The High-Energy Frontier

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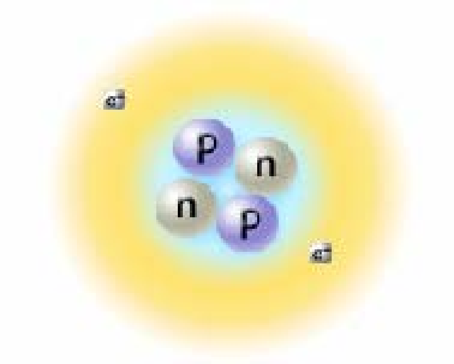
Introduction

7th Solvay Physics Congress in Brussels, 1933

H. A. Kramers N. F. Mott G. Gamow P. Blackett M. Cosyns A. Piccard
E. Stahel P. A. M. Dirac J. Errera C. D. Ellis E. O. Lawrence
E. Henriot F. Joliot W. Heisenberg E. Walton P. Debye B. Cabrera W. Bothe E. Bauer J. Verschaffelt J. Cockcroft L. Rosenfeld
F. Perrin E. Fermi M. Rosenblum W. Pauli E. Herzen R. Peierls
E. Schroedinger I. Joliot N. Bohr A. Joffe M. Curie O. Richardson E. Rutherford M. De Broglie L. Meitner J. Chadwick
P. Langevin T. De Donder L. De Broglie
Absent: A. Einstein and E. Guye

Subatomic World

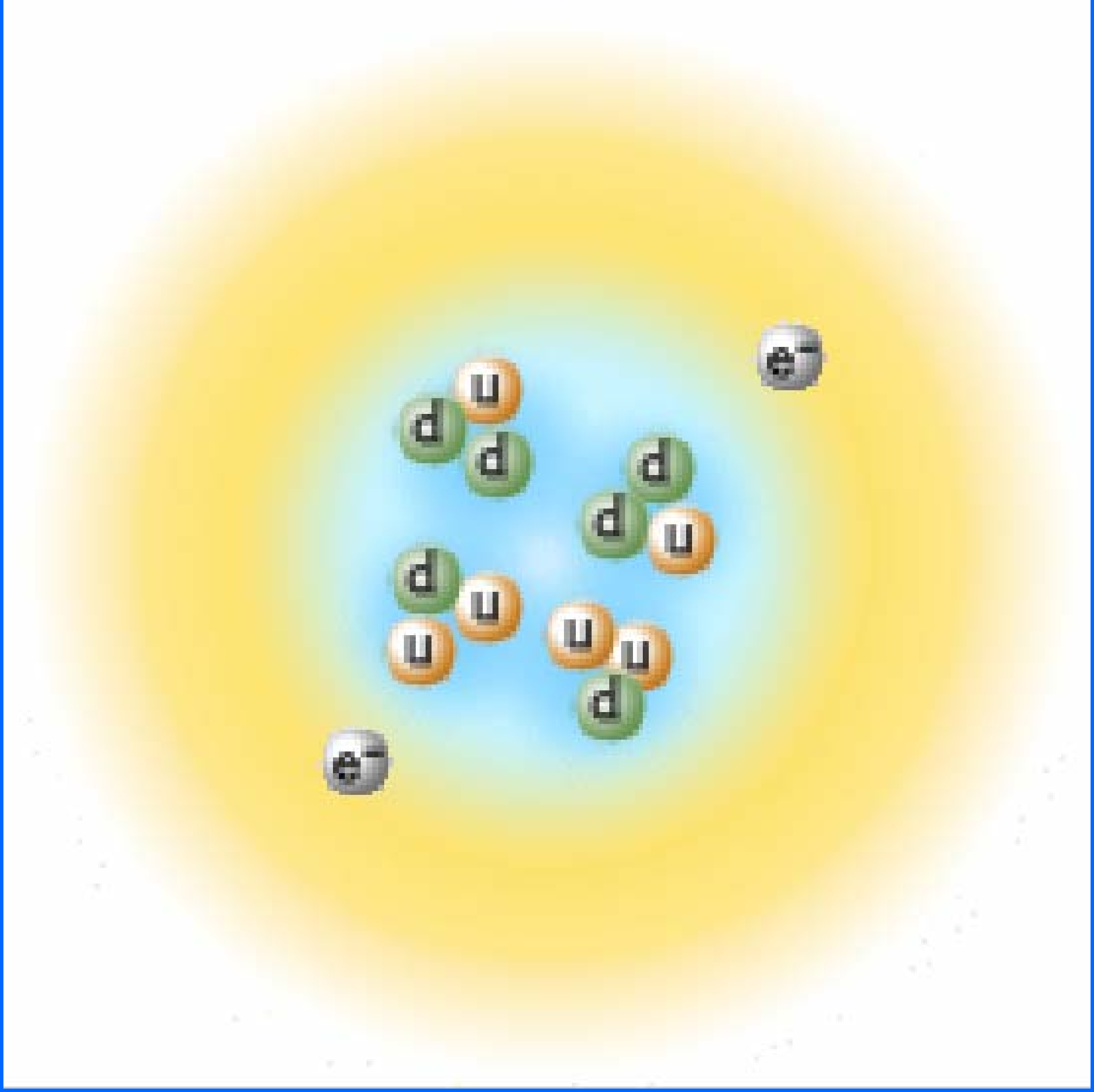
Prior to accelerators



Enter the accelerator

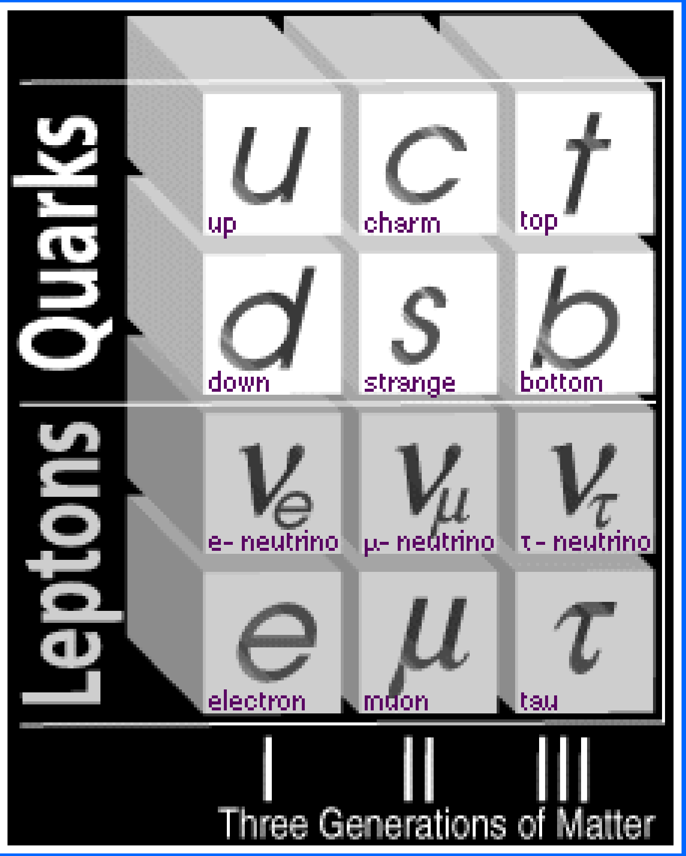
- By mid 1930s, our understanding of the fundamental structure of matter seemed complete.
  - Rutherford had shown that atoms have relatively tiny but massive ***nuclei***.
  - ***Quantum theory*** had made sense of atomic spectra and electron orbits.
  - Discovery of ***neutron*** had explained nuclear isotopes.
- ***Protons***, ***neutrons*** and ***electrons*** provided the basic building blocks of all matter.
- However, some puzzles remained:
  - What holds protons and neutrons together in the nucleus?
  - What are the forces involved in radioactive decays of nuclei?

Quark Concept



Standard Model

- The quark idea is well confirmed.
- Quarks are part of the *Standard Model of Fundamental Particles and their Interactions*.
- Discoveries have shown that there are six types of quarks (given the odd names of *up*, *down*, *strange*, *charm*, *bottom*, and *top*).
- Also, there are six types of particles including the electron, called *leptons*.
- Standard Model accounts for the *strong*, *weak*, and *electromagnetic* interaction of quarks and leptons.



Particle Physics

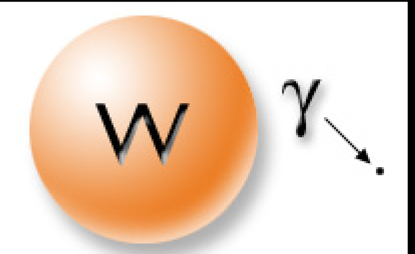
- Study of basic building blocks of matter and their interactions has led to an extraordinarily detailed understanding of the subatomic world.
- This work culminated in the ***unification*** of electromagnetism and radioactivity.
    - They are now understood to be different aspects of the same phenomenon.
- This achievement ranks as one of the great triumphs of the human intellect.
- This understanding was the result of experiments involving:
    - Particle ***accelerators*** that produce particle beams of ever increasing energy.
    - ***Detectors*** capable of measuring the complex interactions produced by the collisions of these high-energy particle beams.

Science Questions

- The Standard Model answers many of the questions about the structure and stability of matter.
- But the Standard Model leaves many other questions ***unanswered***:
  1. Why are there three types of quarks and leptons of each charge?
  2. Is there some pattern to their masses?
  3. Are there more types of particles and forces to be discovered at yet higher-energy accelerators?
  4. Are the quarks and leptons really fundamental, or do they, too, have substructure?
  5. Why so much matter and so little antimatter in the universe.
  6. What particles form the dark matter in the universe?
  7. How can the gravitational interactions be included in the standard model?

Riddle of Mass

- Why do the fundamental particles have mass, and why are their masses different?
- The Standard Model proposes that there is another field not yet observed, a field that is almost indistinguishable from empty space.
- We call this the *Higgs field*.
- We think that all of space is filled with this field, and that by interacting with this field, particles acquire their masses.
- Particles that interact strongly with the Higgs field are heavy, while those that interact weakly are light.
- The Higgs field has at least one new particle associated with it, the *Higgs particle* (or *Higgs boson*).



Why do some particles have large masses while the photon and neutrinos have puny masses?

- It is remarkable that a concept as familiar as mass was not explained until the proposal of the Standard Model.
- In the next little while we aim to detect the Higgs particle if it exists.
- This would be one of the greatest scientific discoveries in recent times!

Higgs Mechanism

Imagine that a room full of power producers chattering quietly is like space filled with the Higgs field ...

Higgs Mechanism

... a well-known power producer walks in, creating a disturbance as she moves across the room and attracts a cluster of admirers with each step ...

Higgs Mechanism

... this increases her resistance to movement, in other words, she acquires mass, just like a particle moving through the Higgs field ...

Higgs Mechanism

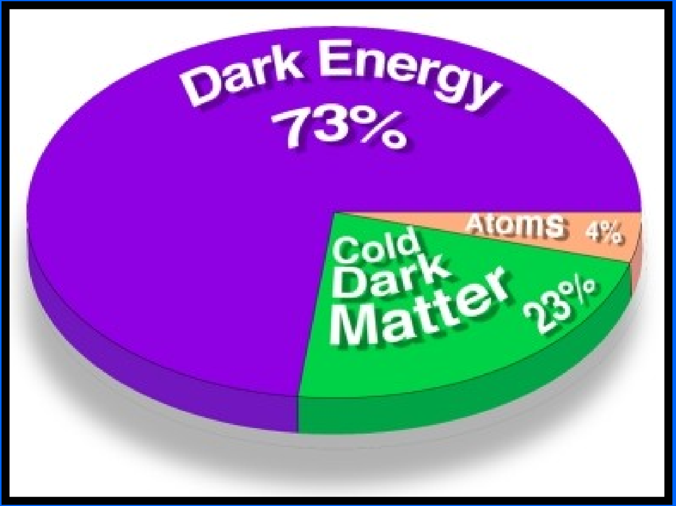
... if a rumor crosses the room, ...

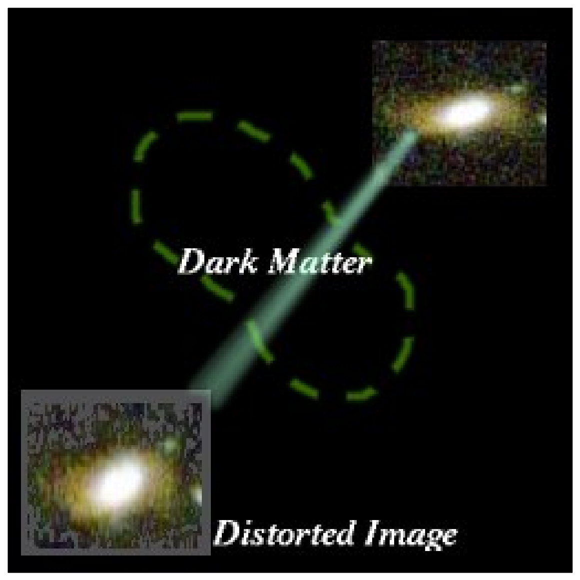
Higgs Mechanism

... it creates the same kind of clustering, but this time among the power producers themselves. In this analogy, these clusters are the ***Higgs particles***.

Dark Matter

- Scientists recently confronted a mind-boggling revolution when they realized that the majority of the universe (96%) is not made of the same type of matter as we are.
- From gravitational effects, we can infer the existence of a new type of matter that we cannot see: "*dark matter*".
- **What is dark matter?** We don't know.
- Upcoming particle physics experiments have a chance of answering this question.

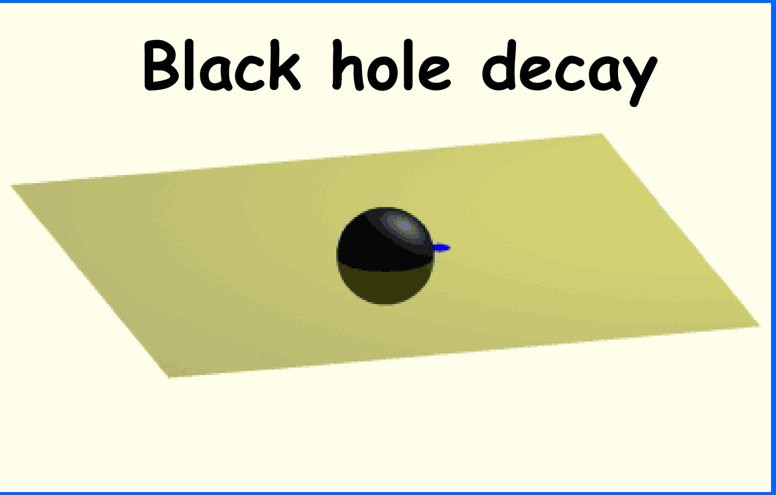




Extra Dimensions

- We think we live in a 3 dimensional world.
- But are we bugs that can not escape our surface?
- Nothing excludes small extra dimensions.
- Some theories, ***string theory***, favour extra dimensions.
- Extra dimensions help to explain the weakness of gravity.

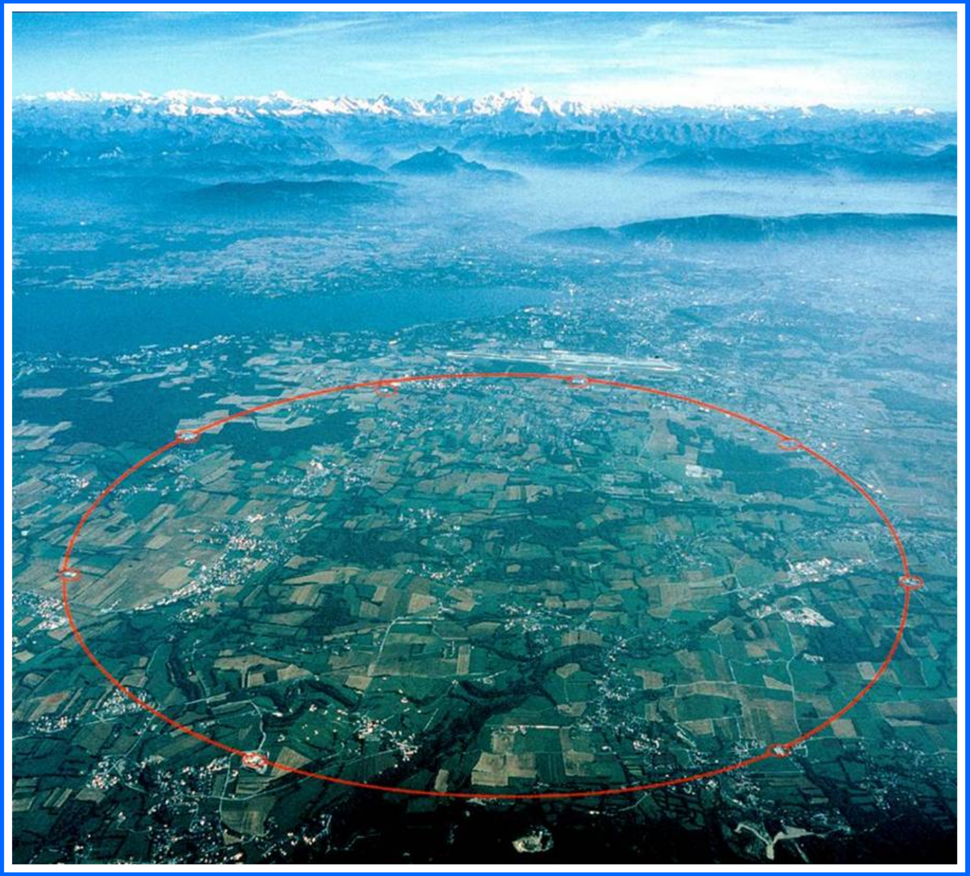
Black hole production



Accelerators

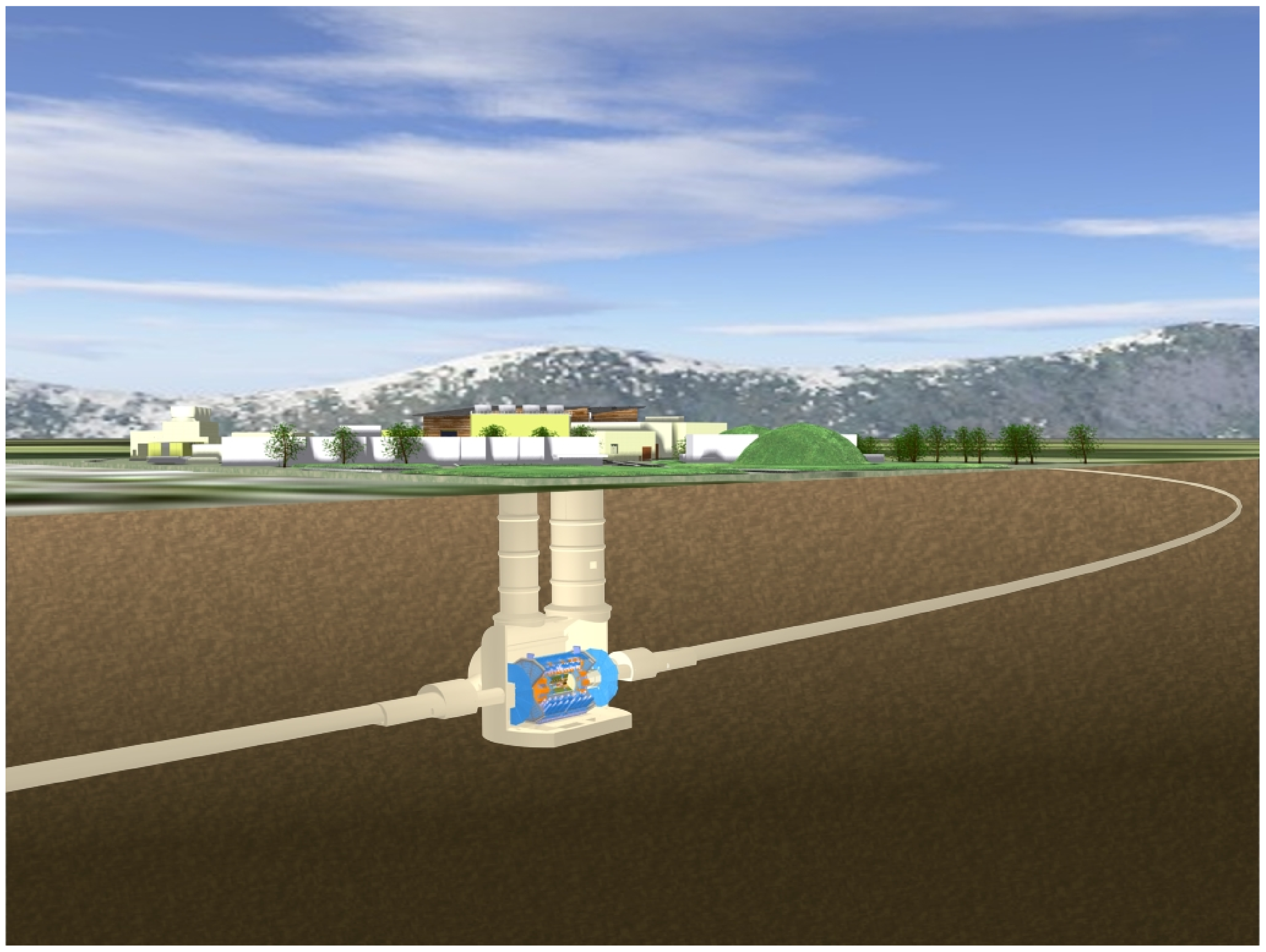
CERN Accelerators

- The greater the energy, the shorter the wavelength, and the smaller the particle that can be studied.
- The ***accelerator*** is a tool that allows physicists to resolve very small structures by producing particles with very high energy.



Large Hadron Collider at CERN

ATLAS Point



Abseiling down the access shaft

LHC Tunnel

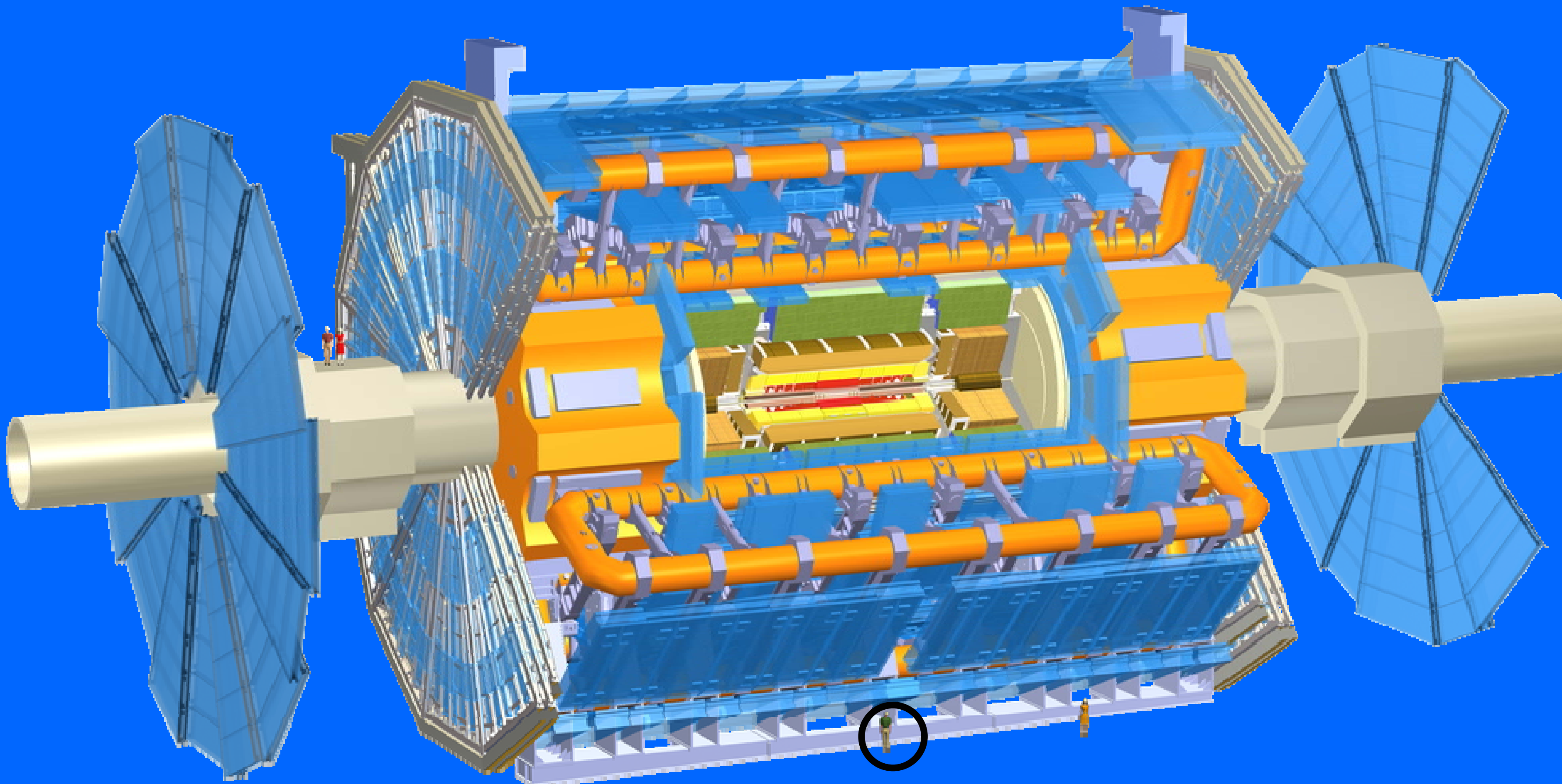
- 27 km distance around circumference.
- Vacuum similar to outer space (11 time better than moon).
- Beams make 11,000 laps per second
- Beam loose race with light to Alpha Centauri by 1 second (nearest star 4.3 light-years away).
- Beam energy: car driving at 1,700 km/hr, or 400 ton train at 150 km/hr.
- $8-billion facility.

Power Demands

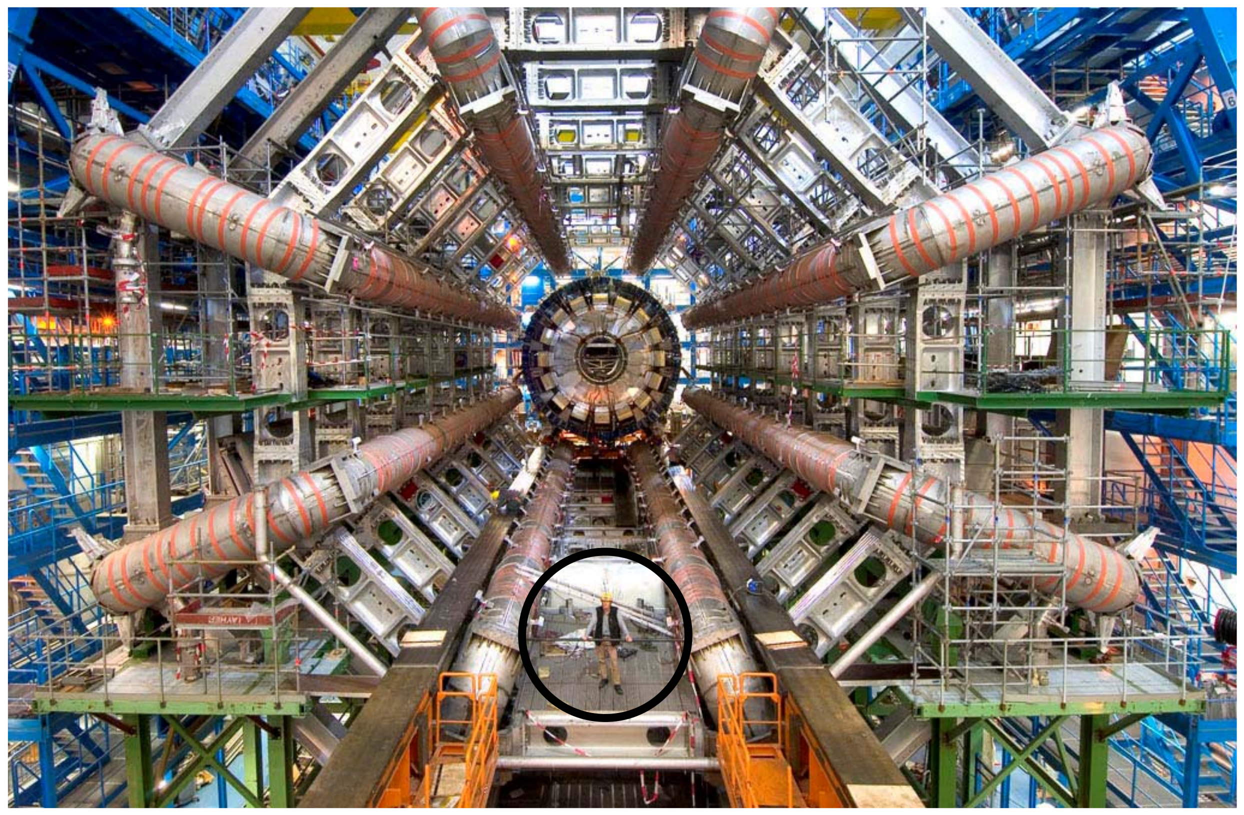
- Worlds largest array of superconducting electromagnets.
- Cooled to superfluid helium at 1.9 K (above absolute zero).
  - 1° colder than outer space.
  - World's largest fridge by 8 times.
- Power consumption: LHC 120 MW (230 MW all CERN)
- In 2009, 800,000 MWh (19 million Euros).
  - Not large increase over previous accelerators due to superconducting technology.

ATLAS Experiment

ATLAS Detector



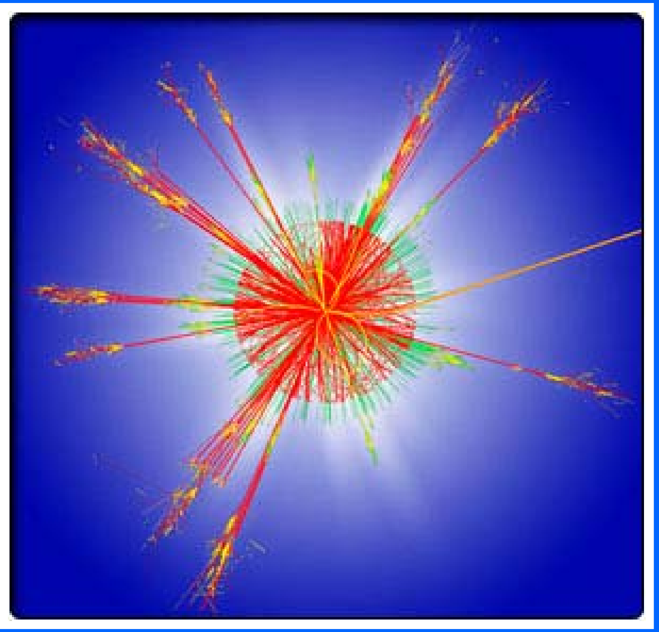
ATLAS Detector



- About 100 m underground.
- Cavern 10 stories high.
- Weight 7,000 tonnes.
- 46 meter long.
- 3,000 km of cables.
- Some components use liquid argon.

Interesting Events

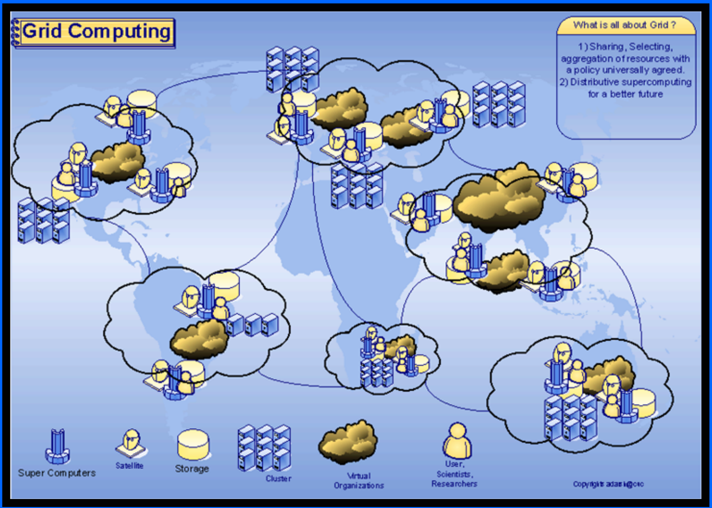
When beams collide, some events are "interesting" and may tell us about exciting new particles or forces, whereas many others are "ordinary" collisions (often called "background").



- The ratio of their relative rates is about 1 interesting event for 10 million background events.
- Such ***interesting events*** could represent the ***discovery*** of a new particle or phenomena.

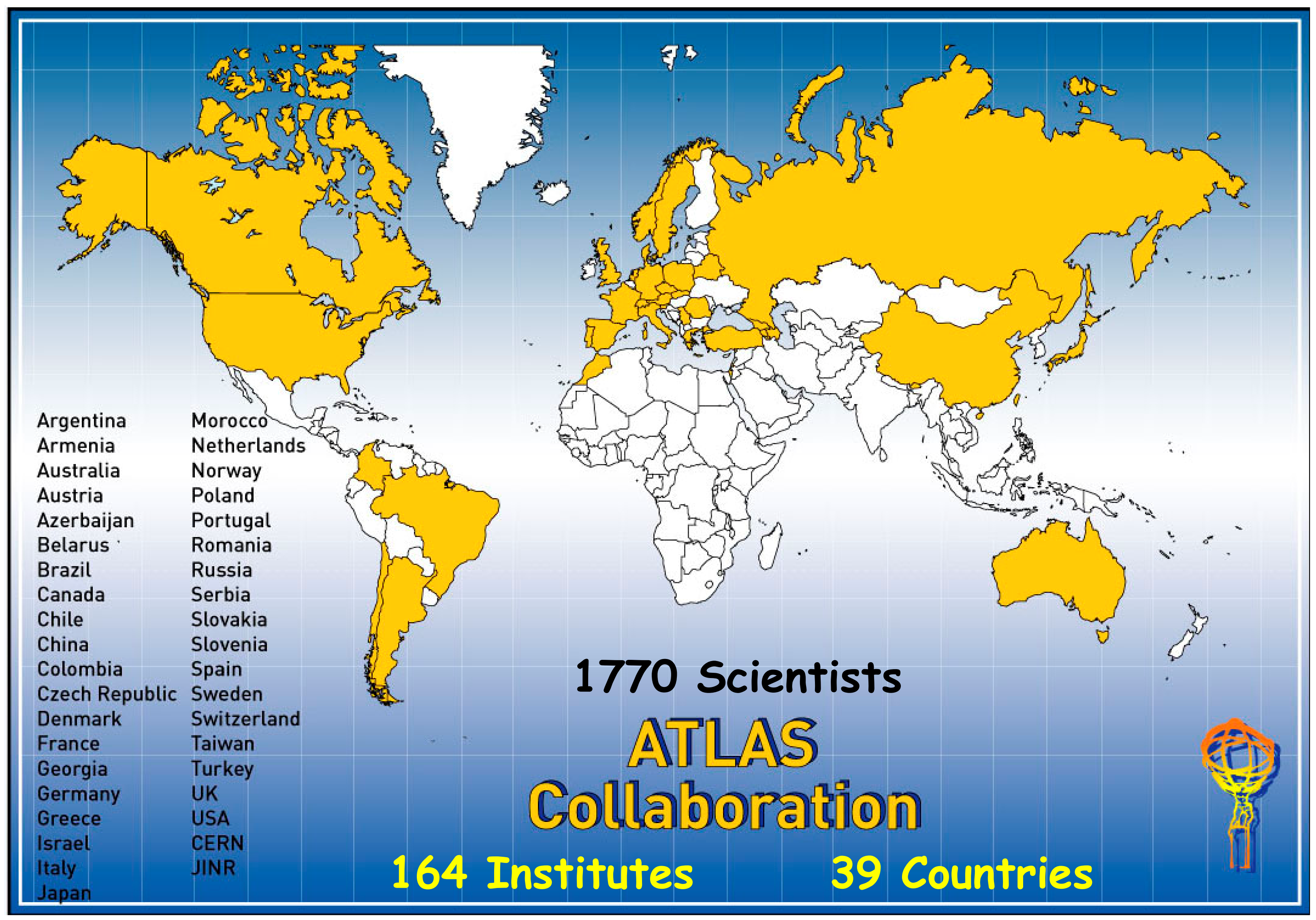
Grid Computing

- In the ATLAS detector there will be about a billion collision events per second (a data rate equivalent to twenty simultaneous telephone conversations by every person on the earth).
- 200 interesting collisions per second (27 CDs per minute)
- Yearly data equivalent to 600 years of listening to music.
- Use virtual computer consisting of available world resources.
- *Grid computing* is like a power grid.

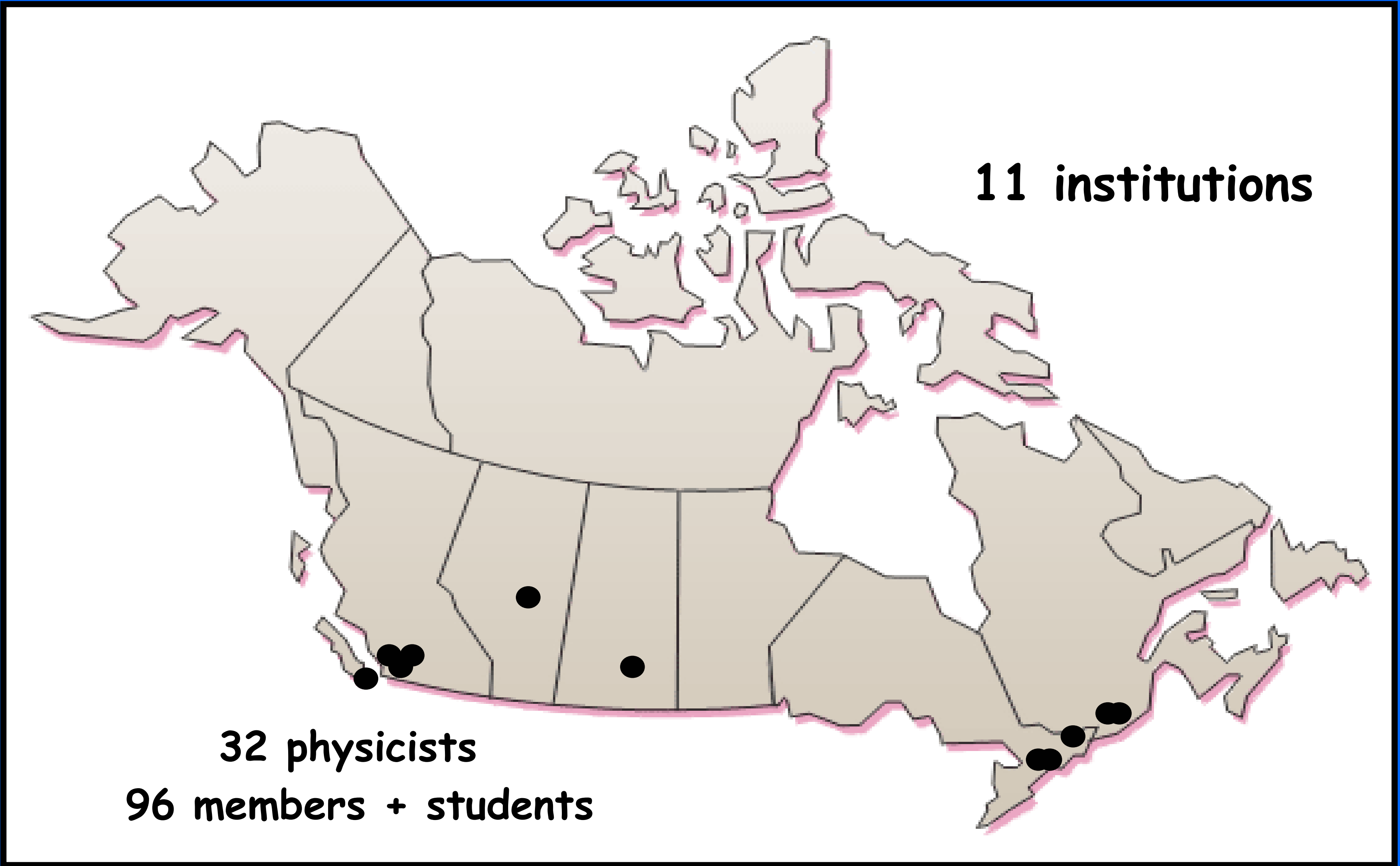


People

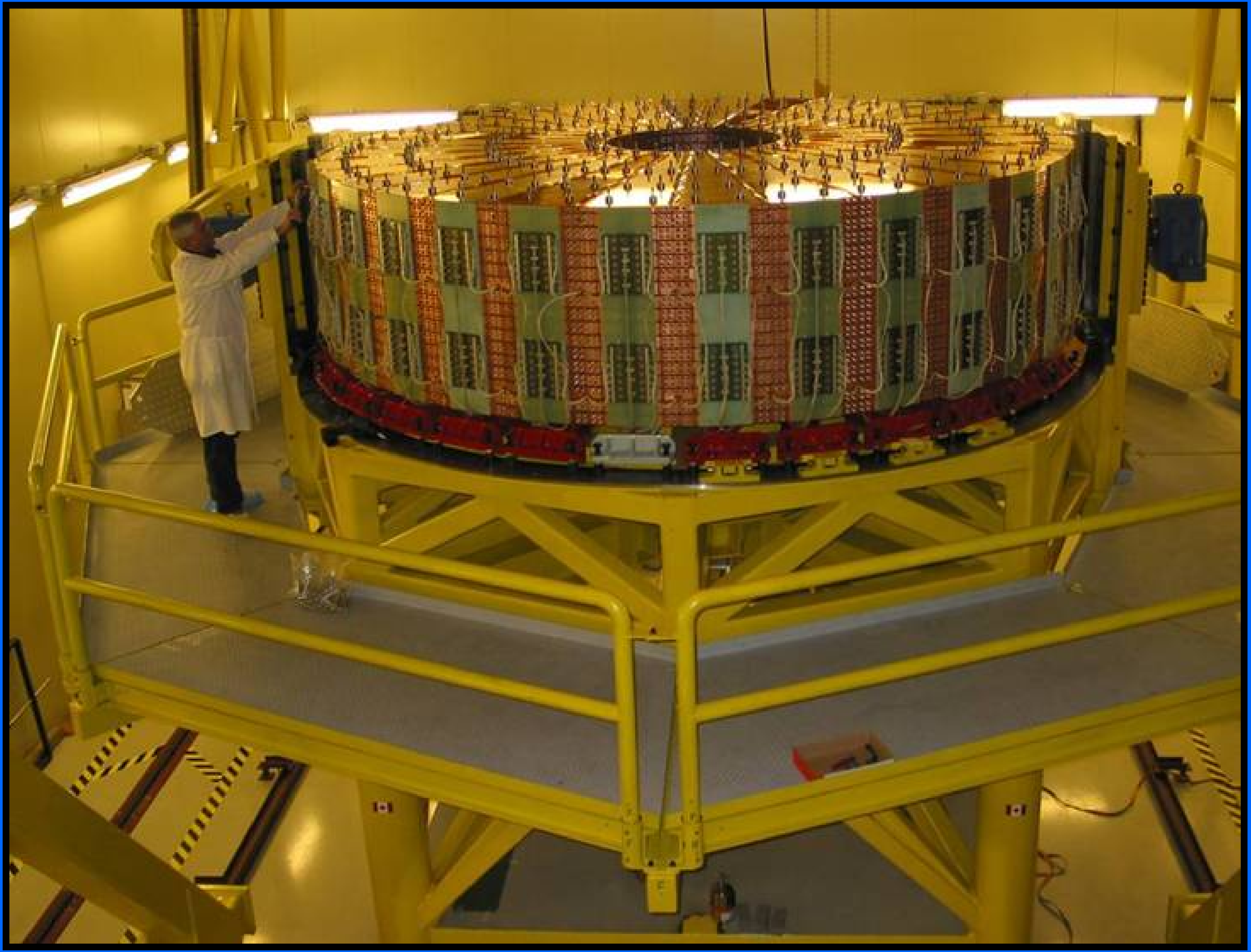
ATLAS Collaborating



Canadian ATLAS Collaboration

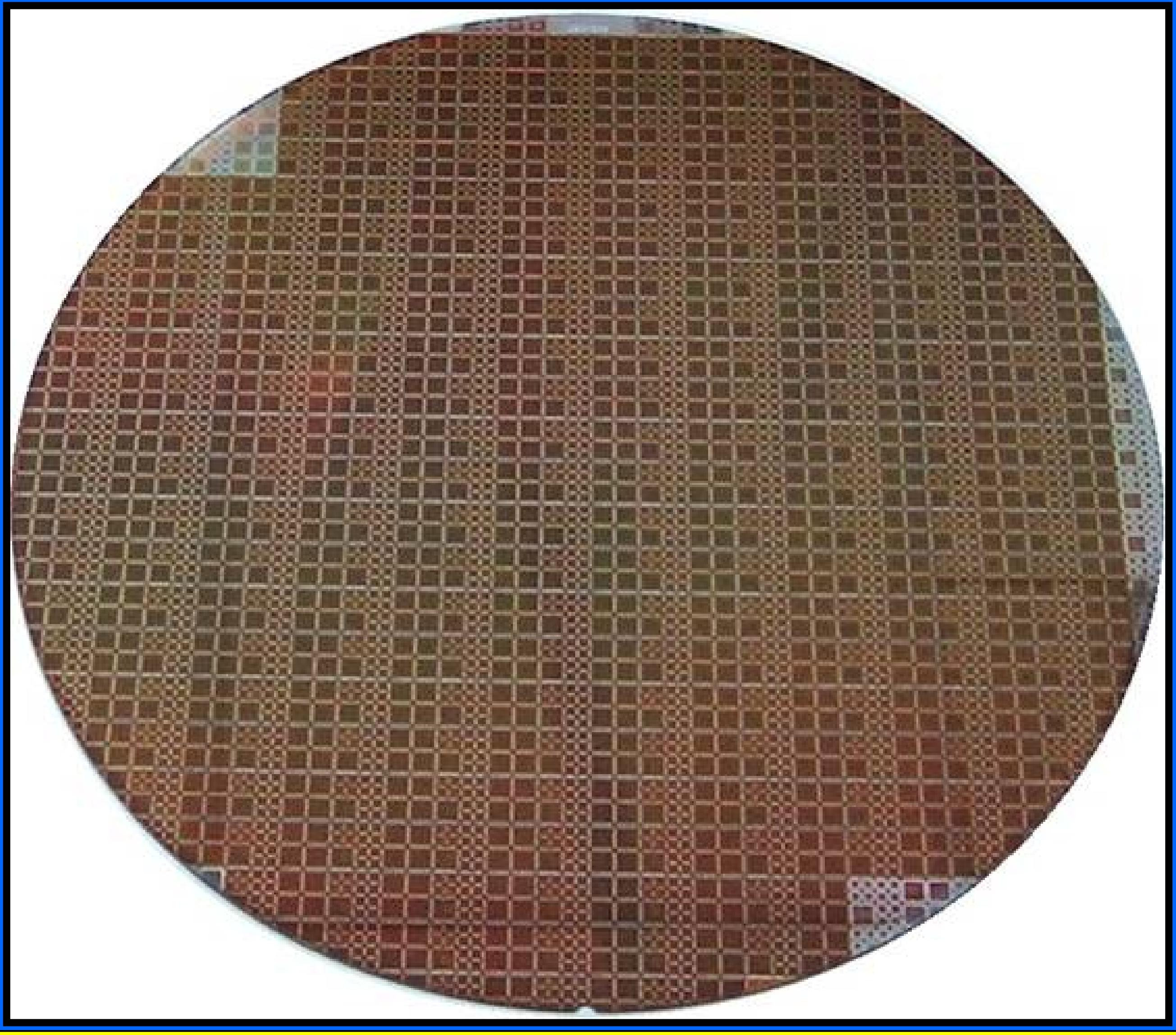


Canadian Contributions

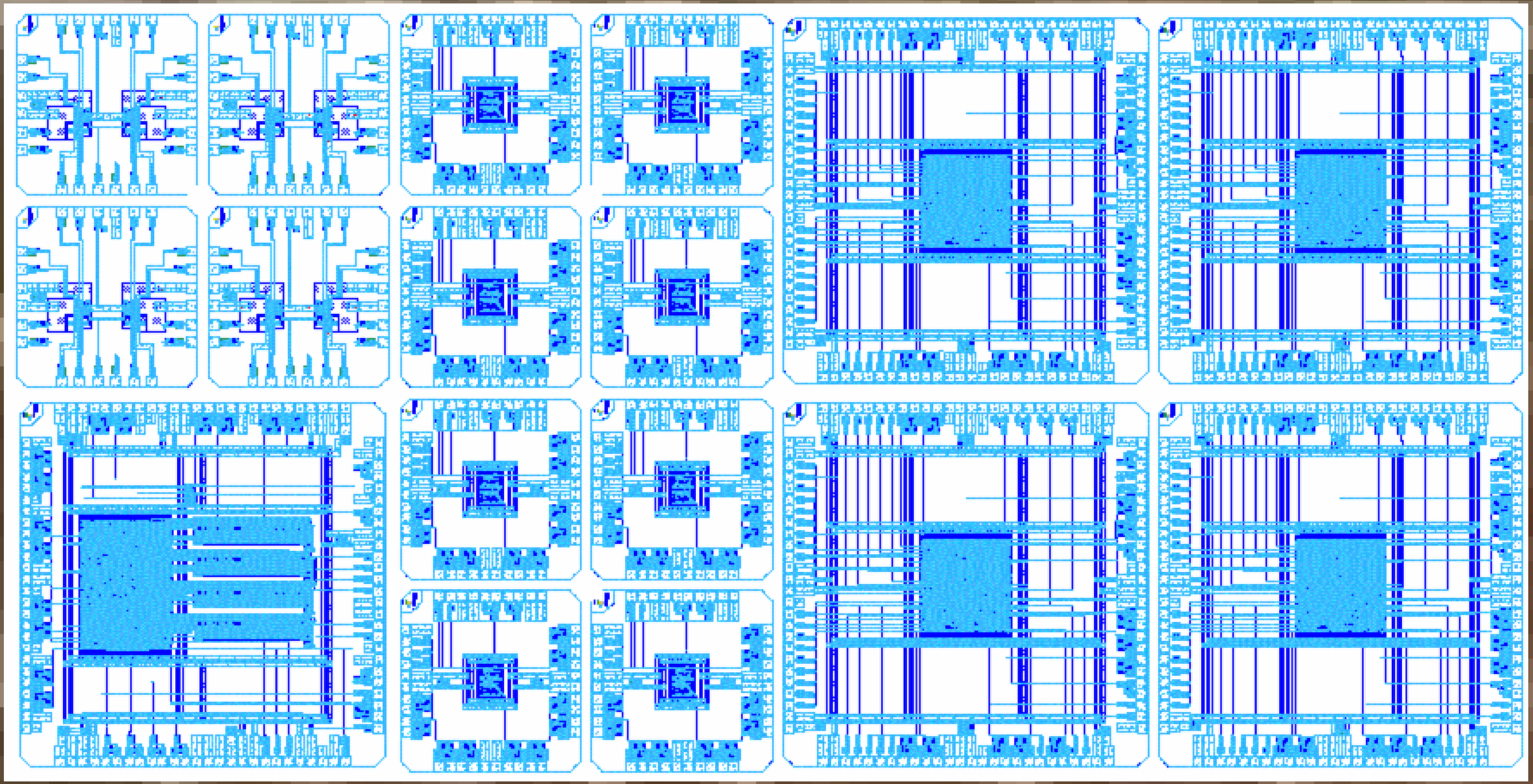


Canadian Contributions

Alberta Contributions



Alberta Contributions



ATLAS Timeline and Readiness

- Dec. 1992: Submitted Letter of Intent.
- Dec. 1994: Submitted Technical Proposal.
- Apr. 1997: Canadian capital funding in place.
- Apr. 1998: Civil engineering began.
- Dec. 2006: Most detector construction completed.
- Feb. 2008: Installation completed.

- Apr. 2008: Most commissioning complete.
- May 2008: Test detector with cosmic rays.
- Jun. 2008: Commission accelerator beams.
- **Sep. 2008: First science!**

Summary and Prospect

- The questions that can be answered at upcoming accelerators are far reaching (origin of mass, dark matter, extra dimensions, etc.).
- The LHC accelerator and ATLAS experiment aim to unlock the mysteries to these questions.
- One of the most important particle physics experiment to come online in 20 or 30 years.
- After 16 years of R&D we are excited to start.
- **Likely that some new discovery will be announced within a couple of years!**