A search for new physics at the LHC: top partners into same-sign leptons.

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Physics beyond the Standard Model

- What is the Standard Model of particle physics?
- Why do physicists like it?
- Why are we not completely satisfied with it?

Modern physics and the Standard Model

Simmetry

Let's review it in "old" physics first.

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1. Theory + experiment $\longrightarrow$ force or potential energy.
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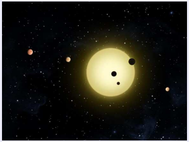
 $+$  $\longrightarrow U(r) = -\frac{GMm}{r}.$

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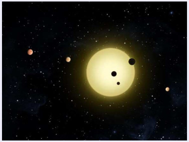
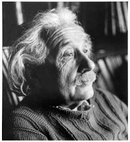
 +  $\longrightarrow U(r) = -\frac{GMm}{r}.$

Depends only on the distance r, simmetry under rotations.
Angular momentum is constant.
Easy equation, the orbits are ellipses.

Simmetries and modern physics

A first success: the birth of special relativity

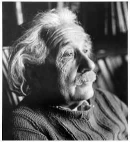


Look! Your equations have more simmetries than we expected!

$$\nabla \cdot \vec{E} = \rho$$

$$\nabla \times \vec{B} = \frac{\partial \vec{E}}{\partial t} + \vec{J}$$

$$\dots$$



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Lorentz transformations

- space and time translations;
- space rotations;
- Lorentz boosts: $t' = \dfrac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}$.

Simmetries first!

- Space and time are homogeneous: no privileged points.
- Space is isotropic: no privileged direction.

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Relativistic mechanics!

$$E = mc^2$$

Unification of mechanics and electromagnetism, under the same simmetry principle.

The Standard Model of particle physics

Goal

Unification and full description of electromagnetic, weak nuclear force, and strong nuclear force.

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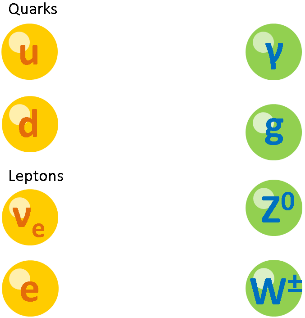

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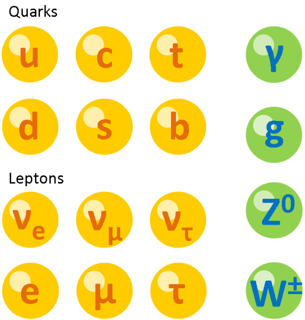


Why do physicists like the Standard Model?

Theory

Very few and simple premises, simmetry principles. Unbelievable predicting power for all kind of phenomena.

Experiment

$$g_{\mathrm{exp}}/2 = 1.001\,159\,652\,180\,85(76)$$
$$g_{\mathrm{th}}/2 = 1.001\,159\,652\,177\,60(520)$$

- Incredible experimental precision: less than one part per trillion.
- Unmatched agreement between theory and experiment.

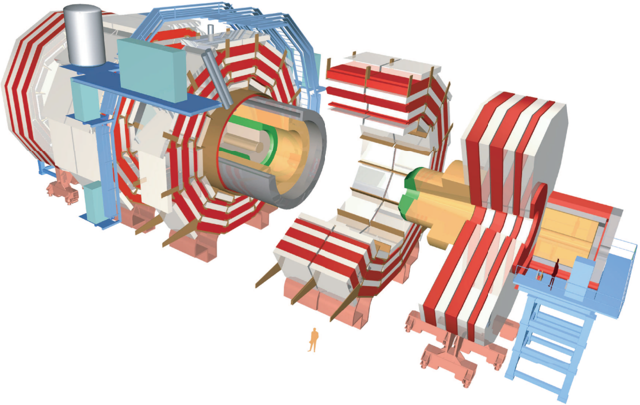
The Large Hadron Collider

pp collisions

The ultimate test for the Standard Model.

The Compact Muon Solenoid

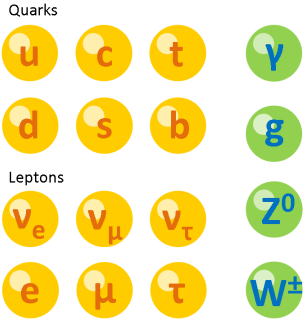
Also known as the CMS detector



Tracker	silicon detectors for the particle momentum;
Calorimeters	scintillators for the energy;
μ detectors	only muons get this far.

Shortcomings of the Standard Model

The hierarchy problem



- Why three generations?
- Why this enormous mass difference?

Nature for the physicist

Beauty $\rightarrow$ similar masses. They now span five orders of magnitude!

Common prediction

New, unknown particles giving part of their mass to the heavy quarks.

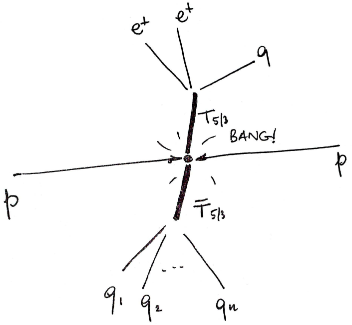
Large masses for a good reason $\longrightarrow$ happy physicists!

The hunt for the top partners

We are looking for their murder scene signature

Decay products

- two same-sign electrons or muons;
- many *jets* (at least four);
- large mass $\rightarrow$ large energy.



Quarks and jets

The strong nuclear force and quark confinement

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A group of particles moving in the same direction.
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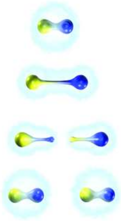
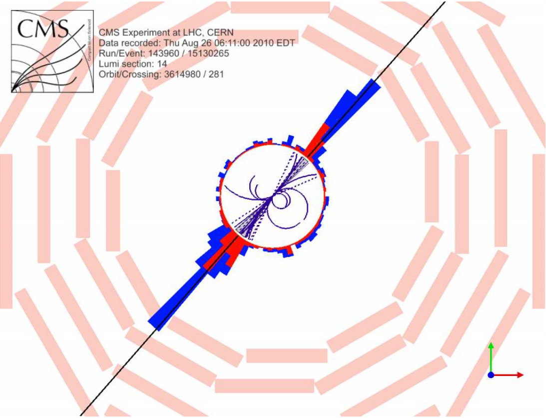
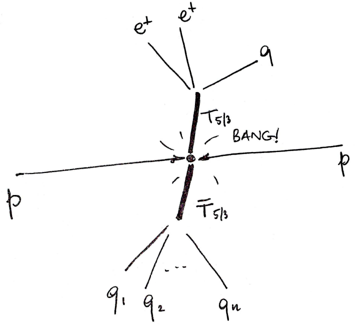


- Force increasing with distance between quarks. Like a spring.
- When energy of the spring $> mc^2$ a new quark is created.
- Quarks are confined in particles with zero net strong charge.



CMS
CMS Experiment at LHC, CERN
Data recorded: Thu Aug 26 06:11:00 2010 EDT
Run/Event: 143960 / 15130265
Lumi section: 14
Orbit/Crossing: 3614980 / 281

Signal vs background



True background: other Standard Model particles decaying in the same way.

Fake background: charge misidentification, leptons coming from secondary decays.

The data analysis

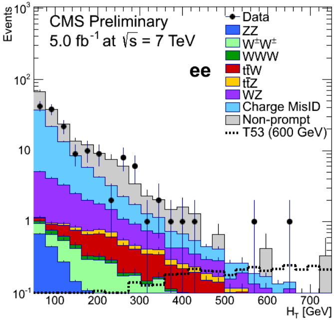
Signal is extremely small! A handful of events out of 40 trillions of collisions.

Selections

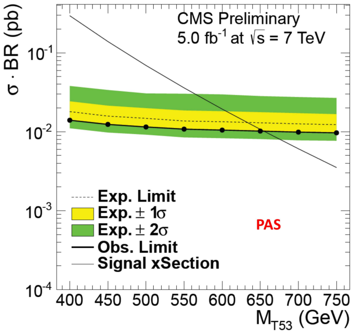
Find the best variables for signal/background discrimination.
Careful checks with Monte Carlo simulations.

Example: H_T

The momentum of the jets in the event, in a plane perpendicular to the beam line.



Do the top partners exist?



Excluded at 95% CL for masses below 655 GeV$/c^2$.