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

What was "old" physics like?

1. Theory + experiment $\longrightarrow$ force or potential energy.
2. potential $\rightarrow$ simmetries $\rightarrow$ simple equations $\rightarrow$ happy physicists!

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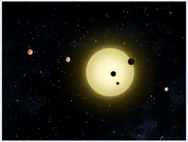
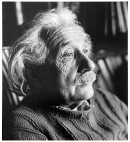
Gravity

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

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

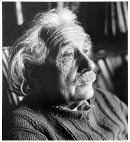


Look! Your equations have more simmetries than we expected!

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

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

$$\dots$$



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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.

What is the most general physical theory compatible with these requirements?

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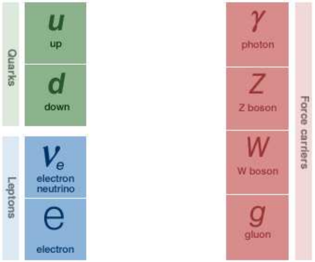
Unification of mechanics and electromagnetism, under the same simmetry principle.

The Standard Model of particle physics

Goal

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

1. symmetry principle. $[SU(3) \times SU(2) \times U(1)$ invariance];



The Standard Model of particle physics

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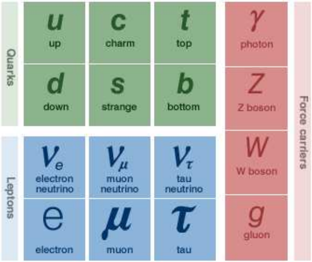
Unification and full description of electromagnetic, weak nuclear force, and strong nuclear force.

1. symmetry principle. [$SU(3) \times SU(2) \times U(1)$ invariance];
2. particles: what is the universe made of?



Why do physicists like the Standard Model

Theory

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

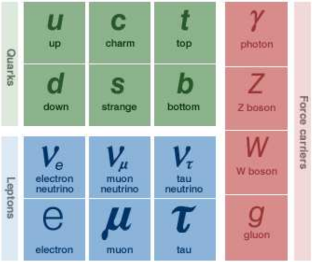
Experiment

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

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

Shortcomings of the Standard Model

The hierarchy problem



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

Nature for the physicist

In order for the theory not to lose its beauty, the quark masses, should be similar. They now span five orders of magnitude!

Many weird difficult mechanisms, different theories.

Common prediction

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

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

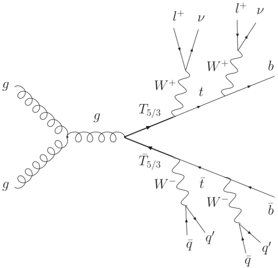
The hunt for the top partners

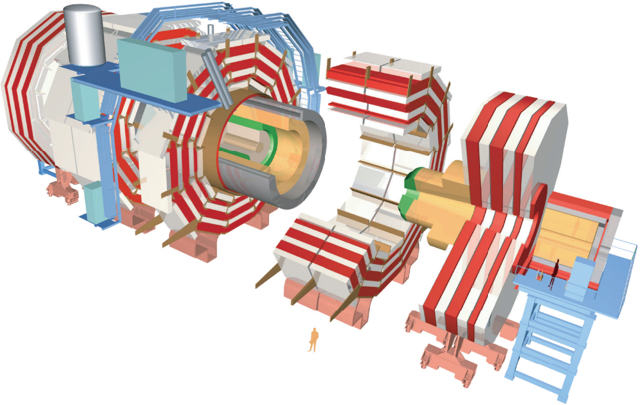
We are looking for their murder scene signature

CMS detector at the LHC.

Decay products

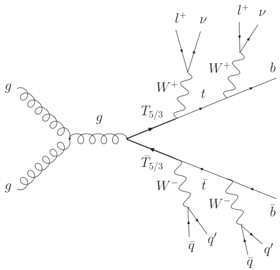
- two same-sign electrons or muons;
- many *jets* (at least four);
- large mass $\rightarrow$ large energy.





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

Signal vs background



True background: similar decays from rare Standard Model processes, *e.g.* $t\bar{t}$.

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

The data analysis

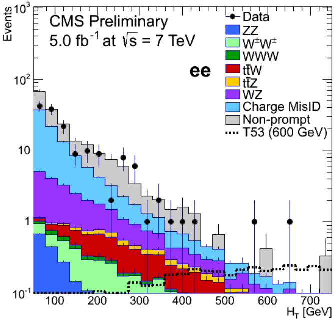
Signal is extremely small! A handful of events out of trillions of collisions.

Selections

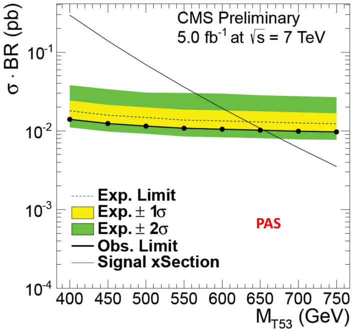
Find the best variables for signal/background discrimination.
Careful checks with Monte Carlo simulations.

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 $[\mathrm{GeV}/c^2]$.