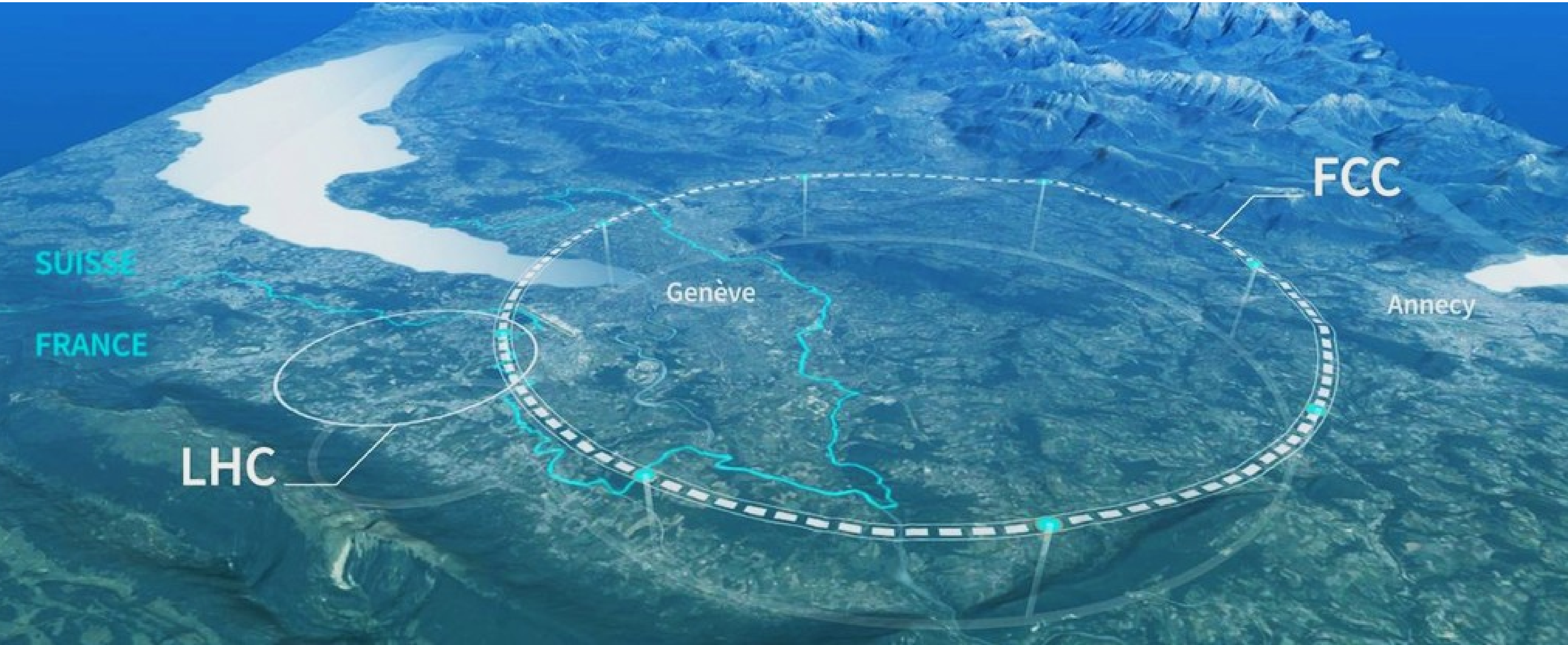
8.FCC - January Research Projects on
the Future Circular Collider (FCC-ee)

Introductory Lecture
[January 6, 2025]



Lecture Outline

Introduction of Course Personnel

Objective of the research projects

Organization of the Lectures

- Prerequisites
- Schedule: lectures and tutorials
- Final Conference and beyond

Course Content Overview

Overview of physics and projects

Personnel

Lecturers

- Christoph Paus, Eluned Smith

Tutorials and hands-on help

- Anja Beck, Jan Eysermans, Dolores Garcia, David Walter

Support

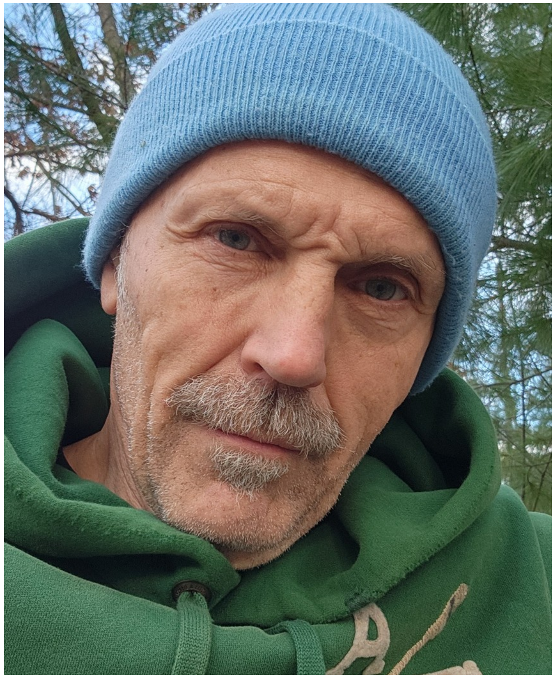
- Luca Lavezzo, Pietro Lugato, Kevin Yoon

Please all introduce yourselves!

The Lecturer, today

Christoph Paus

- physics career
  - started PhD 1992 at L3 (e^+e^-, LEP, CERN)
  - in 1998 moved to CDF ($p\bar{p}$, TeVatron, FNAL)
  - since 2006 mostly CMS (pp, LHC, CERN)
  - started seriously on FCC in 2021



- physics measurements
  - precision electroweak (*Z* boson mass & width, EWK parameters)
  - *B* physics directly related to CKM matrix (Standard Model)
  - Standard Model Higgs boson observation and properties
  - Long series of various Dark Matter searches
  - Searches for: Contact interactions, magnetic monopoles, pentaquarks, excited onia, rare decays

Objective of this Research Experience

Course focus

- introduce experimental methods
- perform typical measurements at the FCC-ee using simulated data

Not the purpose of this course

- provide fully fledge theoretical background
  - quantum field theory courses good for that
  - also nuclear and particle physics standard graduate courses
- provide in depth discussion of how detectors work
  - nuclear and particle physics standard graduate courses
  - maybe specialized course for detector design and construction

Goal in practical terms

- learn how to do research as an experimentalist at the FCC-ee
- be prepared to go to CERN and start an analysis in the summer
- .. or at least know how experimentalists work in High Energy Physics

Organization

Prerequisites

- Basic Physic classes AP level
- Nice to have: special relativity, quantum physics
- Stretch: have heard particle physics 1+2 but not needed

Dates

- Schedule has some flexibility
- First ~2 weeks lectures: Mon-Fri 9am–10:30am (24-506)
- First ~1 week tutorials: Mon-Fri 1pm–2pm (24-506)
- Daily support in person
- Research conference on Friday January 31, 2025

Organization

Execution

- Participation from outside MIT welcome, but local supervisor needed
- Lecture slides will be available from the Web
- Core of the experience
  - Learn basic tools of the trade
  - Perform a complete analysis on FCC-ee simulation
  - Report about your project in short conference presentation
- It is possible to pair up and work together
- *If there is time* summarize analyses in a short note
- Conference at the end of the course, one topic per student

Technicalities

Access to computing resources

- Get account at MIT, if you are not at MIT
- request account by sending email to paus@mit.edu

Access to course software etc

- Make an account on subMIT our computing system
- Go to: https://submit-portal.mit.edu
- Follow instructions (possibly email submit-help@mit.edu)

Video tools

– Zoom: *https://mit.zoom.us/j/93715345658?pwd=6B9qQHzLzNUSPWnn1JH7Onu7SmlITb.1*

Course Content

Five big blocks

- Introduction and overview
- Experimental setup
- Fundamental measurements
- Overview of the FCC-ee program
- Key detector components

Lecture plan not exactly cast in stone

- if you have special wishes let us know

Course Content – more details

Introduction and overview

- introductory lecture

Experimental setup

- Particle accelerators
- Particle detectors

Fundamental measurements

- Cross sections, particle masses, particle lifetimes and widths

Overview of the FCC-ee program

- Physics at the Z pole, the Higgs and top thresholds, new physics

Key detector components

- Tracking, Calorimetry, and Particle Identification (Id)

Interesting Material

Videos: academic lectures and presentations

- CERN: https://cds.cern.ch/collection/Webcast?ln=en
- SLAC: https://indico.slac.stanford.edu/event/8587/page/92-past-ssi
- FNAL: visual media site   check the archives

Wikipedia

- FCC: https://en.wikipedia.org/wiki/Future_Circular_Collider
- LHC: https://en.wikipedia.org/wiki/Large_Hadron_Collider
- CMS: https://en.wikipedia.org/wiki/Compact_Muon_Solenoid
- CDF: https://en.wikipedia.org/wiki/Collider_Detector_at_Fermilab
- also try google, YouTube *etc.*
- fantastic documentation on the Web though, *read with care*

References will be provided throughout the course

The Standard Model *of Particle Physics*

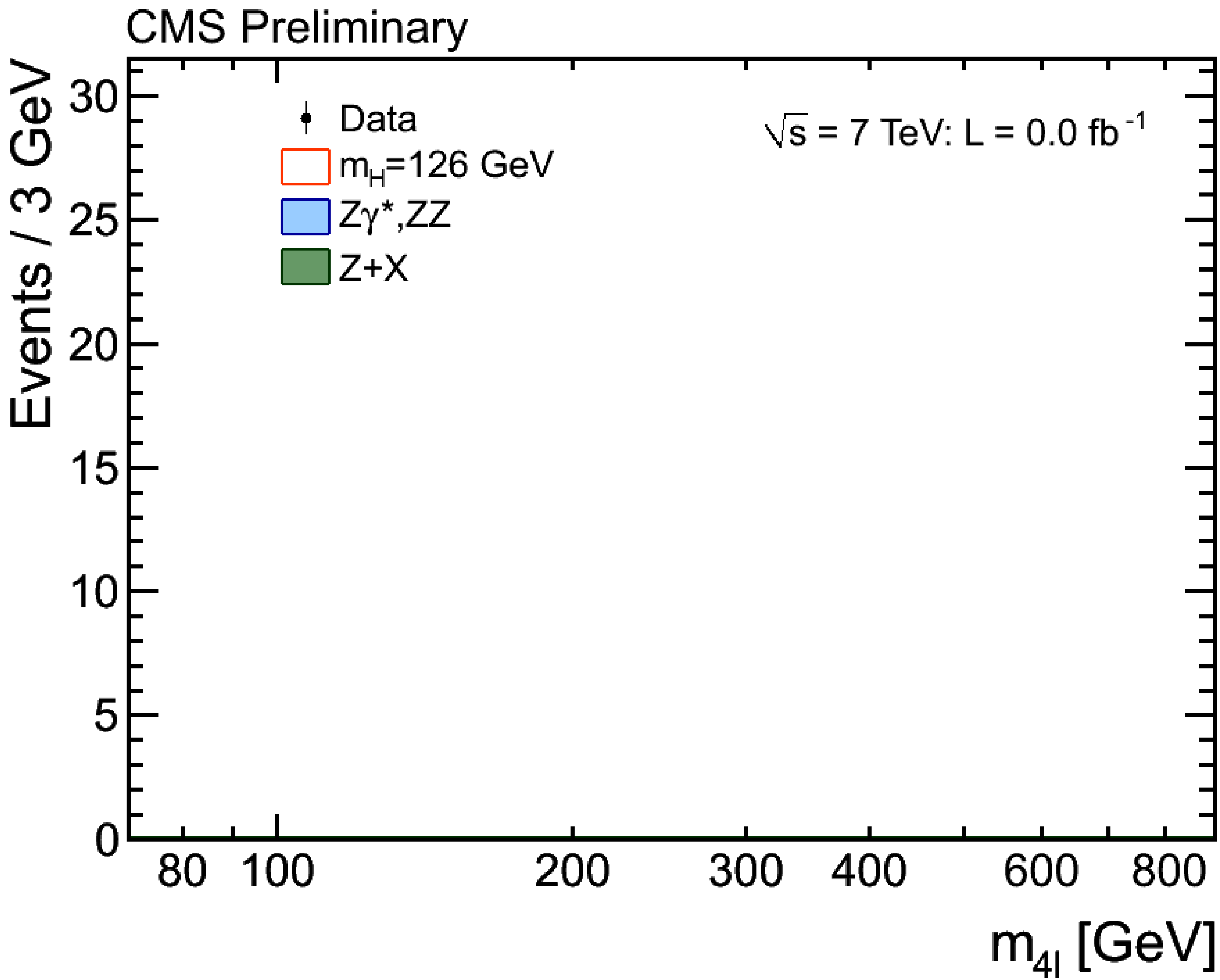
'Last' problem

- Local gauge invariance only conserved for massless particles

Solution (1964-6)

- There should be at least one field to couple to, to generate mass terms – implies that there is at least one Higgs boson.
- LHC found it 2012

Run 1 at LHC brought the Higgs



Historic Event: CERN–Melbourne

CERN

Melbourne

Rolf Heuer:

'We have it!'

4th of July 2012 – new Higgs–like particle discovery

The Standard Model *of Particle Physics*

Remaining obvious problems

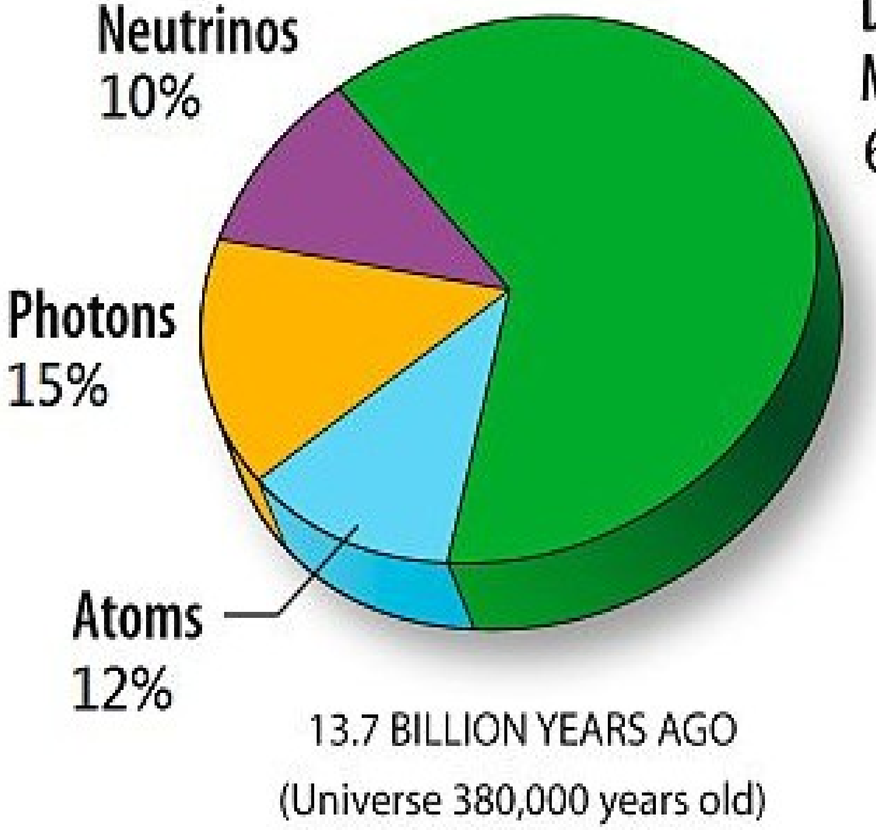
- We have no explanation for what dark matter is
- Why is the value of the Higgs mass the known value? #HierarchyProblem
- Why are forces so different (electromagnetic, weak, strong)?
- Gravity is an alien to the Standard Model – it does not fit! It is super weak!
- Why do we see so much matter and very little anti-matter in the universe
- and there are more interesting questions ...

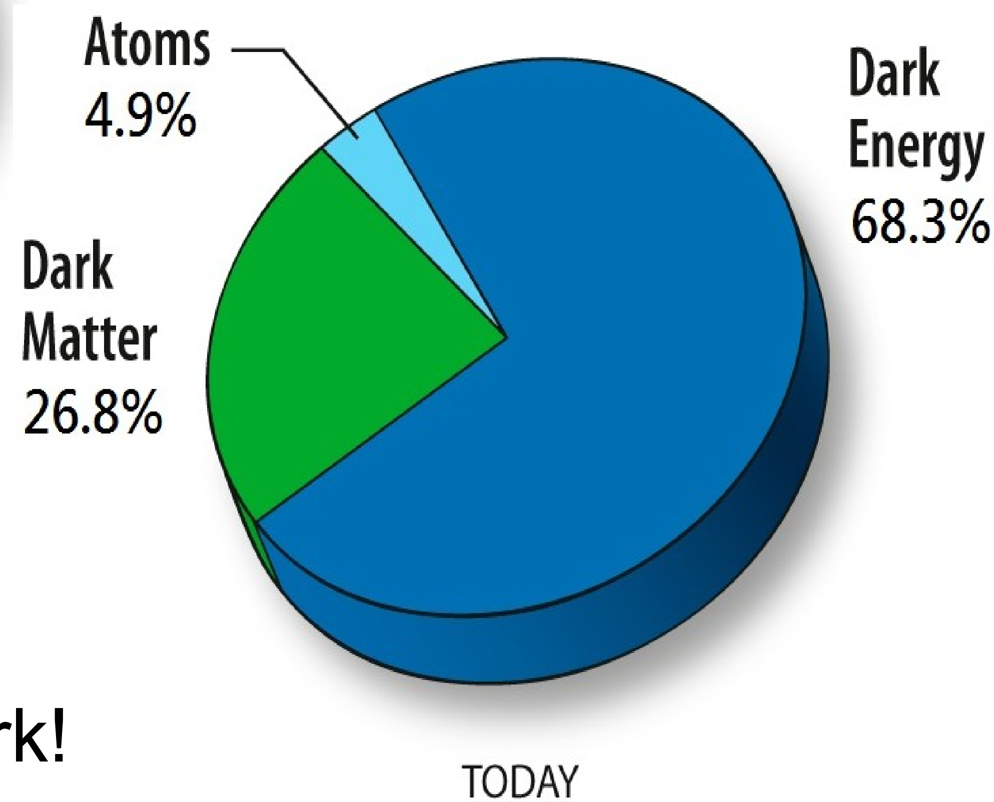
Theorists favorite solution(s) for 1-3

- Supersymmetry by giving each SM particle a super partner
- So far no trace found…

What was/is next for me?

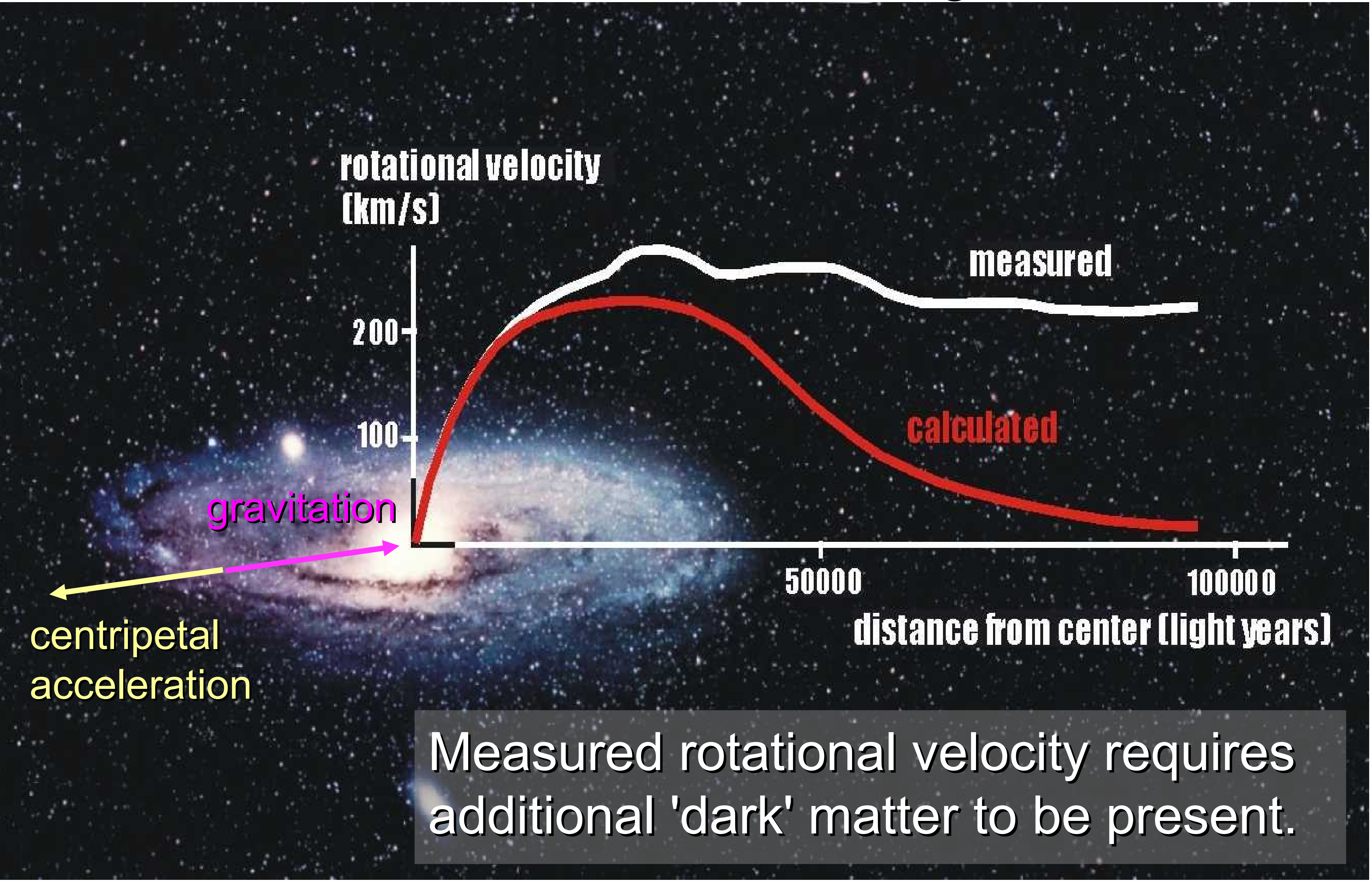
Dark Matter





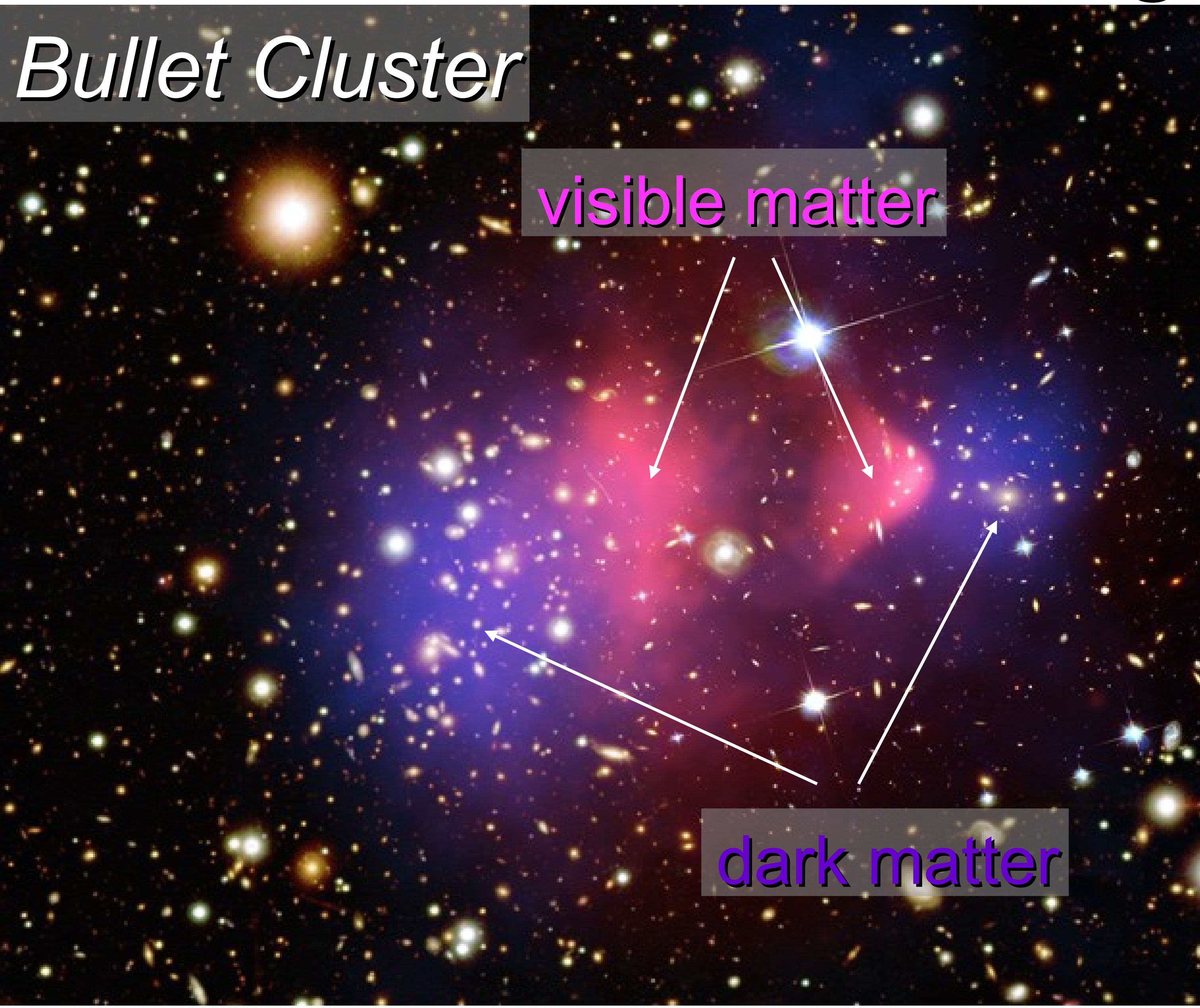
85.6% of all matter is dark!

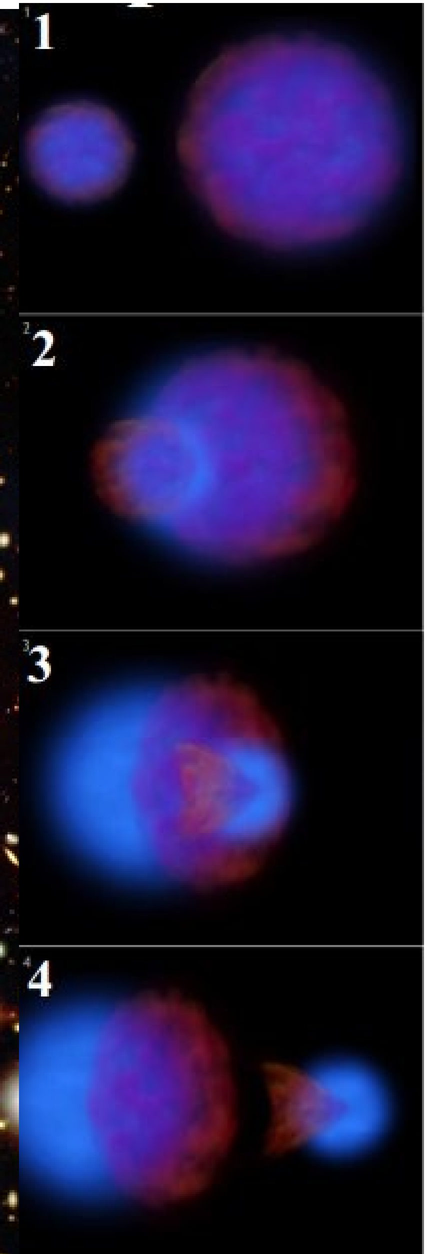
Rotational Velocity



Measured rotational velocity requires additional 'dark' matter to be present.

Gravitational Lensing

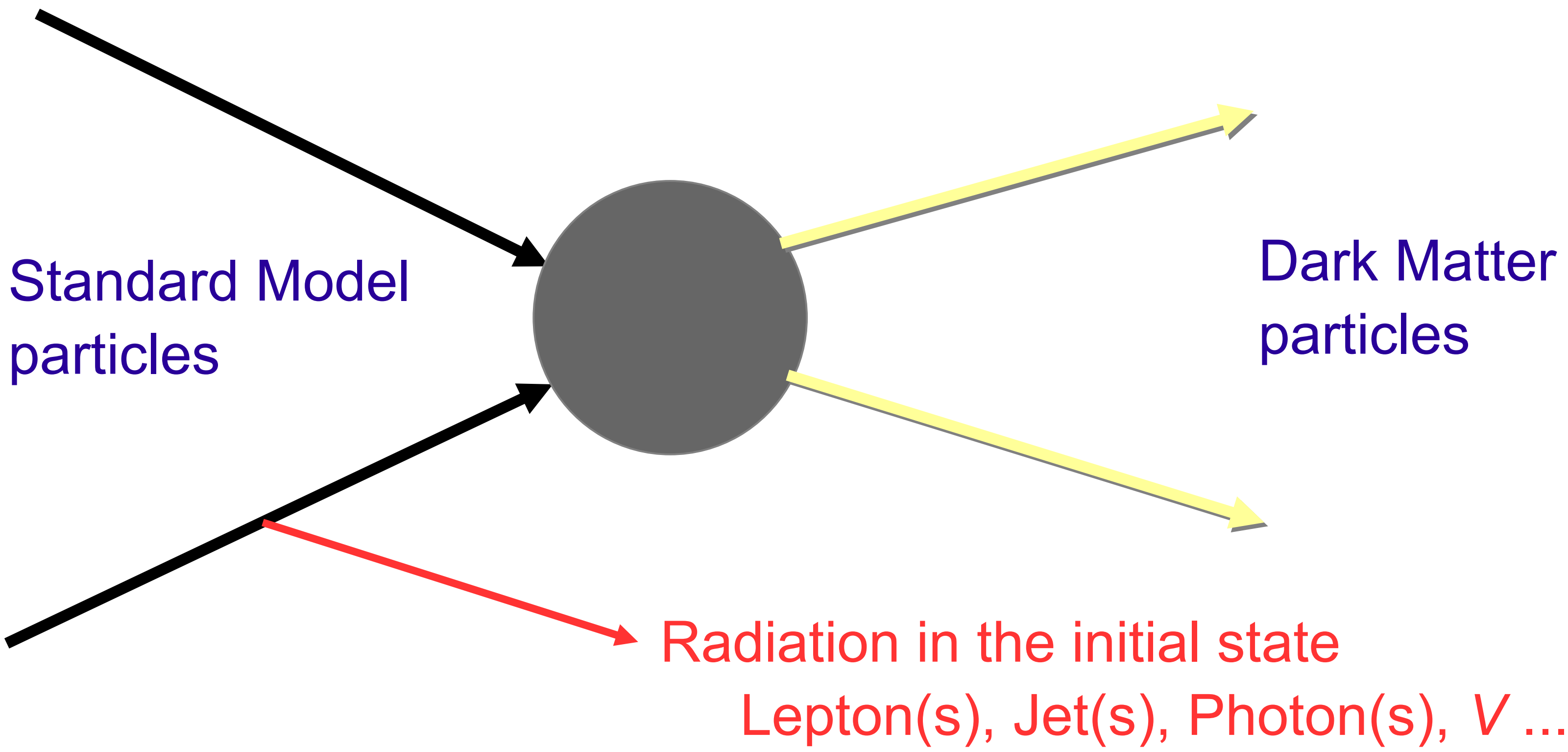




Searching Dark Matter with CMS

Signature

- Dark matter does not interact with detector
- Sooo…. the detector is empty?
- But if the initial state has radiation …. Well defined:



Compact Muon Solenoid

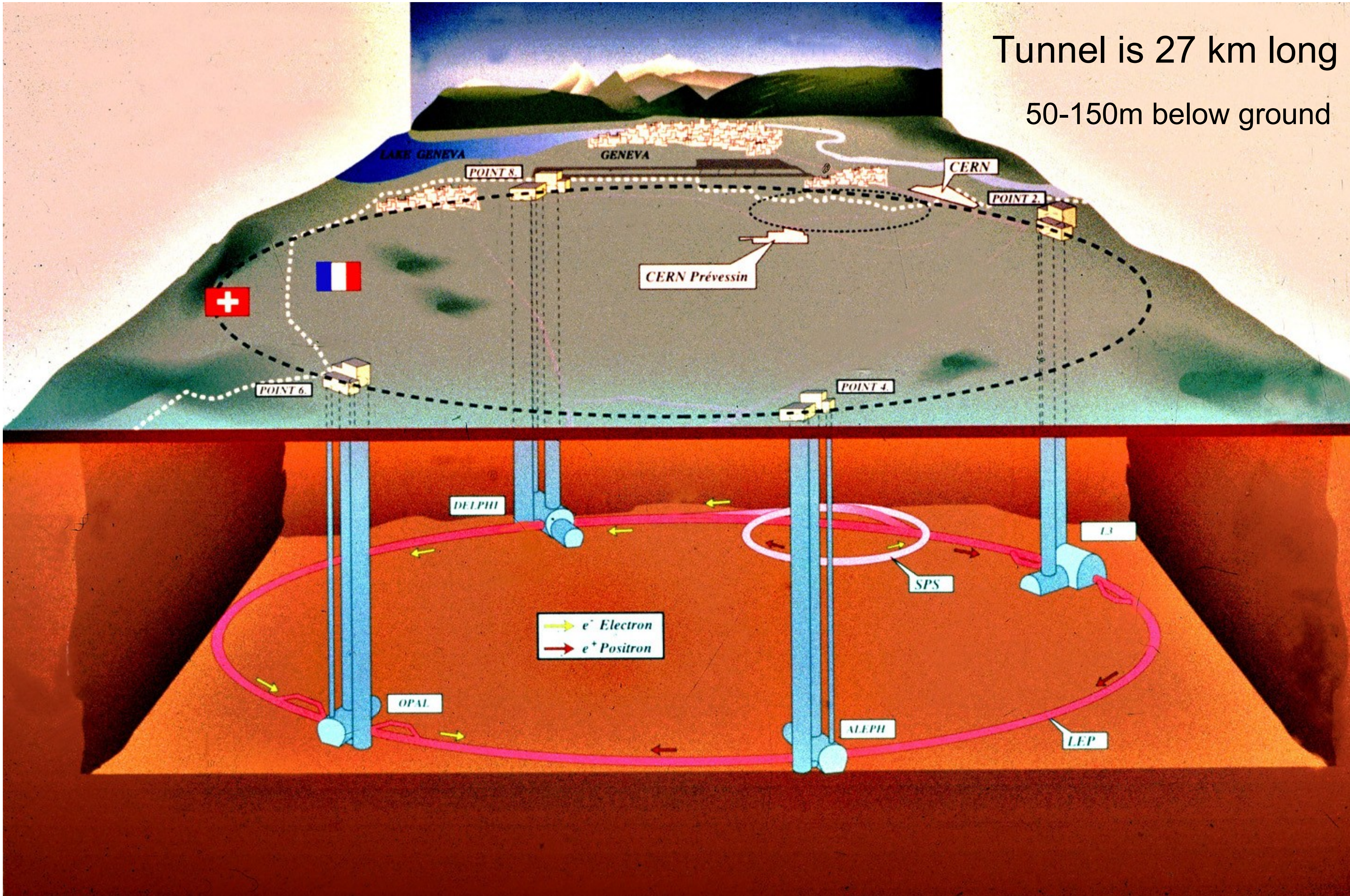
compact [1]

Adjective

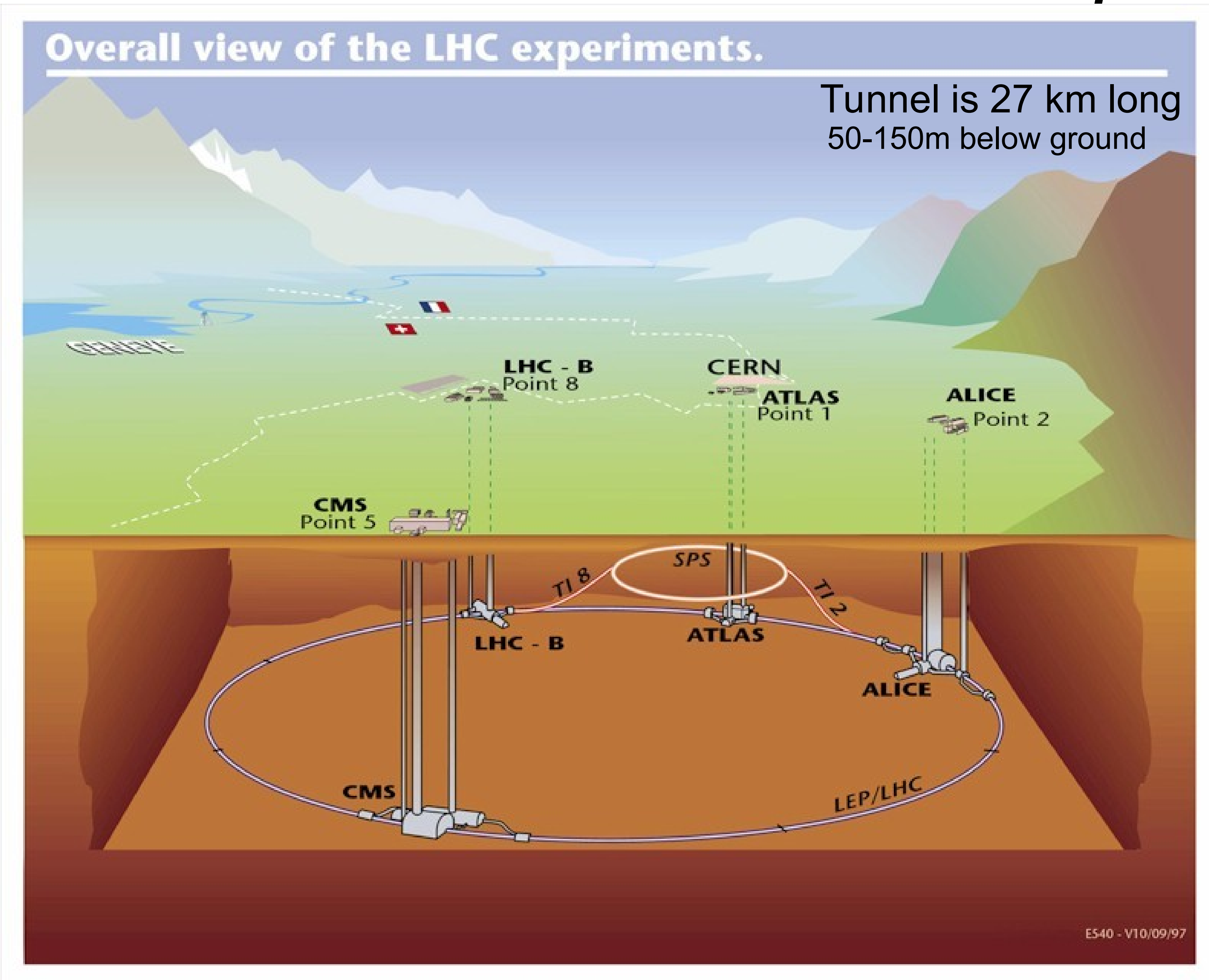
1. closely packed together
2. neatly fitted into a restricted space
3. concise; brief

Overview: CERN (Geneva, Switzerland)

The LEP/LHC Tunnel Setup



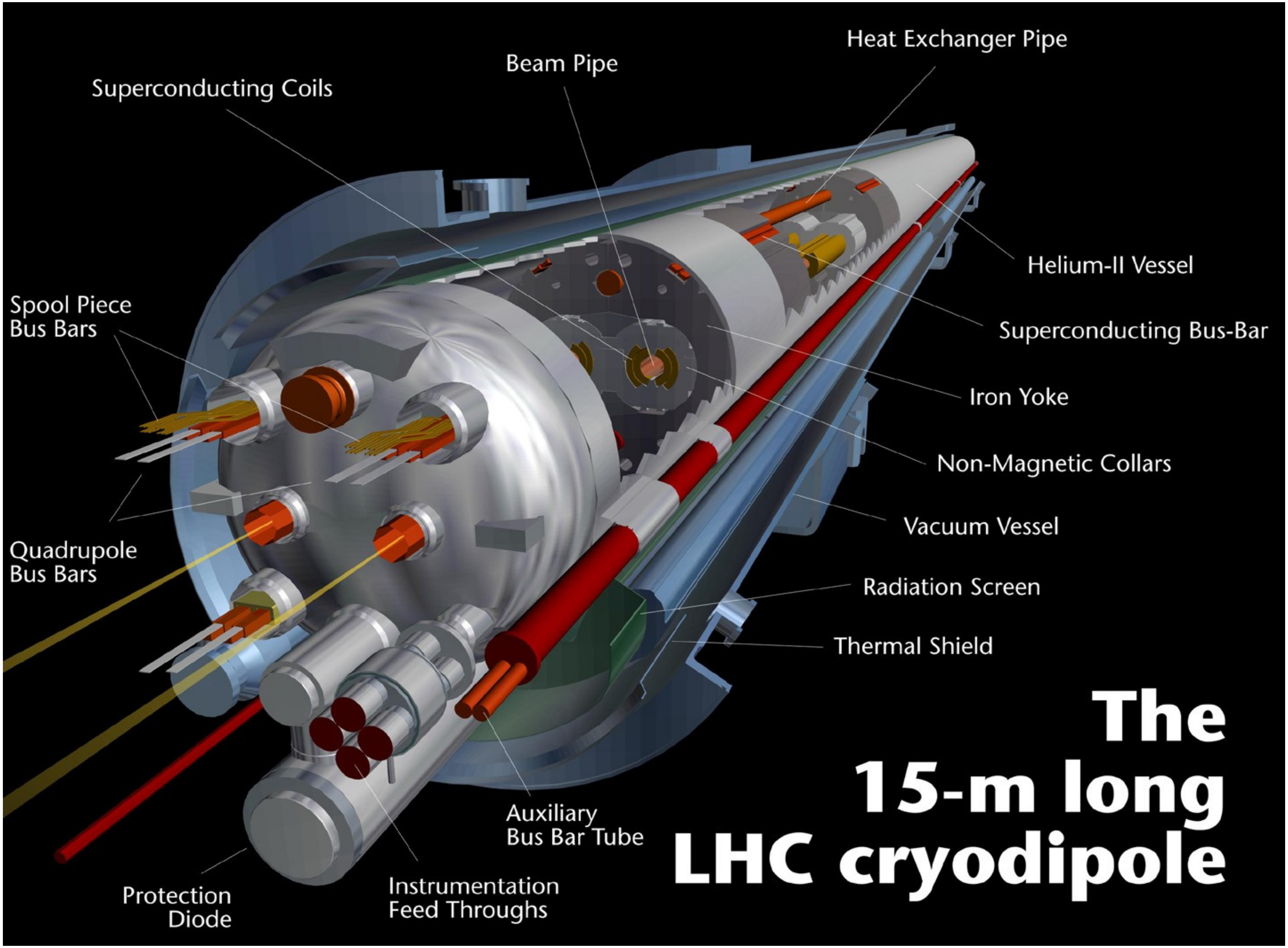
The LEP/LHC Tunnel Setup



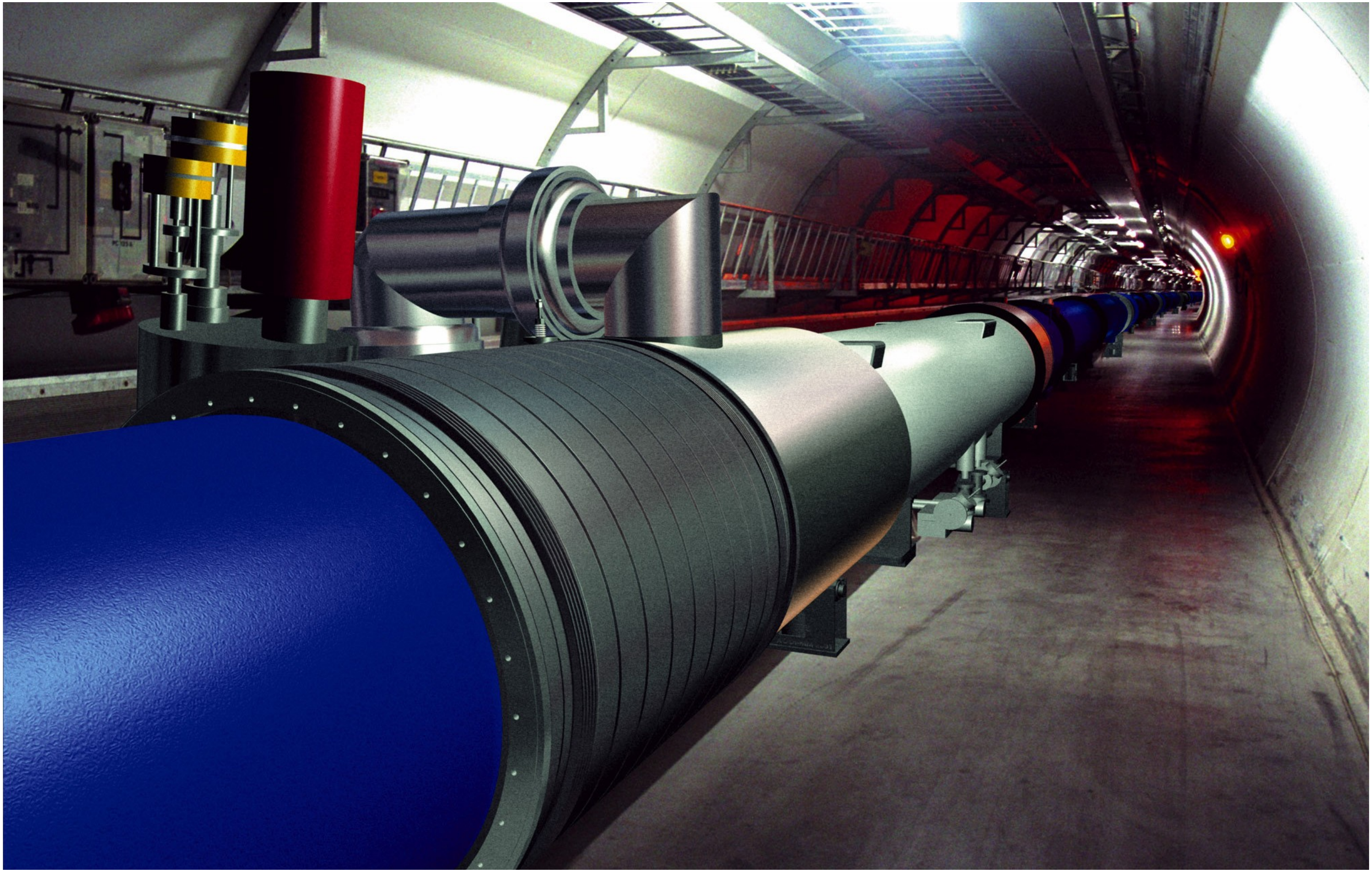
LEP Tunnel before LHC

Empty Tunnel: LEP Disassembled

The LHC Dipoles



LHC Pictures: Simulation



LHC Pictures: Real Dipoles

LHC Pictures: Tunnel with Beamlines

LHC Experiments

Two omnipurpose* detectors

- Atlas
- CMS (C.P. experiment)

One dedicated *B* physics experiment

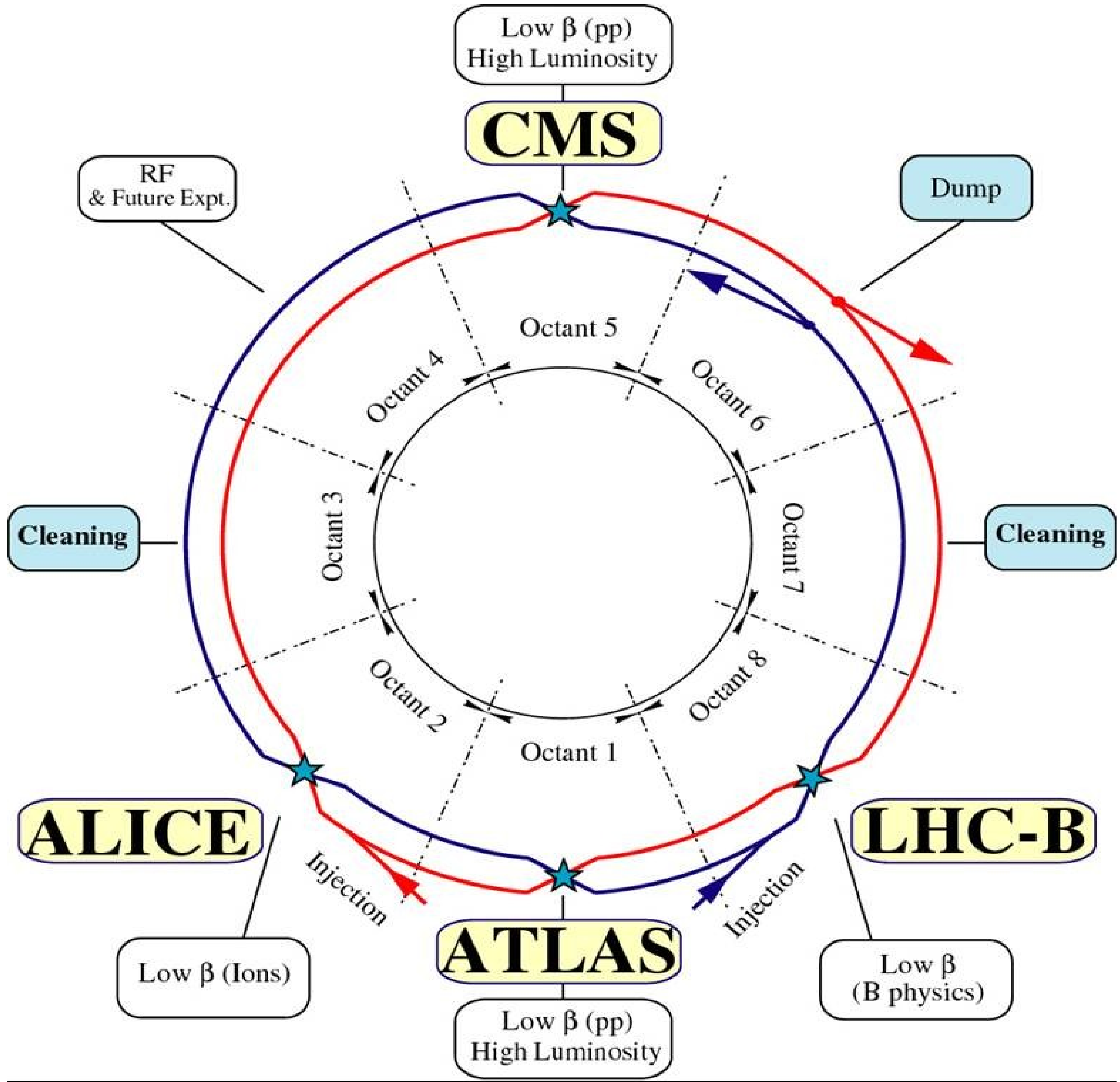
- LHCb (Eluned Smith experiment)

One dedicated heavy ion experiment

- Alice

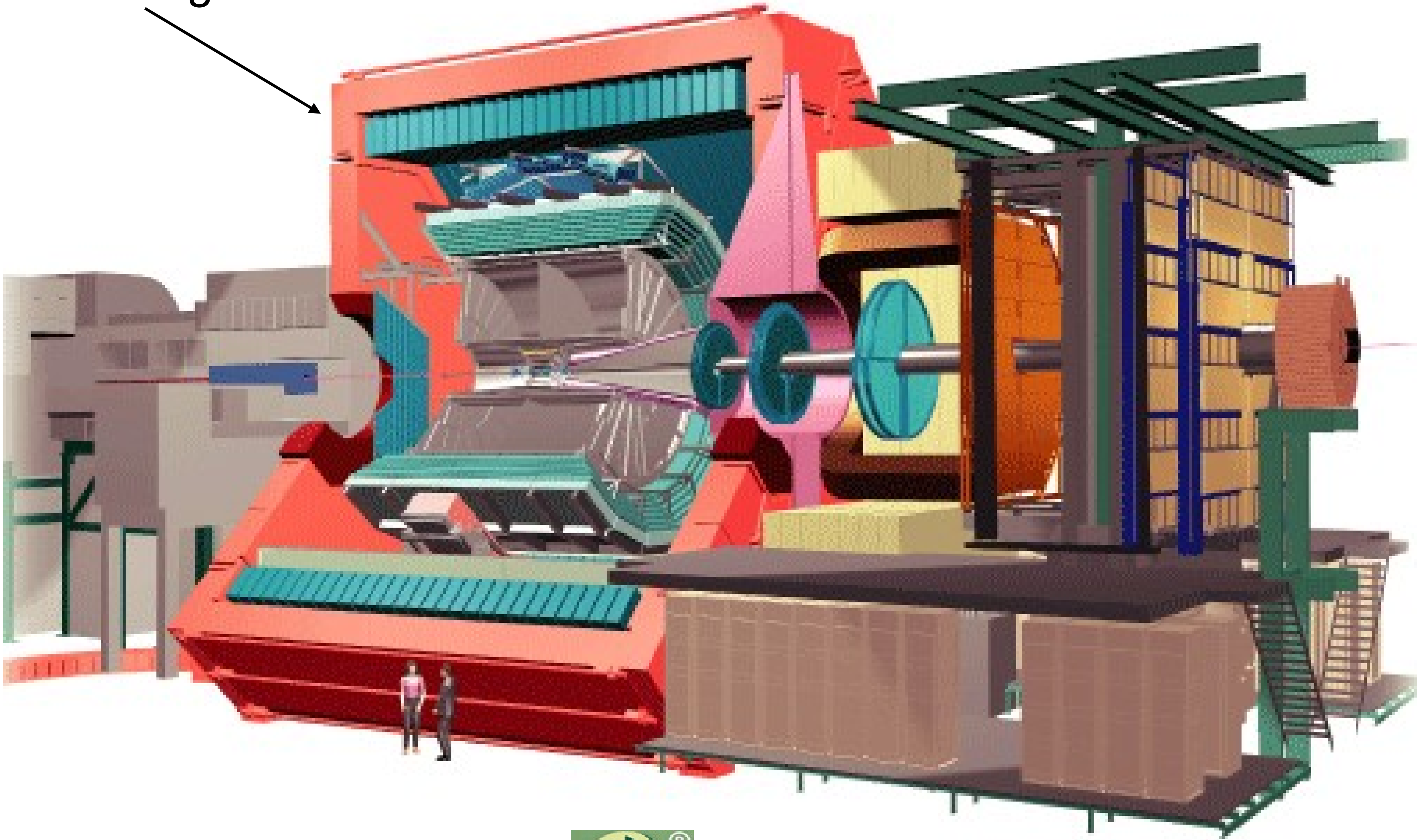
* multipurpose = do heavy ion and *B* physics as well

The LHC Experiments



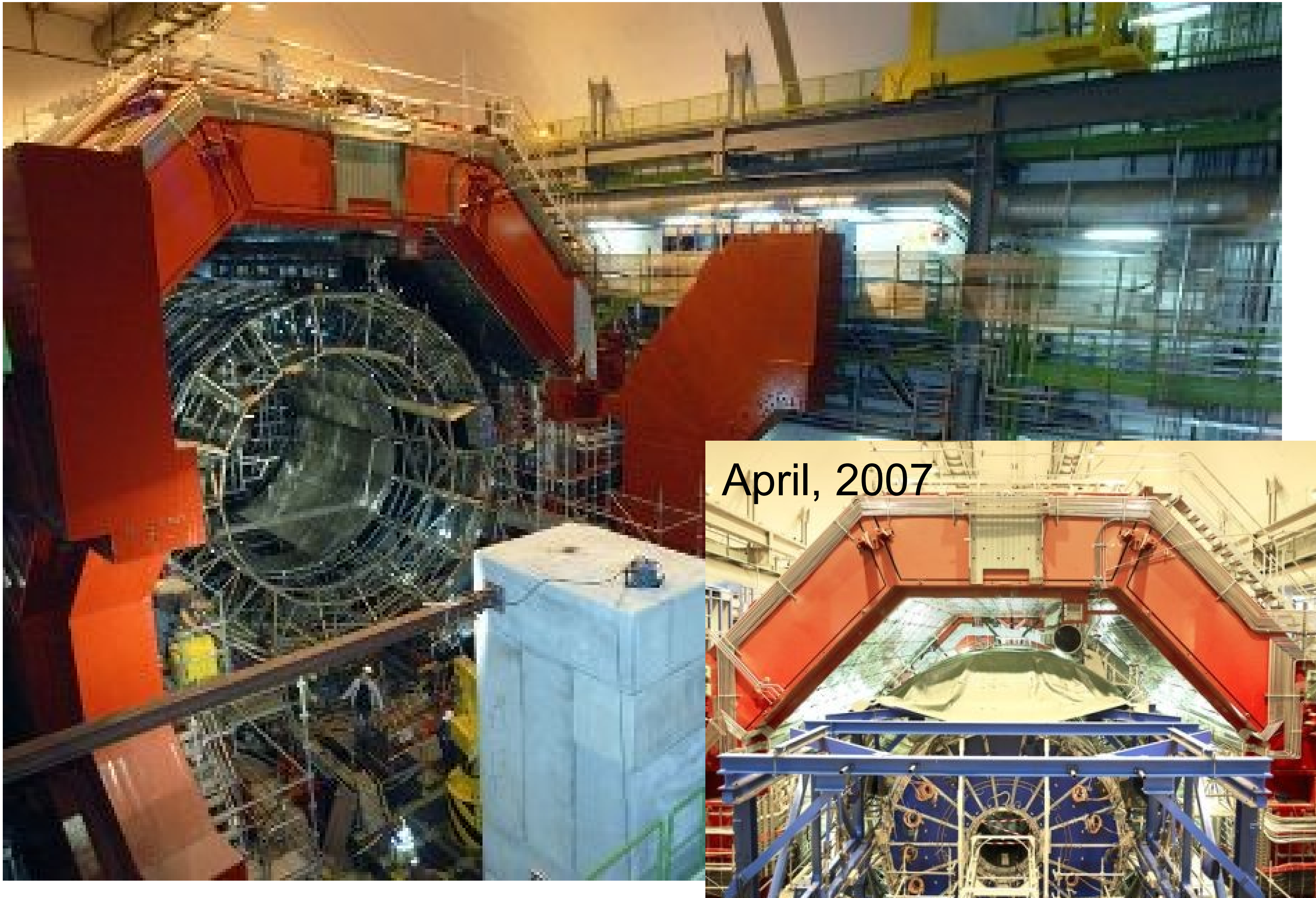
Alice: Detector Sketch

old L3 magnet



particle physicists do recycle

Alice: December 2006



Atlas/CMS Motivation

LHC is a new energy regime: uncharted territory

The guaranteed mission (seek and destroy)

- find the Standard Model Higgs: completes SM, for now
- do not find the SM Higgs: falsify the model because machine fully covers available phase space

The case for beyond the Standard Model

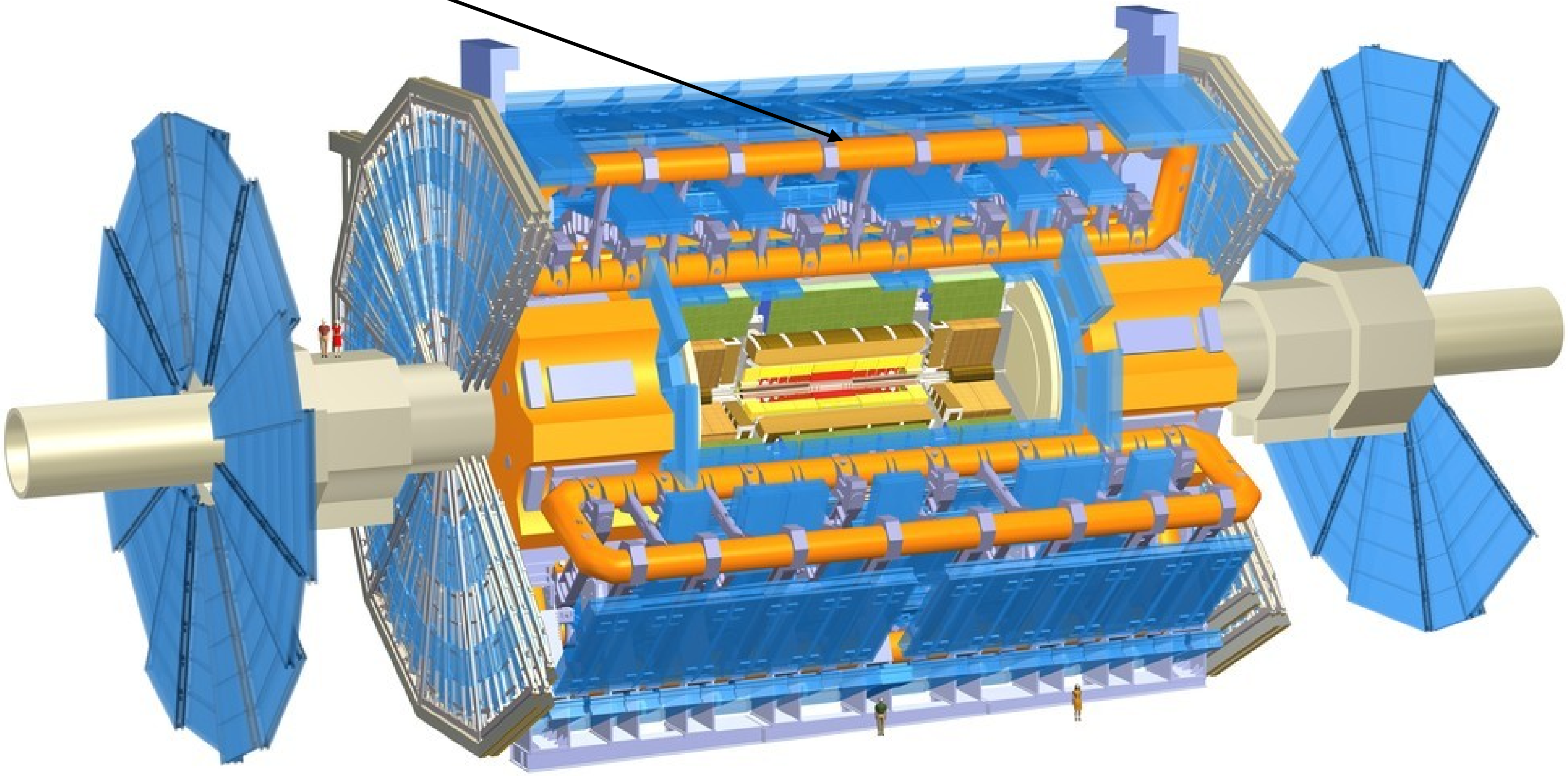
- new energy regime opens new doors
- anything beyond the Standard Model is a sensation
- be it SUSY, extra dimensions, leptoquarks, *Z′*, ... or even better: the completely unexpected

Atlas: Detector Sketch

the biggest collider detector ever, by far

eye catcher: central air core toroid magnet

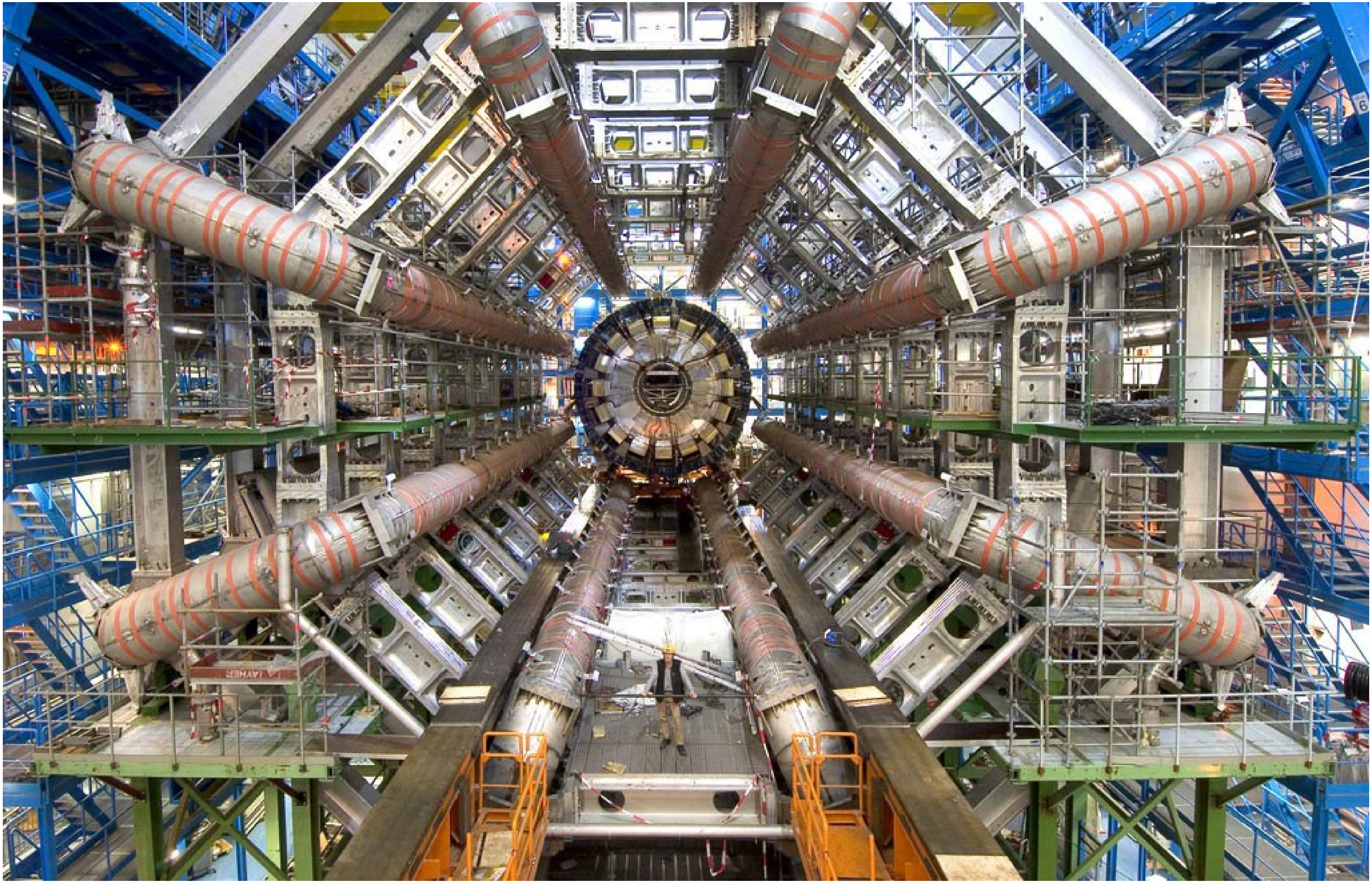
7,000 ton weight, 25 m diameter, 45 m long



light weight construction: if wrapped in plastic it floats on water (22,000 m^3)

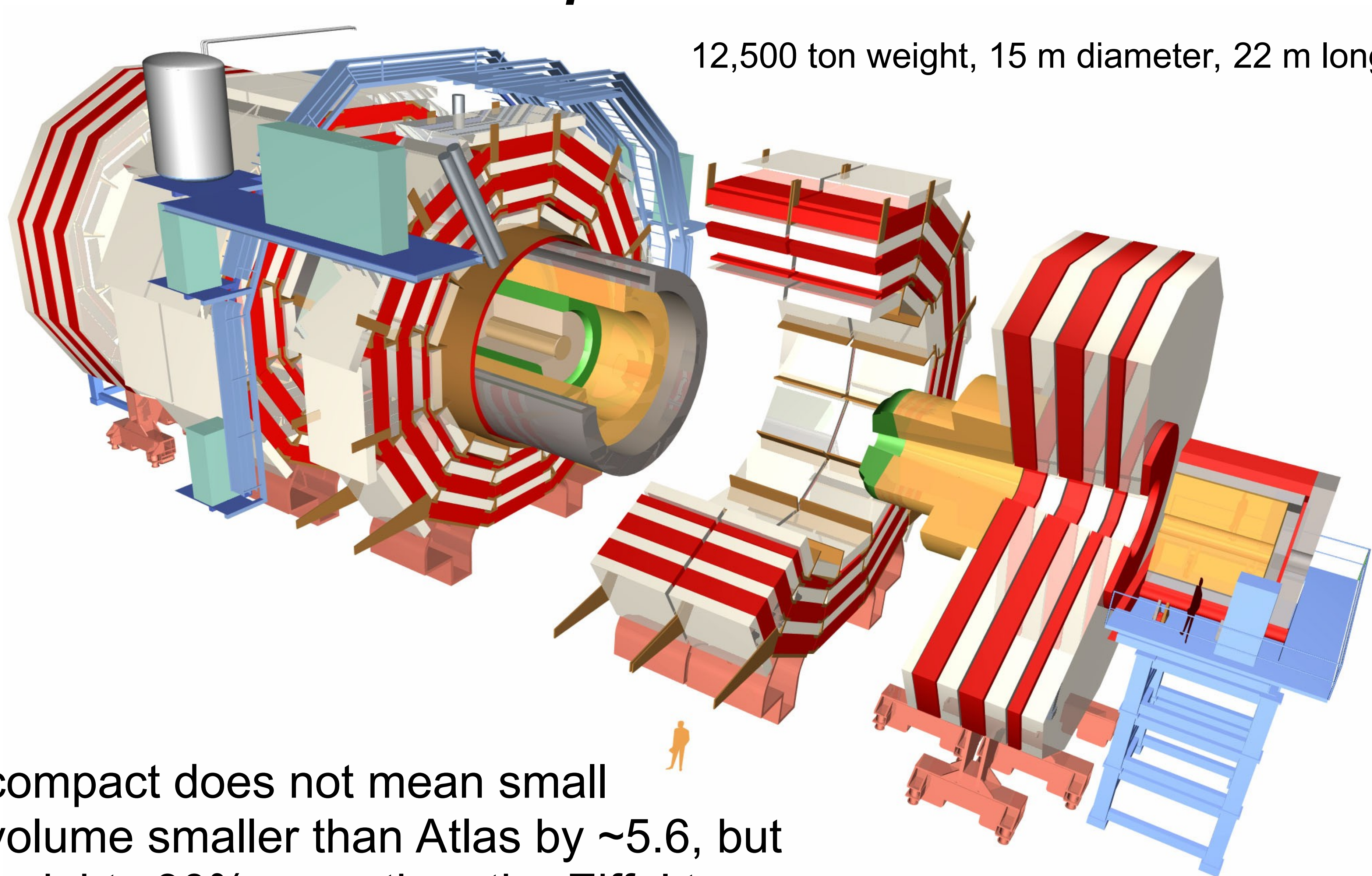
still, weights more than half the Eiffel tower

Atlas: Real Installation



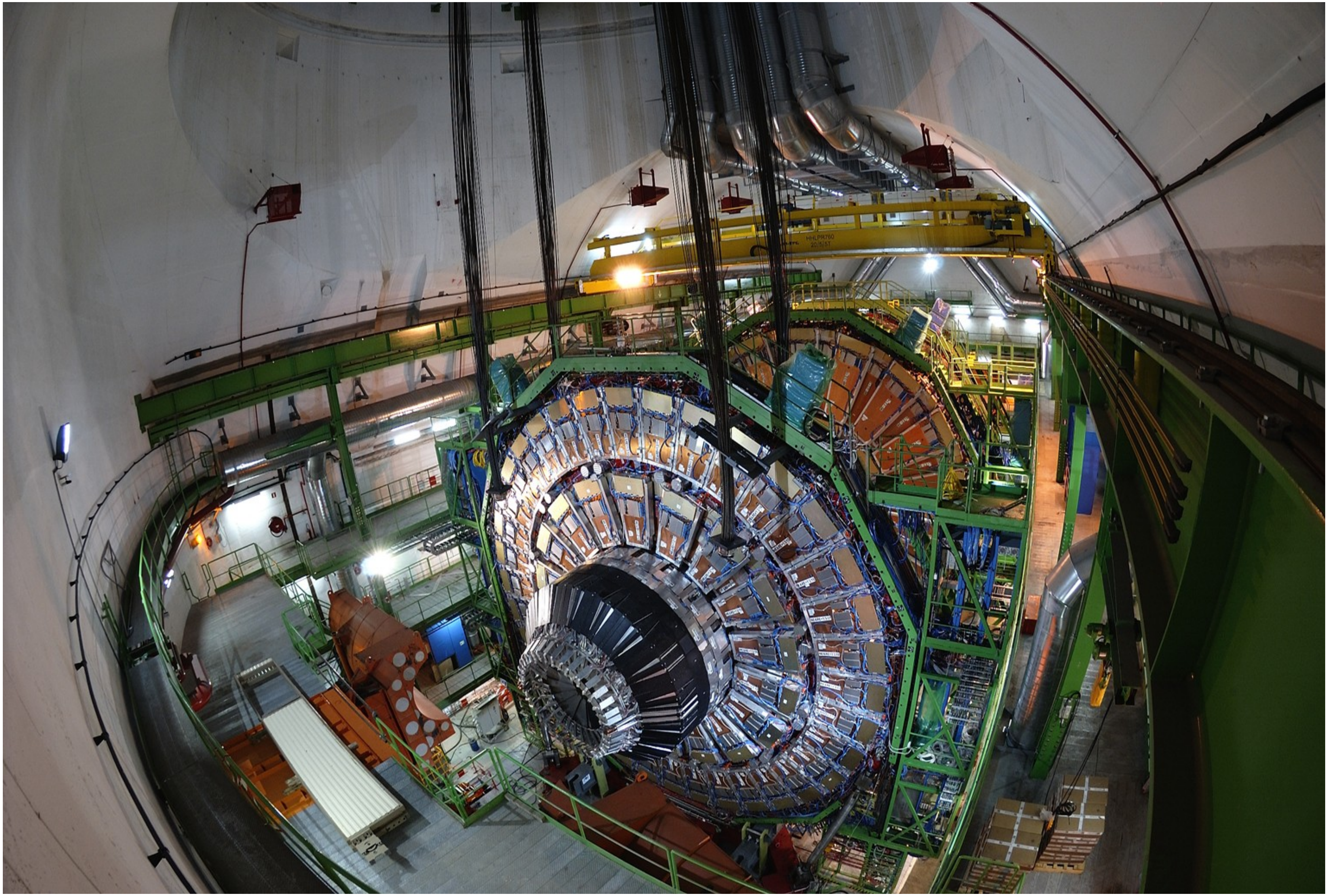
CMS – Compact Muon Solenoid

12,500 ton weight, 15 m diameter, 22 m long



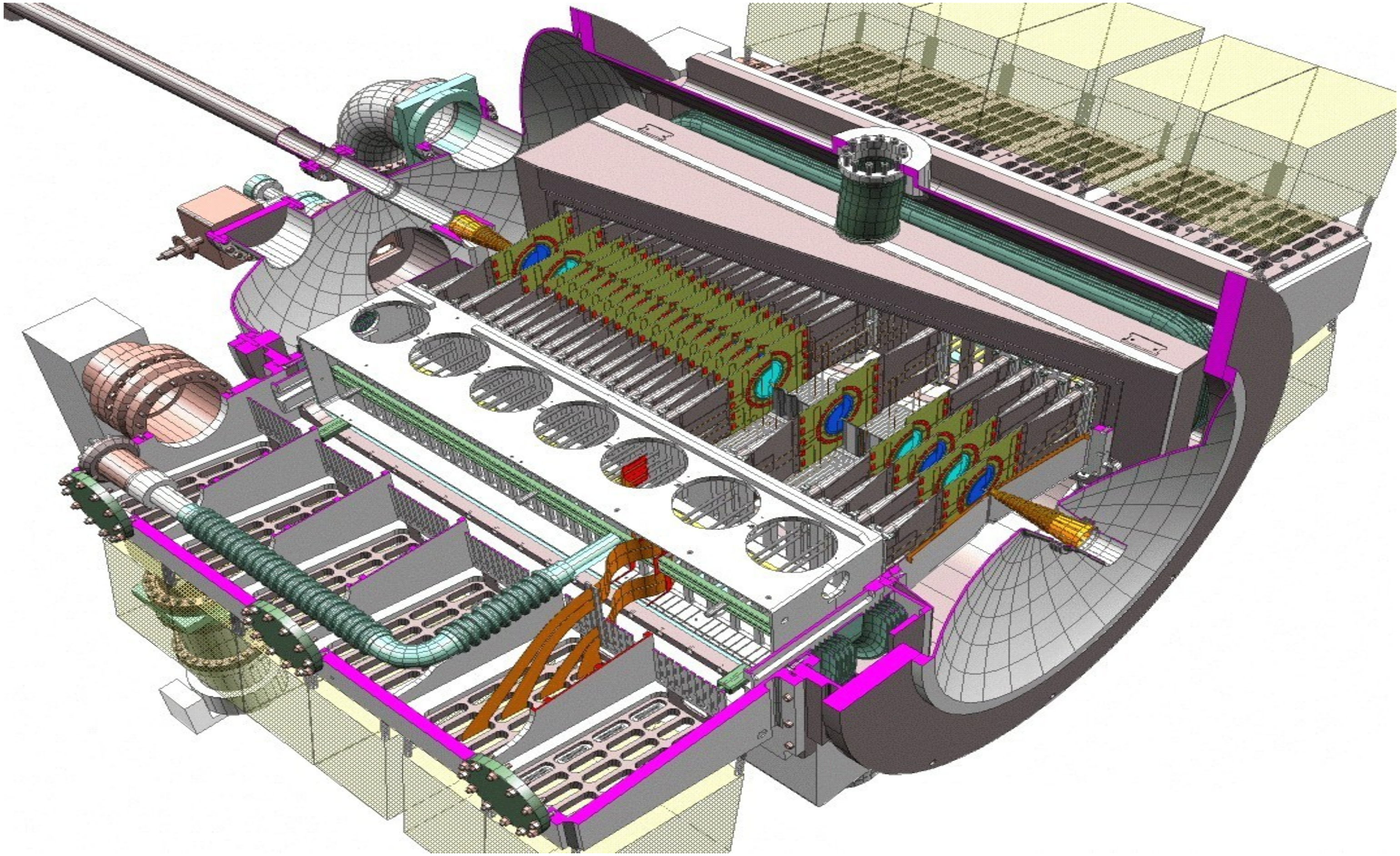
compact does not mean small
volume smaller than Atlas by ~5.6, but
weights 30% more than the Eiffel tower
eye catcher: brilliant design in separately removable slices

CMS: Installation

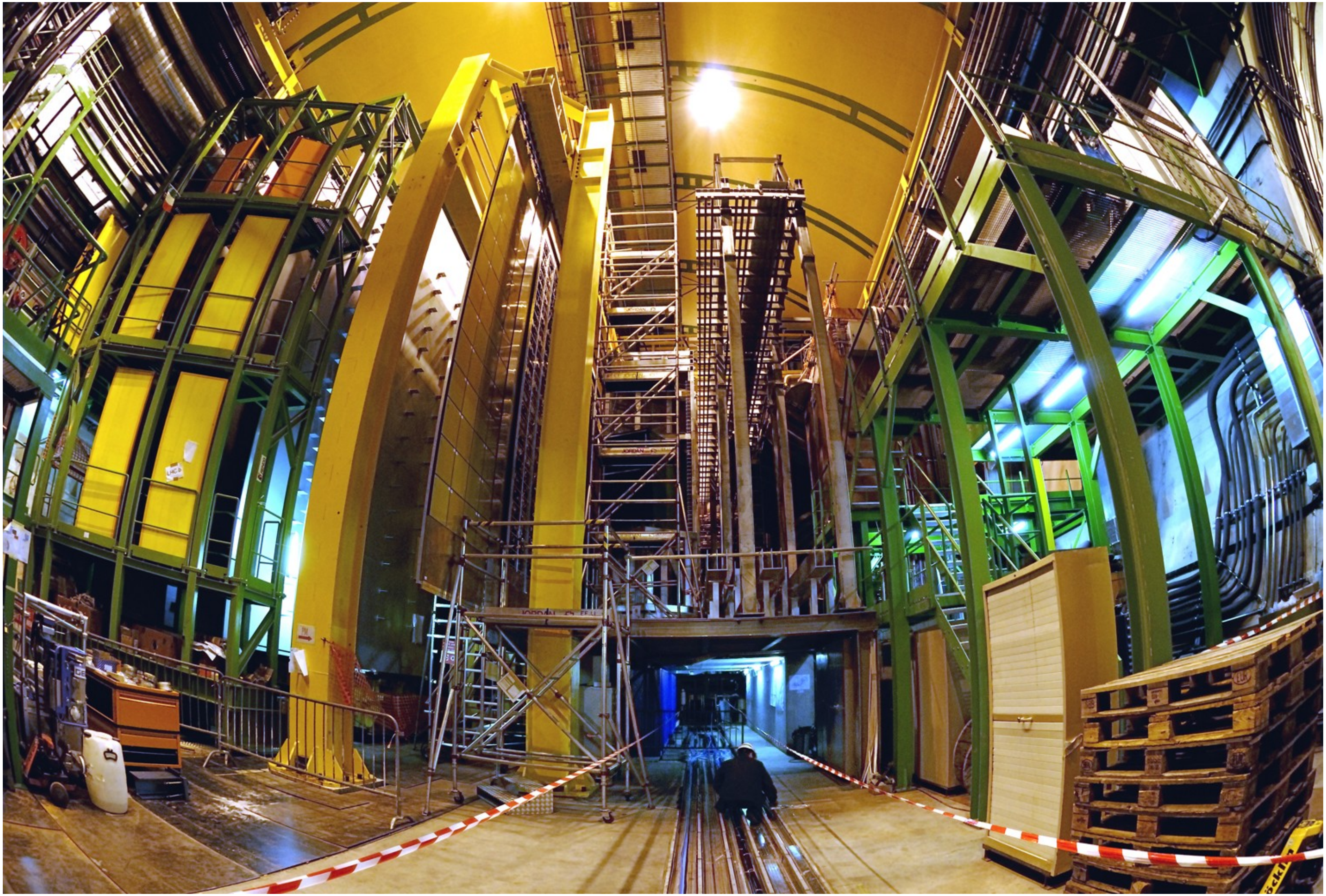


LHCb: Mission and Sketch

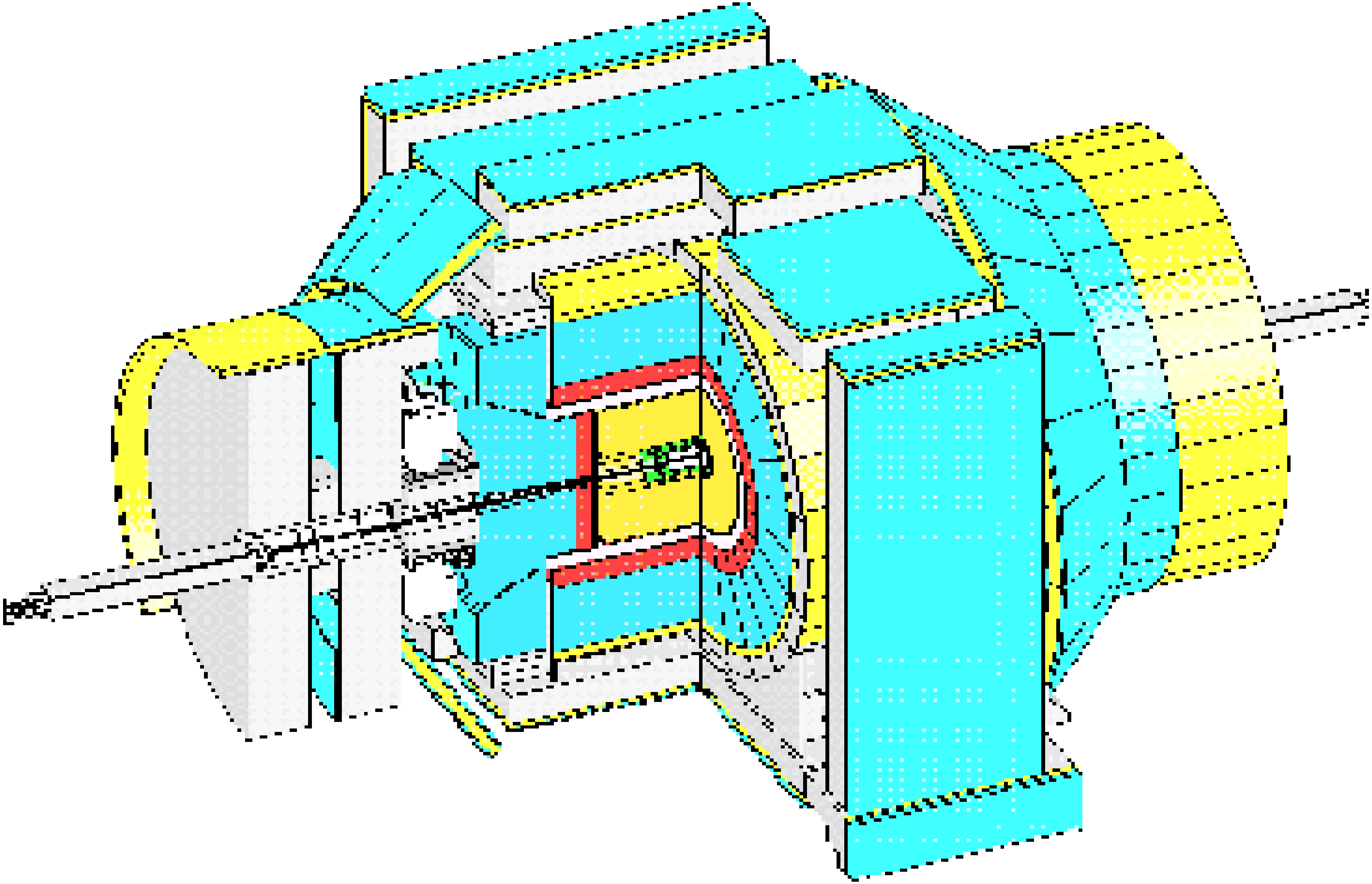
- The Large Hadron Collider beauty experiment
- for precise measurements of *CP* violation and rare decays



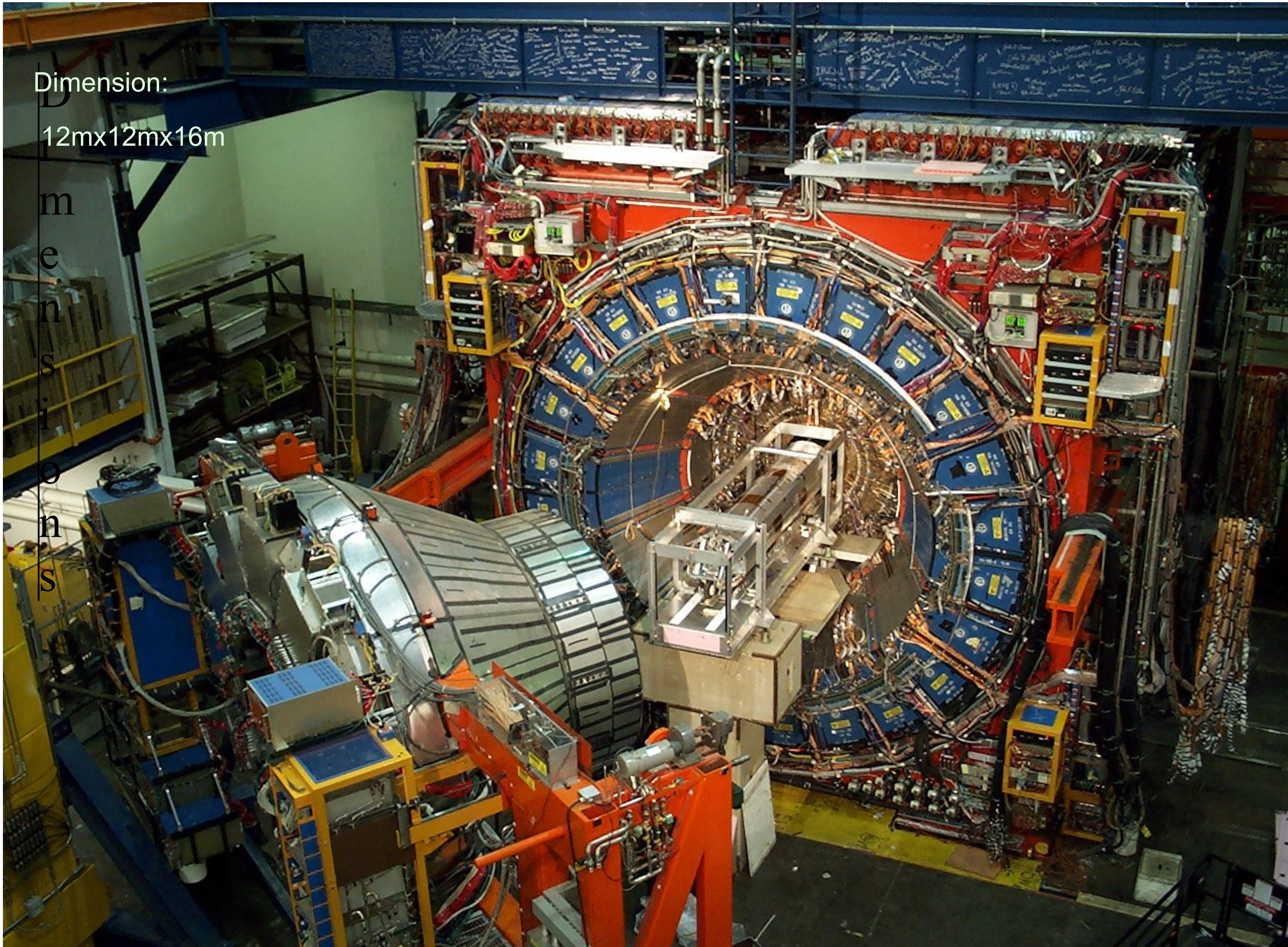
LHCb: At the Interaction Point



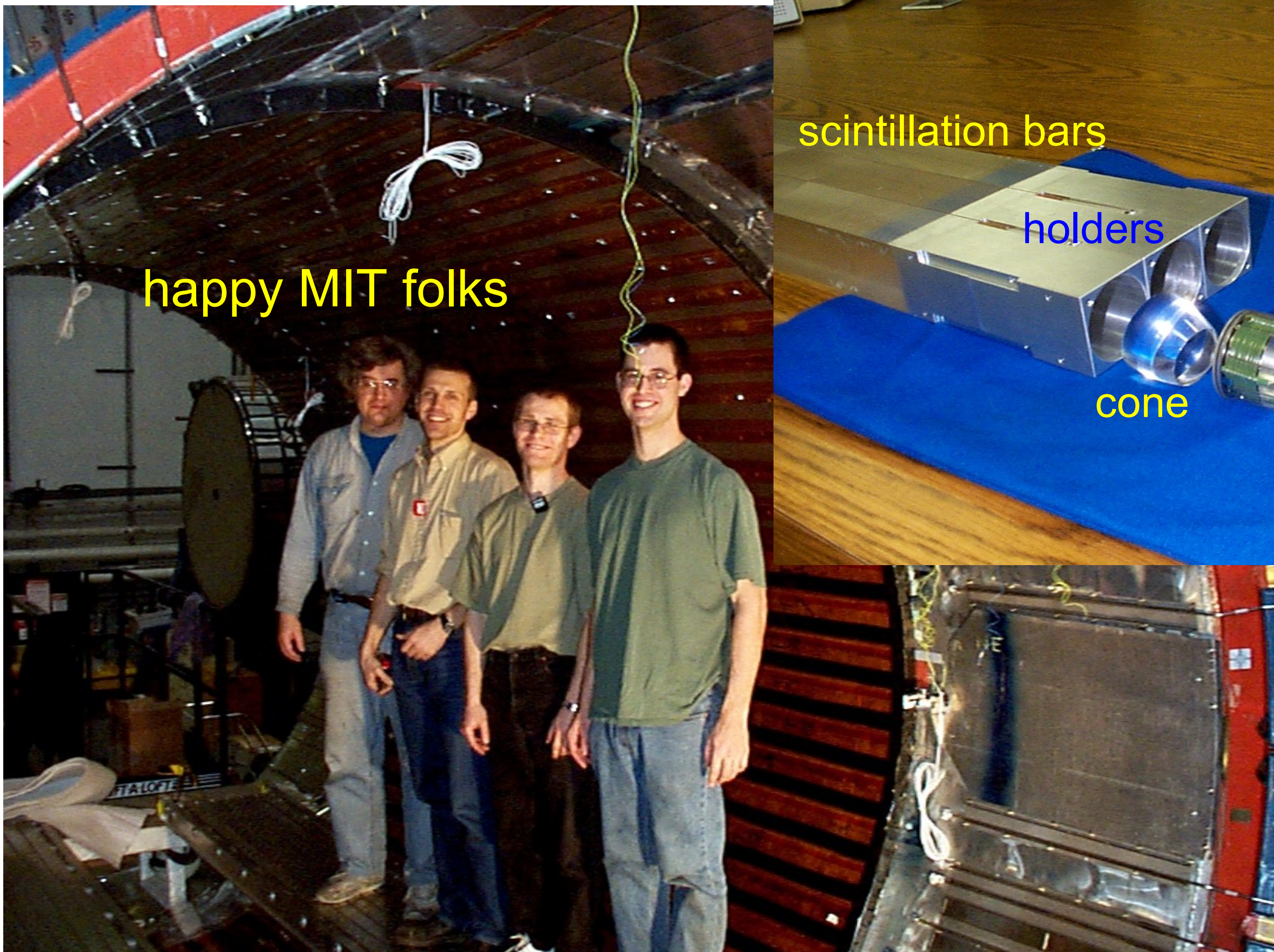
CDF: Sketch

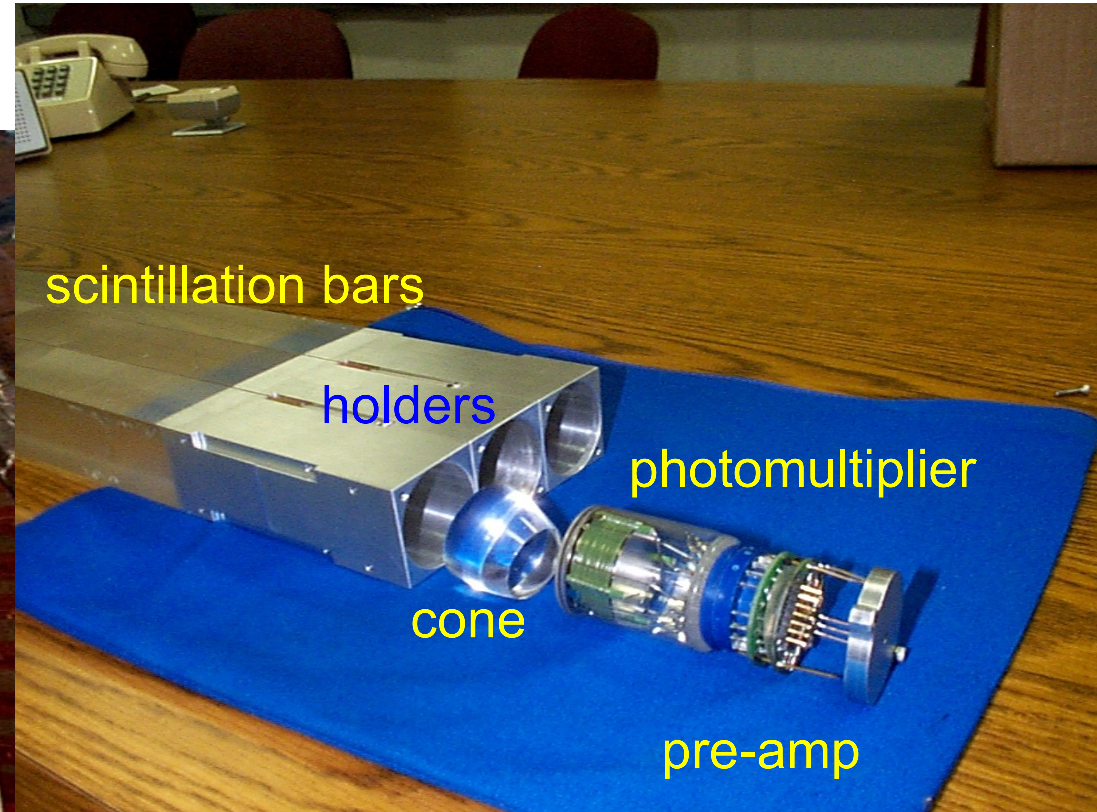


CDF Detector Pictures



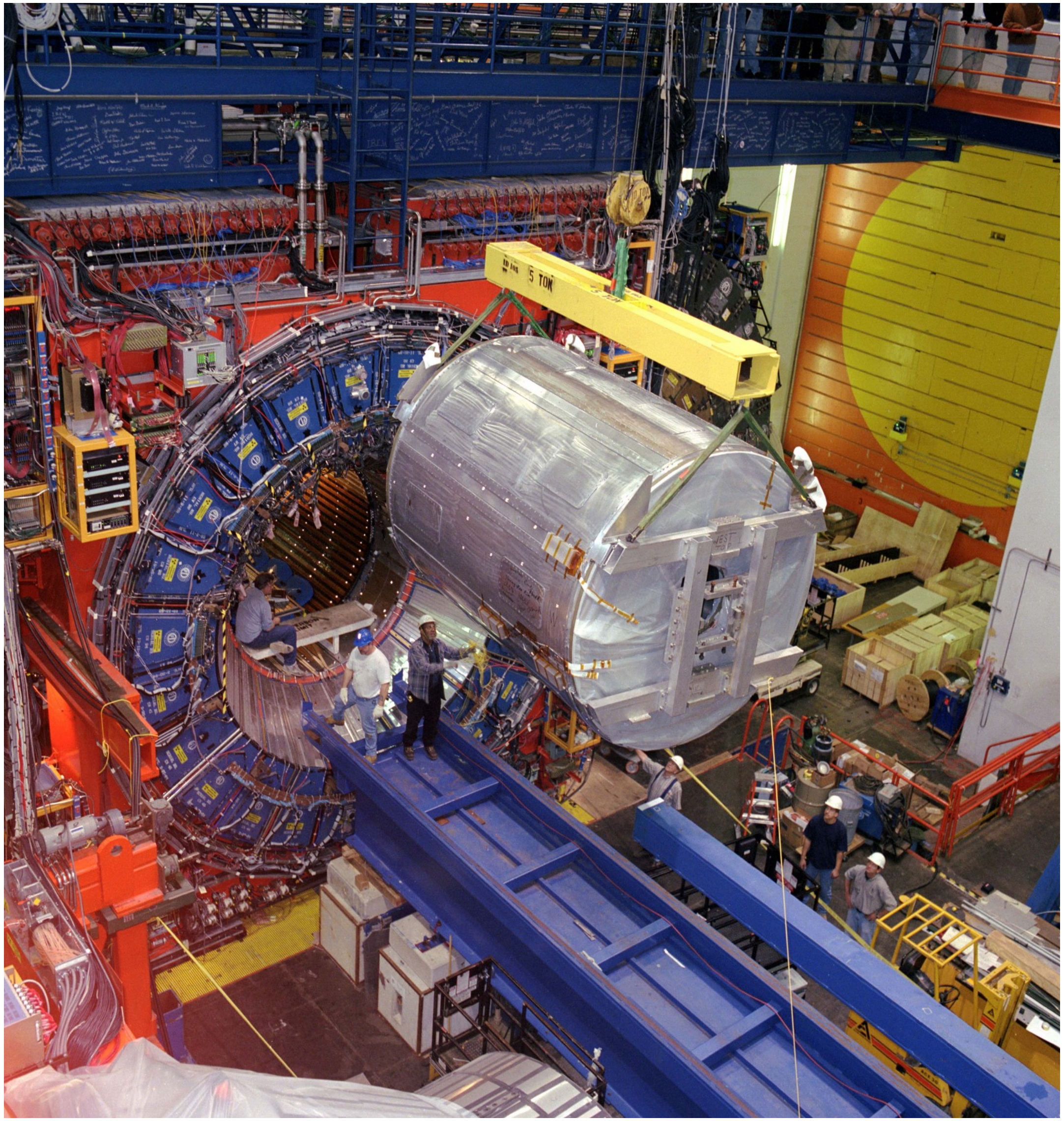
CDF: Time Of Flight Detector

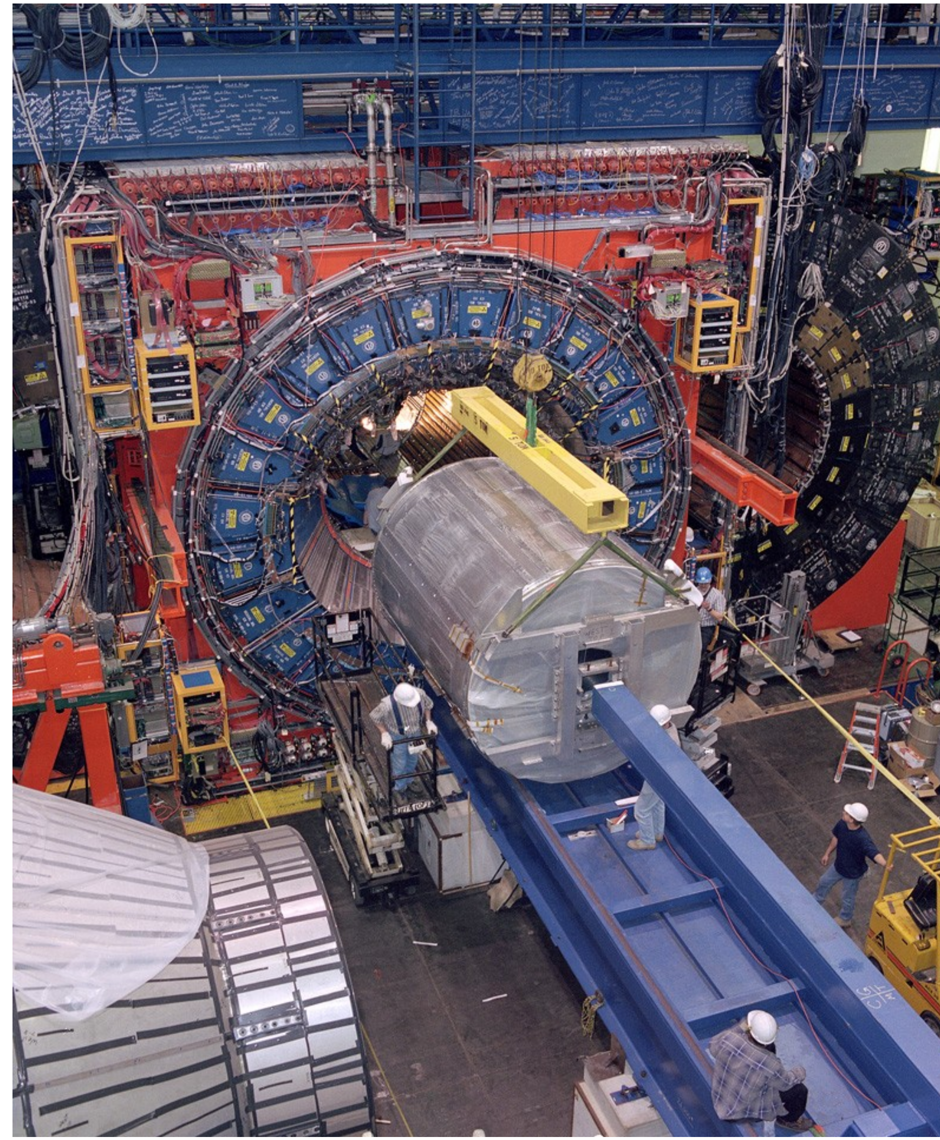




CDF: Central Outer Tracker

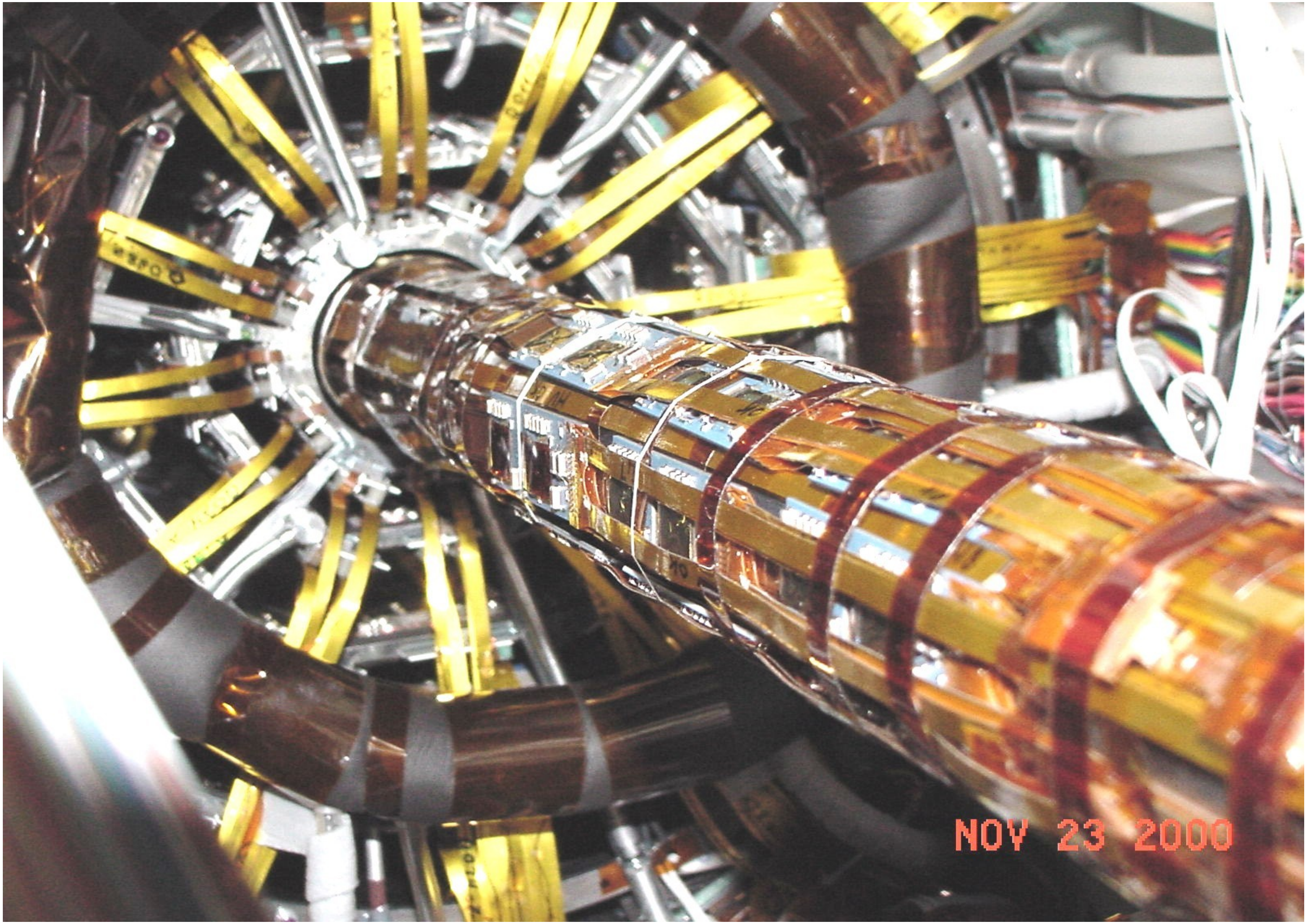
CDF: Central Outer Tracker





CDF: Silicon Detector

CDF: Silicon Vertex Detector



Conclusions

We have a month ahead of us

- Learn how an experimenters work
- Experimental setup
- Basic physics ideas
- Basic measurements
- Give a talk

Instructions for course

- get registered for a user account on subMIT our computing resource
- Review the projects to see which one you are most interested in