CERN, LHC
and the particle adventure

Bernhard Meirose
CERN

- European Organization for Nuclear Research
- World's largest particle physics laboratory
- Situated in the Northwest suburbs of Geneva on the Franco–Swiss border
- 20 European member states
- International facility officially under neither Swiss nor French jurisdiction
- Birthplace of the World Wide Web (W.W.W)
History

- Established in 1954 (originally with 12 member states)
- The acronym CERN originally stood, in French, for Conseil Européen pour la Recherche Nucléaire (European Council for Nuclear Research).
- Werner Heisenberg suggested the name could still remain CERN.
- However, the name that best describes current research at CERN is European laboratory for particle physics!
### Member States and Budget

#### Financing (Budget 2009)

<table>
<thead>
<tr>
<th>Member state</th>
<th>Contribution</th>
<th>Mil. CHF</th>
<th>Mil. EUR</th>
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<tr>
<td>Germany</td>
<td>19.88 %</td>
<td>218.6</td>
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<td>France</td>
<td>15.34 %</td>
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<td>United Kingdom</td>
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<td>Italy</td>
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<td><strong>100 %</strong></td>
<td><strong>1098.6</strong></td>
<td><strong>724.0</strong></td>
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- **Note:** Contributions are calculated as a percentage of each country's GDP.
CERN is so famous that even Tom Hanks went there for vacation.
Main function is to provide the particle accelerators and other infrastructure, like particle detectors, needed for high-energy physics research.

Currently CERN operates a network of 6 accelerators and and a decelerator.

I will talk more extensively about the most powerful accelerator: The Large Hadron Collider (LHC)

However mind that not all experiments or research at CERN surrounds the LHC or even an accelerator.

The CAST experiment for example is searching for hypothetical particles (called "axions") using a specialised telescope for looking at the Sun.
but...

- What is a particle accelerator?
- What is a particle detector?
- And last but most important ...

Why are we building these things in the first place?
Why do we need accelerators?

- All goes back to Sir Ernest Rutherford ...

- He used atoms of helium (minus their electrons) to bombard atoms from a wide variety of materials.

- The helium atoms are produced at radioactive decays of heavy elements (Sir E. had no accelerator).

- He then observed the directions in which the helium atoms were deflected by the target atoms, and found that a few were deflected through very large angles.

- He concluded most of the atom’s mass was concentrated in a small region, the atomic nucleus.
"Seeing" (really!) small things

- Physicists needed a tool like Rutherford´s to look inside the atom, but now they wanted to see inside the nucleus itself...
- How?
- "Easy": you just need more energy ....
- Reason: quantum theory establishes that for each particle, the higher the momentum (p), the smaller the wavelength (λ):

\[ \lambda = \frac{h}{p} \]

h is Planck´s constant, which is the fundamental constant of quantum theory.

- Message is: the greater the momentum, the smaller the particle that can be studied.
So ...

- The more energy (momentum) you have the smaller the things you can observe.
- To give a particle lots of energy you need to accelerate it.
- *How can one do that, in other words, how does an accelerator, like the LHC, work?*
How does an accelerator work?

When a proton travels from the \(+\) pole to the \(-\) pole of a battery, it reaches a high speed.

But when the proton arrives at a \(+\) pole, it is repelled.

To go even faster, you need to add several batteries, one after another.

If the proton is to be accelerated, the polarities \(\pm\) must continually change at the right frequency.

This principle is used in accelerating cavities.
How does an accelerator work (LHC)?

- At the LHC many batteries are put one after the other around a ring of 27 km.
- The high-energy protons travel inside vacuum pipes in an underground tunnel. They are kept in approximately circular orbits by strong magnetic fields produced by superconducting magnets. The higher the energy, the larger the orbit, the longer the tunnel, the more magnets needed, and the higher the cost.
- In the case of the LHC the idea is to create two counter-rotating beams of protons and to have protons from one beam collide with protons from the other, hence the name "Collider".
What else can we use an accelerator for?

- Look inside small things: OK
- **Produce new particles!**
  
  - \( p + p \rightarrow X + Y \) (\( X \) and \( Y \) are two new particles)
  
  - Einstein's theory says that: \( E = mc^2 \)

  - So \( MX + MY = E \) \((p + p)/c^2\) (\( MX \) and \( MY \) are their masses)

  - If \( E \) is enough you can produce new particles never before produced by any previous accelerator! (perhaps you had \( E < (MX + MY)c^2 \))

  - Nice.. but why? What's so special about producing new particles?
Why do we want to detect new particles?

- The particles are signatures of the models, by measuring the particles you are testing the models.
- The current accepted model in particle physics is called the Standard Model.
- Almost all particles predicted by the Standard Model have so far been detected, which means the model (concluded in 1978) passed through extensive experimental tests.
- I will talk a little bit more about the Standard Model and about the final piece missing...
The Standard Model (of particle physics)

- Standard Model is the fundamental model that explains how fundamental particles interact.
- The chart shows the SM particles.
- The formulation of the Standard Model is beautiful but it involves sophisticated mathematics (I’m afraid this involves going to college...)
- In any case, you can see something of this structure by noticing how particles are arranged.
- One particle is missing on the list is called **the Higgs particle**.

<table>
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<th>Charm (c)</th>
<th>Top (t)</th>
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<tr>
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<td>4.8 MeV</td>
<td>171.2 GeV</td>
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<tr>
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<td>$\frac{1}{2}$</td>
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<table>
<thead>
<tr>
<th>Leptons</th>
<th>Electron (e)</th>
<th>Muon (μ)</th>
<th>Tau (τ)</th>
<th>Z Weak Force (Z$^0$)</th>
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<tr>
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<td>1.105 MeV</td>
<td>1.777 GeV</td>
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</table>

<table>
<thead>
<tr>
<th>Bosons (Forces)</th>
<th>W Weak Force (W$^\pm$)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>80.4 GeV</td>
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<tr>
<td></td>
<td>$\pm 1$</td>
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</table>

- Electron neutrino ($\nu_e$): <0.17 MeV
- Muon neutrino ($\nu_\mu$): <15.5 MeV
- Tau neutrino ($\nu_\tau$): 0.1 MeV
What is the Higgs particle?

- **The Higgs a particle** predicted by the Standard Model and its importance relies on the fact that all other particles depend on it to have mass.

- What happens is that in the SM, the particles I just showed interact with something called **the Higgs field**.

- The Higgs field is a sort of infinite medium where the particles are immersed. You can think of this medium as having some viscosity, so when the particles are there they acquire some resistance to variation of velocity.

- **This is what mass is: resistance to variation of velocity.**

- The problem is that one expect this medium to form something like bubbles (quanta of the field), which is the Higgs particle itself.

- **So if there is no Higgs one can infer that this medium also does not exist but then, how is it possible that particles have mass?**
So what if there is NO Higgs...?

- Disclaimer: opinions expressed here may not be of the whole particle physics community. That said...

- **Standard Model predicts a Higgs particle, so no Higgs means no Standard Model.**

- Since the Standard Model worked so successfully until now, this would represent an enormous puzzle.

- So far, all particles predicted by the SM were found: W and Z bosons, quarks (last one in 1995).

- One can fix this with new proposals but whatever this fix would be it will NOT be the Standard Model.
Why could it take years to detect some of the new particles?

- **Problem is in quantum mechanics.**

- Quantum theory tells us that **you cannot predict when a process will occur.** The best you can do is to know its **probability.** There is no way to change this or to force the process.

- If a process like $p,p \rightarrow X + Y$ has a small probability to occur you have collide $p$ with $p$ as many times as possible to be sure. It's like throwing a dice to get a specific number. If you throw it enough times eventually you will get it.

- **The second point is that this probability is a function of the energy of the process.** So some processes are unlikely to happen at the energies of previous colliders but we predict the probability to raise drastically at the LHC energies, so we also expect new particles to appear very soon.

- Some discoveries could have already been made, but we didn't find the particles. **Problem is that another complication to this is that the higher the mass of a particle the smaller the probability to be produced and the theories do not predict these masses,** we have to guess. So when we don't find a particle sometimes we think the problem was that its mass is larger than we thought at first.

- **Point here of course is that these models are not necessarily correct.** It could also be that the problem does not rely on the fact that the particle is heavy **but that it does not exist at all.**
Is there any other reason to search for new particles?

- Searching for the Higgs is an interesting thing, but personally, by far, **not the most interesting one**.
- Since the particles are signatures of the models, by searching for new particles not predicted by the Standard Model, one is **searching for new models, i.e. for new physics**.
- Since the Standard Model was so successful in explaining the experiments, why bother?
- Devil is in the details.
- **With all its success the Standard Model left many things unexplained**.
- This is not to say that it gives a wrong answer, it simply gives NO answer.
Fundamental questions

- Why there is more matter than anti-matter in the Universe?
- How can we understand the gravitational force at the microscopic level?
- What is the nature of the so called dark matter?
- Why is the Universe expanding at an accelerated rate?
- Is the Higgs mechanism correct or is there another way to generate mass for fundamental particles?
- Many more questions that I have no time to go through...
An example: Supersymmetry

- **Supersymmetry (SUSY)** is the most popular beyond Standard Model theory among particle physicists.

- It roughly says that there is a symmetry in Nature that for all existing particles there is a a "superpartner". The electron for example should have a superpartner called the "super electron" or "selectron".

- Nobody knows if it is realized in Nature, reason why we need to test it.

- It is popular because it offers possible explanations by some of the things for which our current Standard Model has nothing to say.

- For example: among the many new particles that SUSY predicts there is one called the "neutralino".

- A neutralino would be heavy, stable and neutral. The fact that is neutral means it does not interact via the electromagnetic force, so it would emit no light. The fact that is stable and heavy means it would interact via the gravitational force. The neutralino is therefore a perfect candidate to explain the puzzle of dark matter.

- But even if the LHC produces selectrons, neutralinos or the Higgs the question is: **How can we detect them?**
Basic Idea of Colliding Beam Experiment

- Colliding Beams: During a colliding-beam experiment, the particles radiate in all directions, so the detector is spherical or, more commonly, cylindrical.
Basic detector components

![Diagram showing basic detector components]

- **Tracking chamber**
- **Electromagnetic calorimeter**
- **Hadron calorimeter**
- **Muon chamber**

Phases:
- **photons**
- **e±**
- **muons**
- **π±, p**
- **n**

Innermost Layer... → ...Outermost Layer
What is ATLAS?

- **ATLAS** (A Toroidal LHC Apparatus)
- It is a **general purpose detector** (broad range of signals).

- Protons will be accelerated in the **LHC** and collide in the middle of **ATLAS**.
• ATLAS has approximately 3000 collaborators.

• In addition to Lund, there are three other Swedish groups in ATLAS, from Uppsala, University of Stockholm and KTH (Royal Institute of Technology, Stockholm).

• The ATLAS project is an international collaboration involving 38 countries. Each of these countries is shown with color on the map in the next slide.
Will new discoveries make our current knowledge obsolete?

- **No.**

- Reason: theories have domain of validity, what we discovered so far was confirmed by experiments and this will still remain as a useful approximation.

- Example: Newtonian mechanics is an excellent approximation to explain movement for things moving in a speed that is small compared to the speed of light.

- For things (like particles in an accelerator) moving close to the speed of light you use Einstein´s theory of relativity but to understand the movement of a car you still use Newton´s theory.

- So Newton´s theory is a special case of Einstein´s theory for $v \ll c$.

- We might discover a new model (by detecting new particles), but the Standard Model will still be an approximation of this model valid to energies smaller than of the LHC.
Will the Large Hadron Collider *destroy* the earth?

**Yes** 30.3%  
75996 Votes

**No** 69.7%  
896 Votes

The vote was started by Wall of the World. Why?

Say your word

- My name:
- My opinion:  
  - No, it will not destroy
  - Yes, it will destroy
- My website:
- My comment:

Invite your friends to say their word

- Friend’s email:

Add my opinion

Read 12345578 comments

Share on: Delicious Digg Stumbleupon Facebook Myspace

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Is the knowledge we learn at CERN useful for society?

- Science can be viewed from an utilitarian perspective, but this is not what drive scientists like myself.

- The main reason to (try to) make discoveries is not to make better mobiles (or worse, to find ways to improve Facebook).

- **The reason to make discoveries in physics is to understand the Universe.** A society that has good science is a better society. The utilitarian part will follow naturally (technology).

- Ask yourself why does anyone want to explore new planets or to discover extraterrestrial life (intelligent or not). Is it because of the utility of it or would you be also interested to know?

- Remember: applied science is only possible if there is basic science otherwise there is no science to be applied to.
For more information

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  - http://microcosm.web.cern.ch/microcosm/LHCGame/LHCGame.html
  - http://video.ias.edu/space-time (talk by Nima Arkani-Hamed)

- Contact: bernhar.meirose@hep.lu.se