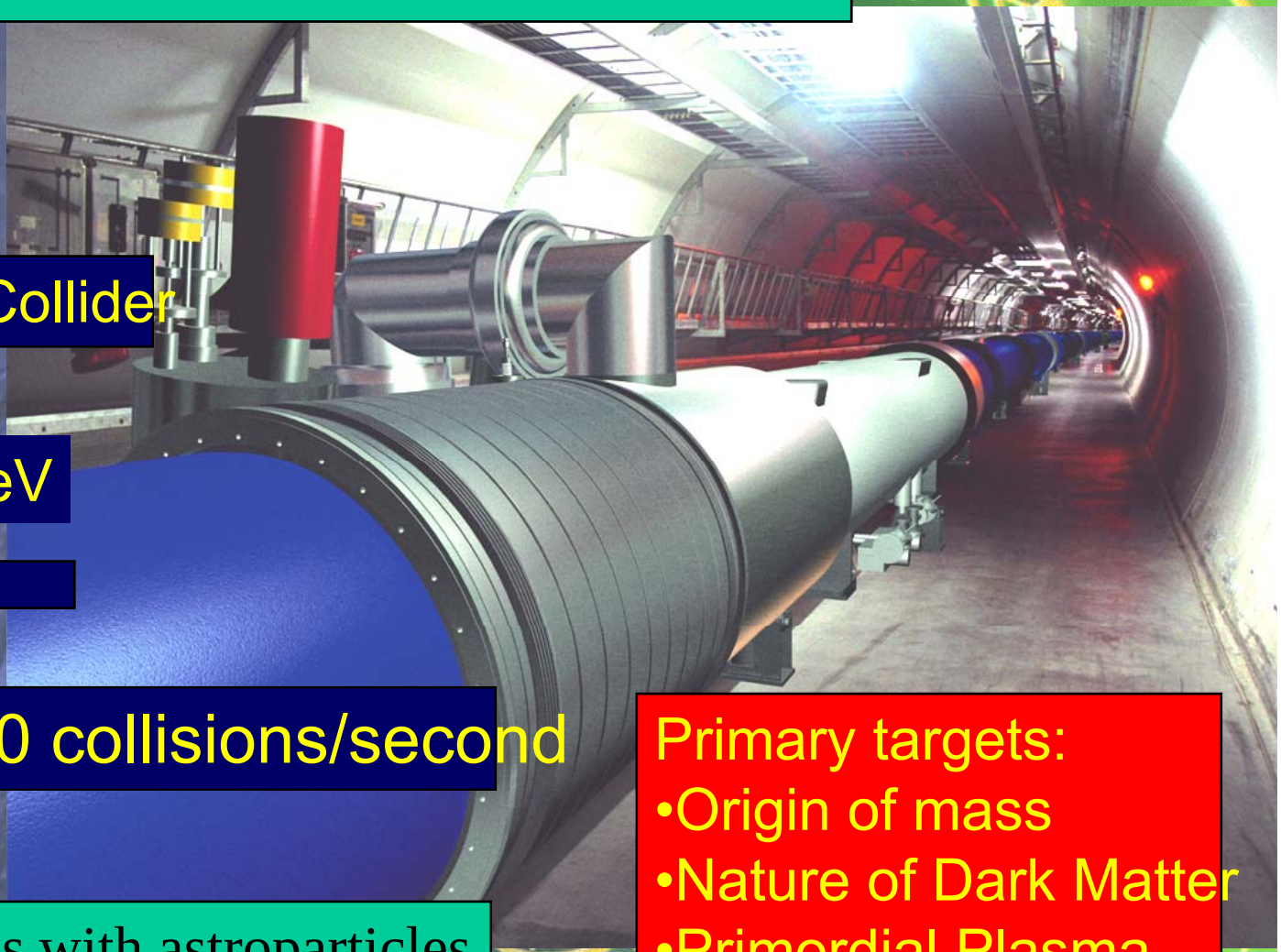
More from Discussion Document

- … Four areas of primary importance to particle physics require **strategic planning:**
  - **Proton lifetime**
  - **Nature of neutrinos**
  - **Dark matter**
  - **Dark energy**
- To ensure that Europe maintains a leading role in and promotes the progress of this important and exciting field, it is **essential that CERN Council and ApPEC coordinate their strategies**"

Present CERN Activities

- LHC experimental programme
  - Several connections with astroparticle physics
- Neutrino physics
  - CNGS, other supporting experiments (HARP, …)
- Axion experiments
  - CAST, OSQAR
- Recognized experiments
  - AMS, …
- Develop and deploy distributed Grid computing
  - Tool also for astrophysics and cosmology?

The Large Hadron Collider (LHC)



Proton- Proton Collider

7 TeV + 7 TeV

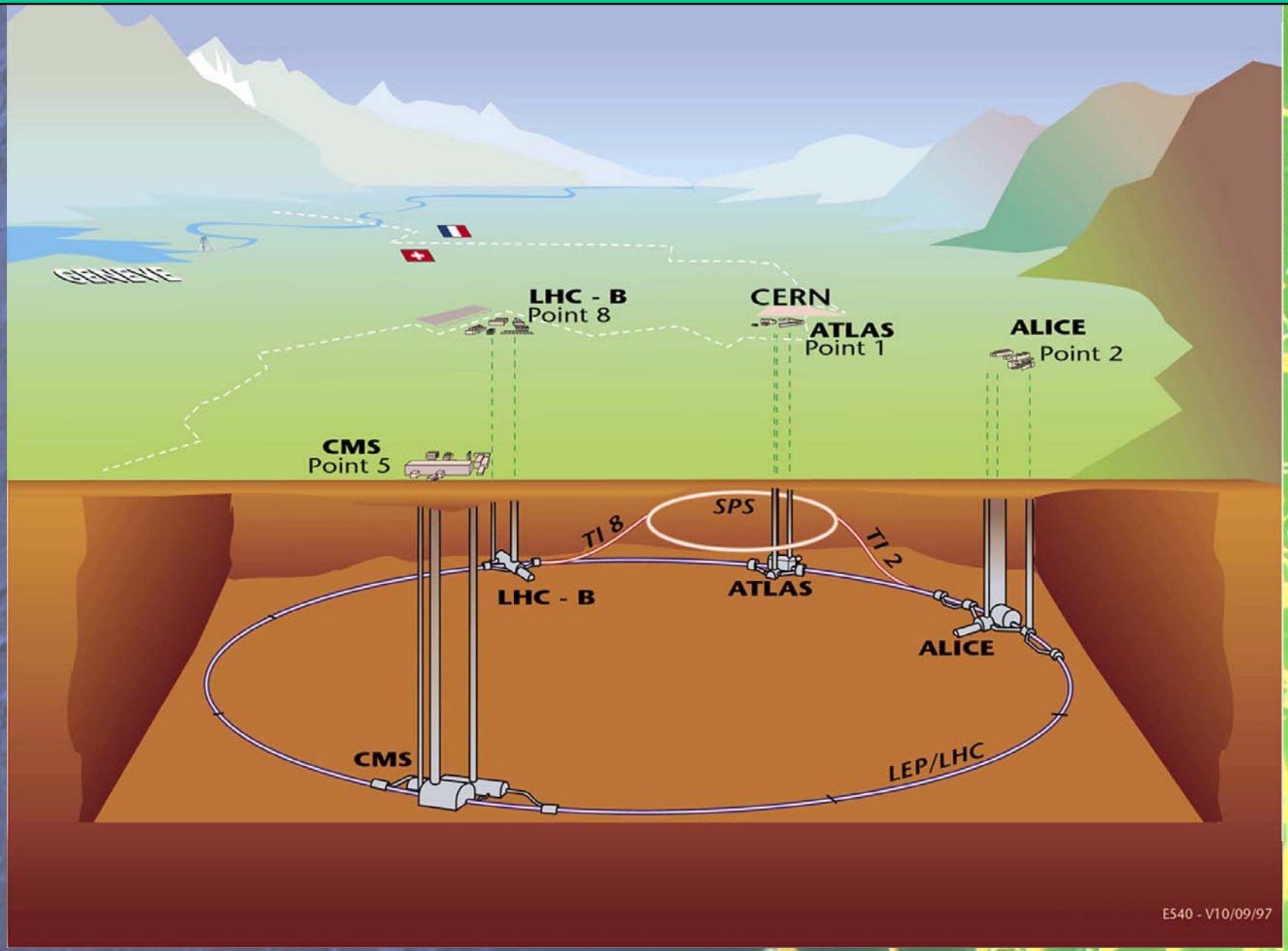
1,000,000,000 collisions/second

Many connections with astroparticles

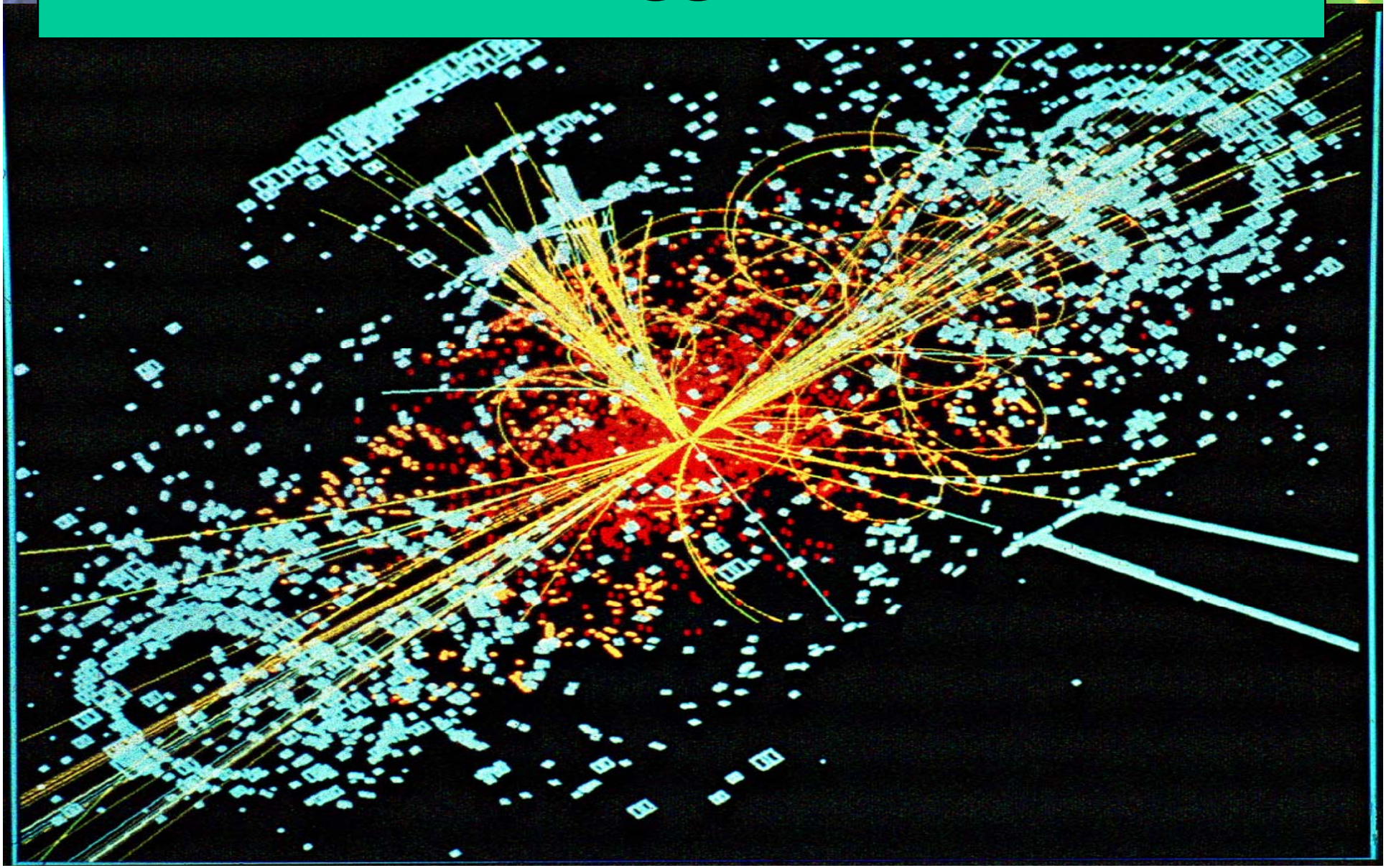
Primary targets:
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

Installation of the LHC Magnets

Overall View of the Large Hadron Collider (LHC)



A Simulated Higgs Event in CMS



The Higgs Boson and Cosmology

- Changed the state of the Universe when it was about 10^{-12} seconds old
- May have generated then the matter in the Universe: electroweak baryogenesis
- Contributes to today's dark energy
- A related inflaton might have expanded the Universe when it was about 10^{-35} seconds old

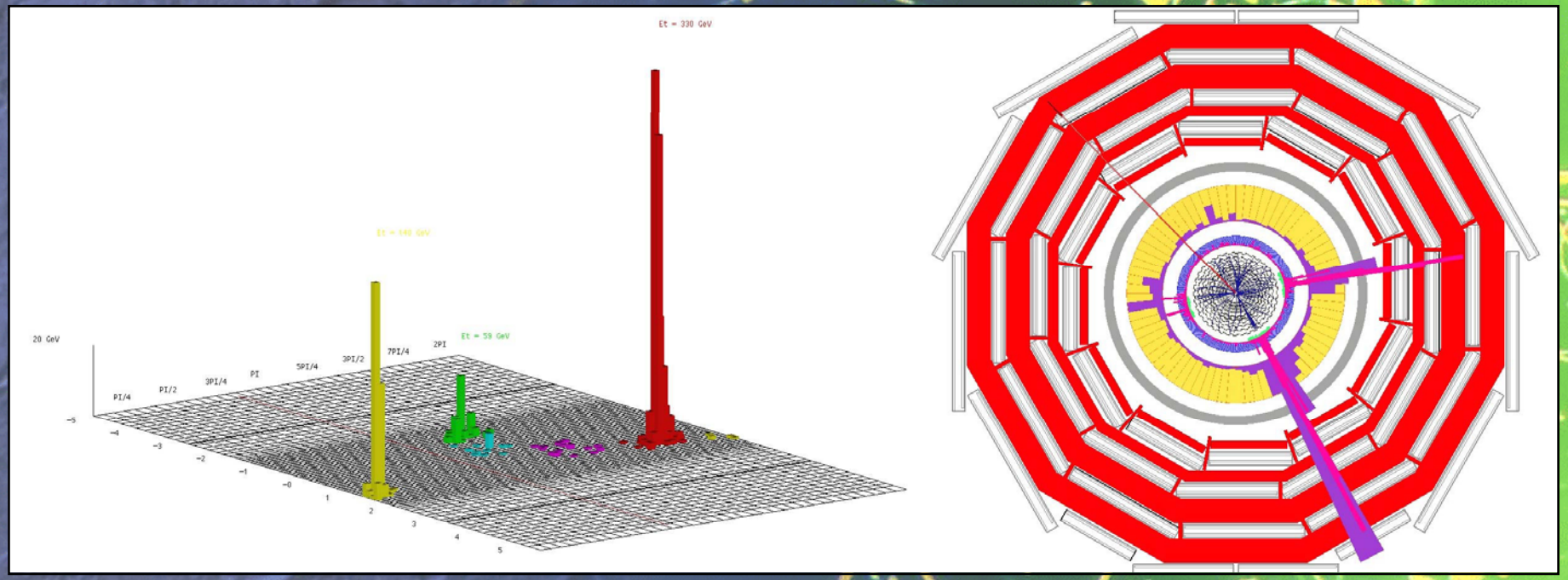
Dark Matter in the Universe

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

‘Supersymmetric’ particles ?

We shall look for them with the LHC

Supersymmetry at the LHC?



Missing transverse energy

carried away by dark matter particles

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?

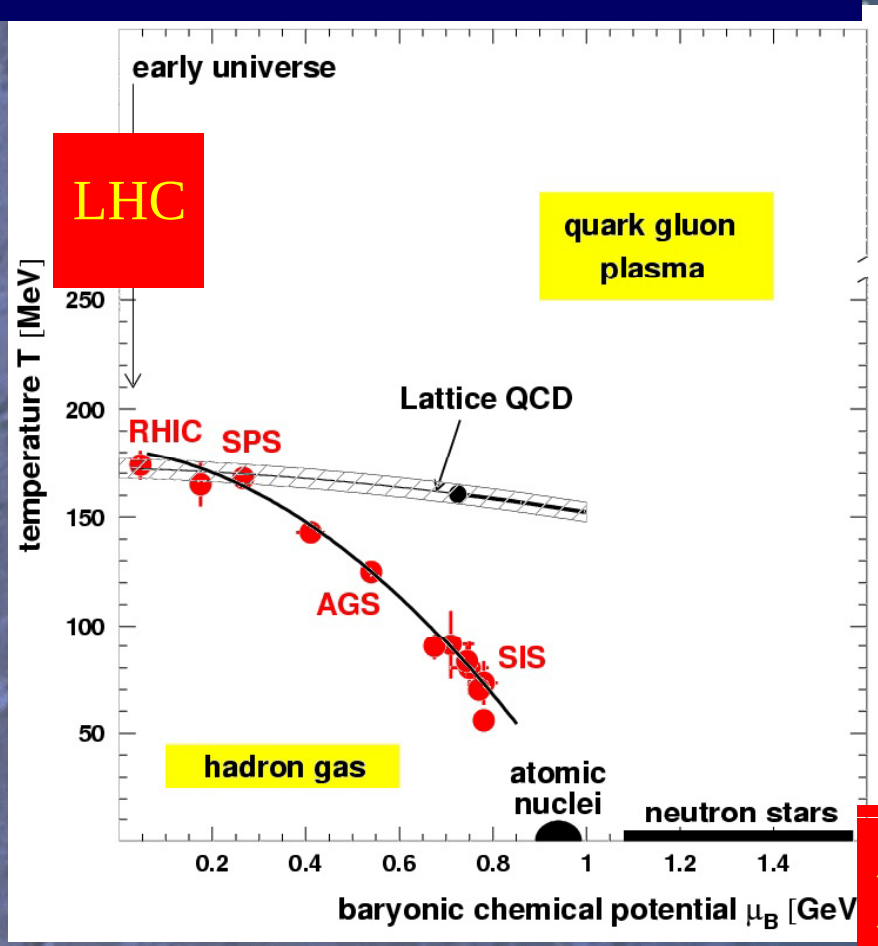
Why does the Universe mainly contain matter, not antimatter?

LHCb experiments looking for answers

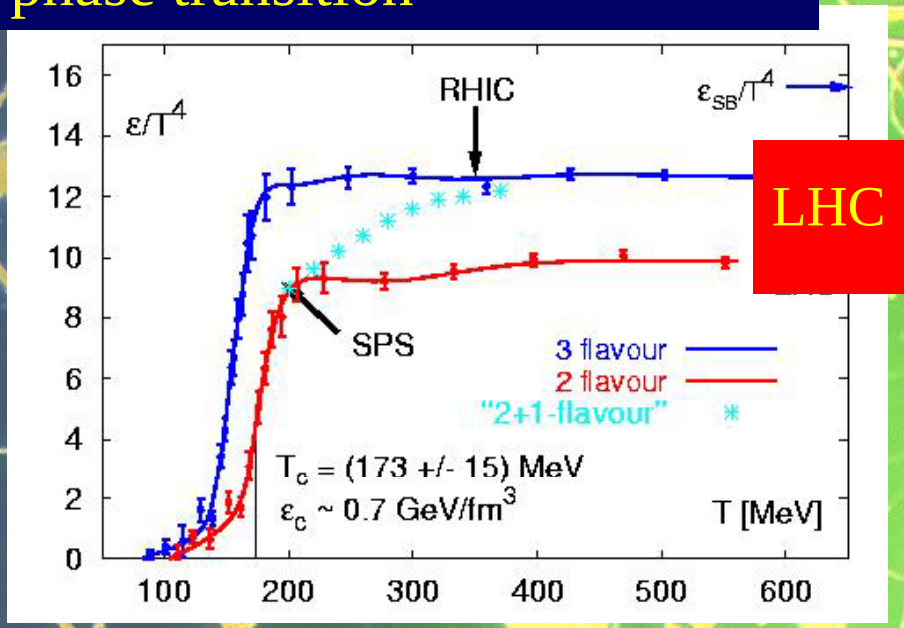
ALICE: Collide heavy nuclei at high energies to create …

Hot and Dense Hadronic Matter

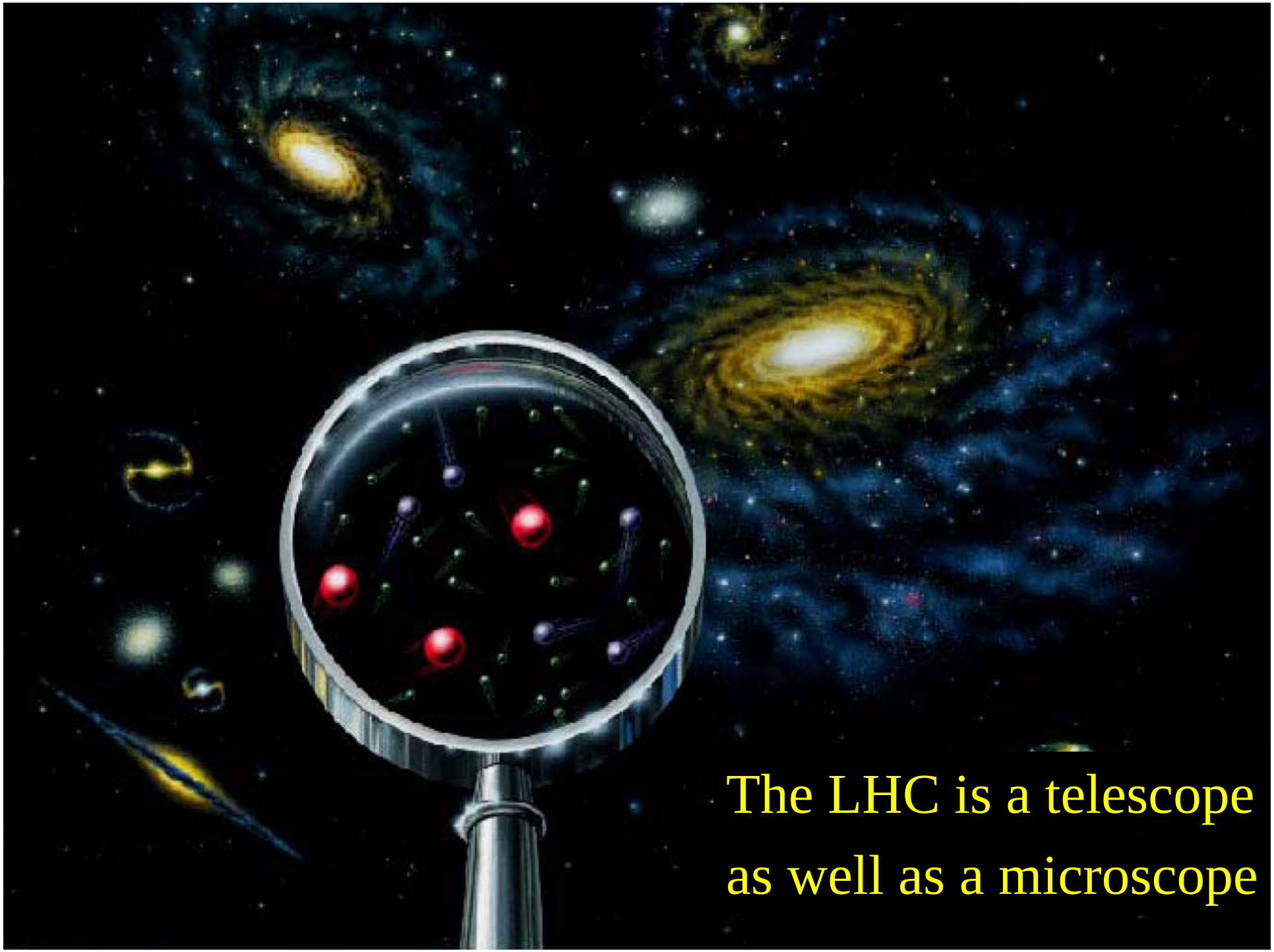
Recreate the first 10^{-6} seconds …



… and probe the quark-hadron phase transition

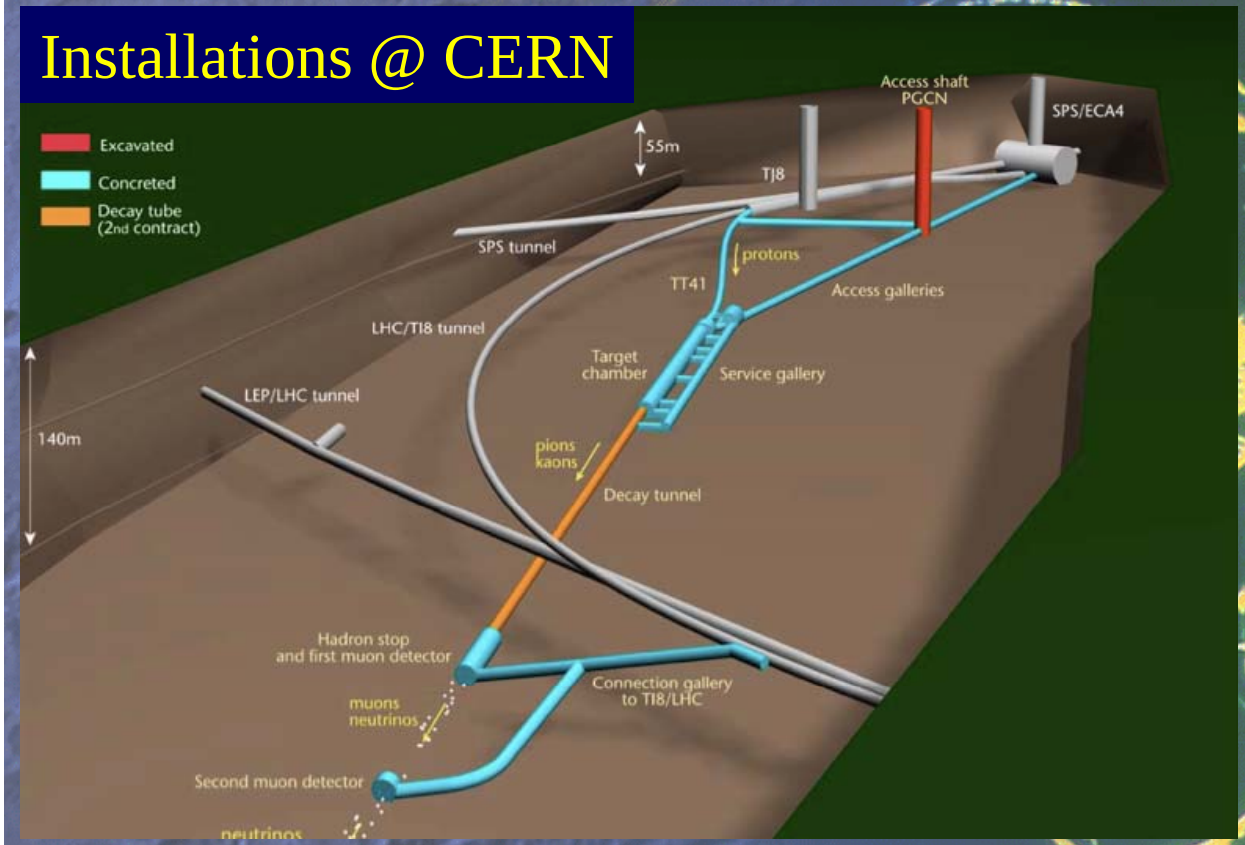


Also: LHCf studying forward physics to help model cosmic ray collisions, …


The LHC is a telescope
as well as a microscope

CNGS Neutrino Project

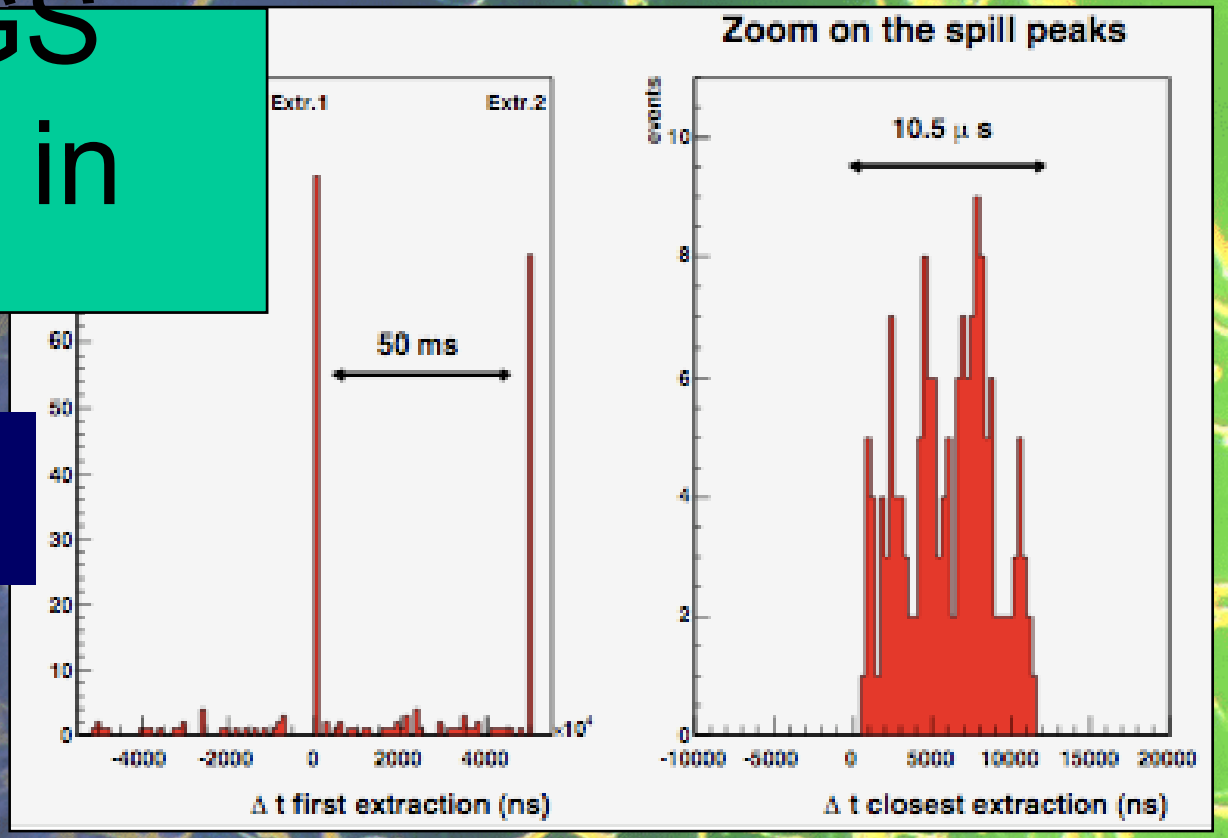
Installations @ CERN



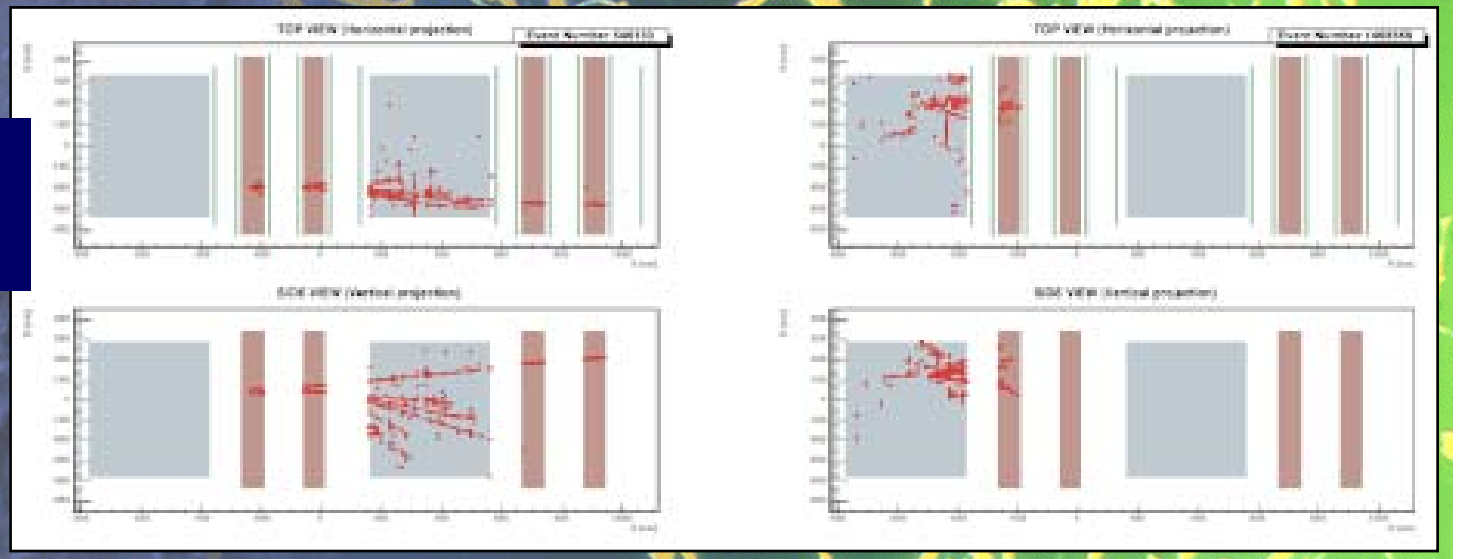
OPERA Experiment @ Gran Sasso

First CNGS Operation in 2006

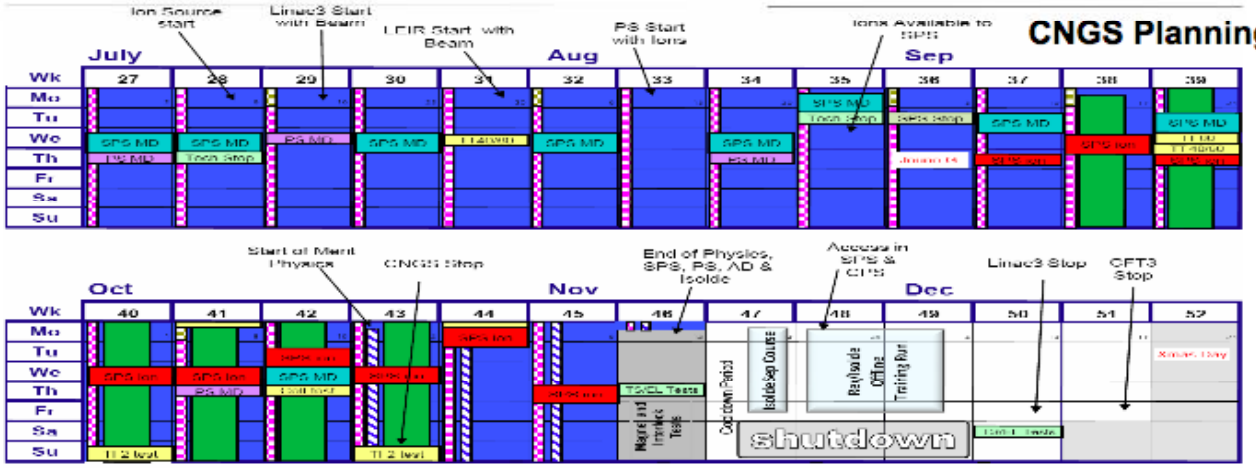
Events in coincidence with spill



OPERA event displays



CNGS Neutrino Project



Week 38: 1 SFTPRO, 1 CNGS, 1 Ion MD during day-time, In the night: possibly no CNGS

- → Final electrical tests on the horn/reflector
- → HW tests of proton beam line
- → Setting up of super cycle

Week 39: 1 SFTPRO, 1 CNGS, 1 Ion MD

- → Setting up proton beam line
- → Setting up secondary beam line

Week 40: First half: 1 SFTPRO, 1 CNGS, 1 Ion MD,
Second half: 1 SFTPRO (long), 3 CNGS, 1 Ion MD

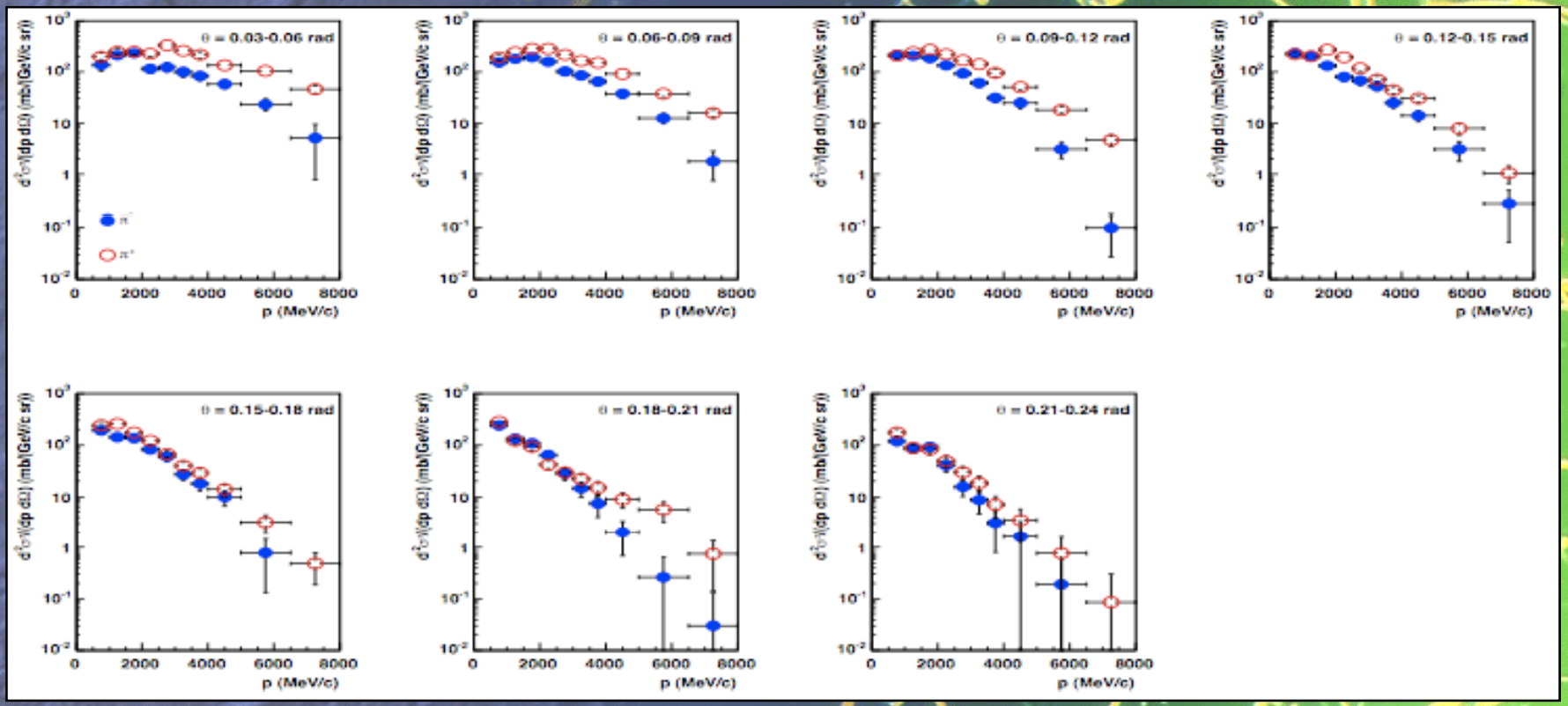
- → Setting up secondary beam line

Week 41-43: 1 SFTPRO (long), 3 CNGS, 1 Ion MD

- → CNGS physics run

Commissioning and physics starting this week

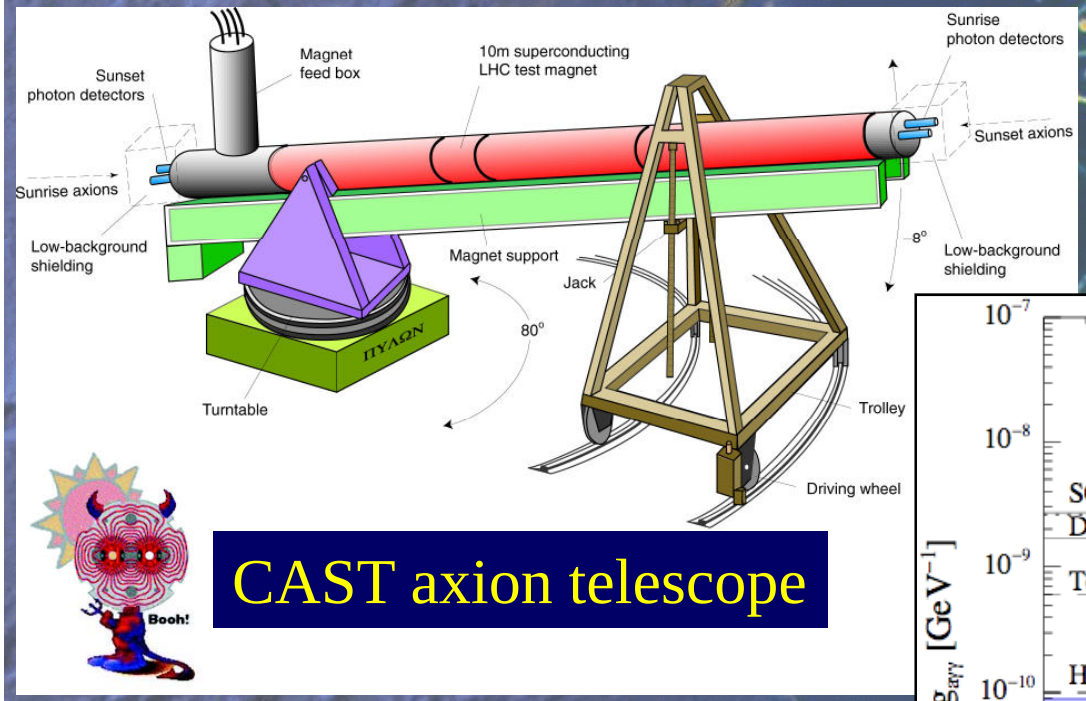
HARP Experiment



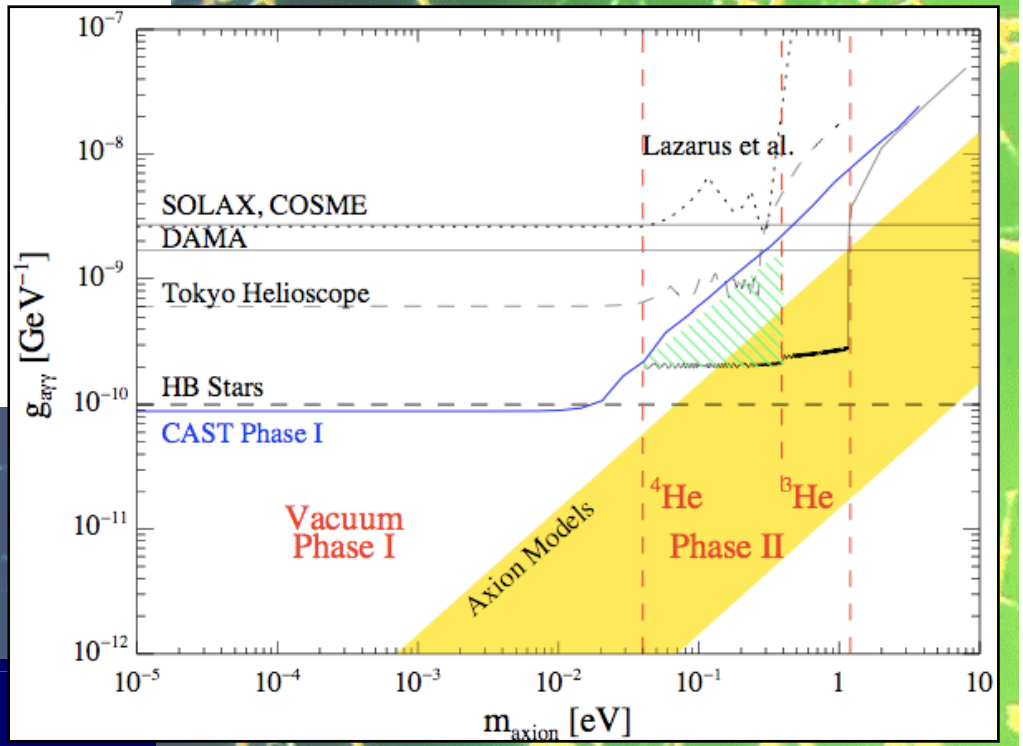
Particle production measurements to provide better flux estimates for:

- accelerator neutrino experiments
- atmospheric neutrino experiments
- neutrino factory design

CAST Search for Solar Axions



CAST axion telescope



Present limit and
Prospective future sensitivity

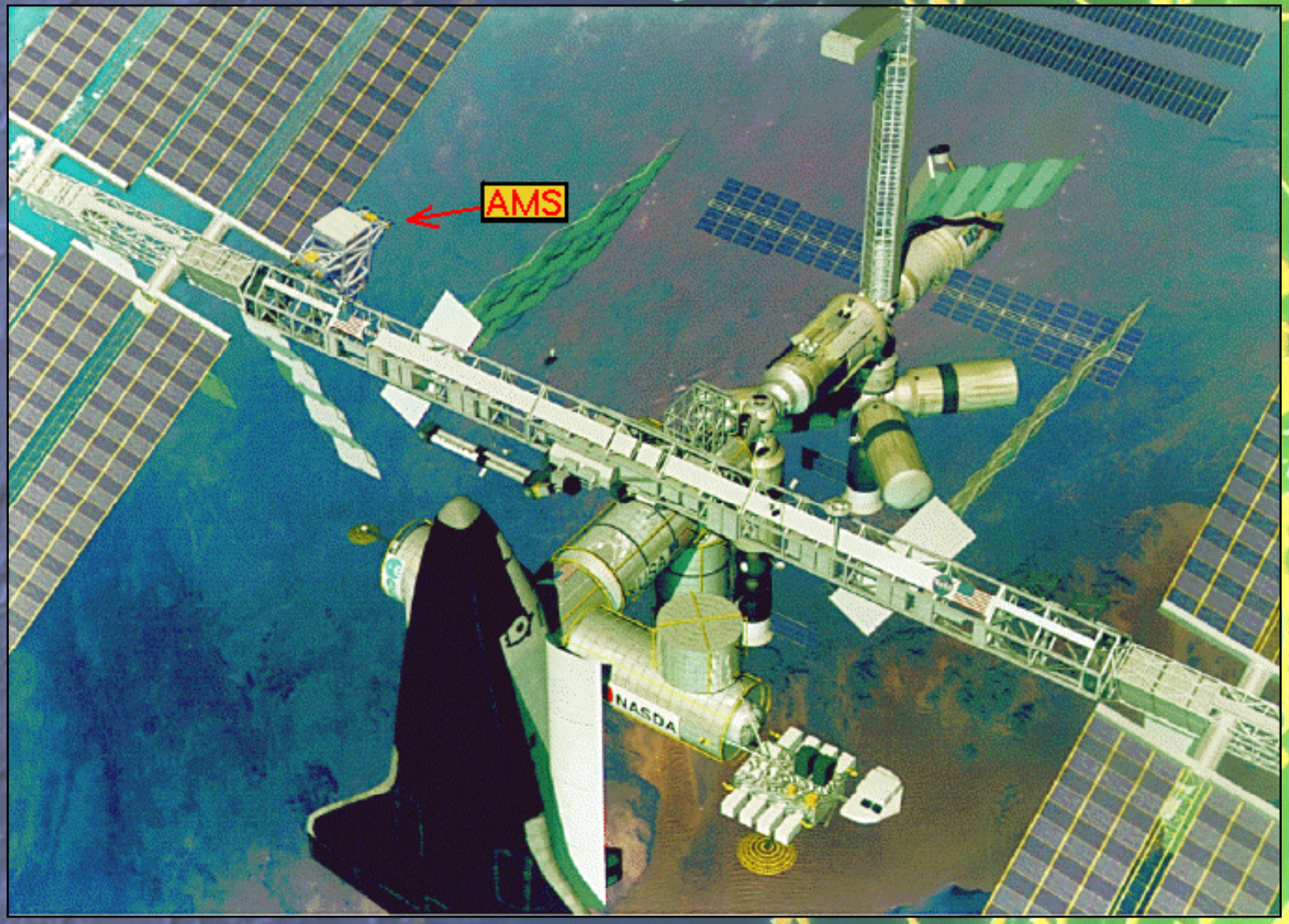
Recognized Experiments:
use CERN facilities, not accelerators

- Search for antimatter in space:
  space station, satellites
- Underwater/ice experiments looking for neutrinos:
  in Mediterranean sea
- Ultra-high-energy cosmic and gamma rays
  in Argentina, space
- Gravitational waves
  at CERN, in space
- Experiments at other accelerators

List of Recognized Experiments

RE1	Alpha Magnetic Spectrometer (AMS) on the International Space Station
RE3	The Pierre Auger Observatory Project
RE5	The Gravitational Wave Detector EXPLORER
RE6	ANTARES: An Undersea Neutrino telescope
RE7	GLAST
RE8	LISA
RE9	NESTOR
RE10	IceCube
RE11	MICE: Muon Ionization Cooling Experiment
RE12	MEG: search for $\mu \, e\gamma$ decay at PSI
RE13	T2K: Neutrino Oscillation Experiment at JHF
RE14	KATRIN: Tritium beta-decay experiment
RE15	WARP: Search for cold dark matter
RE2A	CAPRICE: Cosmic AntiParticle Ring Imaging Cerenkov Experiment
RE2B	PAMELA: Search for Antimatter in Space

Planned Location of AMS

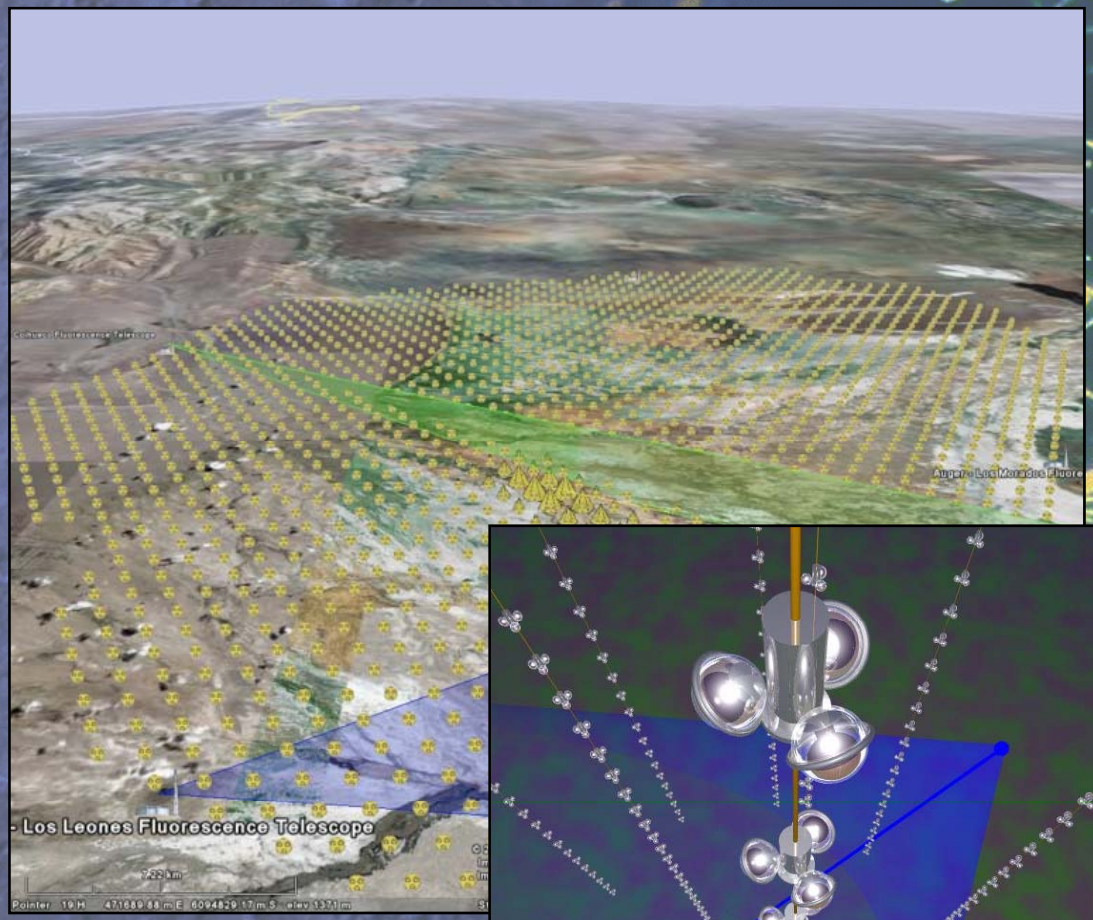


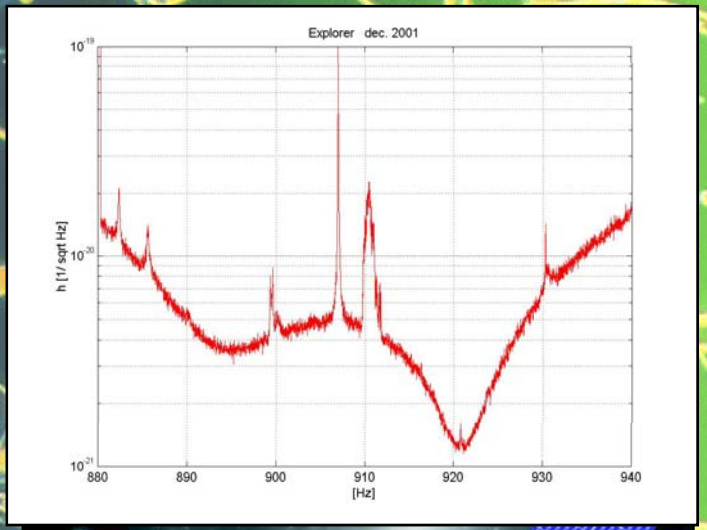
AMS @ CERN

- Prototype for recognized experiments
- Memorandum of Understanding:
  - Office space
  - Computing facilities
  - Clean room: 700 m^2, investment ~ 2.5 MCHF
    - Could be used by other astroparticle, CERN experiments?
  - Science operations centre
  - Payload operations control centre
- No CERN staff, ~ 100 KCHF in logistical support

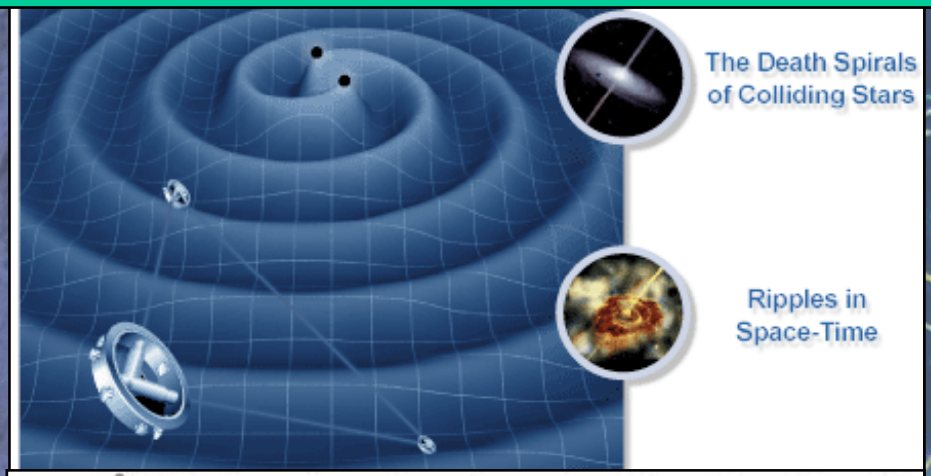
AMS @ CERN

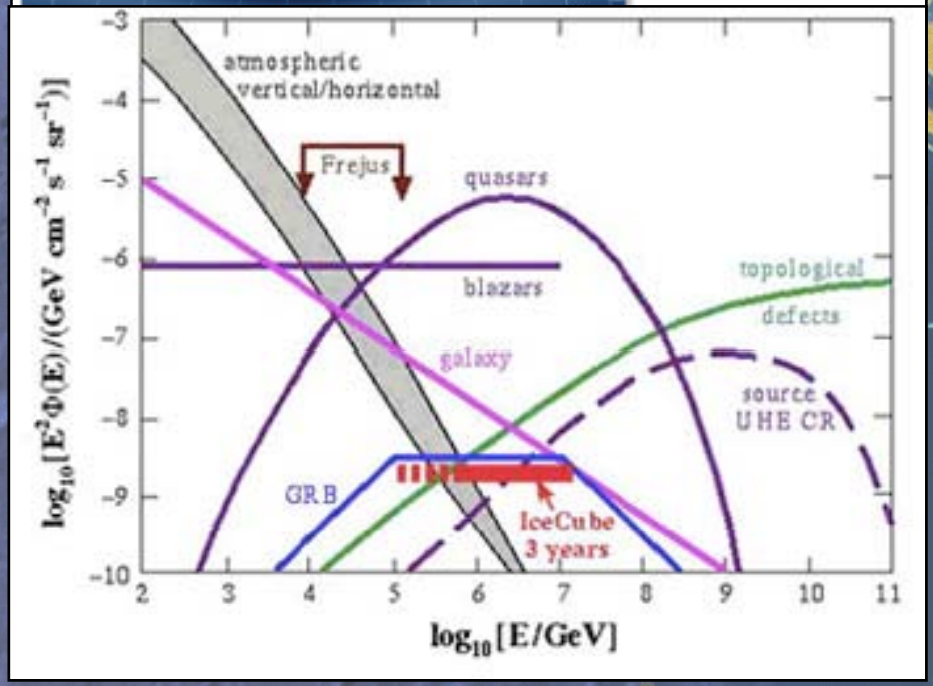
Auger, Explorer, ANTARES, GLAST, ...

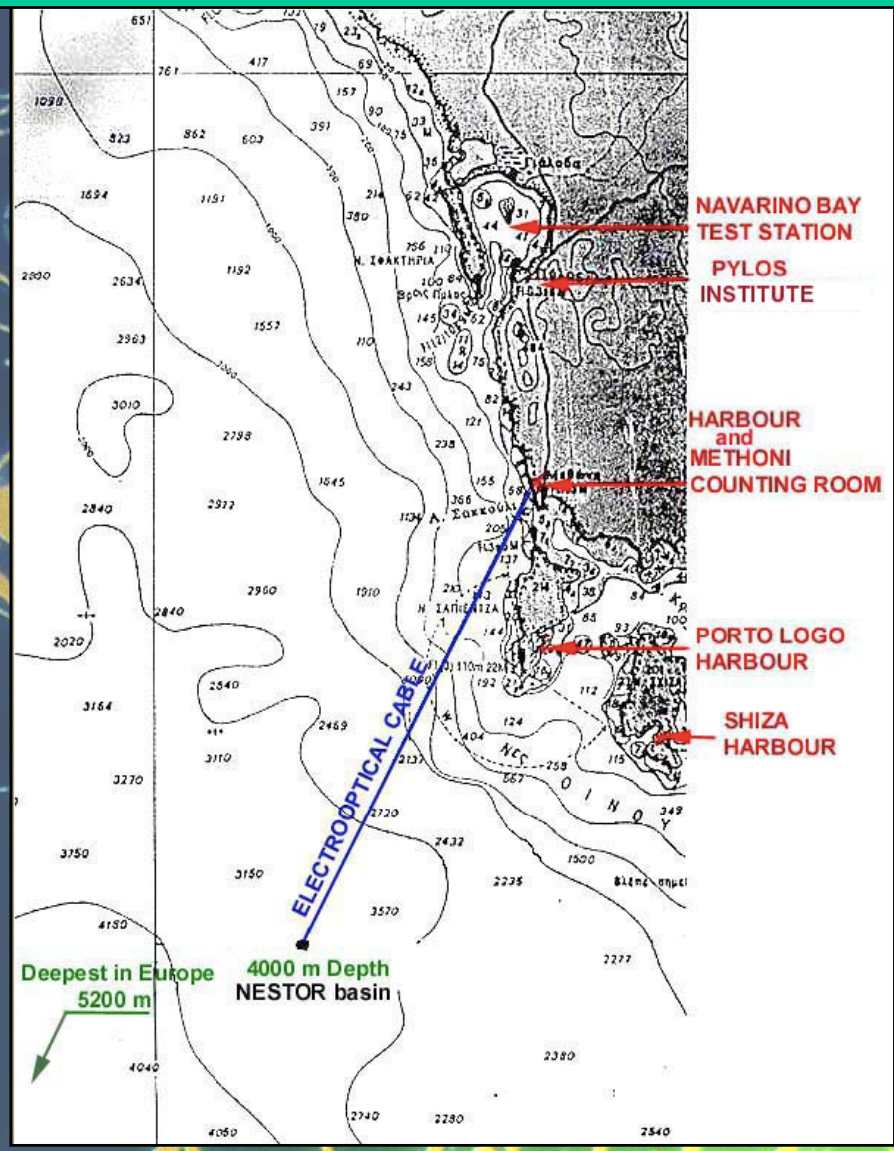




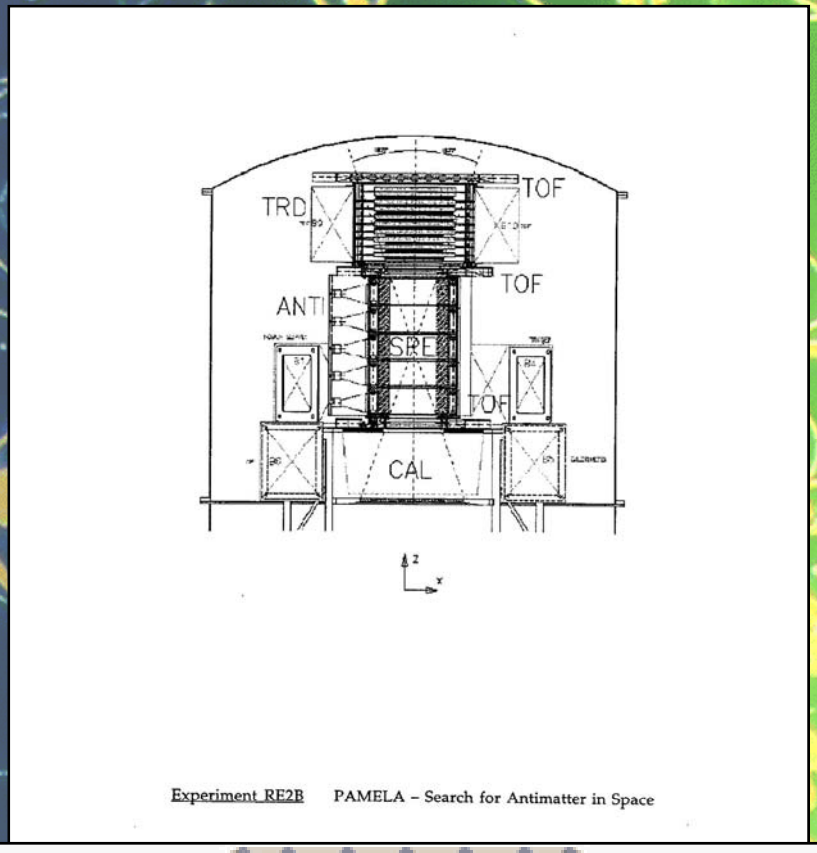
LISA, NESTOR, IceCube, MICE, …

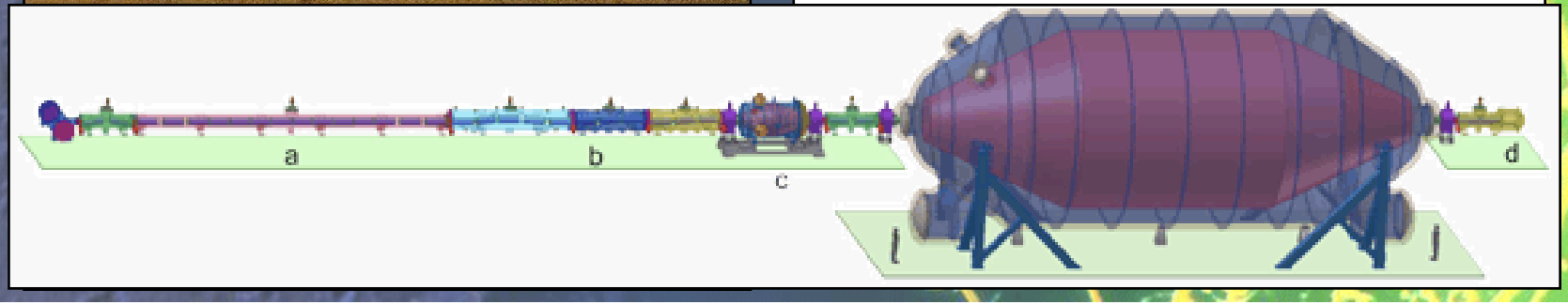






KATRIN, WARP, CAPRICE, PAMELA





EGEE Grid Project hosted by CERN

About 20 applications from > 10 domains on EGEE Grid infrastructure

- **Astronomy & Astrophysics - MAGIC, Planck**
- Computational Chemistry
- Earth Sciences - Earth Observation, Solid Earth Physics, Hydrology, Climate
- Fusion
- High Energy Physics
- Life Sciences - Bioinformatics (Drug Discovery, GPS@, Xmipp_MLrefine, etc.)
- Condensed Matter Physics
- Computational Fluid Dynamics
- Computer Science/Tools
- Civil Protection
- Finance (through the Industry Task Force)

Summary

- Astroparticle physics is not CERN's core business
- Many close connections with accelerator physics:
  - LHC programme, neutrinos, …
- CERN is happy to host non-accelerator exp'ts
- Personally, would welcome more scientific contacts

Astroparticle Users of EGEE

Astrophysics Applications

The **MAGIC** application simulates the behaviour of air showers in the atmosphere, originated by high energetic primary cosmic rays. These simulations are needed to analyse the data of the MAGIC telescope, located in the Canary Islands, to study the origin and the properties of high energy gamma rays. The first data challenge started on the EGEE infrastructure in March 2005.

The ESA **Planck** mission aims to map the microwave sky, performing at least two complete sky surveys with an unprecedented combination of sky and frequency coverage, accuracy, stability and sensitivity. The satellite will be launched in 2007 carrying a payload composed of a number of microwave and sub-millimetre detectors which are grouped into a high frequency instrument (HFI) and a low frequency instrument (LFI) covering frequency channels ranging from 30 up to 900 GHz.

The DataGRID Project

www.cern.ch/grid

EU contract signed by all 21 partners for about 10 millions Euros of EU funding

Project to start early 2001

Flagship project of the EU IST GRID programme

Potential important role with IST CPA and RN EU calls for proposal in 2001

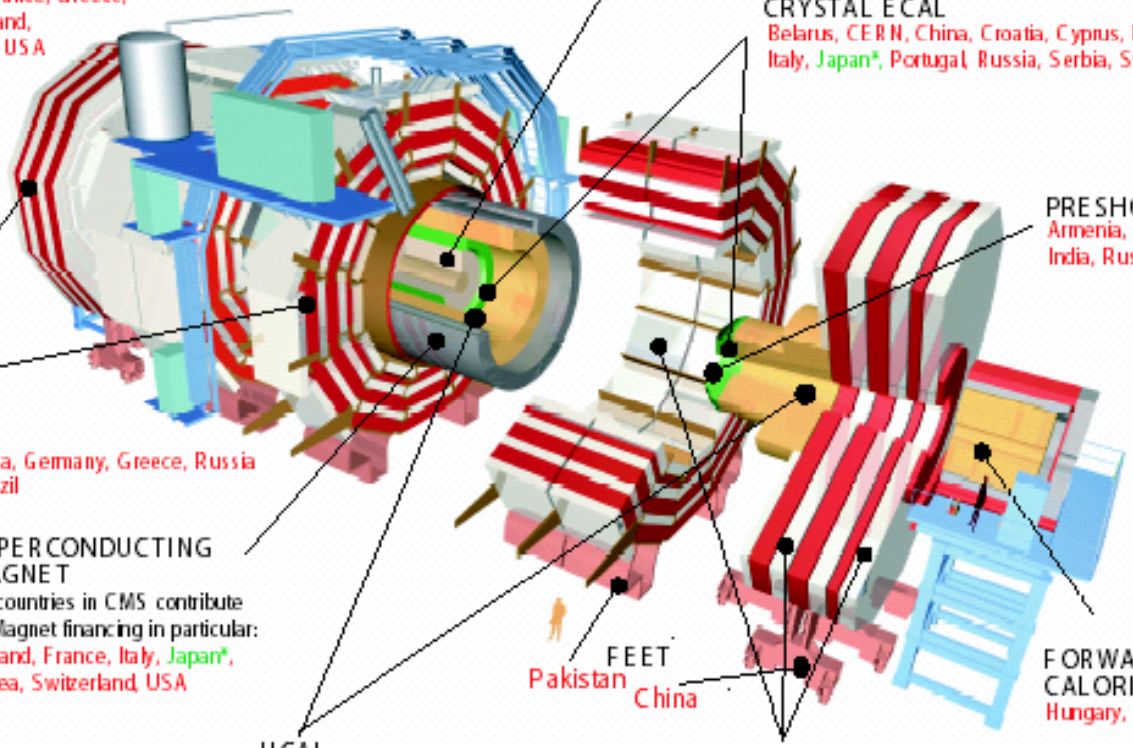
Big Bang ↔ Little Bangs

- The matter content of the Universe
  - Dark matter
  - Dark energy
  - Origin of matter
- Experiments at particle colliders
  - Early Universe
  - Supersymmetry
  - Matter-antimattter asymmetry

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

CMS Experiment

36 Nations, 160 Institutions, 2008 Scientists and Engineers (November 2003)



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

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

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

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

FEET
Pakistan
China

FORWARD CALORIMETER
Hungary, Iran, Russia, Turkey, USA

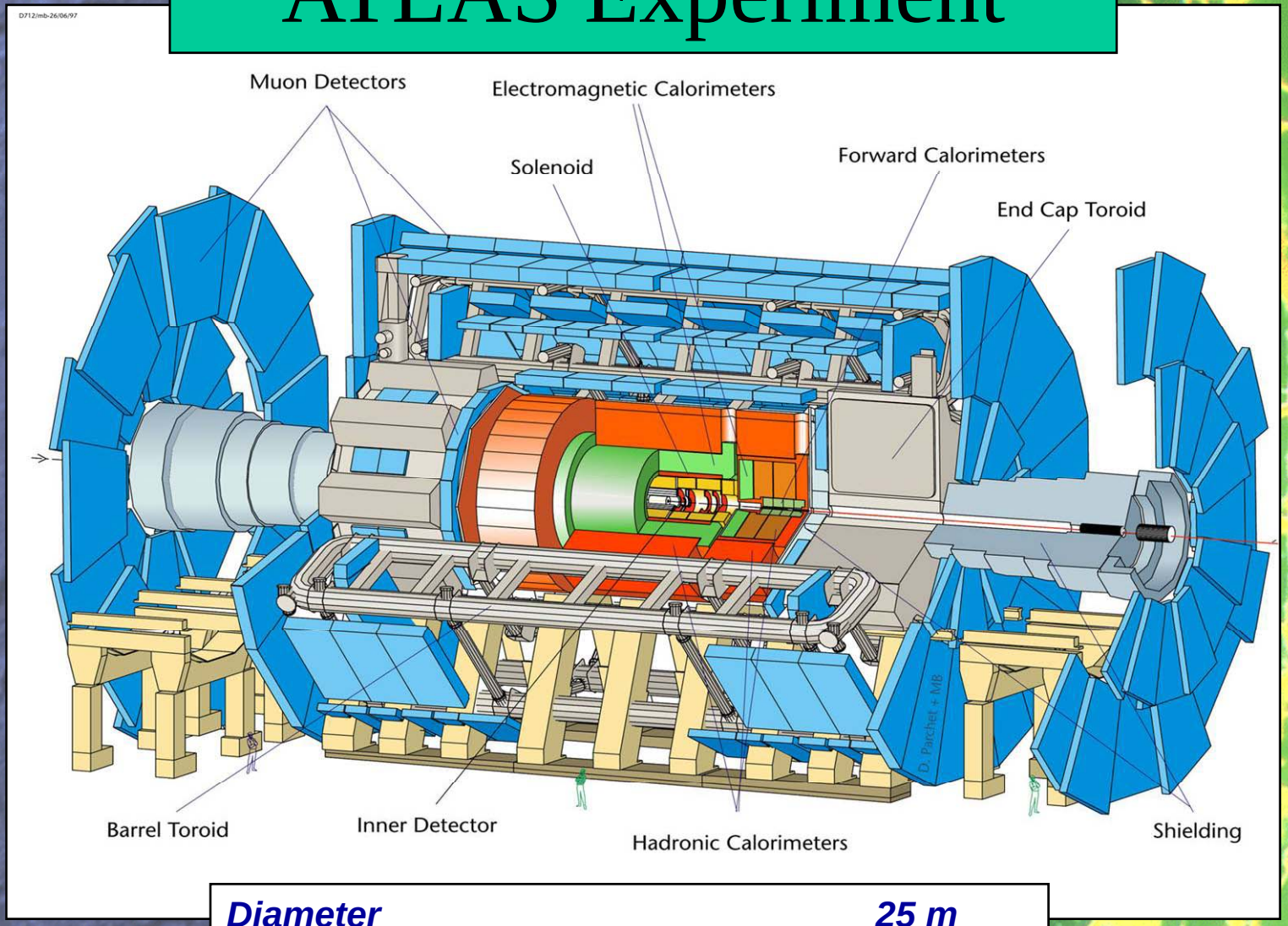
HCAL
Barrel: Bulgaria, India, Spain*, USA
Endcap: Belarus, Bulgaria, Russia, Ukraine
HO: India

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

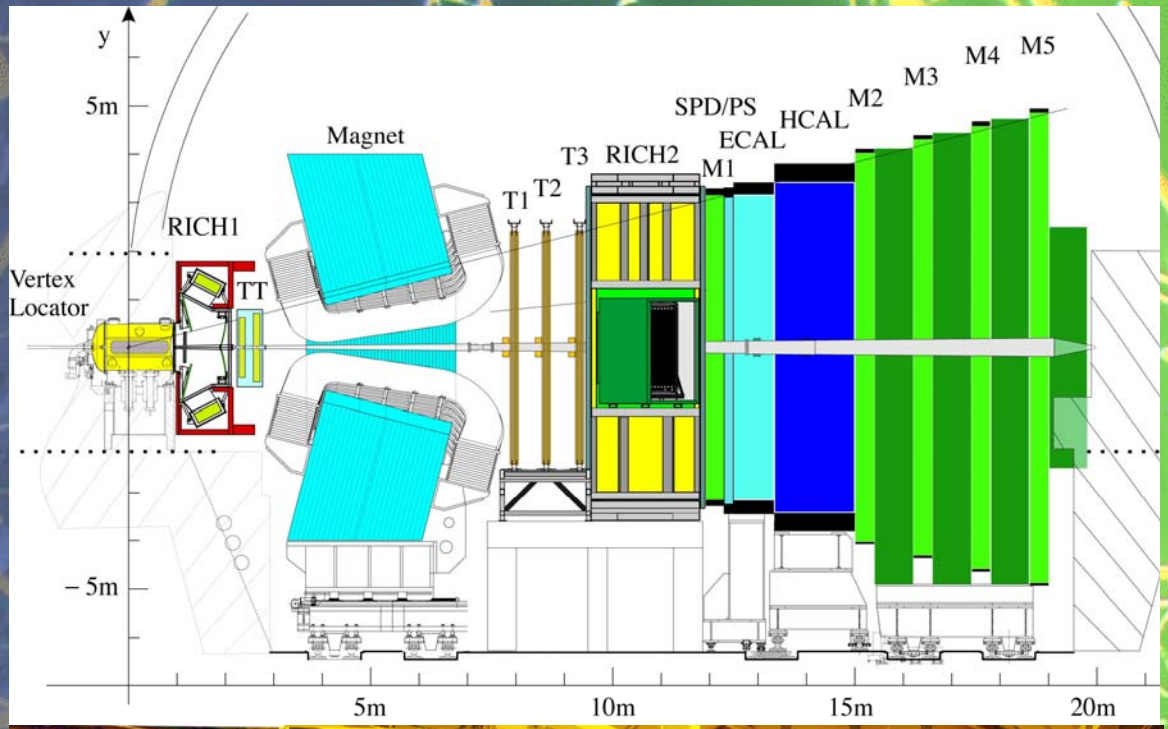
* Only through industrial contracts

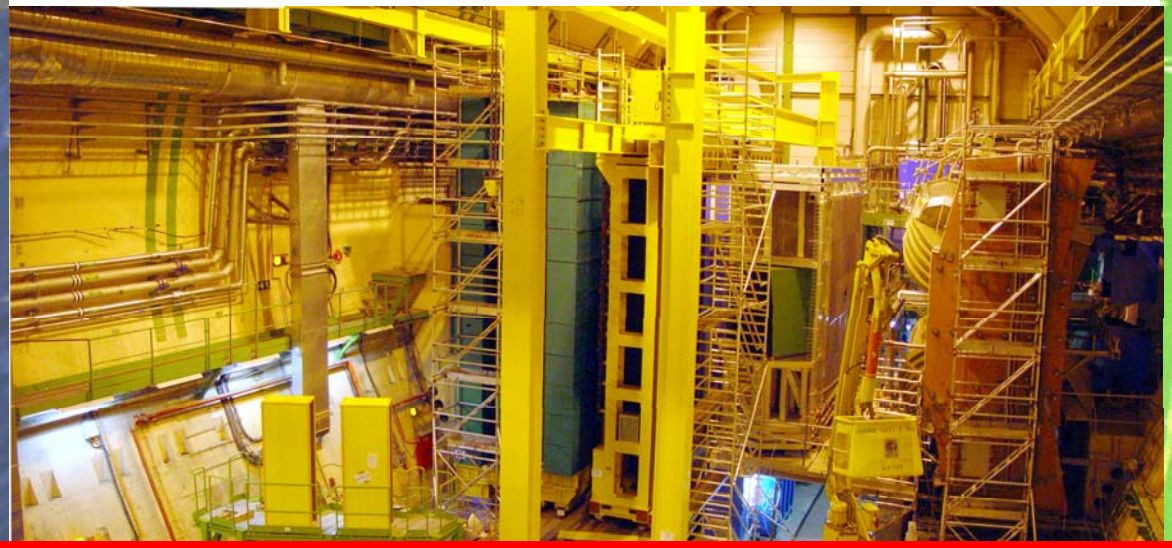
ATLAS Experiment



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

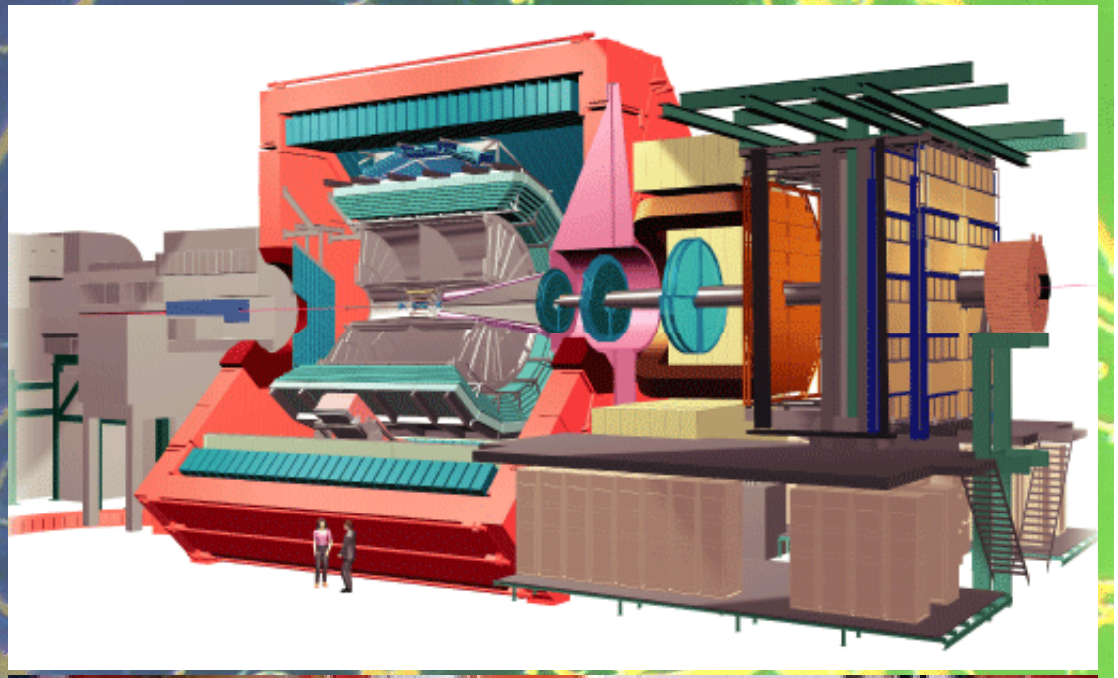
LHCb: Dedicated to B Physics

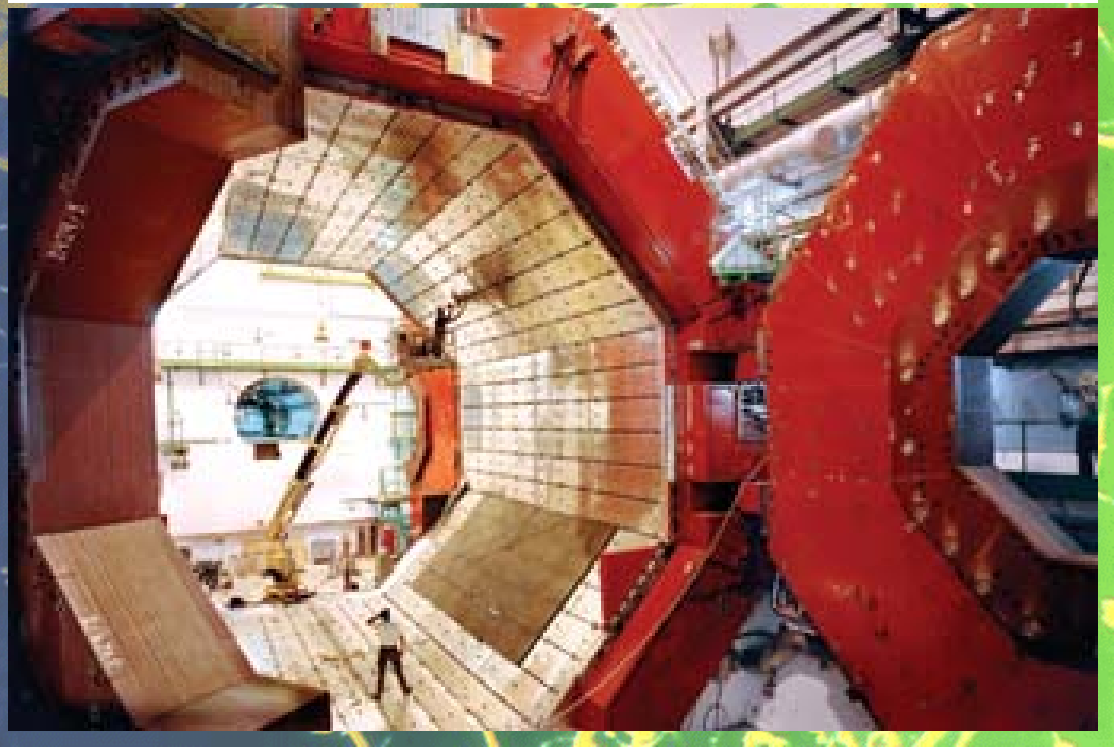




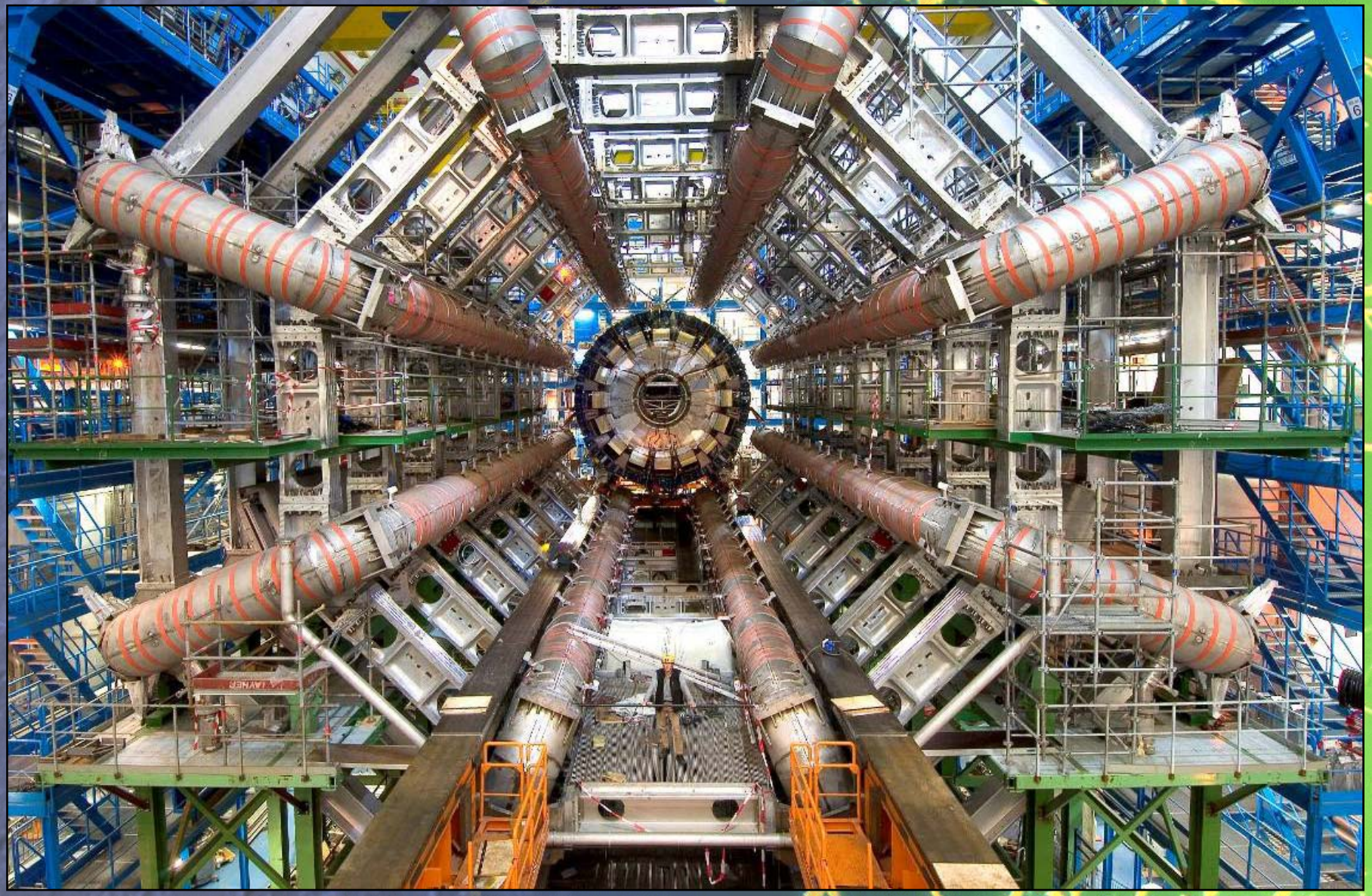
Study matter antimatter asymmetry

ALICE: Dedicated to Heavy-Ion Collisions

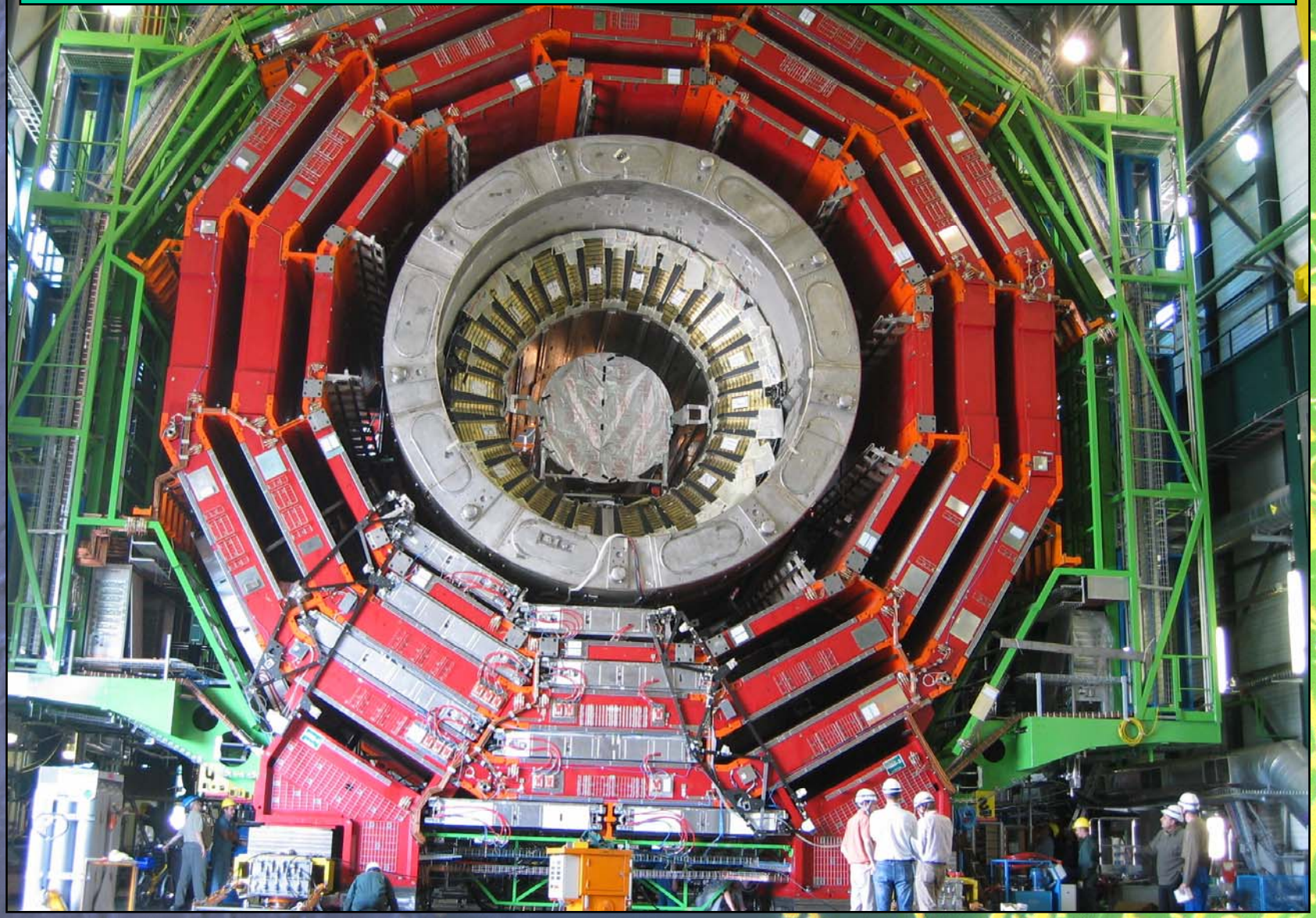




The ATLAS Cavern

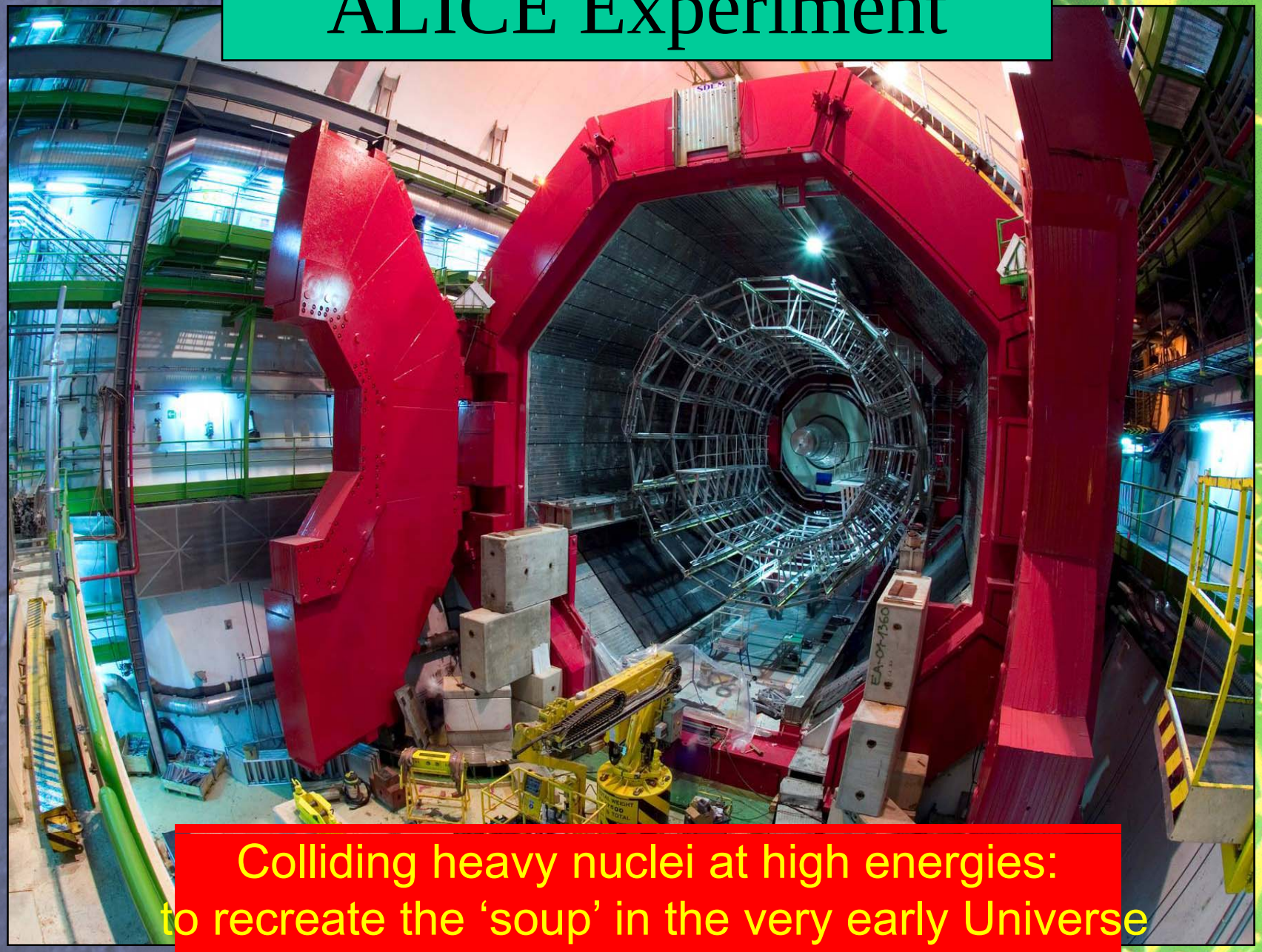


CMS Experiment



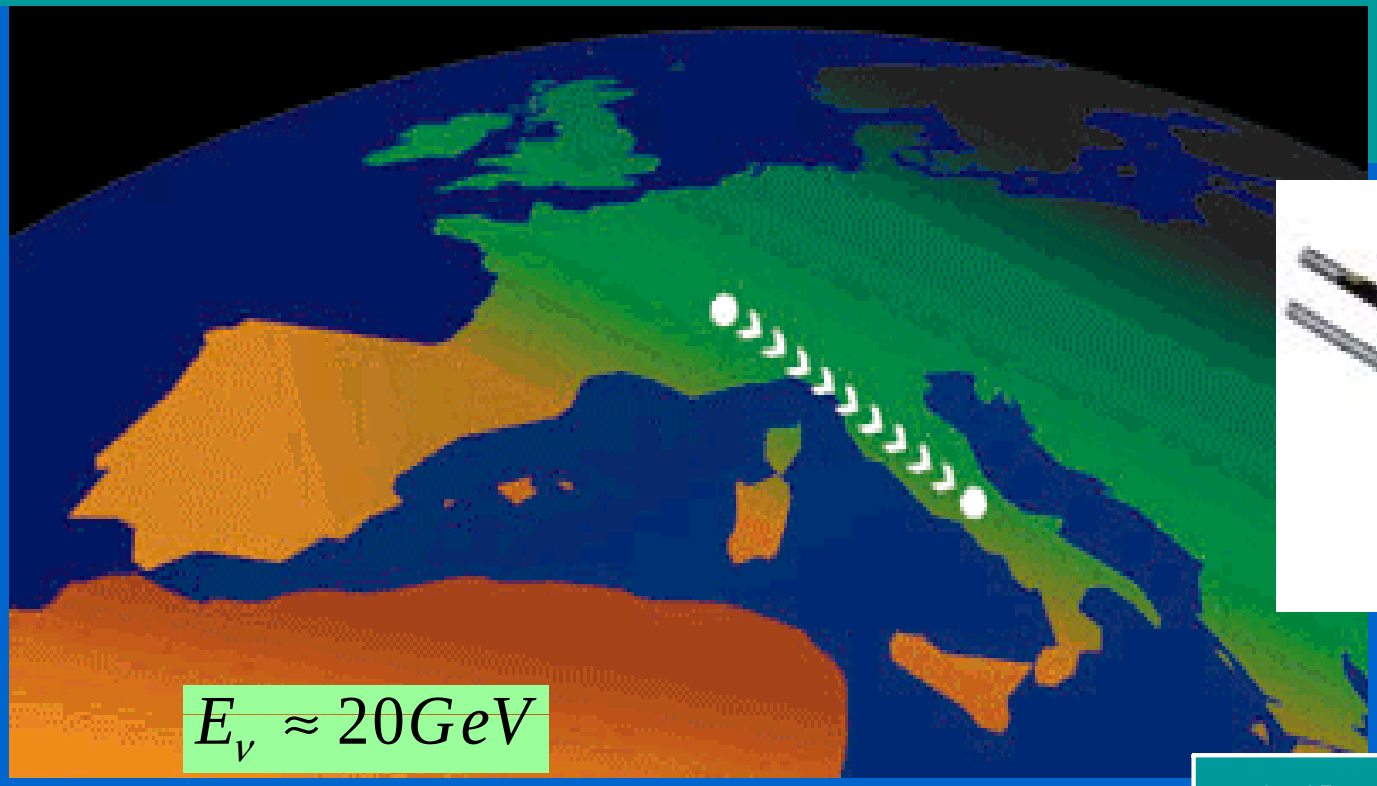
The LHCb Experiment:
will explore Matter and Antimatter

ALICE Experiment

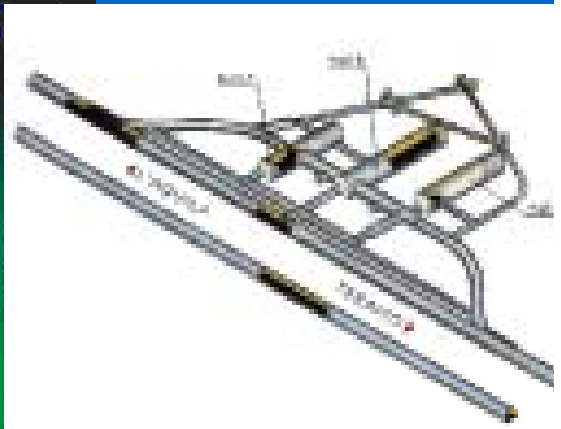


Colliding heavy nuclei at high energies:
to recreate the ‘soup’ in the very early Universe

CERN neutrino beam to Gran Sasso



$E_\nu \approx 20 GeV$



optimized for
τ detection

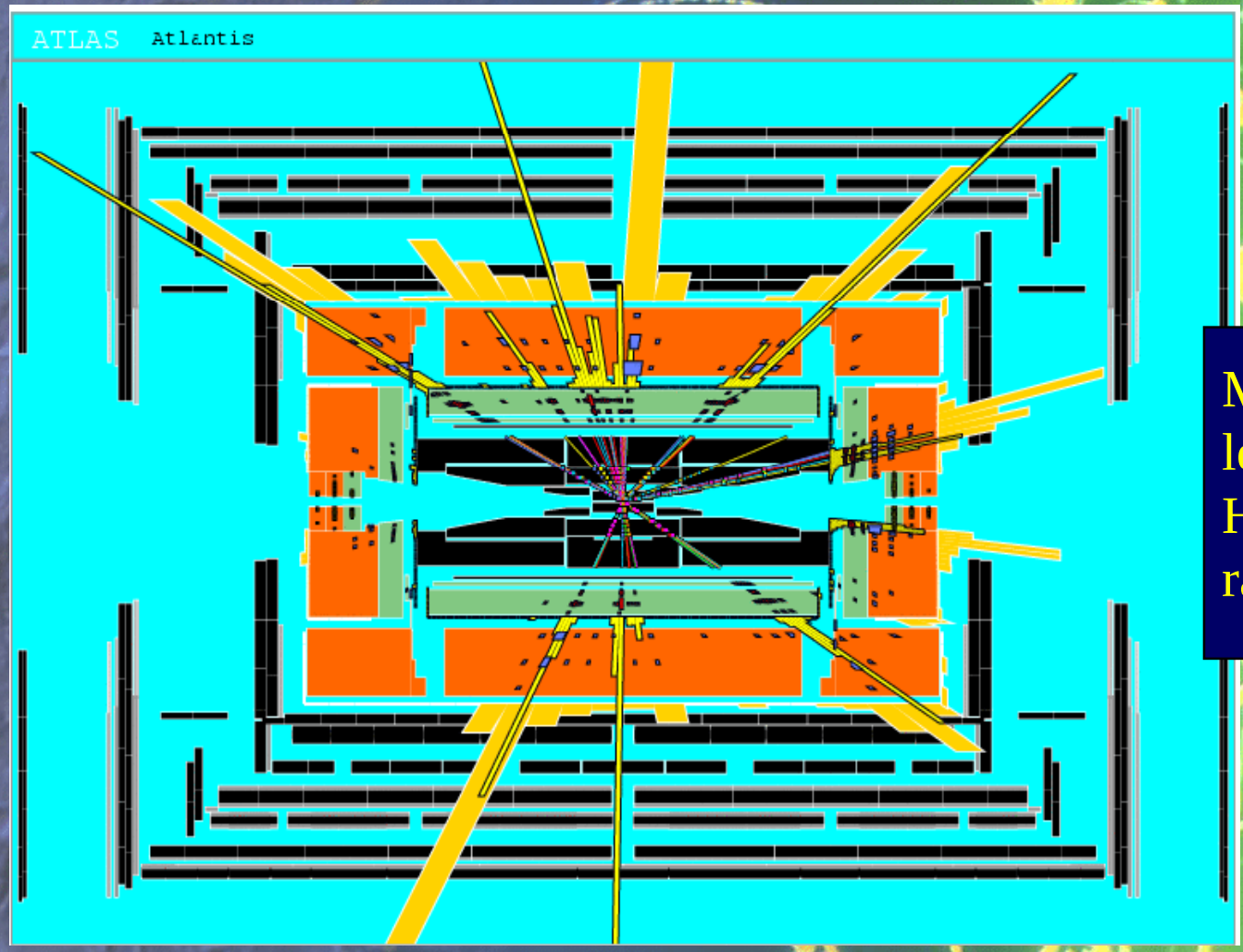
Commissioning:
Spring 2005

Civil works committed in spring 2000

Experimental proposals
OPERA approved Jan 2001

Testing quantum gravity - if gravity becomes strong at the TeV scale …

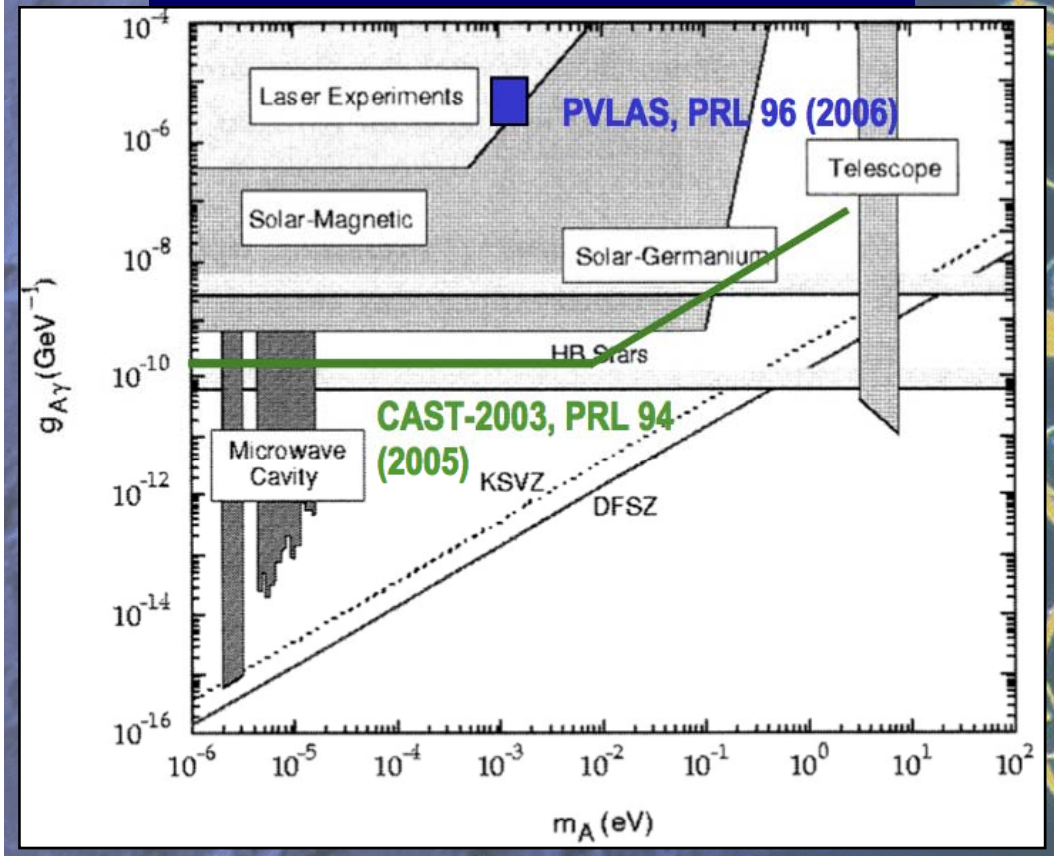
Black Hole Production at LHC?



Multiple jets, leptons from Hawking radiation

OSQAR: Follow-up to PVLAS

PVLAS sensitivity vs others



Prospective future sensitivity