Waiting for LHC

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Outline

1. What is LHC?
   - General Information
   - 10 Facts About LHC[1]
2. Standard Model
3. Questions Unanswered by the Standard Model
   - Unification of Forces and Gravity
   - Higgs Boson and the Masses of the Particles
   - Hierarchy Problem
   - Family and Flavor Problems
   - Dark and Bright Stuff
4. Disaster Scenarios
5. Possible Models to Answer the Questions

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- LHC stands for Large Hadron Collider
- It is an accelerator at CERN
- Protons and Pb ions will be accelerated
- Includes 6 Experiments: ALICE, ATLAS, CMS, LHCb, LHCf, TOTEM

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10 FACTS ABOUT LHC

- When the 27-km long circular tunnel was excavated, between Lake Geneva and the Jura mountain range, the two ends met up to within 1 cm.
- Each of the 6400 superconducting filaments of niobium–titanium in the cable produced for the LHC is about 0.007 mm thick, about 10 times thinner than a normal human hair. If you added all the filaments together they would stretch to the Sun and back five times with enough left over for a few trips to the Moon.

- All protons accelerated at CERN are obtained from standard hydrogen. Although proton beams at the LHC are very intense, only 2 nanograms of hydrogen(*) are accelerated each day. Therefore, it would take the LHC about 1 million years to accelerate 1 gram of hydrogen.
- The central part of the LHC will be the world's largest fridge. At a temperature colder than deep outer space, it will contain iron, steel and the all important superconducting coils.
- The pressure in the beam pipes of the LHC will be about ten times lower than on the Moon. This is an ultra high vacuum.

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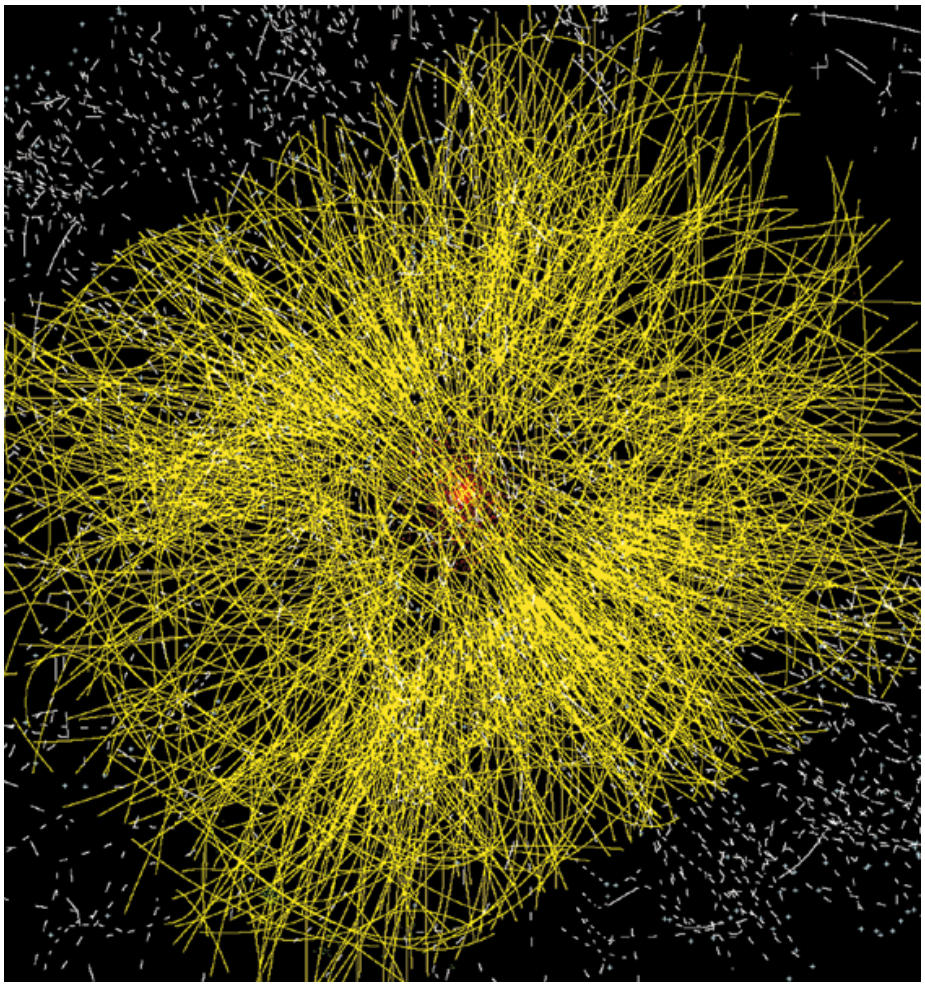
- Protons at full energy in the LHC will be travelling at 0.999999991 times the speed of light. Each proton will go round the 27 km ring more than 11 000 times a second.
- At full energy, each of the two proton beams in the LHC will have a total energy equivalent to a 400 t train (like the French TGV) travelling at 150 km/h. This is enough energy to melt 500 kg of copper.

- The Sun never sets on the ATLAS collaboration. Scientists working on the experiment come from every continent in the world, except Antarctica.
- The CMS magnet system contains about 10 000 t of iron, which is more iron than in the Eiffel Tower.
- The data recorded by each of the big experiments at the LHC will be enough to fill around 100 000 DVDs every year.



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Particles in the Standard Model:

- Quarks

$$\begin{pmatrix} Q=+\frac{2}{3} \\ Q=-\frac{1}{3} \end{pmatrix} \begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$

- Leptons

$$\begin{pmatrix} Q=0 \\ Q=-1 \end{pmatrix} \begin{pmatrix} e \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

- Gauge Bosons: 8 gluons, $W^{\pm}$, Z^0, γ: 12 gauge bosons
- Higgs Boson

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Forces Described By the Standard Model

- Forces appear as a result of the exchange of gauge bosons
- Gluons are responsible for the strong interactions that bind quarks into hadrons
- $W^{\pm}$ and Z boson are responsible for weak interactions. $W^{\pm}$ change the type of the quarks and leptons
- γ is responsible for electromagnetic forces
- Z boson is similar to a massive photon

$$
\begin{aligned}
\mathcal{L} \;=\; & \sum_i \bar{Q}_L^i i \not{\mathcal{D}} Q_L^i + \sum_{q=u,d,c,s,t,b} \bar{q}_R \not{\mathcal{D}} q_R \\
& + \sum_i \bar{L}_L^i i \not{\mathcal{D}} L_L^i + \sum_{q=e,\mu,\tau} \bar{q}_R \not{\mathcal{D}} q_R + |\mathcal{D}_\mu \Phi|^2 \\
& - \frac{1}{4} \mathrm{Tr} W_{\mu\nu} W^{\mu\nu} - \frac{1}{4} \mathrm{Tr} G_{\mu\nu} G^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} \\
& + \sum_{ij} \lambda_{ij}^d Q_L^i \Phi d_R + \sum_{ij} \lambda_{ij}^u Q_L^i \Phi^c u_R + \sum_{ij} \lambda_{ij}^l L_L^i \Phi e_R \quad (1)
\end{aligned}
$$

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Unanswered Questions

- Where is gravity?
- Do all three(four) forces unify?
- Where is the Higgs Boson?
- What is the origin of mass?
- Hierarchy Problem
- What is the origin of the free parameters of the SM?
- Why do we have only three family of leptons and quarks?
- Why is the electric charge quantized?
- What is then nature of dark matter?
- What is the nature of dark energy?
- What is the origin of the matter-anti-matter asymmetry of the universe?

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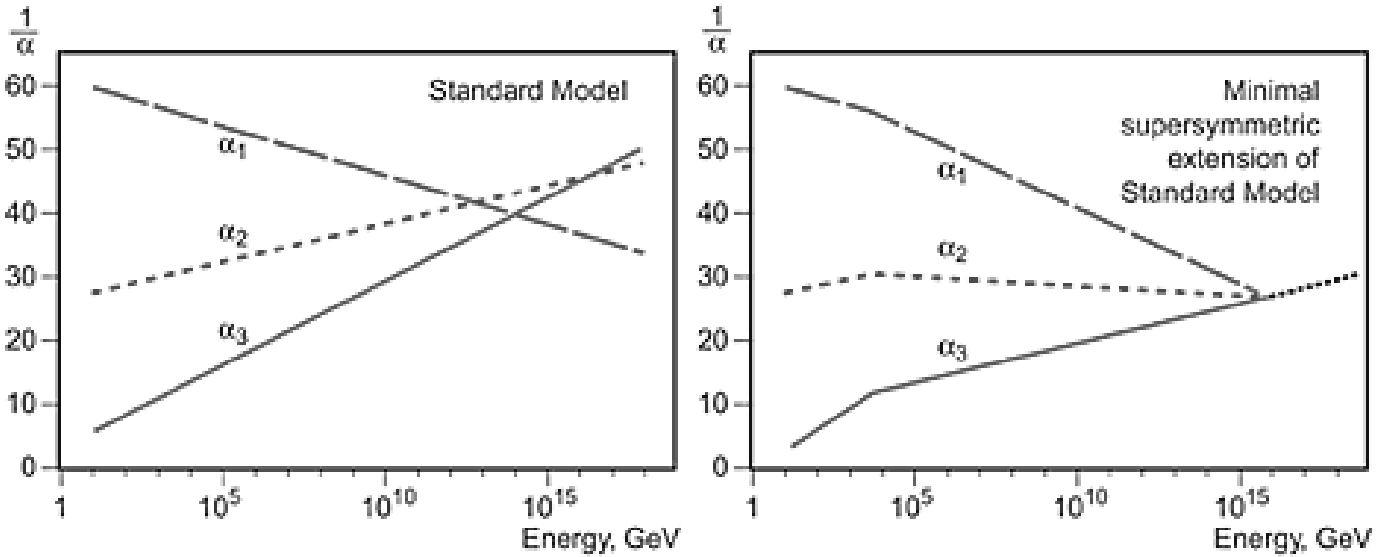
Unification and Gravity

- SM describes all the three forces except gravity.
- Gravity is 10^{40} times weaker than the electromagnetic interactions.
- Each of the three forces has its own coupling constants
- Coupling constants tend to approach each other at high energies.
- They seem to come very close together at energies around 10^{16} *GeV*
- Is it possible to unify all three forces just as electromagnetism unified electricity and magnetism?



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- In order to include the masses in the SM, a Higgs boson has to be introduced.
- The Higgs boson has not been observed yet.
- The Higgs boson mass is expected to be $m_H \simeq 150\ GeV$
- The mass of the Higgs boson receives large quantum corrections
- The corrections are of the order of the new physics scale
- The next known physics scale is the Planck scale.

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- The Newton's constant can be written as $G_N = \frac{1}{M_{pl}^2}$ in units where $\hbar = c = 1$
- Smallness of gravity is the problem of largeness of the Planck mass: $M_{pl} \simeq 10^{19}\ GeV$
- How can it be possible for a single fundamental theory to explain such different hierarchy?

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Family and Flavor Problems

- Why are there three copies of quark and lepton families?
- Why are there equal number of quark and lepton families?
- Why do quarks mix?
- What is the reason of the hierarchy of quark masses? $m_u \simeq 6\ MeV$ and $m_t \simeq 130\ GeV$
- What is the origin of neutrino masses?

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Dark and Bright Stuff

- 73% of the total energy of the universe is in the form of dark energy
- 23% is in the form of dark matter
- 4% is in the form of ordinary matter that we know
- What does the dark matter consist of?
- What is dark energy?
- How is it possible that we have more matter than anti-matter

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Disaster Scenarios

- Possibility of formation of mini-black holes that might eat up the world
- Possibility of formation of strangelets that would transform all ordinary matter into strange matter

Other Models

- SuperSymmetry-SUSY
- String Theory
- Grand Unified Theories (GUT)
- Extra Dimensions
- Technicolor
- Preon Models

Summary

- NO CONCLUSION...

http://cdsweb.cern.ch/record/1092437/files/CERN-Brochure-2008-001-Eng.pdf

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